# Assessment of alternative approaches to implementing Individual Transferable Quotas (ITQs) in the Australian Northern Prawn Fishery (NPF) and identification of the impacts on the fishery of those approaches

# Final Report
**(Including post-presentation revisions)**

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# Contents

# Executive Summary

## Introduction

It is Australian Federal Government policy to move all Commonwealth fisheries to Individual Transferable Quota (ITQ) management by 2010 (Details of the Australian Government's Direction to AFMA, 2005).

This includes the Northern Prawn Fishery (NPF), a multi-species, low volume, high value trawl fishery targeting nine species of prawn within an area of about 800,000 square kilometres off Australia's northern coast, extending from Cape York in Queensland to Cape Londonderry in Western Australia.

There are unique challenges in developing an ITQ system for the NPF due to the multi-species nature of the fishery, the difficulty in predicting banana prawn recruitment, and the potential of highgrading and therefore high compliance costs.

This project was developed to undertake an independent investigation into the options for introducing ITQs into the NPF in an economically efficient way with minimum disruption to the continued performance of the fishery.

The six principal objectives of this project were as follows:

1. Prepare a review of management strategies for fisheries targeting short-lived species, including prawns;
2. Prepare a SWOT[1] analysis of ITQ management strategies when used for managing fisheries for short-lived species, including prawns;
3. Undertake a qualitative analysis of the likely outcomes of introducing alternative options for ITQs in the NPF;
4. Conduct a review of the current stock assessment procedures for the NPF and both the data requirements and analysis necessary to meet the stock assessment needs of ITQ management;
5. Conduct a comparative quantitative assessment of the data requirements and analysis necessary to meet the stock assessment needs of alternative methods of ITQ management; and
6. Conduct a quantitative analysis of the potential economic effects to the NPF of alternative options for moving to ITQs.

This report presents the outcome of the project in two main parts. The first part (Sections 2 and 3) is a largely generic, reviewing approaches to the management of short-lived species, ITQ-based management and the use of ITQs for short lived species. This addresses objectives 1 and 2 of the project. The second part (Sections 4 to 7) addresses the management of the NPF using ITQs, and includes detailed discussion based on the results of analyses and expert consultations undertaken under this project. This addresses objectives 3 to 6.

[1] Strengths, Weaknesses, Opportunities and Threats

## Summary conclusions

- ITQs have been applied with success in a number of fisheries. Evidence shows that ITQ-based management has the potential to provide fishers with incentives to harvest their fixed catch at lowest cost, remove 'race to fish behaviour' and increase the value of landings through better handling and care of fish. Transferability of quota also allows more profitable fishers to harvest a larger share of the total catch, thereby improving efficiency and increasing productivity, allowing for the possibility of greater net economic returns. Even in fisheries where the Total Allowable Catch (TAC) has not been historically binding or set correctly, there is evidence of substantial efficiency gains from trade in quota. Where the TAC is properly set, and quota trades are well established, there are stock improvements and large gains in profitability. Often it is stated that ITQs provide an incentive for users to sustainably exploit the resource, encouraging self-regulation and co-management. In practice this is not always the case and users may dispute the need for measures such as stock rebuilding and reduction of catch limits.
- Problems with discarding and highgrading often accompany ITQs, and these problems generally require onboard monitoring or cooperative arrangements among industry members to mitigate their effects. The problem with the application of ITQs in multispecies fisheries arises essentially when there is a mismatch between available quota and catch rates for individual species. When quota for one species has been exhausted and is not available to be traded, while quota for other species remains, there is a strong incentive to discard and/or misreport. Furthermore, where species are hard to distinguish and cannot be separately targeted, TACs may be limited by whichever species is most severely depleted. However, experience suggests that ITQs can be successfully implemented in multispecies fisheries. New Zealand, Australia, Iceland and Canada, have all used ITQs in their multispecies fisheries with good results. Nevertheless, the application of ITQs to the NPF brings additional problems, given the short-lived nature of the target species and the large environmental uncertainly associated with banana prawns.
- In terms of profitability, implementing ITQs correctly in the NPF depends on the source of uncertainty, the target and the appropriate instrument. If environmental uncertainty is high, or, in some contexts, where there is large variance in the stock-recruitment relationship compared to the harvest function (or compared to the variance in catch per unit of effort), then input controls will be preferred. If the reverse holds, output controls are the better choice. Setting aside potential efficiency gains and added management costs, economic modelling of the NPF shows gains from the use of a TAC and ITQs in the tiger prawn fishery. However, for banana prawns an output control results in both less profit and more variance in profitability. We note, however, that the parameterisation of this model for banana prawns is necessarily more uncertain than for tiger prawns. Furthermore, the use of in-season updates to the TAC would increase the profitability and decrease the variance of TACs. The results suggest that a TAC system may be most appropriate for tiger prawns and either a TAC or a Total Allowable Effort (TAE) system may be appropriate for banana prawns.
- This result on 'mixed instruments' may continue to hold even when a stock-recruitment relationship for banana prawns is known, but it is qualified by the following considerations: (1) mid-season updates for the banana prawn fishery will partially mitigate the loss in profits resulting from setting a TAC in this fishery (compared to a properly applied TAE), albeit not counting the additional management cost associated with the update; (2) model results ignore the cost of 'effort creep' in terms of lost profitability in a TAE system, which historically for the NPF has been a

significant problem; and (3) model results also ignore the potential efficiency gains that accompany ITQs, and although these are difficult to measure for the NPF *ex ante*, they have been considerable in most other fisheries where ITQs have been introduced. These three points taken together may ultimately justify the use of a TAC in the banana prawn fishery. Depending on the costs of the update, the use of a proper mid-season adjustment for banana prawns, as suggested in this report, may in fact be sufficient reason to introduce ITQs to the banana prawn fishery at the same time as that for tiger prawns.

- Given the comparatively mature status of the tiger prawn stock assessment, as well as the biological data on these stocks, we developed a full operating model approach to explore the implications of moving to a TAC-based management system. The specifics of the biological and fishery-operating model used can be found in Appendix 3. Using the model, we found the following results: (a) Increasing uncertainty over the current state of the stock requires a more precautionary approach to setting the TAC. For instance, a 50% assessment CV would generate brown tiger prawn TACs that are 7% lower than could be achieved with an assessment precision of 10%. (b) Analysis of the multi-year performance of a TAC-based management approach driven by the targets and constraints outlined in the Commonwealth Harvest Strategy shows that the harvest strategies are reasonably robust to implementation error and capable of maintaining stocks at their target reference level ($S_{MEY}$). (c) The consequence of the proportion of the two tiger prawn species in the catch being significantly different from the proportion assumed in setting the TAC can be significant. In the case examined, an implementation bias which changed the species proportion in the catch by only 10%, but which resulted in an increase the catch of brown tiger prawns by 33% meant that the harvest control rule was incapable of generating a recovery in a depleted (through simulation) brown tiger stock.

- In terms of setting TACs for the two tiger prawn species, we see no obvious alternative to setting a single combined limit because there is no clear basis for monitoring quota uptake at the species level. In setting this combined TAC it will be necessary to make an assumption about the future species ratio in the catch and to check this against the actual species ratio. In most situations the past history of the fishery suggests that the proportion of the two tiger species in the catch will reflect the proportion in the stock, and hence in the TAC. However, where it deviates significantly from the proportion in the TAC this would compromise the ability of the harvest control rule to ensure a successful recovery of a depleted stock, especially of brown tiger prawns (point (c) above).
- A number of mechanisms are available for mitigating problems arising from the proportion of tiger prawn species in the catch, including changing the spatial or temporal distribution of catches, and restricting the total TAC to catch the correct TAC of the most vulnerable species, assuming a “worst-case” catch proportion. The former would probably allow the full combined species TACs to be taken, whereas the latter would imply some foregone catch for one of the species compared to what the nominal individual species TACs would allow. We modelled the option of starting the second season later (week 35 rather than week 31) which has the effect of reducing the proportion of brown tiger prawns in the catch from 30% to 20% and concluded that while this would be an effective way of altering the proportions in the catch it would lead to a reduction in the available TAC. It would therefore be most sensible to consider this only as a short-term strategy available for use when a stock is depleted and is in need of recovery.

- The uncertainty associated with the abundance of banana prawns, and the absence of a stock-recruitment relationship, makes it difficult to set an appropriate TAC. However, given the past history of the fishery it seems reasonable to assume that past catches have not resulted in recruitment overfishing, and that since the fishery has been effort controlled, catch rates have generally reflected stock abundance (although trends in catchability will have occurred). Therefore, our basic assumption has been that a catch control rule that would constrain catches to the same levels as has been seen in the past would both optimise the economic yield and avoid recruitment overfishing. There is a clear relationship between total season banana prawn catch and the catch rates in the first part of the season. Using this relationship, we investigated the possibility of using a combination of historical catch data to set a preseason TAC together with in-season updates on TAC to allow for the possibility of TAC adjustment and increased profitability. This analysis was undertaken within the confines of a theoretical move to ITQ management; no comparison was made with input control as a means of maximising yield.

- The analyses on banana prawns indicates that if a single mid-season update is to be implemented it should occur after three weeks and initial TACs should be set to moderately high levels (the median of historical catches for example) to prevent fishermen exhausting the pre-season quota and having to wait for an update. If two updates can be employed, weeks 3 and 4 lead to TACs that are closer to the 'real' total catches and yields are, on average, higher. Beyond this finding, the decision over whether a preseason stock assessment to improve prior prediction of total season catches or the setting of TACs to low ($25^{th}$ percentile of predicted catch) or moderate levels (median) is optimal depends on further cost-benefit analysis. The assumed improved prior prediction of total season catches employed in this modelling lead to average gains of 47 tonnes compared to TACs set to the $25^{th}$ percentile of predicted catch and 27 tonnes compared to TACs are set to the $50^{th}$ percentile of predicted catch. The cost of stock assessment and its potential for improving preseason estimates must be better known before it can be determined whether cost-effective gains can be achieved. Were historical relationships between covariate data and total catch used to update preseason estimates of catches, it is important to note that they could change under future conditions and the shift to output controls and should therefore be subject to further investigation.

- Any fishery for tiger or banana prawns is effectively a multispecies fishery. Apart from the catches of the 3 main species (brown tiger, grooved tiger and white banana prawns), red-legged banana prawns, blue and red endeavour prawns, king prawns and giant tiger prawns are caught. On the assumption that, like banana prawns, historical catches have not resulted in recruitment overfishing, and that catch rates have reflected stock abundance, we propose that for endeavour prawns the TAC be determined as the minimum of a) the upper 75 percentile of the ratio of historical catch to the catch of tiger prawns, and b) the maximum historical catch. TACs for the two species of endeavour prawns could nominally be calculated as the historical average species proportion in the catch. However, TACs for individual endeavour prawns are not likely to be implemented on their own, outside of the general species grouping. For red-legged banana prawns, an independent TAC based on historical catch levels could be set.

- The measurement of the cost of monitoring and implementation of ITQs in the NPF can only be approximate. Figures provided in established studies, based on a number of fisheries in Europe and North America, suggest a range of 1.5 to 10.8 million dollars in the NPF (based on gross revenue in the NPF of 72 million AUD in 2006). This range exceeds the cost of monitoring and implementation provided by

AFMA (2006), recently updated to 2006-07 compliance costs, estimated at $824, 711 AUD. Given a 50 boat fleet, and existing catch volume, comparable direct on-board monitoring costs in the NPF are roughly 1.4 million AUD per year. This is considerably larger than the $194,994 AFMA (2006) estimate, and places the overall minimum costs of monitoring, enforcement and implementation (including all of the additional costs specified in the AFMA report) of ITQs in the NPF at about $2 million AUD per year. Note that this includes an increase in observer coverage from current levels to 100% of vessels and fishing days ($1.4 million). In the medium term these levels could probably be cut to 50% coverage, creating a saving of $700,000.

- In terms of cost-benefit, our calculations suggest that a management system using ITEs for banana prawns and ITQs for tiger prawns would generate gains over the current system, and a move to ITQs for all prawns would probably be cost neutral.

- Limitations on the transferability of quota are likely to undermine the opportunities for the industry to develop their own economic efficiencies, and may result in unexpected and undesirable effects in the quota trading market. It is recommended that there are no restrictions on transferability of quota. It is also important to ensure that there is a well-established mechanism (e.g., a brokerage service) for quota trading.

- Assessment of the real costs and benefits of moving to ITQs is very difficult because it relies on the quantification of uncertain additional costs related to surveillance, enforcement, data reporting, effort monitoring, stock assessment and research.

- This report contains a number of technical appendices, including a summary of meetings held with NPF industry representatives, and a report of the NORMAC ITQ workshop held in Brisbane on July 5th, 2007.

# 1. Introduction

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Management of the NPF started in the early 1980s and has been in a state of continual revision since. The fishery is currently managed by input controls and has had individual transferable fishing rights since the mid-80's. There have been several reviews of management options for the NPF, including ITQs and a time unit system, but these studies have concluded that the characteristics of the fishery do not easily lend themselves to management through such systems.

Although transferable fishing rights exist in the fishery, the shift to an output TAC/ITQ system represents a significant alteration in management approach. For some species in the NPF this requires new research into (1) acceptable levels of risk and appropriate management targets and (2) sufficiently precise and reliable stock assessment methods on which to base TACs.

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1. Prepare a review of management strategies for fisheries targeting short lived species, including prawns;
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ITQ-based management and the use of ITQs for short lived species. This addresses objectives 1 and 2 of the project. The second part (Sections 4 to 6) addresses the management of the NPF using ITQs., and includes detailed discussion based on the results of analyses and expert consultations undertaken under this project. This addresses objectives 3 to 6. Finally, an assessment of the likely costs and benefits of moving to an ITQ system is presented in Section 7.

# 2. Management of fisheries for short lived species

Some species that are subject to targeted fishing, most notably squid and prawn species, live for only one to two years. In such cases, historical observations of catch, effort and abundance indices may not be informative with respect to stock dynamics. This has been the case, for example, with banana prawns in the NPF. Often, this precludes the use of traditional estimation methods such as statistical catch-at-age, virtual population analyses and production modelling which rely on correspondence among observed data. Additionally, the disaggregation of such models to finer temporal resolutions (*e.g.* monthly) is ill-suited to once yearly recruitment and often ineffective due to noisy data.

The development of assessment methods for short-lived species has lagged behind those applied to stocks of longer-lived fish. Early discussions (*e.g*. Pauly, 1985) cite the tropical location of commercially important short-lived species (where historically there has been less focus on population dynamics) and a perceived lack of correspondence between catches and stock sizes (and thus poor predictive ability) as the primary reasons for research biased towards longer lived species. Since the mid-eighties, a range of alternative modelling approaches have been developed for short lived species that predict in-year abundance.

Below we discuss several examples of the assessment and management of exploited stocks of short lived species.

## 2.1. Falkland Islands squid

The assessment of the Falkland Islands squid stocks (Agnew *et al.,* 1998) uses depletion modelling (*e.g.* the 'Delury model'; Rosenberg *et al.,* 1990), in which intra-year declines in abundance indices are modelled and monitored. In its simplest form, this approach assumes that each year of the model represents a new stock. Complications arise when there is more than one recruitment pulse in each year. In these cases the intra-year increases in CPUE cannot be accounted for in a simple aggregated model and it becomes unstable. Solutions such as allocating a cohort to each pulse (Brodziak and Rosenberg, 1993) can be effective but require an independent estimate of migration that may not be available. Agnew *et al.* (2006) demonstrated that even with excellent data, the use of depletion models can be problematic in fisheries with multiple recruitment pulses per year. In the management of Falkland Island squid, a target level of escapement is achieved by real-time assessment (by making catchability assumptions). In years when the level of allowable effort results in too-rapid depletion of the cohort (as indicated by the in-season assessment), the season may be closed early. Such an approach relies heavily on regular in-season data reporting (daily in this case).

In 2005 the Falkland Islands Government (FIG) passed a Fisheries Bill enacting legislation to shift the Falklands fisheries to Individual Transferable Effort Quotas (ITEQs) with rights valid for 25 years. The *Loligo* squid fishery was the first Falkland fishery to enter the new ITEQ system in July 2006. A move to an output control based system was considered at

this time, but it was deemed appropriate to continue with input control because of the lower administration and enforcement costs. The purpose of introducing ITEQs was to

- improve the overall performance of the sector;
- promote fishery diversification and autonomous restructuring;
- provide fishing companies with additional security;
- encourage investment in the industry;
- promote industry funded research and development;
- improve international competitiveness;
- financially aid those leaving the fishery; and
- increase profitability including government income from economic rents.

The initial allocation of effort units was based on historical vessel performance. This did not meet with support from the fishing industry as it was felt that some of the smaller companies were allocated a disproportionately large share of the quota. Instead, industry representatives preferred a division of quota based on historical vessel catches. The final decision on quotas was reached during a series of meetings between industry representatives and the Fisheries Director. Company allocations were decided after a lengthy consultative process between Government and industry representatives. Eligibility and participation in the consultative process was restricted to those "loyal" companies that operated the fleet of 16 core vessels that operated continuously in the *loligo* fishery between 2001 and 2005. While the quota system was in effect calculated on the basis of catch share, it is in fact, referred to as an effort allocation.

Real-time management is accomplished through frequent stock assessments using daily catch, effort and biological data in a Delury depletion model which provides initial, current and projected final estimates during the fishing season. The main management goal is to ensure that a spawning stock biomass of 10,000 tonnes remains at the end of the season. This is equivalent to a limit reference point, above which there has historically been no apparent impact of stock size on recruitment. The Fisheries Director retains the option of early season closures in the event that assessments predicted a failure to meet the conservation target. Stock assessment is used to calculate the total allowable effort that can be exerted during a season which is shared between companies according to their respective ITEQs.

Companies are allocated an aggregated ITEQ that applies equally to both the first and second fishing seasons. Preferential allocation of property rights is given to fishing companies that are wholly owned by Falkland residents with exemptions for established fishing companies with majority foreign ownership. There are presently nine local fishing companies operating in the Islands and it is a condition of licensing that residents own at least a 25.1% share of each applicant vessel.

The procedure for trading effort allocations has yet to be tested. There is no formal procedure in place for the sale or trade of effort entitlements. The Director of Fisheries reserves the rights to oversee the trade in ITEQs and the Fisheries Ordinance retains a provision requiring participating companies to demonstrate active involvement, control and efficient use of ITEQs. In order to remain on the eligibility register, companies that are granted ownership rights are expected to use them as a basis for the promotion of investment in onshore seafood and associated maritime industries as opposed to short-term monetary gain. The Director of Fisheries retains the authority to remove a company from the eligibility register if it: shows a repeated pattern of poor financial performance; consistently sells effort entitlements to other companies without re-investing the profits in the seafood business; sells effort entitlements for less than the market value; fails to remain active in the industry at a level commensurate with the type and quantity of rights held.

It is expected that the presence of these principles in legislation, together with the authority of the Fisheries Director to intervene in those instances when companies fail to uphold these principles should be sufficient to encourage holders of ITEQs to use their property rights in the best interests of the Falkland Islands. The Bill also provided for the establishment of a Disputes Commission presided over by a magistrate with a council of elected representatives to provide a resolution mechanism for disputed fisheries-related issues.

## 2.2. Gulf of Maine northern shrimp

The northern shrimp fishery of the Gulf of Maine (managed by the Atlantic States Marine Fisheries Commission) is assessed by depletion modelling (modified Delury model), the results of which are corroborated by a surplus production approach (ASPIC). Where necessary, yield-per-recruit and eggs-per-recruit analyses have been used to investigate management options. Fishery dependent CPUE data show temporal correspondence among catches and relative abundance indices. Mid-season survey indices are used to inform the modified Delury model and fishing mortality estimates. The northern shrimp management plan also benefits from an explicit objective in terms of fishing mortality rate. The yearly fishing mortality target is $F_{50\%}$ = 0.22 (median *F* estimate). This estimate was based on retrospective analysis which found this average level of exploitation was conducive to 'stable' stock dynamics during the '80s and '90s. The fishing season may not be opened if recruitment estimates are sufficiently low or may be closed during the season according to the fishing mortality target and the mid-season assessment.

By reserving the right to close the fishery at any stage, the management authorities retain strict control of exploitation of the resource. Theoretically such an approach allows the fishery to achieve the highest catches whilst controlling biological risk. However, economic efficiency may not be strongly rewarded since this management approach creates the conditions of 'race to fish' fleet dynamics, promoting over-capitalisation and excess capacity. The northern shrimp fishery has been subject to the current fisheries management plan since 1986 (albeit with 2004 amendments including updated objectives and management reference points). Despite the available data and control of closures, the biological status of the fishery is at best uncertain (National Marine Fisheries Service, 2002). Recent stock assessments have been relatively pessimistic. In 2003 and 2004, relatively low biomass levels were estimated (ASMFC, 2004). Amongst other adjustments, the latest amendment to the Magnusson Stevens Act (ASMFC, 2004) recommends a shift to biological management reference points and provides the scope for the introduction of tradable input controls in the form of ITEQs.

## 2.3. Bay of Biscay anchovy

Bay of Biscay anchovy is a short-lived species of highly variable recruitment. The majority of individuals are less than 2 years old. Up until 2002, the fishery was managed using a constant annual TAC based on the average level of historical catches. After 2002, the stock was assessed using 'Integrated Catch-at-age Analysis' (ICA; Patterson and Malvin, 1996). The ICA approach is supported by historic catch-at-age data, the Daily Egg Production Method (DEPM), acoustic estimates of biomass and numbers-at-age survey data. This stock assessment is used to make projections under different TAC scenarios to determine a level that maintains a predicted population within safe biological limits.

The fishery dependent, DEPM and survey data provide virtually no information about recruitment at the time when TAC recommendations are to be made. It has been

hypothesised that the recruitment of anchovy is primarily environmentally driven[2]. Consequently, the working group undertakes a risk analysis of two scenarios; one (WGav) is the average of previous recruitment events; the second is more precautionary (and more arbitrary) and is the average of all previous recruitment events that are below WGav (which under the assumption of normality, is always approximately the 21st percentile). An evaluation of the potential advantages of such an approach (De Oliviera *et al*., 2005) found that conventional models coupled with precautionary TACs may reduce risks and increase yields more reliably than models that incorporate environmental covariates that are weakly or even moderately related to recruitment. The findings of this simulation evaluation suggest that the relatively weak association of environmental factors with anchovy recruitment may be of limited use in setting pre-season TACs.

This management system has not proved particularly appropriate or successful for Anchovy. The fishery is currently closed, with very low levels of recruitment. The anchovy stock has been managed by annual TACs which have been set at a fixed level (in the range of 30 000 t to 33 000 t) independent of the advice (from 1979 to 2004). However, ICES (2006) considers that this management strategy seems to be inadequate for a short-lived species like anchovy, which is dominated by the incoming year class. Since 2002, the total annual catches have been well below the fixed TAC, indicating that when the recruitment is low, a management regime based on such annual TACs has not constrained the fishery.

# 3. Individual Transferable Quotas

## 3.1. Introduction

Many of the world's fisheries have suffered stock declines and reduced economic benefits resulting from 'race-to-fish' conditions and fishery overcapitalisation. Proponents of rights-based fisheries management argue that it discourages such phenomena by providing a mechanism which promotes all measures that increase economic efficiency (Hannesson, 1996; Hilborn *et al., 2005;* Clark, 2007).

Rights-based fisheries management can be achieved in a number of ways, including both input (effort) and output (quota) controls. Individual Quotas (IQs) are generally allocated to fishing operators as a fraction of a maximum overall catch (Total Allowable Catch or TAC) that may be set on an annual basis, or some other time period. A special case of an IQ is the Individual Transferable Quota (ITQ) that includes the right to trade or lease these rights. The term ITQ refers to catch quotas and is thus an output control. Individual Transferable Effort Quotas (ITEQs) are applied in some fisheries and allow fishing effort units to be bought, sold and leased (this is the basis of the method that is currently used to manage the NPF). Other forms of rights-based management include place-based tenure systems (that are typically applied to stocks of sessile organisms) which grant the owner with fishing rights to a given area (Hilborn *et al*., 2003).

ITQ systems were first adopted in the 1970s and are now implemented as a major management component by many nations, including Australia, Canada, Chile, Iceland, Netherlands and New Zealand (OECD, 1997; Arnason, 1996). To a lesser extent, ITQs are used by the US, Portugal and Mexico (OECD, 1997). Generally positive economic and biological results are driving a global expansion of rights-based management (Hilborn *et al*., 2003). In many case studies, the profitability of fishing has increased from improved fishing

[2] This is similar to the Australian banana prawn fishery (Wang and Die, 1996; Die and Ellis, 1999); see Section 4.

efficiency and catch quality (*e.g.* Icelandic fisheries; Arnason, 2005). The reduction in fleet capacity may also be offset by increased employment elsewhere in the industry, the result of a shift in emphasis towards products of greater quality and value. In general, the above phenomena have lead to an increase in economic rents. In addition, some applications to overexploited stocks have been followed by signs of stock recovery (Fujita and Bonzon, 2005).

## 3.2. Advantages of ITQs over non-rights-based approaches

This section discusses some advantages of ITQs over non-rights based management. We acknowledge that in the case of the NPF the current system in place is already a rights-based input control system. We have not found any examples where other fisheries have moved from ITEs to ITQs, so we are unable to comment on the consequences of such a move in this section. Furthermore a cost benefit comparison of these two methods was not originally part of the TOR. However, we do consider the implications as part of the bio-economic modelling approach in Section 5.

By providing a market for permanent property rights, rights-based management establishes conditions for improved economic efficiency (See Text Box 1). Since their rights have a market value, an ITQ/ITEQ owner can leave the fishery at reduced financial losses, or even at a profit. Since an ITQ has both a market value and a fixed catch limit, its owner is likely to pursue all measures that maximise profitability, such as improved fishing efficiency and catch quality. Concurrently, the system reduces the incentive for investment in fishery inputs and thus overcapitalisation. The fishermen are further motivated to approve the optimal long-term harvest strategy, and even to pay for the research needed to determine what this is, and what the current TAC should be. In practice self-management can be complicated. As described by Townsend (1998), the record on collective protection of the resource by operators is mixed. In many cases the operators have conflicting ideas on how the stock should be managed.

The ITQ management of Icelandic pelagic and demersal fisheries has demonstrated these characteristics. Over the last 20 years TAC shares have increased in value by a factor of 20 while fishing effort has halved (Arnason, 2005). Where the TAC is restrictive, operators no longer ‘race-to-fish’ since they are guaranteed a certain amount of catch. The benefits include reduced biological risks and improved safety since fishers can choose not to harvest in dangerous conditions without the risk of reduced catches.

At least three fisheries in British Columbia (halibut, sable fish and groundfish trawl), each now with 10 or more years ITQ experience, appear to have been brought from the brink of bankruptcy through the use of ITQs. The ITQ systems for these fisheries have recently been integrated, as an approach to improving the management of the multispecies fishery.

Where permanent rights are provided, the ITQ system may help to align the interests of the fishers to the long-term health of the stock. Input controls have a stronger tendency to fail in this regard (Grafton *et al.,* 2005). In New Zealand fisheries, examples of responsible exploitation after the introduction of ITQs include voluntary reductions in quotas, industry sponsorship of assessment science, industry lead enhancement programs and the establishment of voluntary codes of practice to reduce bycatch (Annala, 1996).

Individual quota systems have often been introduced without the transferability option. Usually this has quickly proved to be unworkable, and transfers have subsequently been allowed. Interestingly, transferability tends to further increase conservation incentives, because quota owners can now fully capitalize on the increased value their quota shares.

Equity and risk are central issues in the introduction of ITQs (Huppert, 2005). Under the Icelandic system, ITQs are implemented by multiplying a variable yearly TAC by permanent share of the TAC (Individual Transferable Share of Quota, ITSQ). The initial allocation of ITSQs to fishing vessels was either based on the share of catches achieved by those vessels over recent years (*e.g.* Icelandic deep sea shrimp) or was made equal among vessels (*e.g.* Inshore shrimp fishery; Arnason, 1996). By not distributing permanent rights to absolute quantities of catch, the method benefits from management flexibility and the ability to easily adjust for stock declines without the authorities resorting to buy-back schemes that are often costly. In New Zealand, ITQs were allocated free of charge to operators on the basis of their historical catches over a qualifying period. Where these ITQs added up to TACs that were in excess of levels that would allow the stock to move towards a size sustaining maximum sustainable yield, the fishing rights were removed using a voluntary buy back scheme (Annala, 1996).

As indicated above, ITQs have been established in New Zealand and Icelandic fisheries since the late 1970s and mid 1980's respectively. After 8 years Annala (1996) could draw few concrete conclusions about the costs/benefits of the New Zealand fishery. After more than 15 years, Arnason (1996) could identify clear economic benefits of ITQs but mixed biological consequences. It may be several years before positive results of (or problems with) the shift to ITQ management become apparent despite clear immediate costs from additional data collection, research and enforcement or reduction in catches.

There are several case-studies, of which Icelandic cod is an example, where ITQ management has not lead to stock recovery (although it appears to have halted serious declines). The success of the ITQ system is still vulnerable to the setting of inappropriate TACs and/or a lack of compliance with quotas. It should be emphasised that ITQs are primarily an instrument for promoting economic efficiency, a by product of which may be stock recovery (Hannesson, 1996).

**Text Box 1**

**ITQs – General Economic Theory**

The general economic theory of ITQs makes the following predictions (Clark 2007, Sec. 4.3):

1. ITQs instantly defuse the “derby” fishery typical of TAC-based management systems. The need to set a brief annual fishing season (because of fleet overcapacity) evaporates, because the fishermen no longer have to compete for their shares of the TAC. For example in BC’s Pacific halibut fishery, the season expanded from about 6 days per year to the full IPHC season of 250 days immediately when ITQs were introduced in 1991. This in turn facilitated better control and reporting of catches, and incidentally resulted in increased safety at sea.

2. ITQs reduce the incentive for overexpansion of fleet capacity (sometimes referred to as “capital stuffing,” or “effort creep”), since fishermen have nothing to gain from such activities. If excess capacity exists prior to the introduction of ITQs, capacity may subsequently decline over time, as some fishermen sell their quotas and withdraw from the fishery.

3. ITQs strongly affect fishermen’s conservation incentives in a favourable way, at least to the extent that conservation increases the present value of future income flows. This happens because, unlike the situation with non-allocated TACs, each ITQ fisherman can expect to share in the increased value of the fishery as a whole. Empirical support for this prediction is abundant, as ITQ fishermen have often accepted, or even initiated strong conservation measures.

4. ITQs motivate the industry to support and participate in stock surveys and other research activities[3].

Any fishery is vastly more complex than is implied by simple models that are often used in predicting the outcomes of management interventions (see for example, see the presentation of the economic theory of ITQs in Appendix 1). An important source of oversimplicity in many models is aggregation of biological and economic variables. In the real world, resource stocks are structured temporally, spatially and ecologically (e.g. multispecies, subspecies, stocks, etc.) and fishing fleets are structured by type, size and age of vessels. Vessel are owned and/or operated by individuals and companies that may control one or more vessels potentially active in multiple fisheries. The costs of fishing depend on all such structural components. Product prices depend on species, quality, quantity and current demand. The incentives and decision making criteria are therefore complex and require careful consideration when analysing likely outcomes.

[3] Maximizing annual profits year-by-year could imply recruitment overfishing. Although stock-recruitment relationships are notoriously hard to quantify, one can at least make an adjustment to the TAC for precautionary purposes. The question is whether ITQs, would cause fishermen to automatically take stock-recruitment into account. Realistically, this cannot happen because the fishermen have no way to know what the optimal harvest is, without the necessary scientific research. Under ITQs the fishermen are therefore motivated to approve the optimal long-term harvest strategy, and support the research needed to determine what this is, and what the current TAC should be.

What ITQs offer is the facilitation of decentralized decision making in the face of these complexities. But this can also be bad news, because centralized decision making is still necessary to determine TACs, and to overcome the many externalities in fisheries. However, unlike the case of non-ITQ fisheries, ITQ fishermen are more strongly motivated to cooperate with each other and with managers.

## 3.3. Threats to the achievement of economic objectives under ITQs

ITQ management is now relatively well established. While there remain uncertainties over whether this approach leads to biological improvements, there is a growing body of evidence that it represents the most promising means of achieving economic efficiency and sustainable stock levels. In essence, ITQs encourage resources to move to more efficient operators, improving the financial returns of those who remain in the fishery; however, stock improvements generally only result from changes to the TAC.

Aside from the biology, however, many other limitations of the approach have been identified and in this section we explore circumstances in which the economic objectives of ITQs may not be realised in practice.

First and foremost, in order to achieve the economic benefits of ITQs, it is *absolutely essential* that:

1. the fishing industry participates closely in the design and implementation of the ITQ system;

2. the industry supports and participates in full monitoring and enforcement of the quotas, as well as in the control of by-catches, discards, and upgrading - in some cases, on-board observers (financed by the vessel owner) are considered necessary; such observer programs, which are usually impractical under TAC-management alone, are now successfully used in many ITQ fisheries; and

3. the ITQs are flexible, because virtually all marine populations undergo natural fluctuation in abundance; specifically ITQs should actually consist of ITQ shares of the TAC rather than permanent ITQs of a fixed amount of catch[4].

[4] Fixed quotas and the buybacks that often result are not only financially undesirable for the management authority, in some cases they have not protected stock levels (Grafton et al., 2005 cite the British Columbia salmon fishery before 2000).

### 3.3.1. Misreporting, discarding and high-grading

Uptake of allocated quota is monitored through reported catches. As with any TAC managed fishery, there is often a perceived[5] incentive to under-report catches, resulting in an increased need for verification of catch reports and strict enforcement of reporting regulations. Misreporting of catches has a number of downstream implications, including quota overages and the potential introduction of greater uncertainties and bias in the stock assessment.

Further to misreporting, because ITQ management encourages economic efficiency, it also promotes the discarding of less valuable catch or ‘high-grading’ (Squires and Kirkley, 1991). Arnason (1996) found little evidence for high-grading in Iceland fisheries under ITQ management. However, where the price difference among grades is relatively high compared to the cost of fishing, high-grading may be beneficial to the fishers (Rose and Kompas, 2004).

Discarding is a problem because it is wasteful and if it is under-reported it may lead to further distortion of stock assessment results, for example through the underestimation of fishing mortality. This may in turn lead to unsustainable fishing, and hence undermining of the legitimacy of the ITQ management system.

The added problem with misreporting, discarding and high-grading is that these practices are difficult and expensive to mitigate. Misreporting must be discouraged through a robust surveillance and enforcement programme (so there is a clearly perceived probability of being caught) and a significant penalty (so there is a clear deterrent). Both of these are costly to implement effectively. Furthermore, monitoring of discards and enforcement of a discard ban may only be possible through the placement of observers on board vessels, supported by an intensive surveillance and inspection programme.

An alternative to expensive top-down command and control approaches is to establish a co-management structure in which the industry itself responds to incentives to reduce the incidence of discarding. This may include a shared information resource that advises the fleet of locations that should be avoided in order to reduce (for example) the catch of small, less valuable fish.

### 3.3.2. Multispecies fisheries

The problem with application of ITQs in multispecies fisheries arises essentially when there is a mis-match between available quota and catch rates for individual species. When quota for one species has been exhausted and is not available to be traded, while quota for other species remains, there is a strong incentive to discard and/or misreport. Furthermore, where species are hard to distinguish and cannot be separately targeted, TACs may be limited by whichever species is most severely depleted.

Nevertheless, experience suggests that ITQs can be successfully implemented in multispecies fisheries. New Zealand, Australia, Iceland and Canada, have all used ITQs in their multispecies fisheries with good results. Under ITQs fishermen may be motivated to

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[5] This incentive is described as perceived, because under certain circumstances under-reporting may not be in the longer term interests of the fishers – for example when it affects the outcome of the stock assessment by giving a falsely pessimistic view of the status of the stock, and thereby reducing future TACs.

avoid overfished subpopulations, and may even agree to the closure of some areas, as a precautionary measure.

In the BC groundfish trawl fishery, for example, fishermen themselves have devised innovative ways to deal with multispecies complexities. Examples include:

- Alteration of fishing gear;
- Avoidance of certain areas at certain times (or permanently);
- Use of short-term tradeable by-catch quotas; and
- Use of on-board observers, paid for by vessel captains.

Such strategies typically have short-term costs plus long-term benefits. Without ITQs fishermen have little incentive to adopt or approve of these methods, but this may change sharply under implementation of ITQs.

Individual quotas were first used in Australia in 1989, in the eastern gemfish south east trawl fishery.. In 1992 they were extended to cover a further fifteen species and quota has been fully transferable since January 1994. The fishery is now managed using a combination of ITQs and input controls (limited entry, mesh size and area restrictions). According to Fox et al. (2004) productivity in the south east trawl fishery has increased as a result of capacity reduction (through a buyback programme) and the ITQ management regime has allowed that productivity improvement to be maintained. The increase in the expected profitability in the fishery was reflected in the value of boat licences which increased from $60 000 to $85 000 immediately following the structural adjustment. However, although ITQs have been economically beneficial to the industry, they have not been of significant biological benefit, with about 50% of the south east trawl stocks that can currently be assessed being overfished or subject to overfishing (including the eastern gemfish; Caton & McLoughlin, 2005).

Arnason, writing in Hatcher et al (2002) discussed several ways in which ITQs have been successfully used in the management of multispecies fisheries.

Transferability of quota is key to enabling operators to trade in quota for the components of the multispecies complex, thereby enabling them to better match their quota holdings to their vessel(s) pattern of fishing. The problem of quota/catch mismatch should therefore not arise until a TAC is exhausted or close to being exhausted. Having quotas set in accordance with their actual abundance is also an advantage in this respect.

In addition, Vessel operators are able, through judicious adjustment of gear and fishing strategy, to modify the species composition of their catches to better fit with the available quota. In Iceland, for instance, vessels have generally solved the bycatch problem by altering their fishing methods. This activity is not without cost, however, and catch rates of target species may be reduced as a result.

Arnason also suggests setting some quota aside each year (a “quota fund”) that the authorities can use to supply the quota market as the quota prices increase in response to an expected exhaustion of the TAC or if for any other reason vessels cannot buy quota on the market.

### 3.3.3. Highly variable stock sizes

Highly variable stock size is a particular characteristic of fast growing, short lived species. The difficulties of managing fisheries with this characteristic and ways in which they have

been overcome are discussed in Section 2. In Section 3.4 we discuss several cases where ITQs are being used in the management of fisheries for short lived species. Here we discuss in more general terms the problems associated with highly variable stock size and how it can threaten the achievement of economic efficiencies under ITQs.

It is an often cited a criticism of quota-based management that operators may not see the benefits of seasons with unexpectedly high abundances. In essence the TAC setting mechanism is not sufficiently responsive to take advantage of abrupt spikes in abundance due to uncertainties in predicting the size of the incoming year class. One solution is to build flexibility into the quota constraint and allow a certain proportion of excess catch (*e.*g. 5%) that may be deducted from the quota in the following year (commonly known as overcatch provisions). Under the Icelandic ITQ system measures to allow flexibility go further and allow holders to reschedule harvesting of up to 20% of their quota to the following year. A problem with this, however, is that for short lives species in particular, transfers of quota from one year to the next may not be either possible or sufficiently precautionary in the current year. Another means of coping with variable stock sizes in a multispecies fishery is for holders to be allowed to convert up to 5% of their quota to an equivalent price of catch of other species (commonly known as "deemed value" provisions).

Arnason, writing in Hatcher *et al* (2002) argues that share-based ITQ systems (i.e., those in which the quota is a percentage of the TAC) are well-designed to cope with fluctuations in TACs. Not only is the quota automatically adjusted to variations in the TAC, but quota holders are, or at least should be, aware of the associated risk. The market prices for such ITQs will reflect the market's general assessment of and attitude to the risk involved. ITQ fisheries that are subject to large TAC fluctuations include the Icelandic capelin fishery where, over the period 1992 to 2002, the annual TAC varied between zero and 1.2 million metric tonnes without causing any particular problems (Hatcher *et al* 2002).

The theory of ITQs holds that industry profitability should increase and hence firms should be better able to cope with fluctuations in output due to TAC changes. Furthermore Arnason notes that permanent ITQ prices will tend to reflect long term expectations about stocks and will not fluctuate to the same extent as TACs year on year. Hence income variability will be dampened relative to stock variability.

The conclusion is that there is no reason to modify the standard ITQ model to deal with fluctuations in the TACs. But large fluctuations in stock size are still likely to be problematic for the industry when the fishery is managed through TACs. Even when the catch limit is allowed to vary, in years of unusually high abundance there is likely to be a "foregone" catch relative to, say, an input control system. For short-lived species with unpredictable recruitment, some mechanism for in-season (upwards) adjustment of the catch limit based on an updated assessment of recruitment strength may help to mitigate this. Such a mechanism, however, may be costly in terms of the research and management burden, and the magnitude of the adjustment needs to be sufficiently large to justify these costs. An alternative view, and one which should benefit all ITQ holders in the long term, is simply to allow the foregone catch to be foregone, accepting a reduction in short-term economic benefits for long-term stock and ecosystem stability. This option will only hold, of course, in the situation where there is no strong negative relationship between recruitment and high stock sizes (eg where significant cannibalistic behaviour comes into play).

## 3.4. ITQ Management applied to short lived species

While the perceived success of ITQs is leading to a rapid adoption in fisheries for medium and long lived species, there are relatively few examples of the ITQ management of short-lived species. As described in Section 2, there is often greater uncertainty in biomass and hence TAC in these species. Under a precautionary framework. the introduction of ITQs may lead to a reduction in yearly catches and consequently excess fishing capacity. Fishers may end up with capital locked into excess fishing assets that cannot be easily realised. In this section, we review several examples of fisheries for short lived species that are managed using ITQs.

### 3.4.1. South African anchovy and sardine fishery

South Africa's pelagic purse seine fishery, dating back to the 1940s, is its largest in terms of volume landed, with catches totalling several hundred thousand tonnes per year. Sardine *Sardinops sagax* was the initial target species and catches peaked at just over 400 000t in 1962. Subsequently catches declined rapidly and anchovy *Engraulis encrasicolus* (formerly *Engraulis capensis*) became the main target, using smaller meshed nets, between the mid-1960s and the mid-1990s. The two species school together as juveniles and directed fishing for anchovy results in a by-catch of juvenile sardine. Since 1986 the industry has engaged in self-regulation by closing areas for anchovy when the by-catch of juvenile sardine reached unacceptable levels in an effort to re-build the stocks of the latter. Sardine catches have increased steadily since the 1990s and are currently above 250 000t per year (van der Lingen and Durholtz 2005).

These fish are short-lived and prone to large recruitment swings, giving rise to large inter-annual fluctuations in TAC (20% to 90%). Exceptionally strong recruitment over the period 2000-2003 has resulted in a very large anchovy population in recent years (van der Lingen and Durholtz 2005).

Management of the fishery is via an operational management procedure (OMP) that sets separate TACs for anchovy and sardine, although due to their common schooling as juveniles, catches of the two species cannot be simultaneously maximised. The OMP, most recently revised in early 2005 (Cunningham and Butterworth 2005), therefore represents a compromise between catches of the two species.

Recruitment and spawning biomass of anchovy and sardine are estimated through acoustic surveys during May and November respectively (Barange et al. 1999). The TAC for sardine is set at the beginning of the year, based on spawning biomass recorded the previous November. The anchovy fishery depends primarily on the most recent recruitment (from around Oct-Dec of previous year), however, information on the strength of this recruitment is not available at the beginning of the year. In view of this, the anchovy TAC is set at an initial level based on the spawning biomass observed during the November survey and median recruitment from previous years (multiplied by 0.85 as a precautionary discount factor in case recruitment is below the median level). Depending on the results of the recruitment survey in May the initial TAC may be revised up, but not down. A Total Allowable By-catch (TAB) of sardine is set along with the anchovy TAC, and this may also be revised after the survey.

The TAC calculated using the OMP is allocated among the various rights holders in the fishery. Each rights holder gets a fixed percentage of the TAC. Under the terms of the Marine Living Resources Act, 1998 fishing rights are allocated for a maximum of 15 years

(paragraph 18) and are transferable (paragraph 21) subject to application to the Minister. In practice some companies consist of multiple rights holders.

### 3.4.2. New Zealand arrow squid

The New Zealand arrow squid fishery began in the late 1970s. The fishery is made up of squid jigging vessels and trawlers. Due to falling squid prices, the Japanese left the fishery in the late 1980s. The number of squid jiggers fell from the 200 that fished in its peak in the early 1980s to 15 in 1994 (Gibson, 1983).

Arrow squid (*Notodarus* spp) live for a single year in which they spawn once. The biomass available to fishing increases rapidly during the season (as individuals grow) and decreases quickly as the animals spawn and then die. Historical commercial catch and effort data are uninformative with respect to stock dynamics and preseason biomass cannot be estimated. In practice, management assumes a new, discrete stock in each season.

The quota management of New Zealand arrow squid is simplified to a single aggregated species group including both *Notodarus gouldi* and *N. sloanii*. The fishery is divided into four management areas which have individual quotas. While grouping the species is convenient, it may be inconsiderate of an established difference in spatial distribution among species: while they are often caught together, *N.gouldi* are generally found to the north of the Subtropical Convergence and *N.sloanii* to the south (Mattlin *et al.,* 1985).

In the face of high uncertainty in predicted biomass, the ITQ management operates on the basis of a very high, fixed, yearly TACC (Total Allowable Commercial Catch) which may be increased during the year if observed catches are high. Generally, the commercial fishery fails to make their TACC in each area by a large margin. Since 1995, landings have been on average 40% of the TACC across all areas. In one area, the average percentage of TACC met over the last 10 years is just 6%. Four times in the last 18 years have landings for an area exceeded the quota, and only once during the 2003-2004 season did management implement a mid-season increase in an area's TACC.

Implementing high, fixed TACCs has not produced a consistent negative impact on landings. For example, in the Southern Islands management area, a TACC of 32,369t led to declines in landings from 34,534t in 1994 to just 950t in 2000. Unperturbed, management maintained the TACC and landings subsequently returned to 34,635t in 2004. Similarly, with a constant yearly TACC of 50,000t, landings in one of the two North Island management areas dramatically declined from 33,615t (1995) to 521t (2001) only to increase to 9,000t in 2005.

Clearly TACC management of New Zealand arrow squid allows unrestricted output. This is uncharacteristic of ITQ management of longer lived species, and is effectively an input rather than output based system. Little has been written about the economic consequences of the New Zealand ITQ management of arrow squid. The cost per tonne of the ITQs is likely to vary strongly among years according to the available stock biomass. By not restricting catches, the fishery may not benefit from the same economic improvements observed in other ITQ systems: overcapacity may not be discouraged, and improvements in fishing efficiency rewarded, to the same extent as ITQ managed fisheries elsewhere. A possible advantage of setting very high TACCs is that quota enforcement costs are likely be less. It might be expected that there would be deleterious biological consequences of such management. However, there is little evidence that the high, fixed quotas have lead to declines in stock biomass that have not subsequently recovered to relatively high levels.

### 3.4.3. Icelandic shrimp

The Icelandic shrimp fishery became commercially important during the 1960s. The majority of shrimp fishing is located to the north of Iceland and has both onshore and offshore components. While many Icelandic stocks have been subject to ITQ management since the 1970s, the shrimp fishery was a relatively late addition. ITQs were introduced to the inshore fishery in the 1980s to be joined in 1988 by the offshore fishery, the last Icelandic fishery to do so before the establishment of the 1990 general fisheries management act. As described above, the Icelandic system is based on a transferable share of a variable yearly TAC. The yearly TAC for Icelandic shrimp is determined by stock assessment that uses standardised CPUE from log books, trawl survey data post-1973, and standardised trawl survey data available since 1988. Preseason, the biomass available to fishing is estimated using a stock production model coupled with an observed negative correlation between cod abundance and prawn recruitment. The TAC is typically set in the range of 25-35% of the estimated biomass available for fishing. A preliminary TAC is set in June and adjusted in October if high recruitment is estimated. The fishery is not subject to early closures.

The initial allocation of TAC share for the deep sea shrimp fishery was set according to the historical share of total catches in certain 'base' years. Initial allocation was different for the inshore shrimp fishery where TAC-shares of were allocated equally among vessels that recently participated in the fishery.

### 3.4.4. New Zealand flatfish

Similarly to arrow squid, New Zealand flatfish are managed as a species group made up of eight individual species including flounders (*Rhombosolea* sp.), sole (*Pelotretis* and *Peltorhamphus* sp.), brill and turbot (*Colistim* sp.). With the exception of brill and turbot, individuals generally live to 3-4 years of age.

The fishery is managed by ITQs and size restrictions to allow fish to reach size at maturity. The available fishery dependent data are not informative of stock dynamics and consequently, New Zealand flatfish are not subject to stock assessment. Instead a maximum constant yield (MCY) of 2,230t was determined in 1990 on the basis of average catches from 1983 to 1988. The purpose of this reference point is not clear. A constant TACC has been applied that is three times MCY (6,670t) and landings have exceeded the MCY in every year since its calculation. The current TACC is sufficiently high that landings have averaged 58%, and not exceeded 80% of TACC since its inception.

The management of the New Zealand flatfish fishery is comparable to that of New Zealand arrow squid. Similarly to arrow squid, there is no apparent decline in landings the product of setting of high, constant TACC.

# 4. The Australian Northern Prawn fishery

In this section, we provide a short introduction to Australia's Northern Prawn Fishery (NPF). The NPF is both multispecies (nine species in four groups) and targets short lived species. As discussed previously, these characteristics have, in the past, presented significant difficulties for the realisation of economic efficiencies under ITQs. Currently, the fishery is already managed using transferable property rights in the form of ITEQs. In the case of the NPF, inputs are allocated in the form of tradable gear units expressed in headrope length. Given that the NPF currently implements a system of property rights, many of the advantages postulated for ITQs already apply. For example, strong incentives already exist for operators to protect the long term health of the resource. It is worth noting that the current input controls implicitly limit output by restricting fishing to times and areas in which the abundance of the targeted species provides profitable fishing efficiencies. The introduction of ITQs into this fishery is the subject of the remainder of the report.

First established commercially in the late 1960's, NPF is currently one of the most valuable Commonwealth fisheries. It is located off the north coast of Australia covering an area of approximately 800,000 square kilometres. The fishery extends to the outer edge of the Australian Fishing Zone (AFZ) and follows the coast east from Cape Londonderry in Western Australia, to Cape York in Queensland (**Figure 1**). The inshore nature of prawn fishing and area closures limit fishing to approximately one third of the available water.


**Figure 1 The northern prawn fishery (Australian Fisheries Management Authority, 2007)**

The fishery consists of three targeted genera, 4 species groups, and 9 species, which are:

- White banana prawn *Penaeus merguiensis*;
- Red-legged banana prawn *Penaeus indicus*;
- Grooved tiger prawn *Penaeus semisulcatus*;
- Brown tiger prawn *Penaeus esculentus*;
- Blue endeavour prawn *Metapenaeus endeavouri*;
- Red endeavour prawn *Metapenaeus ensis*;
- Western king prawn *Metapenaeus latisulcatus*;
- Red spot king prawn *Penaeus longistylus*; and

- Giant tiger prawn *Penaeus monodon*

White banana prawns and the two species of tiger prawns make up approximately 80% of catches. The remainder is made up primarily of endeavour and red-legged banana prawns.

The seasonality of catches has changed over time as a result of management interventions. **Figure 2** depicts three phases. The first is 1970 to 1985 during which there were no specific controls over fishing seasons. At this time, fishing on tiger prawns extended throughout the year with a dip in the March to May period when vessels shifted their attention to banana prawns. The banana prawn fishery has always been a very seasonal phenomenon with most of the fishing happening in the autumn when the prawns aggregate and form dense shoals or "boils" that are easily targeted and give rise to very high catch rates for a short period of time. The second phase is 1986 to 2003 during which the fishery was split into two seasons the first from late March/early April to mid-May/early June and the second from early August to mid-November. The two-season strategy was established to protect spawning by tiger prawns and also to allow prawns to grow to a larger size before being caught. While the overwhelming picture in this phase was for catches in the first season to be dominated by banana prawns and catches in the second season by tiger prawns, there was still a significant catch of tiger prawns in the first season prior to their winter spawning as the catches of banana prawns declined rapidly. There is also some catching of banana prawns in the second season[6]. In recent years there has been a voluntary code of practice within the industry to avoid catching tiger prawns during the first season. This is in an effort to prevent catching on the spawning stock. This has been incentivised through a decision rule in which the first season can be extended by several weeks (for banana prawns) if at a specified time in the season the catch rate of banana prawns is above a certain threshold and the total accumulated catch of tiger prawns is below a fixed limit[7].

Harvesting of banana prawns is carried out during the day and catch rates decline rapidly over the first few weeks of the season. Twin-rig otter trawling is the most common fishing method and is efficient enough to limit trawls to less than twenty minutes. Fishers use advanced and expensive methods of fish location. For example, during the banana prawn season, spotter planes are often (but not always) used to identify boils of prawns and relay the relevant GPS information to the fishing vessels.

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[6] In the case of white banana prawns this is usually fairly limited. The maximum catch was about 1100 tonnes in 2001, but the average is closer to 200 tonnes. In the case of red-legged banana prawns, which are caught mainly in the Joseph Bonaparte Gulf, the catches are more evenly spread over the two seasons and much less variable from year to year. The average catch in the second season is about 225 tonnes. The catches of the two species do not appear to be correlated over time.

[7] In2006 and 2007 the Decision Rule read as follows:

> *(a) If the average daily catch rate of banana prawns for the 4th week of the first season exceeds or equals 500 kg/boat/day*
> ***AND***
> *(b) If the pro-rata total tiger prawn catch for the whole 4 weeks is less than 26.4 tonnes (6.6 t/week*4)*
> ***THEN***
> *(c) The season is extended for a further 2 weeks*
> ***AND***
> *(d) All existing spatial closures and other management measures will be extended.*

There was also the potential to extend the season for a further 2 weeks if the catch rate was still above the 500 kg/boat/day threshold and the pro-rata total tiger prawn catch for the whole 6 weeks was less than 39.6 tonnes (6.6 t/week*6).

In the tiger prawn fishery, most operators remain at sea for the entire season. During the banana prawn season, vessels either return to port or tranship their landings to a mothership, which meets the trawlers every two to three weeks.

Catch and therefore gross production value, varies widely among years. Gross production hinges strongly on the catch of the more marketable banana prawns and market value. For example, in 2000-2001 the gross value of production reached AUS $175M, by no coincidence the year holding the record harvest of banana prawns. In 2005, total production value was estimated at AUS $74M, a year in which total catches were approximately 5,000 tonnes. The majority of the harvest is sold to the markets of Japan, China and Spain.

The factors driving the variability in the catch of prawns are different among the three species groups. Common banana prawns are short-lived species with stock dynamics that are largely determined by environmental factors (Die and Ellis, 1999). There is little evidence thus far of a negative relationship between fishing effort and future stock abundance for these species (Staples and Maliel, 1994). Endeavour prawns on the other hand, live for two years and there is some correlation between estimated stock size and recruitment which suggests that recruitment overfishing is possible. Tiger prawns are longer lived and have even less variable recruitment. Whilst the unpredictability of the banana prawn fishery has made it difficult to assess, tiger prawns have been subject to stock assessments for many years (Dichmont *et al*., 2003; 2006a-c). Such assessments have demonstrated that excessive fishing during the 1990s was followed by significant reductions in stock size. Catches of banana and tiger prawns are generally comparable and 2-3 times greater than that of endeavour prawns which are not usually targeted and are a bycatch species of operations targeting tiger prawns.

Important changes in fishing efficiency due to the introduction of technologies such as of GPS have prompted restructuring to reduce fishing effort. Today, the fleet consists of 52 vessels, a marked reduction from the 280 that fished during the 1980s (Dichmont *et al*., 2006a). Initially, fishing rights were allocated in boat units based on a formula using hull & horsepower. Now input rights are allocated as individual gear units that control the amount of gear (headrope & footrope length) each vessel is entitled to use. All gear units are fully transferable by either sale or lease. The total amount of gear in the fishery is capped and when effort reductions are required, the total amount of gear is reduced and each operator reduces his gear proportionally. Other input controls include extensive spatial and temporal closures to protect habitats, juveniles and pre-spawning animals. The Australian northern prawn fishery is often cited as a model of successful management in terms of profitability and sustainability (*e.g.* Hilborn *et al.*, 2005).

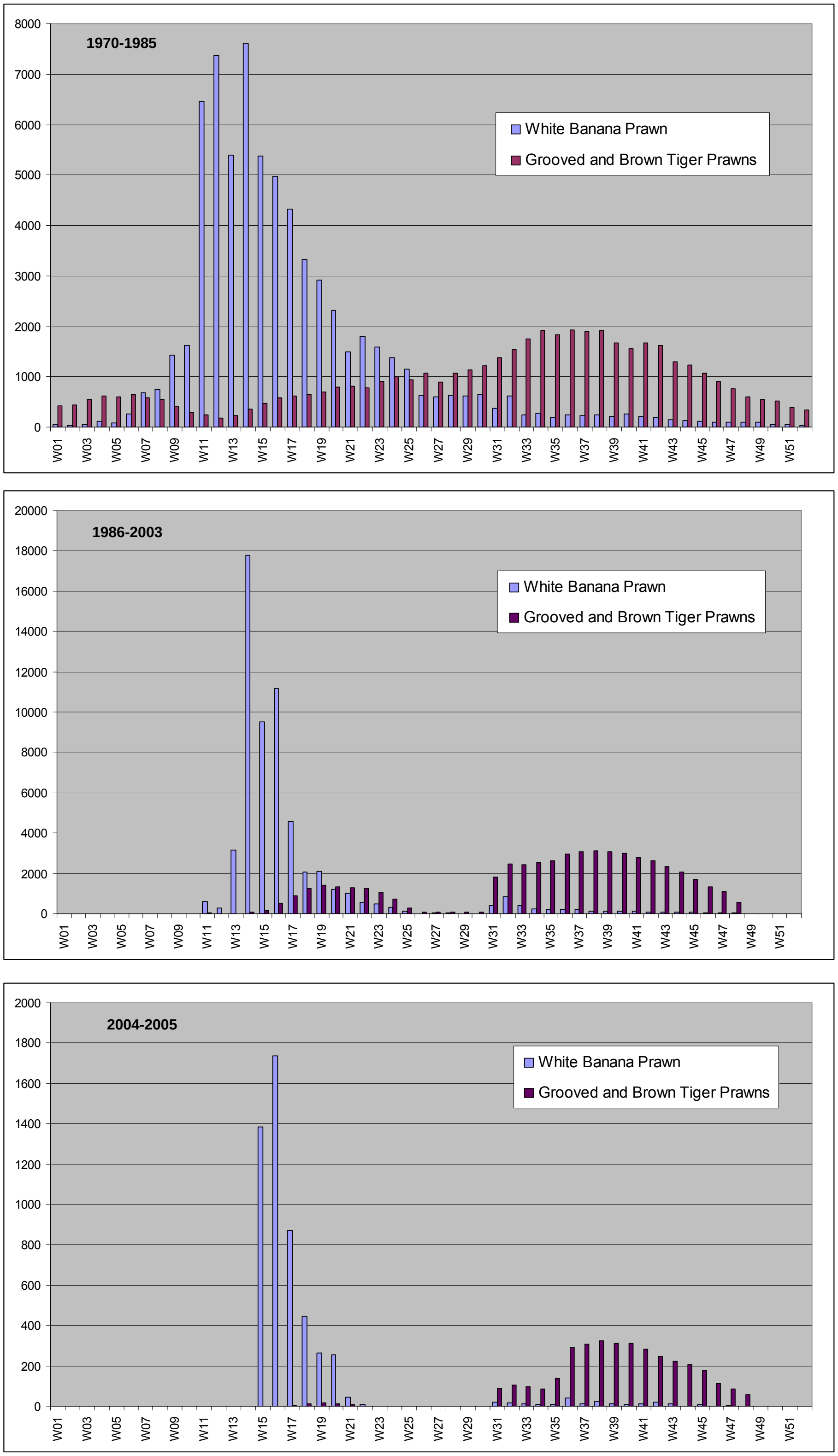


**Figure 2 Changes in the seasonality of catches in the NPF resulting from management interventions: total aggregate catch (tonnes) by week for white banana prawns and the two species of tiger prawns in three periods – 1970 to 1985; 1986 to 2003, and 2004 to 2005.**

# 5. Economic performance of ITQs in the NPF

One of the primary objectives of a move to ITQs is improved economic performance of the fishery. In the northern prawn fishery, however, the proposed move is not from a non-rights based system to a rights based system, but from an input rights-based system to an output rights-based system. This section explores the likely consequences of such a change using a general bioeconomic model, parameterised for tiger and banana prawns. The results provide insights on what is likely to be the optimal management system for each species group.

## 5.1. Introduction

As described in Section 3, ITQs generate well-established gains in efficiency and profitability in a variety of fisheries. They may be problematic, however, in cases where stock declines significantly within season as a result of harvest (in which case some element of a race to fish at high biomass levels and catch rates will be preserved), and when there is substantial environmental variability in stock, making total allowable catch difficult to estimate (Section 3.3). Section 6 demonstrates clearly that the issues associated with implementing ITQs in the NPF are very different for different parts of the fishery – most notably tiger prawns and banana prawns. For example, there is a clear basis for setting TACs for tiger prawns based on the stock assessment and this management strategy appears to be well capable of meeting the requirements of the Commonwealth Harvest Strategy. For banana prawns, however, the situation is very different. For the same reasons that a satisfactory stock assessment has not yet emerged for these species (short life cycle, highly variable recruitment, and highly variable catch and effort data), implementing ITQs in an efficient way will be significantly more difficult. In this section we use an established bioeconomic model of the NPF (Kompas and Che 2003) to explore which instrument (output or input controls) is appropriate for tiger and banana prawns. This also provides approximate measures for the expected returns from ITQ management. We also provide a summary of estimates of the cost of implementing and enforcing ITQs based on established studies.

The exploration of which instrument is appropriate for tiger and banana prawns is a relatively new contribution (in terms of demonstrating the effects in a bioeconomic model in an actual fishery), but the results accord with common sense. Ignoring the effects of effort creep under input controls and the efficiency gains that generally accompany ITQs, the choice of instrument depends on the source and extent of uncertainty. If environmental uncertainty is high, or, in some contexts, where there is large variance in the stock-recruitment relationship, compared to a harvest function (or the variance in CPUE or catchability), then input controls will be preferred. This issue is really the choice of instrument compared to the desired target. If there is a good deal of environmental uncertainly, setting catch will likely miss the target, with lost profitability in years when abundance is especially high. If there is more variance in the harvest function, compared to stock, then output controls will be the preferred instrument[8]. The model that establishes this result in this report is based in structure on the 'stand alone' bioeconomic model of the NPF (Kompas and Che 2003), combined with an established study on the technology of harvesting banana prawns (Kompas et al.2004). The biology in this model is based on a Ricker specification, and does not include more recent and elaborate delay-difference approaches as in the 'Economic MSE Model" currently under development by CSIRO/ABARE/ANU. The relevant target in all cases in this report is Maximum Economic Yield (MEY).

[8] These two issues also affect the assessment: high recruitment variability may confuse estimation of steepness and hence of the target effort, and high catchability variability will result in high uncertainty in TAC calculations.

## 5.2. Instrument choice and the source of uncertainty

A major focus of fisheries economics is designing the appropriate set of instruments to achieve desired management objectives, such as sustainability and economic efficiency. An important consideration when choosing between alternatives is the uncertainty associated with total harvest or total allowable catch (TAC) controls, and the uncertainty associated with effort controls, denoted by total allowable effort (TAE). The principal causes of uncertainty are: unexpected realizations in terms of the stock size such that the TAC is set at too high or too low a level, and unexpected realizations in terms of the catch-effort relationship such that fishing effort is set at an inappropriate level.

Uncertainty in stock size is often cited as one of the main limitations of TAC controls in fisheries. This is because some knowledge of stocks is required to be able to set a TAC that, in turn, also determines any quota allocations vessels may obtain under an individual transferable quota system. If the TAC is set too high because the stock is less than expected then managers risk placing excessive pressure on stocks in low abundance years, with the potential for substantial reductions in the total catch in the future. If the TAC is set at too low a level because fish stocks are greater than expected, managers reduce the profitable opportunities available to fishers. A similar problem also exists in terms of effort controls except that although uncertainty about stock size still impacts the TAE, greater uncertainty arises in the catch-effort relationship, usually denominated by the catch per unit of effort (*CPUE*). If the *CPUE* is higher than expected then a fishery manager risks setting a TAE that is too large and thus places at risk the sustainability of fish stocks and also increases the per unit cost of fishing in future years. If the CPUE is less than expected then the TAE will be set at too low a level, and this will also the reduce the profitable opportunities available to fishers. In both cases (TAC or TAE controls) unexpected realizations in stock size or in the *CPUE* will result in errors and a failure to achieve management objectives.

The bottom-line is clear. Setting effort creep aside (and ignoring in-season updating), which instrument is most appropriate (input or output controls) depends on the source and magnitude of uncertainly. If environmental uncertainty is high, (or, in some contexts, where there is large variance in the stock-recruitment relationship), compared to the variance in catchability, then input controls will be preferred. If the reverse holds, output controls are the better choice (although it should be noted that this conclusion ignores the increase in estimation/implementation error that is likely with output controls). This issue is really the choice of instrument compared to the desired target. If there is a good deal of environmental uncertainly, setting catch will likely miss the target, with lost profitability in years when abundance is especially high (see Danielsson 2002a, 2002b). The following sections test this by examining instruments used for tiger and banana prawns in the Northern Prawn Fishery (NPF).

## 5.3. Bioeconomic model

To compare TAC and TAE controls under uncertainty we need a biological model of the stock recruitment relationship and a specification regarding the relationship between fishing effort and the total catch.

### 5.3.1. Biological Model

The spawning stock-recruitment relationship is based on Ricker's equation (Ricker, 1954), i.e.,

$$R_t = \alpha_1 \hat{S}_{t-1} e^{\beta_1 \hat{S}_{t-1}} + \xi_1 \quad (1)$$

where $R_t$ is the total number of recruits produced in year $t$ and $\hat{S}_{t-1}$ is the spawning stock of the previous year (estimated as the number of prawns). The parameters $\alpha_1$ and $\beta_1$ determine the relationship between recruitment and the number of spawners in the previous year while the term $\xi_1$ represents uncertainty, or the stochastic behaviour of the spawning stock-recruitment relationship.

The underlying relationships within the stock-recruitment relationship must also be modeled. First, the spawning stock is taken as a proportion ($\gamma$) of the total female stock, assuming that female prawns constitute half of the total stock of prawns and the sex ratio (males to females) is 1:1, i.e.,

$$\hat{S}_{t-1} = \left(\gamma\ S_{t-1}\right) / 2 \quad (2).$$

Following Penn *et al.* (1995) and Wang and Die (1996) the spawning stock $\hat{S}_t$ is assumed to be the result of annual recruitment $R_t$ and also fishing effort, defined

$$\hat{S}_t = \alpha_2 R_t e^{-\beta_2 (F_t + m)} \quad (3)$$

where $F_t$ is fishing mortality at year $t$ and $m$ is the annual natural mortality rate; $\alpha_2$ and $\beta_2$ are the parameters. Using existing studies from the NPF, Wang and Die (1996) define fishing mortality in year $t$ as follows:

$$F_t = q * E_t = q * B_t * N_t \quad (4)$$

where $q$ is the 'catchability coefficient' and $E_t$ is fishing effort at year $t$; $B_t$ is the number of standard boats; and $N_t$ is nominal fishing days. The share coefficient on effort is estimated to be one in Wang and Die (1996).

Fishing effort is determined as total 'standard' boat days in the fishery, which is a multiple of total 'standard' boats ($B_t$) and nominal fishing days in the season ($N_t$). In the NPF, one unit of fishing effort is defined as the daily effort of a 'standard' boat that equates boat day units between large and small vessels. In practical terms, this capacity can be measured by boat engine power and a measure of hull units, or the length or the weight of boat. For example, in the NPF boat size is measured in terms of A-units, as a simple linear combination of a kilowatt of engine power and a cubic meter of hull. Thus if we define a standard boat size as $\bar{A}$ units then the total standard boat numbers at year $t$ is given by

$$B_t = \sum_{i=1}^{M} \frac{A_{it}}{\bar{A}} \quad (5)$$

where $M$ is the number of boats in the fishery and $A_i$ the size of boat $i$ in units in year $t$. If there is technological change then (4) needs to be adjusted such that

$$F_t = q * E_t = q * TEC_t * B_t * N_t \quad (6)$$

where $TEC_t$ measures the percentage change in technology (measured by 'fishing power' in the NPF) at year $t$.

## 5.3.2. Catch per unit of effort (CPUE)

To assess the effect of uncertainty on *CPUE*, we must also specify a relationship between catch or total catch and the biology of the fishery. Based on previous work on the NPF, Wang and Die (1996) use the following specification for the catch rate

$$h_t = \alpha_3 R_t \frac{F_t}{F_t + m}(1 - e^{-\beta_3(F_t + m)}) \quad (7)$$

where $h_t$ is the annual catch in tonnes that increases asymptotically to a maximum of $\alpha_3 R_t$ as fishing effort tends to infinity (Wang and Die 1996).

Using (7) *CPUE* at a given point in time is:

$$CPUE_t = \frac{h_t}{E_t} + \xi_2 \quad (8)$$

where $\xi_2$ represents stochastic behaviour associated with CPUE. From (7), under input controls catch is obtained as a function of effort, or

$$h_t = \alpha_3 R_t \frac{qE_t}{qE_t + m}(1 - e^{-\beta_3(qE_t + m)}) + \xi_2 \quad (9a)$$

and, from (7), under output controls effort is obtained as a function of catch

$$E_t = \frac{1}{q}\left[\frac{1}{\beta_3}\ln\left(\frac{1}{1 - \frac{h_t}{\alpha_3 R_t}}\right) - m\right] + \xi_2 \quad (9b)$$

## 5.3.3. Economic Model

To formalize the bioeconomic model, further specifications are required in terms of total revenue and total costs. Annual total revenue of the fishery *($TR_t$)* is defined as the multiple of annual fish catch and the annual (average) price of fish,

$$TR_t = p_h h_t \quad (10)$$

where $p_h$ is the price of fish drawn from an inverse demand curve. Following Danielsson (2002a) and Campbell, *et al.*, (1993) this price is determined using the following specification with data from the period 1990-2003 (ABARE 1990-2003),

$$p_h = p_0 (H_0 / h_t)^{1/\varepsilon} \quad (11)$$

where $\varepsilon$ is the elasticity of demand for catch and $p_0$ is the unit price of the catch when the volume of the catch is $H_0$.

Annual total cost of employing the fleet is assumed to be the sum of labor, material, capital and other costs. Labor costs are represented as a share of total revenue because of the share system for the remuneration crew that also accounts for material costs such as packaging and gear maintenance expenditures. Repair and depreciation costs and other costs (of which fuel is a major component) are assumed to depend on fishing effort that is defined as total ‘standard’ boat-days with the number of ‘standard’ boats ($B_t$) computed as per equation (5). Thus that total harvesting costs are expressed as

$$TC_t = c_F + c_L h_t p_h + c_M h_t p_h + c_K E_t + c_O E_t \tag{12}$$

where $c_L$ and $c_M$ are the share cost of labor and materials per each Australian dollar of output, $c_K$ and $c_O$ are, respectively, the average repair and depreciation and other costs per unit of effort, and $c_F$ is a fixed cost component. The average repair and depreciation cost of a unit of effort ($c_K$) is estimated by dividing total repair and replacement costs by total effort. Average other costs ($c_O$) per unit of effort are estimated by dividing total other costs by total fishing effort.

Using (11) and (12) the annual fishery profit is as

$$\Pi_t = p_h h_t - (c_F + c_L h_t p_h + c_M h_t p_h + c_K E_t + c_O E_t) \tag{13}$$

### 5.3.4. Optimization Model

The stated aim of the Australian government is to maximize economic efficiency in its fisheries subject to a long-term sustainability constraint. Consequently, we specify that the management objective is to maximise expected discounted profits over time. The control variable in the case of TAE control is fishing effort ($E_t$), defined as the number of nominal days fished, while with a TAC the control is exercised via the total catch ($h_t$). Thus with a TAE, assuming fishing effort is observable and also enforceable, total expected discounted profits over period T are given by

$$\max_{E_t} \sum_{\mathrm{t}=1}^{\mathrm{T}} \hat{\Pi}_{\mathrm{t}} = \sum_{t=1}^{T} \frac{1}{(1+\delta)^t} \sum_{t=1}^{T} p_h h_t(E_t) - (c_F + c_L h_t(E_t) p_h + c_M h_t(E_t) p_h + c_K E_t + c_O E_t) \tag{14}$$

where $\delta$ is the discount rate and $\widehat{\Pi}_t$ is the net present value of profit at year *t*, subject to equations (1), (3), and substituting from (9a), where appropriate, to obtain a single control variable in effort.

The problem for the regulator that uses exclusively a TAC control is to maximize expected profits, or

$$\max_{h_t} \sum_{\mathrm{t}=1}^{\mathrm{T}} \hat{\Pi}_{\mathrm{t}} = \sum_{t=1}^{T} \left( \frac{1}{(1+\delta)^t} \right) (p_h h_t - (c_F + c_L h_t p_h + c_M h_t p_h + c_K E_t + c_O E_t) \tag{15}$$

subject to equations (1), (3), and substituting (9b), where appropriate, to obtain a single control variable in harvest. Solving equations (14) or (15) also requires that spawning stock at the period 0 ($\hat{S}_0$) be known.

### 5.3.5. Model Parameters (tiger prawns)

To make the comparisons between TAC and TAE controls under uncertainty we need to specify parameter values for (14) and (15), as well as the biology. Many of these values are in terms of the stock-recruitment model given in (1) and fishing mortality in (6). The parameters for the two main types of prawns (brown tiger and grooved tiger prawns) caught in the fishery are provided in Table 1. Further details on the sources and calculations used to derive the parameters are provided in Kompas and Che (2003).

In addition to using parameter values from other studies, the stock-recruitment equation, given by equation (1) and the *CPUE*, given by equation (8), were estimated using annual time-series database over the period 1971-2000. Initial values are drawn from measures in Wang and Die (1996). Both equations were estimated using Non-Linear Least Squares (NLS) estimation techniques in Microfit. The estimating equation for the stock recruitment relationship is

$$R_t = \alpha_1 \hat{S}_{t-1} e^{\beta_1 \hat{S}_{t-1}} + u_t(\overline{u}, \xi_3) \qquad (16)$$

where $u_t$ is the residual of the regression with mean value $\overline{u}$ and standard deviation $\xi_3$. The estimating equation for the *CPUE* relationship is as follows:

$$CPUE_t = \frac{h_t}{E_t} + u_t(\overline{u}, \xi_4) \qquad (17)$$

**Table 1: Parameter Values Used in the Optimization Models**

| Parameters | Source | Units | Parameter Values | |
|---|---|---|---|---|
| | | | *Brown Tiger* | *Grooved Tiger* |
| **Biological model** | | | | |
| $\hat{S}_0$ | CSIRO | *million prawns* | 15 | 18 |
| $R_1$ | | *million prawns* | 187 | 309 |
| $\alpha_1$ | Wang & Die (1996) | | 14.41 | 45.96 |
| $\beta_1$ | Wang & Die (1996) | | 0.0096 | 0.0548 |
| $\alpha_2$ | Wang & Die (1996) | | 0.111 | 0.047 |
| $\beta_2$ | Wang & Die (1996) | | 0.354 | 0.302 |
| *m* | Wang (1999), Wang & Die (1996) | *annual rate* | 0.045 | 0.045 |
| $\gamma$ | Crocos (1987a, 1987b) | *annual rate* | 0.3 | 0.2 |
| **Fishing model** | | | | |
| $\alpha_3$ | Wang & Die (1996) | | 14.08 | 15.18 |
| $\beta_3$ | Wang & Die (1996) | | 0.494 | 0.544 |

| | | | |
|---|---|---|---|
| Standard A-unit vessel | CSIRO | *A-unit* | 400 |
| Catchability rate of one unit fishing effort | Wang (1999) | *CPUE(kg/day)* | 8.8*(10^-5) |
| **Economic model** | | | |
| The initial price ($P_0$) | ABARE (2006) | *$/kg* | 24 (tiger) 11.80 (banana) |
| The initial catch ($H_0$) | ABARE (2003) | *ton* | 1,800 |
| Price elasticity of demand | Author's calculations | | 15 (tiger) 18 (banana) |
| Share of labour cost per $1 output | ABARE (1994-2001) | | 0.24 |
| Share of materials costs per $1 output | ABARE (1994-2001) | | 0.38 |
| Average repair and depreciation cost per a unit of fishing effort ($c_K$ ) | ABARE (1994-2001) | *$per 'standard' boat- day* | 926 |
| Average other costs per unit of fishing effort ($c_O$ ) | ABARE (1994-2001) | *$per 'standard' boat- day* | 1,890 |

where $u_t$ is the residual of the regression with the mean value $\overline{u}$ and standard deviation $\xi_4$. The estimated results for the two equations are provided in Table 2 where the standard deviation has been converted to a percentage deviation.

The estimated parameters and standard deviations (in percentage terms from mean) of the regression equations for (16) and (17) are provided in Table 2. The results both support the previous biological studies and also the application of the *CPUE* equation given by (8). Table 2 also shows that the variance in the stock-recruitment relationship is smaller in all cases than that for *CPUE* for tiger prawns.

**Table 2: Non-Linear Estimated Results for the Ricker Equation (16) and the *CPUE* Equation (17) Using 1971-2000 Data**

| **Ricker Equation** | **Brown Tiger** | **Grooved Tiger** |
|---|---|---|
| Coefficient $\alpha_1$ | | |
| Estimate | 14.41 | 45.96 |
| *t*-ratio | 6.09 | 9.26 |
| p-value | 0.000 | 0.000 |
| Coefficient $\beta_1$ | | |
| Estimate | 0.0096 | 0.0548 |
| *t*-ratio | 3.16 | 4.16 |
| *p*-value | 0.004 | 0.000 |
| Standard deviation of the residuals of the regression | 21.45 | 15.92 |

| ***CPUE* Equation** | **Brown Tiger** | **Grooved Tiger** |
|---|---|---|
| Coefficient $\alpha_3$ | | 1 |
| Estimate | 14.03 | 15.18 |
| *t*-ratio | 2.91 | 1.94 |
| *p*-value | 0.007 | 0.063 |
| Coefficient $\beta_3$ | | |
| Estimate | 0.494 | 0.544 |
| *t*-ratio | 3.04 | 1.5 |
| *p*-value | 0.005 | 0.147 |
| Standard deviation of the residuals of the regression | 25.53 | 23.15 |

## 5.4. Results (tiger prawns)

Given the nonlinear relationships in the bioeconomic models and the stochastic nature of the problem, a genetic algorithm (Goldberg 1989) imported into MAPLE was used to solve for the optimal solution to the TAE control problem in (14) and the TAC control problem in (15). The optimal solutions for a non-stochastic ($\xi_3 = \xi_4 = 0$) version of the model and also a stochastic version using the estimated standard deviations in Table 2 for tiger prawns and in Table 3 bananas. In both cases the discount rate is set equal to 3 per cent and the time horizon is 50 years, long enough to guarantee that optimal results are sufficiently close to their steady state values before diverting to meet a terminal condition in year 50.

Table 3 shows that in the absence of uncertainty and with perfect information and enforcement, the TAC and TAE controls yield identical results for tiger prawns. Ignoring additional costs associated with each management method (additional monitoring/compliance costs with ITQs, additional monitoring costs associated with effort creep in ITEs) and the associated benefits of ITQs in terms of efficiency gains, it makes no difference which instrument is used if there is no randomness or uncertainty.

**Table 3: Optimal Solutions (Tiger Prawns) of the Base-case and Stochastic Models with a Discount Rate ($\delta$ = 3 %)**

| | | Unit | **TAC control** | **TAE control** |
|---|---|---|---|---|
| **1** | | | | |
| | **Total Expected Profit (mean value)** | *A$* | 365,000,000 | 365,000,000 |
| | **Mean value at steady state** | | | |
| | Annual harvest | *tonnes* | 2,350 | 2,350 |
| | **Average values per year in** | | | |
| | Annual harvest | *tonnes* | 2,250 | 2,250 |
| **2** | **Stochastic recruitment and CPUE model** | | | |
| | **Total Expected Profit (mean value)** | *A$* | 338,000,000 | 316,000,000 |
| | • Standard deviation | *millions* | 21,000,000 | 49,000,000 |
| | **Mean values at steady state** | | | |
| | Annual harvest | *tonnes* | 2,180 | 2,120 |
| | **Average values per year in** | | | |
| | Annual harvest | *tonnes* | 2,120 | 2,060 |

By contrast, there is a difference between the two instruments when the estimates of uncertainty in the fishery are included. The stochastic model assumes variance in stock and CPUE, calibrated to the NPF tiger prawn case, so that the variance in the stock-recruitment relationship is less than the variance in CPUE. The first thing to note is that uncertainty generates lower optimal profit levels compared to the base case, as expected, and regardless of the management device used. However the key comparison is between input and output controls.

Given that the estimated standard deviation in the stock recruitment relationship is lower than in the CPUE relationship a TAC control out-performs a TAE control in terms of expected profits. The differences are not large (3% in mean annual harvest, equivalent to $1.4 million, 6% in total discounted long-term profits). The standard deviation, however, is also considerably lower with TACs (43% of the TAE figure).

*Note that profits are a measure of total profits over a 50-year period, discounted to the present or in current values. Dollar values in year 50, for example, are worth far less today; a dollar 'tomorrow' is worth less than a dollar today (roughly 95 cents at a 5 per cent interest rate). Note as well that endeavor prawns are treated as 'economic bycatch' in the model, adding only to revenues and not to costs, with no stock-recruitment relationship.*

## 5.5. Results (banana prawns)

There is no well-developed stock-recruitment relationship for banana prawns, and some even suggest that it is a random draw. Results in Kompas et al. (2004) however indicated a downward trend in stock, using a time trend as a proxy, accounting for all inputs into fishing and seasonal effects. Nevertheless, without a stock-recruitment relationship it is impossible to mimic the tiger prawn model context, as above. (If this could be done, and the relative

uncertainties could be estimated and if the variance in the stock-recruitment relationship exceeded the variance in the CPUE, as expected for banana prawns, then clearly input controls will be superior to output controls.) Instead, the results are generated by estimates of average catch in banana prawns and associated variance, drawn from an extended version of Kompas et al. (2004). The harvest equation is left unchanged, and calibrated by the frontier production function, again given in Kompas et al. (2004). In equations (14) and (15) changes in stock are just represented my mean trend values and a standard deviation. In this case there is environmental uncertainty is greater than the estimated value of catch per unit of effort drawn from Kompas et al. (2004).

Table 4 shows the results on profitability over a 50-year horizon, at a discount rate of 3 per cent. Profits under input controls are larger, though again the difference is not great nor significant (a 2% increase in annual harvest volume, equivalent to about $900,000), and a 6% increase in discounted long-term profits). However, there is gain in reduced variance with the TAE (50% of the TAC variance). TAE would appear to be the preferred instrument. This makes sense. With environmental uncertainty, it is difficult to set a TAC. Indeed, this result may even hold once a well-developed stock-recruitment relationship is established for banana prawns.

However, the results are not as categorical as with tiger prawns. Uncertainty in parameterization is greater with the banana prawn model than with tiger prawns, increasing uncertainty in the result. Furthermore, the model does not include the option of updating the TAC in-season (as is used, for instance for South African anchovy). In-season sampling and TAC adjustment may offset these results, but on the other hand the cost of performing the in-season assessment also has to be considered. Finally, the result ignores the efficiency gains that likely result form ITQs. These can be considerable, even in a fishery where the TAC is not set by an MEY target (Kompas and Che, 2005).

**Table 3: Optimal Solutions (Banana Prawns) of the Base-case and Stochastic Models with a Discount Rate ($\delta$ = 3 %)**

| | | Unit | **TAC control** | **TAE control** |
|---|---|---|---|---|
| 1 | Base model | | | |
| | **Total Expected Profit (mean** | A$ | 462,000,000 | 462,000,000 |
| | **Mean value at steady state** | | | |
| | Annual harvest | tonnes | 3,690 | 3,690 |
| | **Average values per year in** | | | |
| | Annual harvest | tonnes | 3,250 | 3,250 |
| 2 | **Stochastic environment and model** | | | |
| | **Total Expected Profit (mean** | A$ | 412,000,000 | 438,000,000 |
| | Standard deviation | millions | 179,000,000 | 91,000,000 |
| | **Mean values at steady state** | | | |
| | Annual harvest | tonnes | 3,468 | 3,520 |
| | **Average values per year in** | | | |
| | Annual harvest | tonnes | 3,080 | 3,160 |

## 5.6. Discussion

Both theory and practice indicate substantial benefits from ITQs, in terms of increased efficiency and profitability, in many different fisheries. Instrument choice however depends on the source and extent of uncertainty. Setting aside the cost of dealing with effort creep and any direct efficiency gains that come from introducing quota, our results suggest that for tiger prawns a TAC system would deliver slightly higher profitability (3% annually) and less variability than a TAE system. For banana prawns the results are less clear, suggesting that there would be lower variability in catches and slightly higher profitability (2% annually) but this could be offset by in-season updates.

Clearly, it would seem sensible to examine the implications of a TAC based system for tiger prawns, and the possibility of either continuing with the TAE system for banana prawns or implementing a TAC system supported by some other means of reducing variance in catches, such as in-season updates. We examine the options for TAC control and updates for tiger prawns and banana prawns in Sections 6.3 and 6.4 respectively.

# 6. Setting TACs in the NPF

## 6.1. Introduction

Given the existence of well established property rights in the NPF, the most significant change in moving to ITQs is the shift from input controls to output (TAC) controls. Input controls inherently adjust for the rapid changes in stock biomass associated with fishing on a single cohort of a short lived species such as in the NPF because catch per unit of effort decreases as stock biomasses reach low levels. However, they require continual adjustment to ensure that management objectives, in particular average stock levels and an avoidance of recruitment overfishing, are met. Effective management using output controls is more dependent on reliable, pre-season prediction of yield to set TACs. The efficacy of output controls will therefore largely be dependent on the ability to undertake a stock assessment, or some form of risk analysis to provide information on sustainable yields.

It should be noted that in an ITQ system the calculation of TACs serves two purposes: to ensure that stock status targets are met, and to establish the annual quantity of tradeable rights. Other management tools are also used to meet conservation targets, such as seasonal and area closures. The NPF has a number of well established conservation based seasonal and area closures, and we would not propose to change these at this point. Our consideration is therefore TACs that would be additional to current management methods.

During the 1990s the application of ITQs in the NPF was considered, but the method was rejected largely on the basis of uncertainties over stock dynamics. Today, there is a much better understanding of the stock dynamics, at least for the tiger prawn component of the fishery. Stock assessment methods have improved and now provide a better quantitative foundation for setting TACs. However, introducing output controls across the entire fishery would require the collection of additional data for the other species, particularly banana prawns, and the research of new stock assessment methods that may be costly for industry.

The two species of tiger prawns are subject to a stock assessment undertaken by CSIRO (Dichmont *et al* 2003) which is used as the basis for setting limits on effort. With some modification, this stock assessment can be used to generate scientifically defensible catch limits (Section 6.3). While work is continuing on the other species, including the on-going survey time series, there are currently no stock assessments in place that could inform the

process of setting TACs although in principle one could use more empirical approaches, such as using a stock or environmental index proxy for recruitment.

In the following sections we discuss the basis for setting TACs for the information rich portion of the fishery (tiger prawns) and the other portions of the fishery that are, relatively speaking, information poor (primarily banana prawns).

## 6.2. Strategies for setting TACs

Based on experience from the case studies described in Section 3.4 and elsewhere, we identified the following options for setting TAC levels in the NPF:

Option 1: Set TAC at a level prior to the start of the season and do not adjust it (non-adaptive strategy)

a. Set TAC at precautionary low level and risk missing out on catch
b. Set TAC at higher level and risk depleting the stock

Option 2: Set TAC at a level prior to the season and use closures to restrict fishing if recruitment is lower than expected (adaptive strategy).

Option 3: Set a TAC that may be modified in-season but do not use closures (adaptive strategy)

a. Set initial TAC at a precautionary low level and increase it as information is apparent: risk of lower catches but precautionary for the stock
b. Set initial TAC at a higher level and either increase or decrease it in-season: risk to the stock is higher because decreases may not be possible.

Following consultation with stakeholders, the remainder of our analysis focuses on Options 1 and 3. Option 2 was rejected as not being viable on the basis of stakeholder input. In essence it was felt that the uncertainty that would result from the possibility of an early fishery closure would give rise to an exacerbation of the incentive to race to fish (i.e. to catch as much of the available quota as quickly as possible before the season ends). This would not be a desirable outcome for the fishery.

Having outlined these options, the first question is what units of the fishery to set TACs on. At one extreme there is the entire NPF – all nine species and all areas – while at the other extreme there are the separate stocks of individual species, such as the 7 potential stocks (in 4 areas) of tiger prawns that have been identified on the basis of habitat discontinuities and catch/effort data – Dichmont et al 2001)[9].

Faced with this kind of problem, the preferred and possibly the safest option would be to set TACs and quota allocations to units of the fishery that are essentially the same as those used in the assessment, i.e. for the 7 stocks of tiger prawns. Any other approach (i.e. setting TACs on some aggregate of stock/species units) requires assumptions about the composition of catches and may result in lower TACs to ensure that one or other of the stock/species units are not overfished.

[9] The contribution of these different stocks to the spawning of the following year's biomass may vary, however, due to the lack of detailed information (e.g. genetic data to distinguish genuine stock boundaries) the stock assessment is currently on the scale of the entire NPF.

Tiger prawns and banana prawns are easily distinguishable and are fished in quite different ways. Setting separate TACs for these parts of the fishery is therefore sensible and achievable. By contrast, it is not obvious that it will be possible to set TACs separately for the species within these two groups. In the following sections we explore the options and implications of this.

## 6.3. Setting TACs for Tiger prawns

### 6.3.1. The TAC unit for tiger prawns

The two species of tiger prawns are not readily distinguishable from each other – neither in the fishery itself, nor in the market (there is no price differential between the two). The two species have different habitat preferences: adult brown tiger prawns are fished mostly in 10–20 m over coarse sediments while grooved tiger prawns are taken mostly from fine mud sediments in deeper waters, but the fishery does not apparently target one species or the other preferentially. There is, however, a difference at the stock assessment level, because brown tiger prawns are considered to be more vulnerable than grooved tiger prawns to overfishing by virtue of a lower steepness in the stock-recruit relationship and higher variability in recruitment[10].

The species composition of the catches (**Figure 3**) shows that grooved tiger prawns usually account for more than 60% of the catch in the second season and in recent years it has been closer to 80%. Over the period the proportions of the two species in the catch followed the proportions in the stock fairly closely (calculations performed using data from NPFAG, 2006) but the exact nature of the relationship appears to have been slightly different before and after 2001. Thus a future assumption that the tiger prawn species composition of catches may vary in proportion to the species composition in the stock may be reasonable.

[10] Grooved and brown tiger prawns were previously assessed as overfished. The 2001 stock assessment by CSIRO concluded that the biomass of both species was depleted. Spawning biomass of brown tiger prawns was estimated at 42–54% of BMSY, while grooved tiger prawn spawning biomass was estimated at 66–86% of BMSY. The 2006 assessment concluded that the stocks of both species have recovered and are no longer overfished relative to the limit reference point (0.5 BMSY).

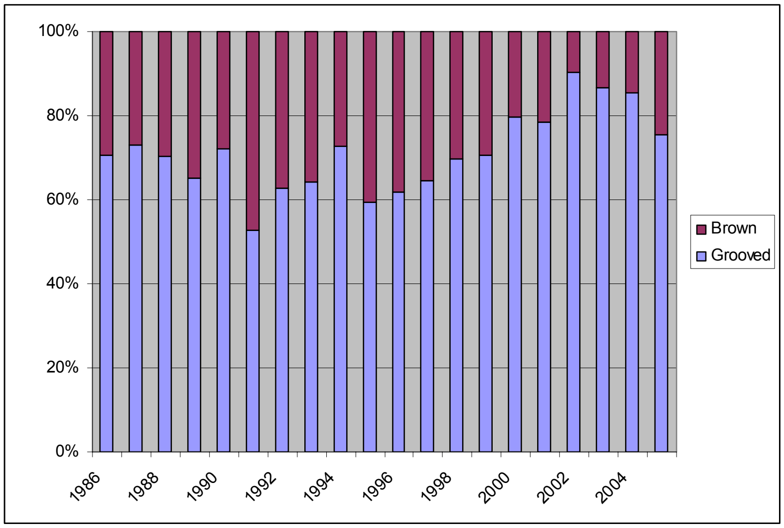


**Figure 3 Overall species composition of the tiger prawn catch by year from 1986 to 2005 for catches summed over the period week 31 to week 49 where the weekly catch of both species combined was greater than 10 tonnes. The period of relatively stable proportions (1986 – 2001) is used for calculations later in this section.**

The problem of setting TACs for the tiger prawns (and others) is a classic multispecies one. Were individual TACs to be set for each species (and, potentially, each assessment area), there may be situations where the TAC on one species was so low as to constrain the catch of the other species by virtue of the proportions of the two in the catch. Equally, if a combined TAC is set it would come with an assumed proportion of species in the catch in each area.

For instance, if the proportion of grooved tiger prawn was assumed to be 70%, a nominal TAC of 2000 tonnes would comprise 600 tonnes of brown and 1400 tonnes of grooved tiger prawns. In reality, the actual catch of the two species would only be known after the season, following application of the catch allocation procedure (see below). If the real proportion departs from this, then the conservation target for one or other species may be compromised.

If, on the other hand, a precautionary proportion was to be adopted so as to meet the conservation target of the most vulnerable or depleted species, assuming a worst-case rate for the catch proportion, the catch of the other species would be artificially constrained (eg in the example above if brown tigers were in need of recovery, and the maximum expected proportion of brown tiger prawns was 40%, the total catch would have to be 1500 t to ensure a catch of brown tigers of no greater than 600t, which would constrain the grooved tiger catch to 900 t).

Catch data for tiger prawns are reported in logbooks for both species combined (this is also true for endeavour prawns). Separate catches for each species are inferred for stock assessment purposes using a *post hoc* catch allocation tool developed by CSIRO (Venables et al 2006). This uses surveys and other information to allocate total catches to species by virtue of assumed patterns of occurrence on a 6 mins lat by 6mins long grid. The work by Venables et al 2006 demonstrated clearly that species composition patterns for tiger prawns in the NPF are complex and dynamic (e.g. see **Figure 4** as an example).

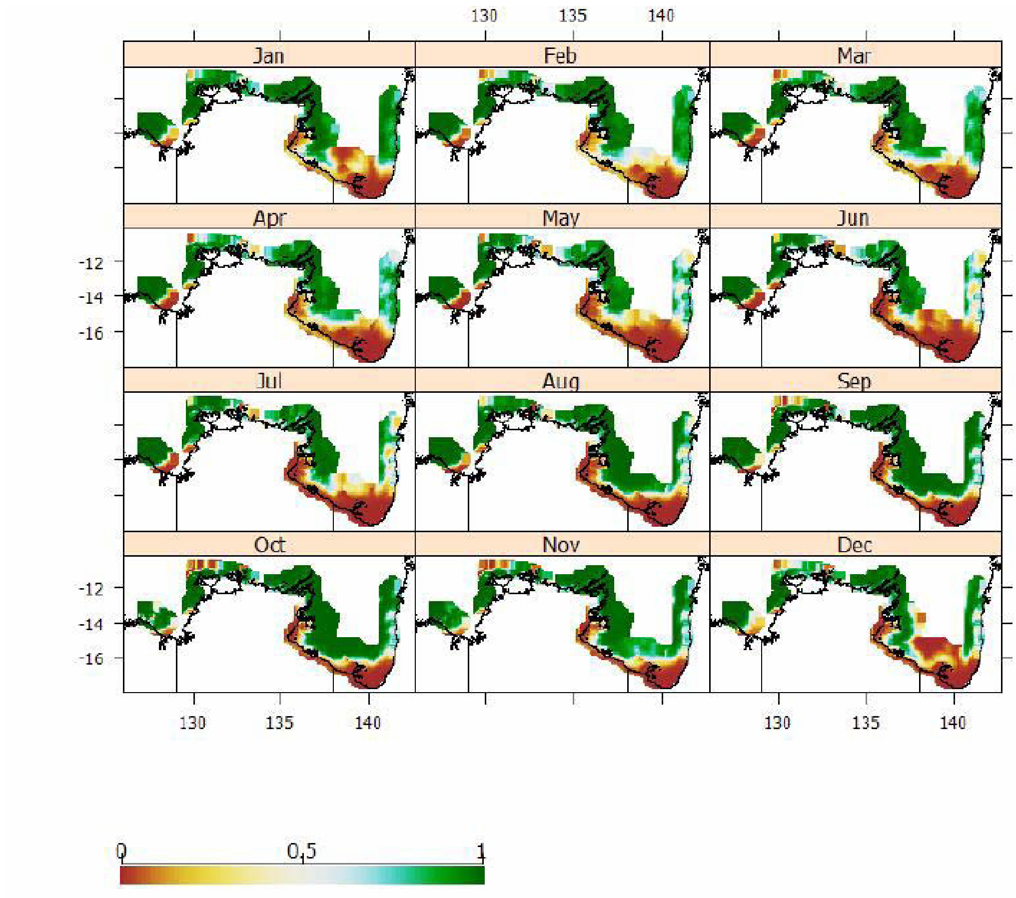


**Figure 4 Figure 36 from Venables et al 2006 showing catch allocation by month for tiger prawns. The scale shows the proportion of the catch assigned to grooved tiger prawns.**

In terms of setting TACs for the two tiger prawn species, we see no obvious alternative to setting a single combined limit because there is no clear basis for vessels monitoring quota uptake at the species level. How, then, should we set out to avoid the problem of ensuring that conservation targets for both species are met, and that catch ratios are the same as TAC ratios? Some options for dealing with this possible implementation error are available:

1. Monitor the catch composition in-season, and develop a real-time estimate of total catch of individual species, closing the fishery when one is exhausted. This is likely to lead to some catch being foregone, and will be particularly difficult to implement in real time, adding considerably to the inefficiencies of operations. We do not recommend further consideration of this option.
2. Initially assume an average catch ratio from, for example, **Figure 3**, or use the relationship between catch ratio and stock size ratio to set an assumed ratio in the catch each year based on assessments of stock status. Monitor the catch composition closely, and adjust it in subsequent seasons to meet conservation targets if it is outside acceptable boundaries. This may result in the total TAC being less than the sum of the possible individual species TACs.
3. As (2), but find other methods of correcting the problem (for instance implementing time/area closures in which the catch ratio departs from the TAC ratio, see **Figure 4**).

Where the ratio can be adjusted through area/time management this method may avoid foregoing available catch

4. To guard against overfishing of brown tiger prawns, use a figure at the lower end of the range (say 0.6). One might choose to drop to this lower end of the catch ratio range only when brown tigers require recovery. A similar mechanism could be used when grooved tiger prawns require recovery. This would result in foregoing some catch on one species.

Considering option (3), there is a significant trend in the species ratio during the season (**Figure 5**). These data suggest that a delay in the start of the season by just two to three weeks would make a significant difference in the species ratio for the whole season. This would have the effect of reducing the portion of the TAC that is taken as brown tiger prawns. A delay of three weeks, for example, increases the average proportion of grooved tiger prawns in the catch for the period to nearly 0.8. Without this it is 0.7. Consequently, changing the start of the season would allow the proportions of the two species in the catch to be adjusted. A quantitative analysis of the potential outcome of a delayed start to the season is provided in Section 6.3.5.2.

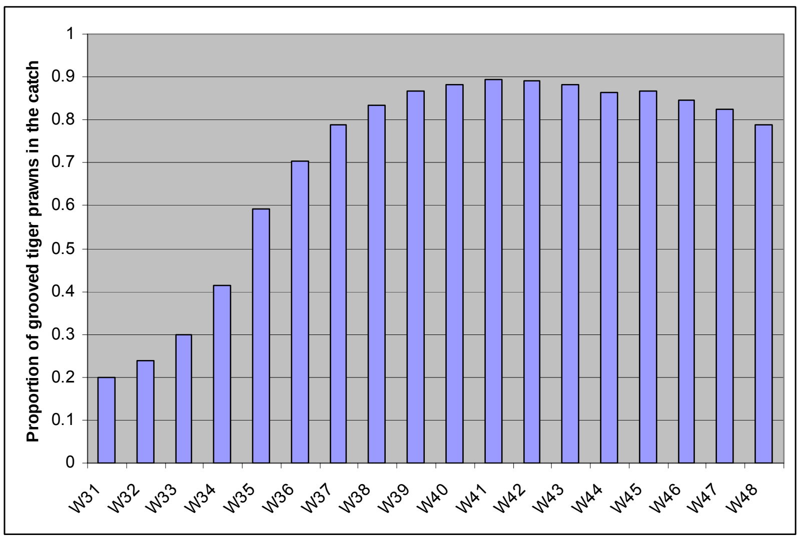


**Figure 5 Average proportion of grooved tiger prawns in the tiger prawn catch during the season from week 31 to week 48 over the period 1986 to 2005 for weeks where the combined catch was greater than 10 tonnes.**

Furthermore, although the picture is not static, the catch in the southern part of the Gulf of Carpentaria is predominantly brown tiger prawns, and (in some of the models in Venables et al 2006) this is also true for the nearshore parts of the eastern side of the Joseph Bonaparte Gulf. The rest of the area of NPF is dominated by grooved tiger prawns. Constraints on the catch taken in these areas could allow a greater TAC overall because of the more robust assumptions about future species ratios in the catch that this would allow. This would, however, require in-season reporting of catch data by area, and verification of those reports in some way. Observer data reported during the season may provide ground truthing to make sure the assumptions about species composition were not significantly incorrect. When quotas in a particular are exhausted, the area would need to be closed and surveillance used to verify compliance with that closure. The use of VMS in the fishery would obviously greatly simplify this process with respect to the licensed fleet, but would not help with unlicensed vessels.

### 6.3.2. Using the stock assessment to set TACs

Tiger prawn fishery dynamics are complex due to year-round recruitment with a variable peak, within-year changes in both spawning patterns and catchability, in addition to a high natural mortality rate, inconsistent catchability among years and seasonal migratory behaviour (Dichmont *et al*., 2006a). An important question mark still stands over the stock structure of the tiger prawns of the NPF. Dichmont *et al.* (2001) proposed seven possible stocks of tiger prawn within in the NPF. While the spatial heterogeneity of tiger prawns is well established, insufficient genetic research has been undertaken to reject the current assumption of single tiger prawn stock, although there is also a general acknowledgement that catches have more of an effect on local stock components than on the whole stock.

In their detailed Management Strategy Evaluation (MSE) of tiger prawns Dichmont *et al*. (2006b) investigated three approaches to setting target effort levels: (1) a Catch-Per-Unit-Effort (CPUE) regression approach that aggregates tiger prawn species, uses yearly data and simply estimates change in relative abundance; (2) a surplus production model that estimates yearly biomass of the tiger prawn species combined; (3) a weekly Deriso-Schnute model (Dichmont *et al.,* 2003; a.k.a. 'statistical catch-at-age with auxiliary data' or 'Integrated Analysis') that assesses the species specific stocks and can account for within-year changes in recruitment. The Deriso-Schnute approach has been applied for many years and is considered the standard method in the stock assessment of the tiger prawns of the NPF.

In their evaluation, Dichmont *et al*., (2006b) found the surplus production method to be unreliable; estimating an unrealistically large and unproductive stock. The performance of the simple CPUE regression approach relative to the greatly more complicated weekly, multi-species, multi-stock, Deriso-Schnute method, is particularly significant. The authors concluded that the sophisticated population dynamics model did not reduce risk of bias in the estimation of reference points such as effort at MSY and does not increase the probability of consistently achieving spawning stock sizes close to that at MSY. Spatially disaggregating the assessment model did not help management strategies to achieve targets. Additionally the authors expressed concern that unknown stock structure and migration could confound the implementation of a spatial assessment model. These findings present a problem because the MSE also demonstrated that reductions in overall effort quotas would not prevent some areas from receiving high levels of fishing pressure and thus target effort levels with a spatial definition may be necessary. Dichmont *et al*., (2006b) conclude that "The Deriso-Schnute method proved sensitive to the specification of catchability and assumptions over the correlation in recruitment among areas". The authors cite the inability to allocate effort by stock and species as the reason for the shortcomings of the Deriso-Schnute stock assessment method.

The development of the MSE by Dichmont *et al* (2006b) offers a forewarning of the potential difficulties in attempting stock assessment in the remaining species of the NPF for which the observed data are less informative of stock dynamics and recruitment and population dynamics are subsequently less predictable. Dichmont *et al*'s (2006b) MSE offers a framework in which input and output controls may be compared.

Given that the current assessment method is based upon input control (effort data), the switch to an output control system (ITQ) will mean that the assessment will have to be modified to allow determination of TAC rather than TAE. Furthermore, the behaviour of the fleet is likely to undergo both short-term (an effective adaptive period) and longer-term changes in practices as the fleet becomes used to the new management regime.

In terms of the data needs or changes required for such an assessment, it is likely that only a minor adjustment to the population dynamics model would be required to use existing data

sets. In the current model, effort dictates the level of fishing mortality that is applied to the stock but when moving to an output, TAC-based management regime, one can compute the exploitation rate as a ratio of the catch to the exploitable stock biomass. The only other change to the population dynamics model required would be adjustment for fleet behaviour over time (i.e. compensating for changes in catchability when conditioning the model on CPUE),

Given the comparatively mature status of the tiger prawn stock assessment, as well as the biological data on these stocks, we developed a full operating model approach to explore the implications of moving to a TAC-based management system. The specifics of the biological and fishery operating model used can be found in Appendix 3. The main issues addressed in this work were as follows:

- The relationship between the assessment precision and the tiger prawn TAC.
- The multi-year performance of a TAC-based management approach driven by the targets and constraints outlined in the Commonwealth Harvest Strategy.
- Using a delay in the start of the season to improve yields and limit the proportion of brown tiger prawns in the catch

### 6.3.3. Relationship between TAC and the assessment precision

The application of the precautionary approach advocates that lower precision in the outputs of the stock assessment should translate into lower TACs due to the higher level uncertainty regarding whether or not the stock is subject to overfishing or is in an overfished state. To explore the potential loss of realisable TAC with decreasing precision in the stock assessment, the operating model was used as follows:

- for a given initial recruitment value, a (stochastic) equilibrium population is simulated – i.e. run for many years with recruitment variability until at equilibrium;
- on each sample from this population, a stock assessment was simulated via a simple randomisation of the perceived spawning stock and recruits (to mimic the data coming from the surveys) using a log-normal deviate with a pre-specified CV;
- a single year TAC was then set according to the harvest strategy – target is SMEY over a five year projection, with an 80% escapement probability for the spawning stock to be above 0.5 * SMSY;
- for a given assessment CV, we obtained a distribution of calculated TACs, and the loss in TAC was calculated as follows:
    - The "true" TAC, C_true, is the mode from the TAC distribution (i.e. the distribution of TACs made up of the TAC related to each population trajectory/sample) with zero assessment CV – the perfect assessment;
    - C_cv is the mode of the TAC distribution for the given assessment CV;
    - % TAC_lost = (C_true-C_cv) * 100/C_true.

This calculation was performed using parameters for brown tiger prawns. The main reason for this was that brown tiger prawns display the highest propensity for recruitment over-fishing (low steepness) and the highest variability in recruitment, so are likely to be the species affected most by such a process. The initial population was set to begin at unexploited equilibrium, as there is some uncertainty as to the level of current biomass and this represents a simple starting point. The calculation was performed for a range of assessment CVs – from 0% (perfect assessment) to 60%, in increments of 10%. A linear model was fitted to the estimated values of % *TAC_lost* and a summary plot is provided in Figure 6.

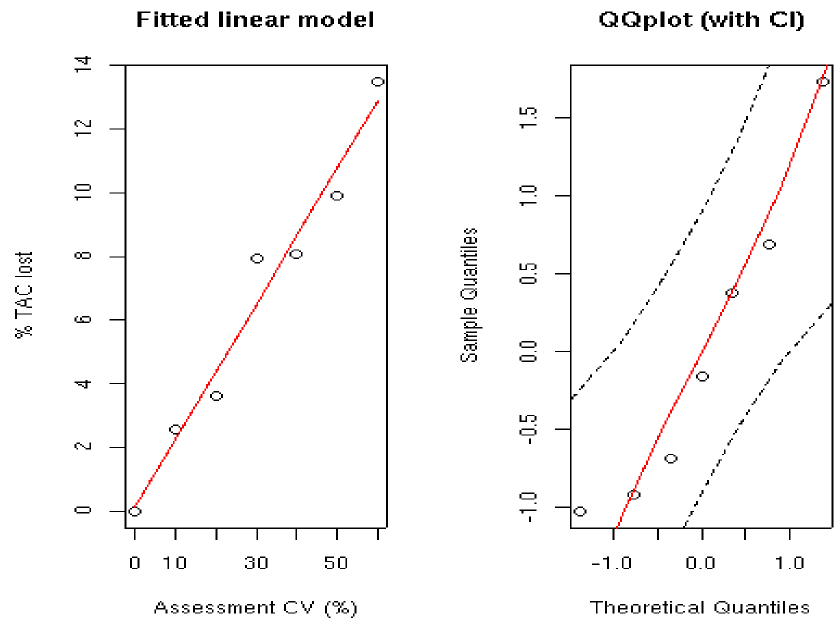


**Figure 6 Summary plot of the linear model fitted to the calculated values of the percentage of realisable TAC lost, as the assessment precision decreases, for Brown Tiger prawns. On the left, we have the fitted linear relationship, and on the right is the QQ plot of the residuals and the associated confidence intervals.**

The actual estimated linear relationship was:

$$\% \ TAC\_lost = 0.34 + 0.21274 * CV\_assessment$$

with an adjusted $R^2$ of 0.9619. While the linearity of the relationship seems - for the sample size we have - to be fairly clear, it is not clear as to whether the cost of increasing the precision in the assessment would outweigh the benefit in terms of an (on the average) higher TAC. One thing is clear: the precautionary nature of the harvest strategy, the low steepness and the recruitment variability undoubtedly combine to give lower TACs as we decrease the precision of the stock assessment.

### 6.3.4. Performance of a TAC management regime given the Commonwealth Harvest Strategy

The Commonwealth harvest strategy gives us the basis for defining a harvest control rule for setting multi-annual TACs. Using our simple randomisation approach to simulating stock assessment, we can define a fairly simple management procedure. With this we can explore, for given levels of assessment and implementation precision, how a TAC-based management system performs over a given time-period, relative to the performance measures detailed in the harvest strategy: the target spawning stock is $S_{MEY}$, with an 80% escapement probability of being above 0.5 * $S_{MSY}$**.** We defined the following harvest control rule, given the details of the harvest strategy:

The TAC for the following year is the maximum TAC which satisfies the following two conditions:

1. Over a five year projection period, the mean (year-averaged) spawning stock has a probability of 0.5 (or greater) of being above $S_{MEY}$.
2. Over a five year projection period, the mean (year-averaged) spawning stock will have a probability of 0.8 (or greater) of being above 0.5 * $S_{MSY}$.

The TAC was considered to be a single-species TAC, and to this end the parameters used in the operating model – from the steepness to the recruitment variability to the MSY ratios - were simply averaged over brown and grooved tiger prawns. We note that this is a naïve assumption, and is made only to semi-quantitatively look at what happens to such a "stock" that posseses a mixture of the two species' biological characteristics. As was the case in the previous section, all the relevant "real" quantities (from the initial recruitment value, to the stock biomass to the TACs themselves) are calculated relative to an initial spawning stock size of 1. The reason for this is that there is considerable uncertainty in the actual estimates of this parameter, given the current stock assessment scenarios. Also, the purpose of this analysis is to explore the potential implications of such a management regime, not the setting of actual TACs for the fishery. Fixing the initial spawning stock size to 1 deals with both these issues – the TACs we calculate are completely consistent inside the model, but are relative and have no meaning in terms of actual levels of catch.

We did not have the relevant data to calculate MEY for this operating model, so a proxy of *1.2 ** $S_{MSY}$ was employed throughout. As before, we began the population at unexploited equilibrium for the first three cases, but for the fourth, to simulate how the procedure would perform in a rebuilding scenario as opposed to a fish-down one, we began the population at 30% of $S_{MSY}$. The management procedure[11] was then applied for a period of five years for four cases:

1. A 10% assessment CV, with perfect implementation of the TAC;
2. A 50% assessment CV, with perfect implementation of the TAC;
3. A 50% assessment CV, with a uniformly random implementation error of $\pm$ 5%
4. A 50% assessment CV, with a uniformly random implementation error of $\pm$ 5% and with the stock initiated at 30% of $S_{MSY}$.

[11] In this procedure, the stock assessment was simulated via randomisation of the spawning stock and recruitment numbers; the harvest control rule sets the TAC for each sample of our population.

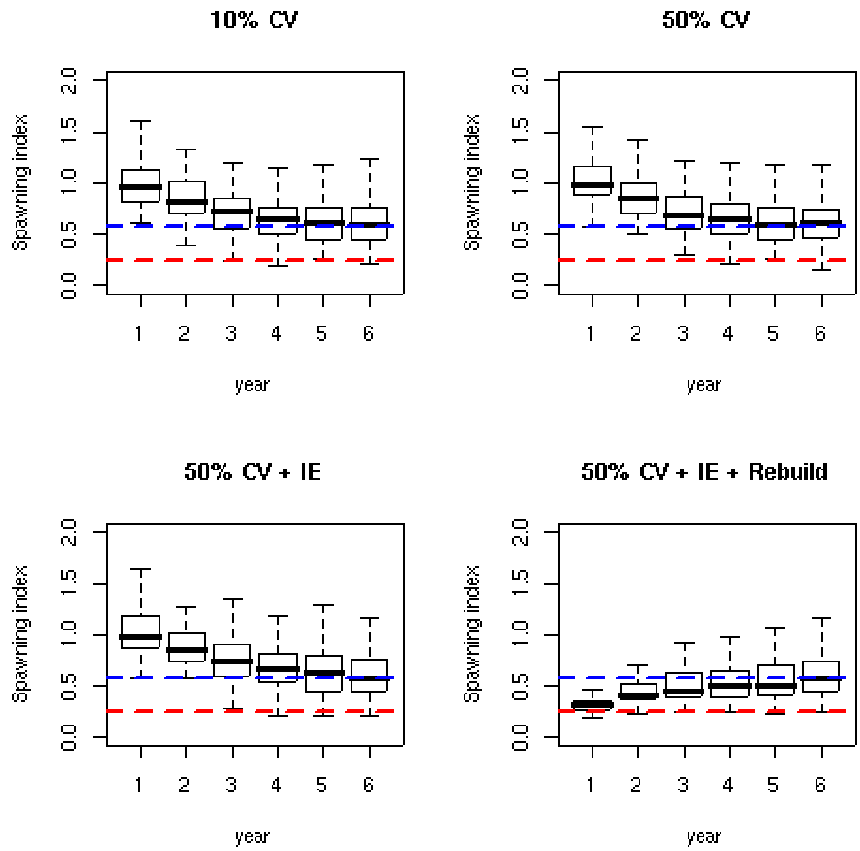


**Figure 7** **Spawning stock dynamics for a 10% (upper left) and 50% (upper right) assessment CV, with no implementation error and with a 50% CV with ±5% implementation error at unexploited equilibrium (lower left) and at 30% of $S_{MSY}$ (lower right). The upper/blue dotted line represents $S_{MEY}$, with the lower/red dotted line representing the limit biomass level of $0.5 * S_{MSY}$.**

It should be noted that the following assumptions are made when defining our reference points, performance criteria and the projection simulations:

- Key biological parameters such as natural mortality, steepness, growth etc. are assumed known and, as such, we are assuming that SMSY is not changing over time.
- Given we are assuming no updates in our estimates of SMSY, and we are assuming that SMEY = 1.2 * SMSY, both our reference spawner levels are not changing over the management period.

Figure 7 shows a boxplot of the spawning stock trajectories for cases 1, 2, 3 and 4 when applying the management procedure. For all cases, the spawning stock is tracking towards the target level of MEY, and is clearly well above the limit level of 0.5 * $S_{MSY}$ at the end of the management period. Although not shown, a run of 10 years was performed for case 2, and it is clear that the stock settles down to the target levels after around 6 years, when beginning from unfished conditions as we are doing in this case, but it is to be expected that the same thing would occur in a rebuilding scenario (Case 4) projected further into the future. As for the case where we have a small level (±5%) of random implementation error (cases 3 and 4) the situation is almost exactly the same as when the TAC is taken without error. For the rebuilding case (case 4), we also see that the TAC-regime is able to bring the stock

dynamics up from the depleted initial level (close to the limit reference point) to a point very close to the target spawning abundance, while also meeting the 80% escapement probability with respect to the limit reference point.

Table 1 summarises the performance of each of the cases, with respect to the goals outlined in the harvest strategy, and we can see that all cases perform well, bringing the stock close to the target level over the five year period, and avoiding taking the spawning stock level below the limit reference point with a very high probability.

**Table 1 Performance summary of the four simulation cases. Here, $S_{final}$ represents the spawner abundance in the final year of the management period.**

| *Scenario* | *$p(S_{final} > S_{MEY})$* | *$p(S_{final} > 0.5 * S_{MSY})$* |
|---|---|---|
| *Case 1* | *0.52* | *0.97* |
| *Case 2* | *0.54* | *0.95* |
| *Case 3* | *0.51* | *0.96* |
| *Case 4* | *0.48* | *0.98* |

Indeed the only real differences seen between the three fish-down cases (1, 2, and 3) are the CVs in the projected spawning stock dynamics and the calculated TACs – for the more precise assessment the projected stock is less variable, and the estimated TACs are, on average, higher. For the lower precision assessment case, the stock is more variable in the future and the TACs are lower, to a degree as was predicted by the work done in the previous section. The levels of implementation error looked at here had virtually no effect at all on the results when compared with a perfect implementation scenario.

For the simulations and the simple management procedure detailed here, in terms of meeting the objectives of the harvest strategy, it would appear that having a very precise stock assessment (a CV of 10%) does not increase the performance of the management strategy versus a more uncertain assessment (a CV of 50%). Indeed, even some TAC implementation error and a starting abundance level very close the to the limit reference point did not stop the procedure taking the stock very close to the specified objectives over a fiver-year management period.

The good performance of this management procedure is due in no small part to the assumption of static biological and economic parameters during the projection period – both SMSY and SMEY are assumed to be fixed ratios of the initial spawner abundance, which is fixed to 1. If there were strong dynamic changes in key parameters such as growth and/or steepness as well as strong changes in the costs of fishing (affecting MEY) then the management procedure would very likely not have performed as well as it did here. If there were such changes in the underlying reference points and performance criteria then this somewhat simplistic view of stock assessment (random mis-specification of population abundance indices) will not be able to tell us whether a TAC-based system of this kind will perform well or not, and a more complex and robust management strategy evaluation would be advisable.

The real difference is in the realised TAC one would expect to obtain with different levels of assessment precision. For a sequence of assessment CVs (from zero to 60%) we showed in the previous section that there appeared to be a linearly increasing trend in the percentage of lost catch compared to the “true” TAC (i.e. that which would be set if we could assess the stock perfectly) as we decreased the precision of the stock assessment. For Cases 1, 2 and 3 as detailed previously in this section, we compared how much of the total catch taken over the management period differed due to assessment precision and implementation error. Over the whole period, the total catch taken for Case 1 (10% assessment CV) was around 6-

7% higher than that taken in Cases 2 and 3 (50% assessment CV for both, and then some implementation error). This figure is in rough agreement with the empirical relationship we saw, with respect to assessment CV and percentage of TAC lost, as the increase in the percentage of TAC lost when going from a 10% to a 50% assessment CV is just over 7%. It would seem to be sensible to consider then a cost-benefit analysis of investing in the scientific program further so as to increase the precision of the assessment, to yield a more optimal TAC.

#### *6.3.4.1. Setting TACs as if the entire tiger prawn "stock" were brown tiger prawns*

In the above simulations we treated the brown and grooved tiger prawns as a single stock, and averaged all the relevant parameters to achieve this. However, brown tiger prawns are more vulnerable than grooved tiger prawns – they are more prone to over-fishing (lower steepness) and display a higher level of recruitment variability, as well as an earlier start to the fishing season – and it may be useful to consider the whole stock with these dynamics. The aim was to see how much TAC one would lose by assuming more precautionary biological parameters. This comparative run was done using the biological and fishery parameters of brown tiger prawns, assuming Case 4 as described above: a stock initialised at 30% of SMSY, with a 50% assessment CV and with the same implementation error term.

We used the Brown tiger's biological parameters when calculating the TAC but we apply this TAC to both the averaged stock and the stock of pure Brown tiger prawns. While the performance statistics for the stock of pure Brown tiger prawns were almost identical to those assuming an averaged stock - p(Sfinal > SMEY) = 0.48, p(Sfinal > 0.5 * SMSY) = 0.97 – the percentage drop in the aggregate TAC over the projection period for the brown tiger prawn-only stock relative to the averaged stock was 19.8%. The status of the averaged stock was, as one might expect, above MEY and almost certainly above the limit reference point at the end of the management period.

### 6.3.5. Multispecies issues for tiger prawns

#### *6.3.5.1. Consequence of departing from the assumed proportion of species in the catch*

In section 6.3.1 we presented several options for dealing with the multispecies problems arising from setting a single tiger prawn TAC. **Figure 3** showed that on average the proportion of grooved tiger prawn in the catch has been around 70%, varying between 60% and 80% as the relative stock sizes of grooved and brown tiger prawn have varied. We also proposed that the assumption that the proportion of species in the catch would normally be the same as the proportion of species in the stock should hold under most circumstances. This should mean that the proportion of species in the catch would also be roughly the same as the proportion in TACs. However, there are two important caveats to this. The first is that since the population growth rate of brown tiger prawns is slightly lower than for grooved tiger prawns one might expect that the proportion of brown tiger prawns in the TAC would be slightly lower than the proportion in either the stocks or the catch. The second is that under the situation where one stock is being rebuilt according to the decision rules and the other is at $S_{MEY}$, the proportion in the TAC for the species that is being rebuilt would usually be lower than the proportion in the stock and the catch.

This could, potentially, compromise the ability of the decision rule to rebuild the stock. We showed above that a 5% implementation error would not cause the current decision rules any problem. We investigated this special rebuilding case though assuming a 10%

implementation *bias* rather than simply random error. The rationale for this is that in **Figure 3** the maximum deviation from the proportion in the catch expected from the proportion in the stock was 10%, in 1991. In this year the expected proportion of grooved tiger prawns in the catch was about 64%, based on the proportion in the stock, but the fishery actually caught only 53% grooved tiger prawns – i.e. the proportion of brown tiger prawns increased from 36% to 47%. Assuming that the normal expected proportion of brown tiger prawns is about 30%, if an additional 10% of the total catch was also brown tiger prawns in one year (i.e. the proportion of brown tiger prawns was 40% of the total rather than 30% of the total) the actual, absolute increase in brown tiger prawn catch would be 33%.

We therefore examined the effect that such an over-catch would have on the ability of the decision rule to recover a brown tiger prawn stock. The initial conditions were set to be at 30% of virgin conditions, with a 50% assessment CV and, as mentioned, a constant 33% positive bias in the catch taken and we then applied the harvest control rule used throughout this section for a period of five years. The brown tiger prawn stock status, given this level of over-catch, was as follows: p(Sfinal > SMEY) = 0.36, p(Sfinal > 0.5 * SMSY) = 0.8. The stock is quite a way below the MEY target point, and barely satisfies the limit reference point condition.

Clearly, such a level of bias away from expected proportions of the two tiger prawn species in the catch would significantly affect the ability of tiger prawns to recover. This confirms that there is a need to monitor the proportions of the two species in the catch, and take corrective action as appropriate.

We suggested that it might be necessary to assume a conservative catch proportion when one or other of the stocks is recovering, and that this would necessarily mean that the total potential combined catch would not be realised. Another option would be to find ways of changing the temporal or spatial distribution of catches so as to adjust the species composition of the catch to one that is nearer to the proportions in the TAC.

#### *6.3.5.2. Delaying the start of the season (see Section 6.3.1)*

The data in Figure 5 suggest one such solution. Adjusting the start date of the second season could significantly alter the proportion of the two species caught, from about 70% grooved tiger prawns under a start in week 31 to 80% under a start date of week 35.

Although this would allow an adjustment of the catch proportions, which might be particularly important to avoid the problems described above, this might also have an effect on the TAC that can be taken. We performed a simple calculation, whereby the fishing season started in week 35 but the same TAC was applied over the whole season, versus opening the season in the normal manner. The initial stock was simulated to begin at MEY, and the two scenarios were then simulated for one year into the future.

When delaying the start of the season by three weeks, on average the stock levels (both in spawner numbers and stock biomass) were lower than when the season was allowed to begin normally. This difference was small, and in relation to the inherent uncertainty in the stock dynamics themselves, and not significant in any statistical sense. The reasons for this are contained in the biology of the stock over the year. The biomass is on its downward phase – recruitment is falling, and natural mortality begins to decrease the stock biomass. Also, spawning in the combined stock begins to rise as the season commences, so we are in effect placing a higher exploitation rate on this temporal part of the stock, as the total catch taken is the same, but it is spread over a shorter season.

There is also an issue of availability in this period – the Brown tigers are slightly more available to be caught than the grooved before week 35, and vice versa after week 35. Given this, a delay in the fishery might raise the exploitation rate on the Brown tigers purely by the fact that we are in effect taking the same aggregated TAC but the Brown stock is less available, which would lead to a raised harvest rate on the (exploitable) Brown stock. While we cannot say definitively which mechanism is the dominant cause, it is more likely to be due to the decreasing biomass trend in this period – the availability issue switches either side of week 35 and we are assuming a mixed stock for this simulation. We could therefore be fishing both sections harder (the stock biomass of both the brown and grooved tiger prawns is decreasing in this period from natural causes) by having the same TAC in a shorter time period.

The conclusion would be that a delayed season opening, without a reduction in the total TAC, may make the situation worse for both species. Clearly, if a season adjustment is to be used to correct a species proportion in the catch to be equal to the species proportion in the TAC, new TACs would have to be calculated rather than simply adjusting the season with existing TACs. Thus it may be a useful short-term measure for correcting the proportion, and may result in less foregone catch than restraining the total catch to using the highest possible proportion of the most vulnerable species (i.e. options 2 and 3 in Section 6.3.1)

## 6.4. Setting TACs for Banana prawns

### 6.4.1. The TAC unit for banana prawns

The situation for banana prawns is similar to tiger prawns, in that there are two species that make up the catch and they are not separated in the catch reports. However, the natural geographic separation of species is much greater in this case. In the commercial fishery, red-legged banana prawns are caught almost exclusively in deep water (>45 metres) in Joseph Bonaparte Gulf (JBG) and white banana prawns elsewhere. Calibration trawls have confirmed this (**Figure 8**): in an area to the west of Croker Island (approximately) calibration trawls were mixed and in the western Joseph Bonaparte Gulf they were pure red-legged banana prawns.  A fairly simple two area allocation, e.g. in line with Darwin, with appropriate levels of precaution built in, would work well to constrain the catches on the basis of the two species. This could include a depth component west of Darwin to account for the deeper distribution of red-legged banana prawns.

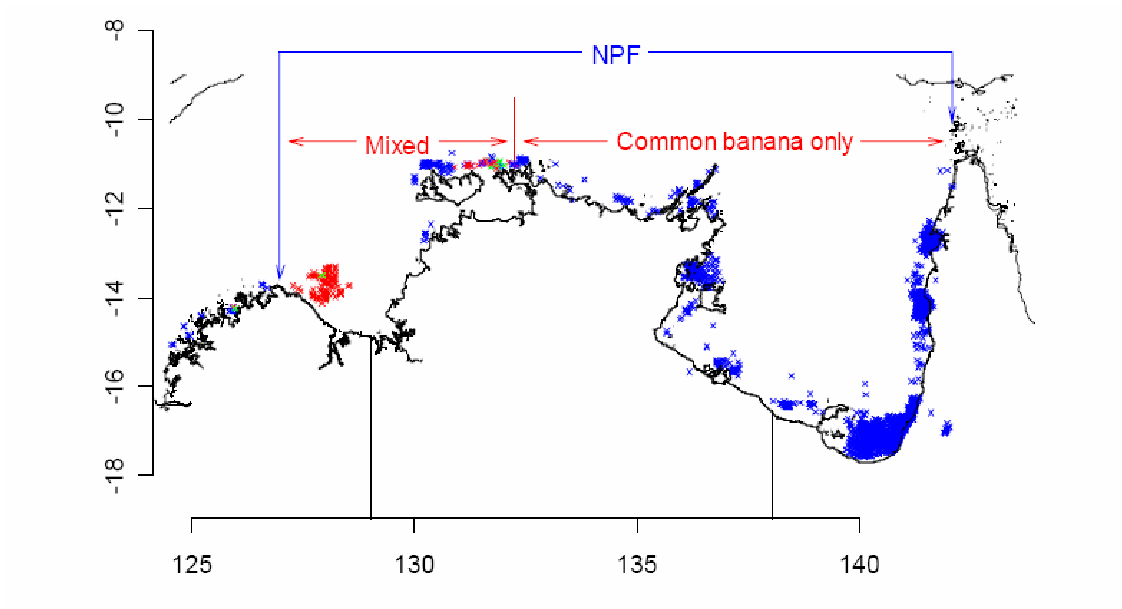


**Figure 8 Figure 50 from Venables et al (2006) showing the geographic separation of banana prawn species in calibration trawls.**

## 6.4.2. Information for setting TACs on banana prawns

The dynamics the banana prawns are more uncertain than for tiger prawns, due to the lack of a quantitative stock assessment. A stock assessment for banana prawns is under development by CSIRO and collaborators[12], but current indications are that for some time to come this will not be suitable for predicting recruitment and catch in the coming season. Problems in assessing stock status include the short life cycle of banana prawns (shorter than tiger prawns), highly variable recruitment, and highly variable catch and effort data. The main season for banana prawns (April-June) lasts only a few weeks, with rapid depletion. A large proportion of the catch is taken in the first 2-3 weeks (**Figure 2**) as vessels target the dense aggregations. In short, banana prawns are much less predictable than tiger prawns.

For these species it will be difficult, therefore, to determine catch limits that do not lead to under-fishing in some seasons and possibly over-fishing in others. Under circumstances where recruitment is markedly lower than expected, the quotas may be set too high. If one assumes that under an ITQ system the current limitations on effort would not apply, the product could be unprecedented fishing effort as fishermen attempt to meet their quotas.

Given that high uncertainty in the stock size and robustness of the stock, very conservative catch limits may have to be set in order to reduce the probability of overexploitation. However, where biologically precautionary quotas are to be set, the degree of under-fishing and therefore unrealised returns increases with uncertainty in the stock status. Whilst precautionary management may be advisable, in a low volume, high value fishery such as northern prawn it could also prove costly. In 2006, under-fishing by 100 tonnes would have cost the fishery between AUS $1M and AUS$2M.

[12] Including Norm Hall, Associate Professor, Centre for Fish & Fisheries Research, School of Biological Sciences and Biotechnology, Murdoch University, Murdoch W.A.

In the absence of a stock assessment, survey data (which may themselves contribute significantly to a stock assessment) may be used directly to indicate the relative strength of the incoming recruitment. The survey undertaken in February each year prior to the start of the first season (April) provides data that may be useful in predicting the size of the incoming year class, but more work is required before this can be used with confidence for either pre-season setting of TAC or in-season update for banana prawns.

Although it is most desirable to set TACs using the results from stock assessments or surveys, they can also be set using a variety of other approaches, ranging from some percentile of the distribution for the historical catch to adjusting catches based on the trend in abundance inferred from monitoring data. In the absence of a means of estimating abundance for banana prawns a plausible approach to setting TACs is to use past seasons' catch data, based on the premise that previous harvests have not severely impacted long-term productivity. Specifically, that previous catches have not lead to stock depletion to levels that could strongly affect recruitment (stock levels have previously existed in a noisy plateau of a stock-recruit relationship). If this is true, keeping future harvests consistent with those from past seasons is a reasonable way to proceed. As a background to this (but by no means a rigorous test of the applicability of the assumption, particularly given the effort creep in the fishery), **Figure 10** shows the average CPUE (catch per day per vessel) and total effort (days) from 1970 to 2005. This approach also it makes no assessment of whether the stock status is consistent with some pre-determined target.

Ideally, the less responsive the method of setting the TAC is to the data on abundance, the more precautionary the TAC setting formula needs to be (Punt 2006). Any TAC set pre-season for banana prawns would therefore need to be low compared to historical catches to avoid the potential for overfishing in years of poor recruitment. This is likely to give rise to a significant forgone catch in years of good recruitment, and hence reduced yields in the longer term.

To avoid this outcome, the initial TAC could be supplemented by an update after the season is underway[13]. The basic idea is that during the first few weeks of the season new information becomes available that significantly improves knowledge about the relative strength of the incoming recruitment – in essence is it a good year, or a bad year?.

Primary candidates for the banana prawn are data from spotters and / or analyses of catch and effort data reported from the fishery. Discussions with various stakeholders in early June indicated that while spotter aircraft can be very effective at locating mud boils and directing shrimp boats to them, the data they provide are too variable to be of value in predicting the strength of the incoming recruitment (for example, it is impossible from the spotter to determine whether the boils identified are caused by prawns or some other species). Catch and effort data obtained from the early period of the fishery are therefore viewed as the best information currently available to update a precautionary pre-season TAC.

[13] See Appendix 2 for a theoretical treatment of an in-season update of TACs under ITQs.

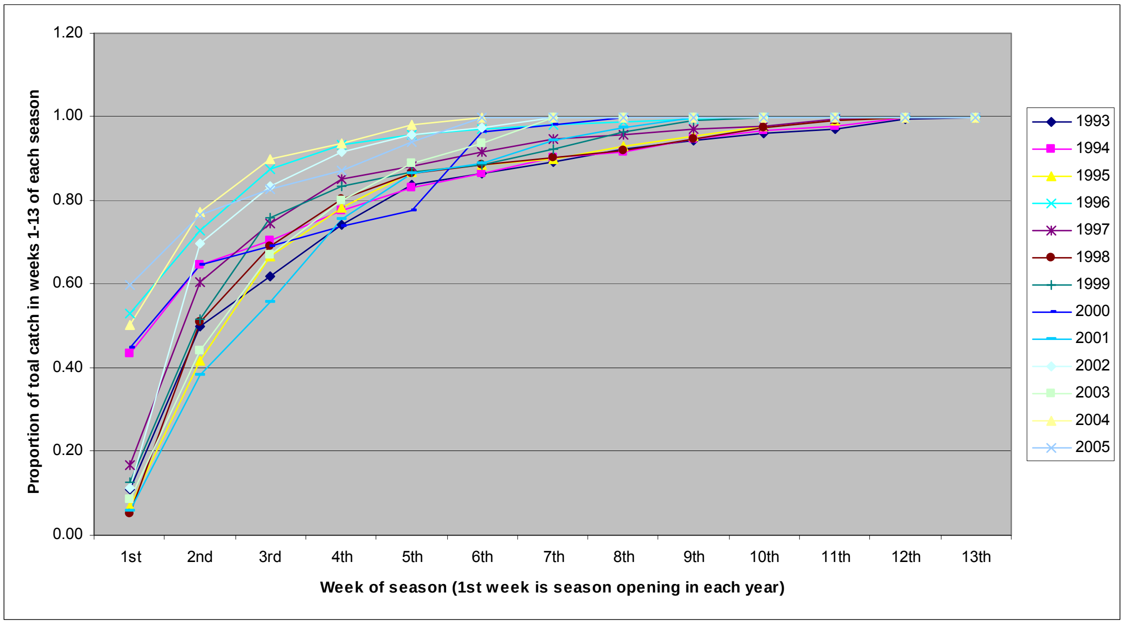


**Figure 9 Cumulative catch of white banana prawns (all stocks) during weeks 1-13 of seasons from 1993 to 2005 (AFMA data)**

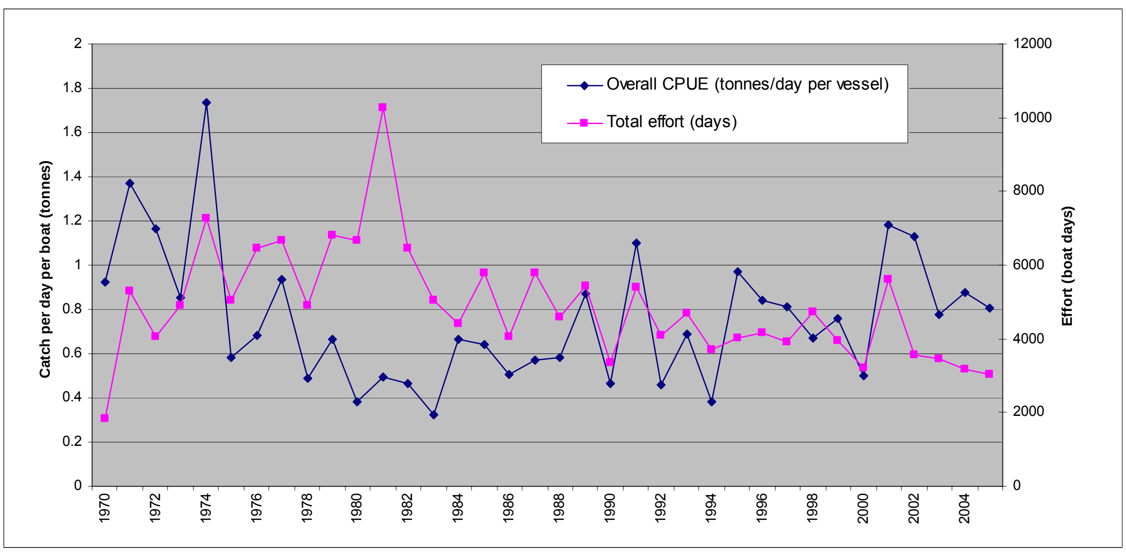


**Figure 10 Average catch per day and total effort targeting white banana prawns in the Northern Prawn Fishery 1970 to 2005 (AFMA data)**

### 6.4.3. Pre-season TACs for banana prawns

As described in the preceding section, in the absence of a stock assessment, a reasonable basis for setting a pre-season TAC for white banana prawns is to use information on catches from past seasons. Punt (2006, informal communication) suggested using an average catch from the first few weeks of the season. Equally, a suitably precautionary lower percentile of the distribution of historical annual catches could be used.

The average total catch for the first two weeks of the season over the period 1993 to 2005[14] (irrespective of actual season start date) is 1,685 tonnes. This is 57% of the average total season (13 weeks) catch over that period. Not surprisingly, this is well below the total catch for the whole season in most years over the period, although it does exceed the total season catch in two years – 1994 and 2000 (**Figure 11**). This is effectively an example of option 1(a) from Section 6.2). The average for the whole of the first season (here taken to be up to the end of June) is just under 3,000 tonnes. Setting the TAC to this level would be a less precautionary strategy (option 1(b) from Section 6.2) and over the period 1993 to 2005 would have (not surprisingly) exceed the catch roughly half the time.

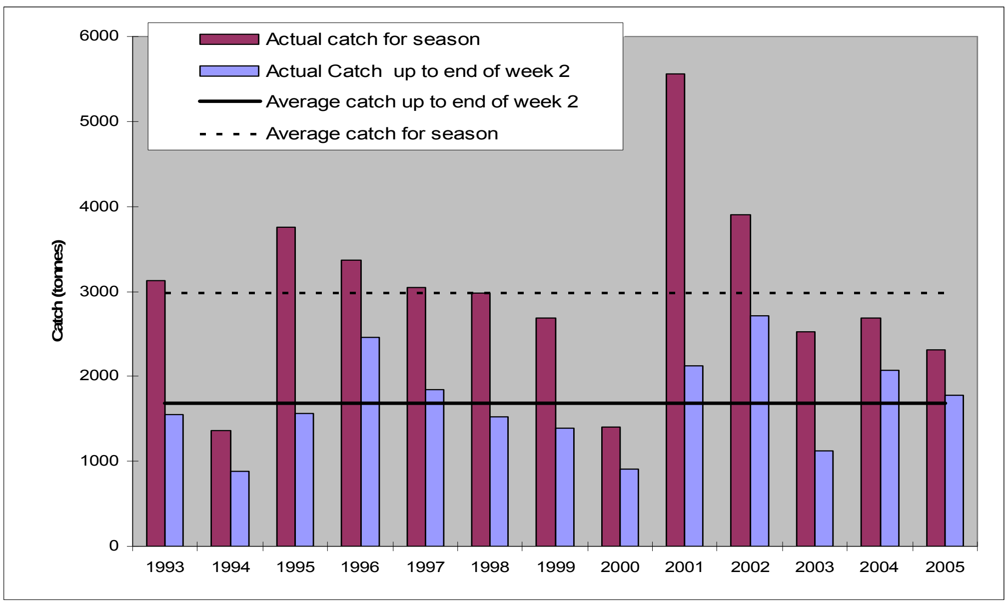


**Figure 11 Catches of white banana prawns over the period 1993 to 2005 compared to options for setting pre-season TACs**

### 6.4.4. In-season updates for banana prawns

Punt (2006) suggested an approach that combined setting a low TAC at the start of the season, to be updated shortly after the start of the season on the basis of new information (option 3a from Section 6.2). This could be achieved for banana prawns through the following procedure (for example).

[14] This period was selected in light of the history of management interventions; 1993 was the year when the number of A class units was reduced to 53,800.

- Set the initial TAC equal to the average historical catch for the first two weeks of the season (low start strategy);

- Update (increase) the TAC after the first two weeks of the season depending on the value of an index of abundance for the first week according to the following equation:

$$TAC_y^2 = TAC_y^1 + \frac{\overline{C}_y^2 I_y^w}{\overline{I}_y^w} \quad (1)$$

where

$TAC_y^1$ is the TAC set at the start of year *y* (e.g. the average catch during the first two weeks of the year),

$TAC_y^2$ is the revised TAC taking the data for the first week into account,

$\overline{C}_y^2$ is (for example) the average catch during weeks 3-4 of the season,

$\overline{I}_y^w$ is the average index of abundance for the first week of the season, and

$I_y^w$ is the index of abundance for the first week of year *y*.

This equation could lead to marked increases in the TAC during the season but it will never lead to a reduction.

To investigate the utility of CPUE as the index we investigated the relationship between early season catch per day and total catch for the season. **Figure 12** illustrates a series of correlations, where average daily catch per unit effort (nominal CPUE) from different portions of the early part of the season is positively related to the catch for the whole season. An *implicit* model is therefore assumed relating weekly CPUE to total catches (see below).

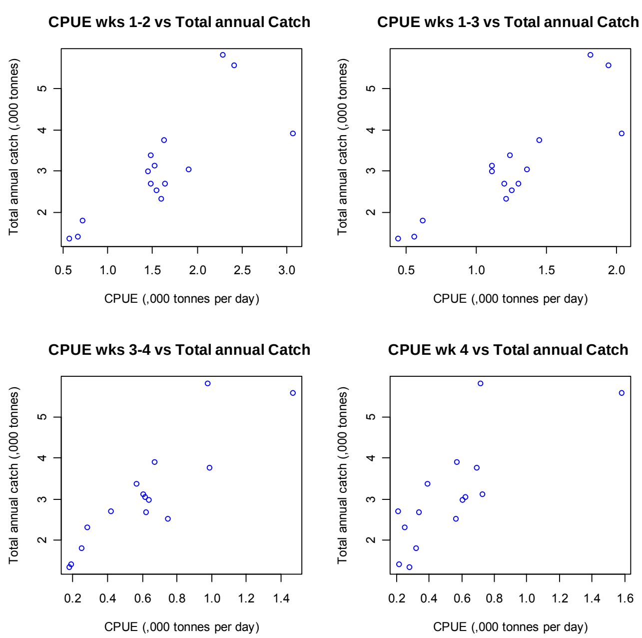


**Figure 12. The positive correlation between early season catch-per-unit- effort (nominal) and total catch of banana prawns (1993-2005)**

Historically, between, 40-80 per cent of the total yearly catch of banana prawns occurs in the first two weeks of the season. This rises to 60 - 90 per cent by the third week. It follows that if initial pre-season TACs are set which are relatively precautionary, an update within the first three weeks is necessary. Members of management and industry believe that updates after a single week would not be practical and that only changes to the quota after two or three weeks would be possible. To allow for a later update in week three, less precautionary TACs should be set to prevent fishers from waiting for an extension of their quota (but with increased biological risk). Additionally, a maximum of two updates were considered viable with a second update occurring no later than week four. In this paper, the performance of these four fundamental strategies are compared. In addition, the effect of moderate increases in precision and accuracy in preseason catch estimates (the product of an hypothetical stock assessment or other quantitative methods using covariate data) are also analysed. These eight TAC update strategies are summarized in **Table 2**.

**Table 2. The eight TAC setting strategies under analysis for white banana prawns.**

| **preseason catch estimated from historical data** | Update in week 2 | Update in week 3 |
|---|---|---|
| no additional update | **1.1a** | **2.1a** |
| additional update in week 4 | **1.2a** | **2.2a** |
| **improved preseason catch estimate** | | |
| no additional update | **1.1b** | **2.1b** |
| additional update in week 4 | **1.2b** | **2.2b** |

The Bayesian statistical approach offers a rigorous means of updating prior knowledge (Gelman *et al.,* 1995; Punt and Hilborn, 1997). We used this statistical framework to 'fit' linear models to the observed data. Total catch and CPUE data are then simulated. For each simulation a prior distribution of predicted catch is updated by the simulated CPUE indices. For example, given the positive relationship between CPUE and total catch, high observed (simulated) CPUE indices provide posterior support for high catches. A TAC can then be set to a percentile of each predicted catch distribution and compared with the simulated total catches to assess the performance of different TAC update strategies.

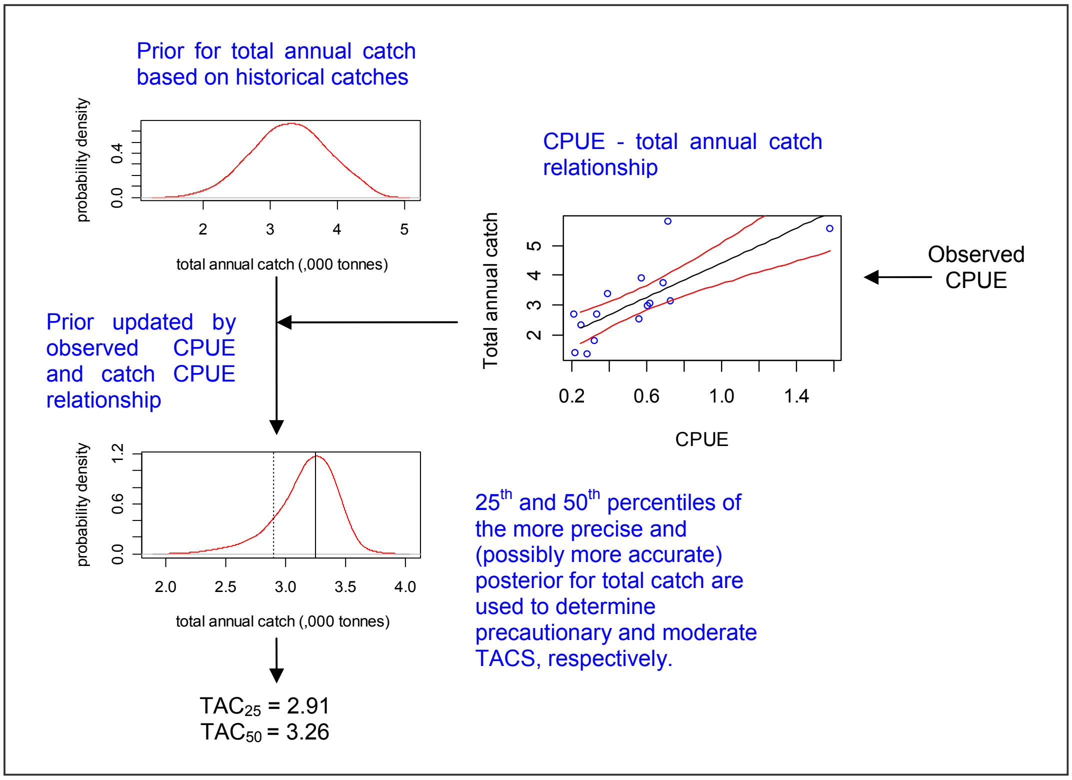


**Figure 13. A diagram illustrating how observed CPUE is used to update the prior for total catch, the posterior of which, is used to determine TAC.**

### *6.4.4.1. Approximating the positive relationship between CPUE and total catch*

The observed correlation among the observed CPUE and total catch was approximated by the following linear model:

$$C_y^{obs} = a_w I_{w,y}^{obs} + b_w \quad \textbf{(1)}$$

Where $C^{obs}$ is the observed total catch in year *y*, $I^{obs}_{w,y}$ is the CPUE over weeks *w* in year *y* and the parameters $a_w$ and $b_w$ are the slope and intercept parameters of the linear model for a relationship between *C* and *I* in weeks *w*.

The subscript *w* refers to a period of the fishing season for which CPUE and C are related, and is determined:

$$w = \begin{cases} 1 & weeks[1:2] \\ 2 & weeks[1:3] \\ 3 & weeks[3:4] \\ 4 & week[4] \end{cases} \quad \textbf{(2)}$$

Observed CPUE and total catch data were conditioned on the model and parameters via the lognormal likelihood function:

$$P\left(C^{obs} \mid a,b,I^{obs}\right)=\prod_{w=1}^{4}\prod_{y=1991}^{2005}\left(\frac{1}{C_y^{obs}\cdot\sigma_w\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(C_y^{obs}\right)-C_y^{pred}\right)^2}{2\left(\sigma_w\right)^2}\right)\right) \qquad \textbf{(3)}$$

Where $\sigma_w$ is the log-normal standard deviation over weeks $w$, $C^{pred}$ is the predicted total catch that is calculated by:

$$C_y^{pred}=\log\left(a_w\cdot I_y^{obs}+b_w\right) \qquad \textbf{(4)}$$

Uniform (and thus relatively 'uninformative') priors were assigned to the slope and intercept parameters (**Table 3**).

**Table 3. Prior specification of linear model parameters**

| Prior | Specification |
|---|---|
| slope (*i*) | ~U(0.5,6) |
| intercept (*i*) | ~U(0,3.5) |

The fit of the model to the data is illustrated in **Figure 14**. The variability in the relationships is closely related to the number of weeks of data included; weeks 1-3 data exhibit the least variable relationship and week 4 data the most.

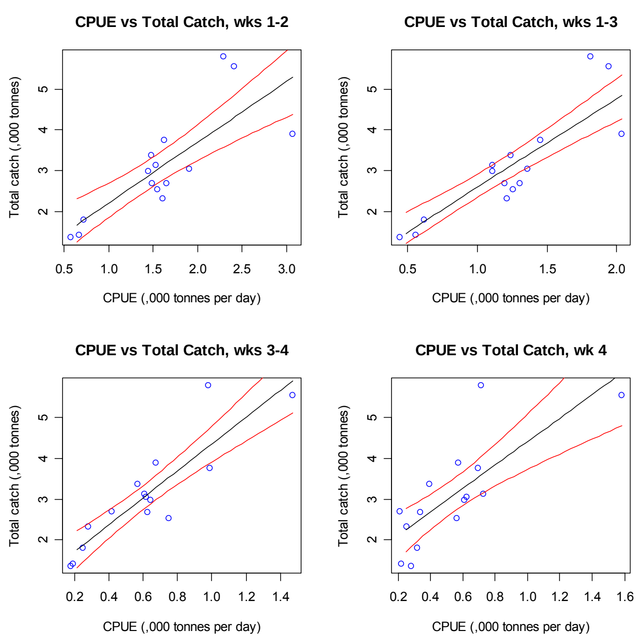


**Figure 14. The observed (points) versus posterior prediction (lines) of total catch given CPUE. Each point represents the average CPUE and total catch for the years 1991-2005. The central line represents the median posterior estimate of catch, the upper and lower lines represent the 90 per cent probability interval.**

The posterior estimates of the slope and intercept parameters for each of the four relationships are shown in **Table 4** and **Figure 14**. In order to preserve the uncertainty in the model fitting process these distributions are used in the prediction of CPUE. As expected there is a negative posterior correlation (also expressed in the covariance matrices) among slope and intercept parameters (**Figure 15**). These posterior covariances are carried from the initial model fitting into the evaluation of the simulated data to prescribe bivariate normal parameter (slope × intercept) distributions for each 'fitted' CPUE-total catch relationship.

**Table 4. The posterior estimates of model parameters including covariance.**

| **Total Catch vs CPUE** | **weeks 1+2 (*w* =1)** | | **weeks 1-3 (*w* =2)** | | **weeks 3+4 (*w* =3)** | | **week 4 (*w* =4)** | |
|---|---|---|---|---|---|---|---|---|
| | **slope (*a*)** | **intercept (*b*)** | **slope (*a*)** | **intercept (*b*)** | **slope (*a*)** | **intercept (*b*)** | **slope (*a*)** | **intercept (*b*)** |
| **mean** | 1.469 | 0.758 | 2.150 | 0.457 | 3.310 | 1.046 | 2.886 | 1.527 |
| **St. Dev.** | 0.290 | 0.481 | 0.293 | 0.360 | 0.527 | 0.367 | 0.718 | 0.456 |
| **5%** | 0.941 | 0.094 | 1.602 | 0.037 | 2.438 | 0.451 | 1.718 | 0.766 |
| **95%** | 1.888 | 1.670 | 2.548 | 1.156 | 4.164 | 1.657 | 4.067 | 2.266 |
| **covariance** | | | | | | | | |
| **x slope (*a*)** | 0.084 | -0.123 | 0.083 | -0.088 | 0.263 | -0.159 | 0.535 | -0.287 |
| **x intercept (*b*)** | -0.123 | 0.229 | -0.088 | 0.123 | -0.159 | 0.126 | -0.287 | 0.216 |

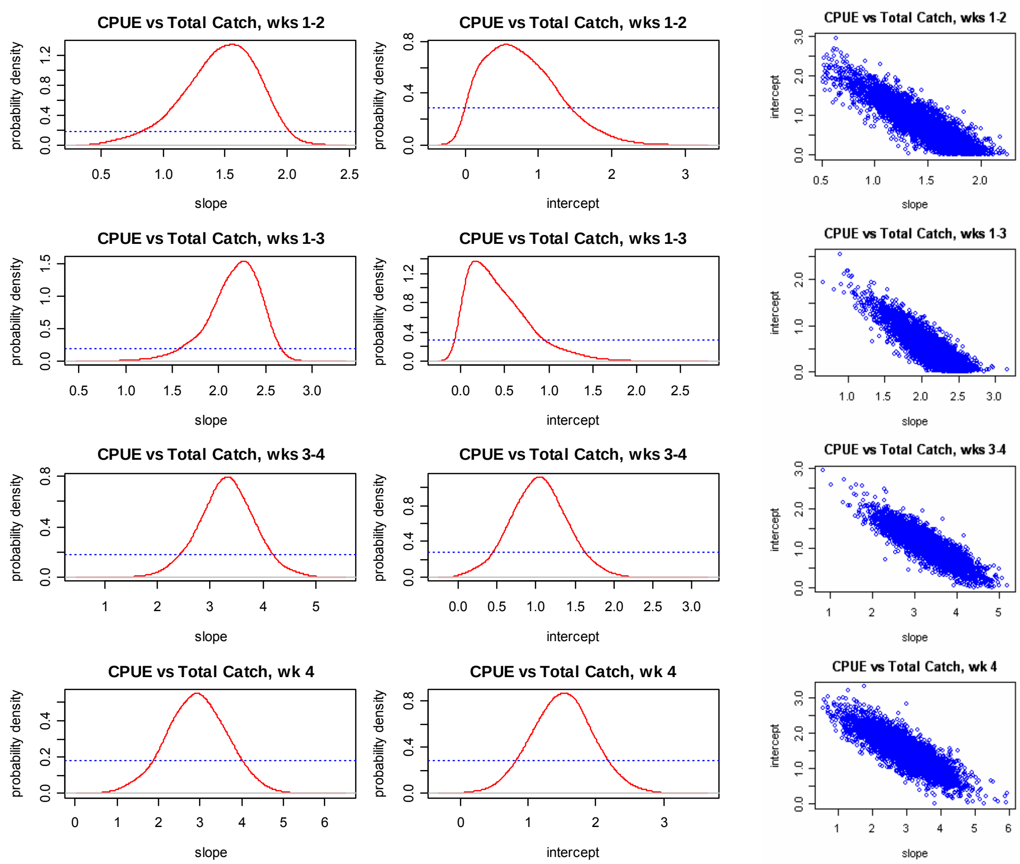


**Figure 15. The posteriors of linear model parameters including covariance plots. The dotted horizontal lines of the posterior density plots represent the uniform prior distributions of the slope (*a*) and intercept (*b*) parameters.**

### *6.4.4.2. Simulating total catch and CPUE data and evaluating the performance of different TAC update strategies*

The initial model was run in the WinBUGS software (version 1.41 – see Appendix 4) and was used to simulate 10,000 (*i*) instances of: total catch versus average CPUE in weeks 1+2 (required for strategies 1.1 and 1.2); total catch versus average CPUE in weeks 1-3 (required for strategies 2.1 and 2.2); total catch versus average CPUE in weeks 3-4 (required for strategy 1.2); total catch versus CPUE in week 4 (required for strategy 2.2). Each of these simulations was considered as a realization of reality and the fitted model parameters used to update prior estimates of total season catch. It follows that the model simultaneously estimates 80,000 posterior distributions of total catch, sets a TAC according to some percentile of each distribution and then calculates the difference between the simulated 'real' catch and this TAC. The output is a distribution representing the size of the TAC relative to the available catch (simulated catch). The simulated CPUE data enter the model in the following likelihood functions:

(Scenario 1.1a/b)

$$P\left(I^{sim} \mid a,b,C^{pred}\right)=\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_1^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{1,y}^{sim}\right)-I_{1,y}^{pred}\right)^2}{2\left(\sigma_1^{sim}\right)^2}\right)\right) \quad \textbf{(5)}$$

(Scenario 1.2a/b)

$$P\left(I^{sim} \mid a,b,C^{pred}\right)=\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_2^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{2,y}^{sim}\right)-I_{2,y}^{pred}\right)^2}{2\left(\sigma_2^{sim}\right)^2}\right)\right) \quad \textbf{(6)}$$

(Scenario 2.1a/b)

$$P\left(I^{sim} \mid a,b,C^{pred}\right)=\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_1^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{1,y}^{sim}\right)-I_{1,y}^{pred}\right)^2}{2\left(\sigma_1^{sim}\right)^2}\right)\right)\cdot$$
$$\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_3^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{3,y}^{sim}\right)-I_{3,y}^{pred}\right)^2}{2\left(\sigma_3^{sim}\right)^2}\right)\right) \quad \textbf{(7)}$$

(Scenario 2.2a/b)

$$P\left(I^{sim} \mid a,b,C^{pred}\right)=\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_2^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{2,y}^{sim}\right)-I_{2,y}^{pred}\right)^2}{2\left(\sigma_2^{sim}\right)^2}\right)\right)\cdot$$
$$\prod_{y=1991}^{2005}\left(\frac{1}{I_y^{sim}\cdot\sigma_4^{sim}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\left(I_{4,y}^{sim}\right)-I_{4,y}^{pred}\right)^2}{2\left(\sigma_4^{sim}\right)^2}\right)\right) \quad \textbf{(8)}$$

Where $I^{pred}_{w,y}$ is calculated by the inverse of the fitted linear function:

$$I_{w,y}^{pred}=\frac{\left(\ln\left(C_y^{pred}\right)-b_w\right)}{a_w} \quad \textbf{(9)}$$

Where the parameters *a* and *b* are those fitted in the initial modelling. These parameters are 'cut' from their prior distributions (the posteriors of the previous analysis detailed in **Table 4**and illustrated in **Figure 15**) preventing information from the likelihood function from updating these distributions (effectively, a parametric bootstrap of slope and intercept parameters).

The prior (the preseason estimate) for total season catches can is either determined by the historical total season catches or an improved prior that is somewhat more precise (20%) and more accurate (the mean lies between the uninformative prior and the simulated level of total catch).

**Table 5. The prior specification of total catches.**

| Prior | Specification |
|---|---|
| Prior for total predicted catch $C^{pred}$ (strategies *a*) (based on historical catch) | ~N($\mu^a$,$\sigma^a$)I(1,6)<br>$\mu^a=2.96$<br>$\sigma^a=1.08$ |
| Prior for total predicted catch $C^{pred}$ (*b*) (improved by stock assessment or quantitative methods) | ~N($\mu_i^b$,$\sigma^b$)I(1,6)<br>$\mu_i^b=(2.96+C_i^{sim})/2$<br>$\sigma^b=0.87$ |

*$C_i^{sim}$ is the simulated total season catch in simulation i. Numbers are in thousands of tonnes.* 'I( , )' refers to interval censoring, in this case limiting catches between 1 and 6 thousand tonnes.

For each simulation, this prior is updated by the likelihood function and the simulated CPUE indices. After all updates have been implemented the difference between a precautionary TAC (set to the 25$^{th}$ percentile of predicted total catch) and a moderate TAC (set to the median of predicted total catch) and the 'true' (simulated) total catch is calculated. Over each of the eight strategies, the 10,000 simulations provide a distribution of predicted total annual catch, a precautionary and moderate TAC, and therefore 10,000 differences between these TACs and the 'true' (simulated) catch. These distributions can be used to analyse (1) the relative performance of the different TAC update strategies, (2) the implications of precautionary and moderate TACs and (3) the possible benefits of preseason improvements in the precision and accuracy of total catch estimates.

The methods above are used only to increase TAC during the season. This is to prevent the promotion of race-to-fish fleet dynamics and possible buy-backs of quota. This approach is used in the absence of a means of estimating biomass and it makes no assessment of whether the stock status is consistent with some pre-determined target.

#### *6.4.4.3. Results*

The results of the analyses are tabulated in **Table 6** and illustrated in **Figure 16** and **Figure 17**. The potential for fishermen to reach their initial quota before update, given low and moderate initial TACs, is summarised in **Table 7**.

The mean difference indicates how far on average the allocated TACs were from the 'real' (simulated) catches. The standard deviation indicates how variable these differences were. For example, a distribution of differences with a negative mean indicates that on average TACs were smaller than the achievable catch. Were two strategies to lead to distributions of TAC minus catch with a mean of zero, the distribution with the largest standard deviation reflects the strategy that makes the biggest errors in the setting of TACs (TACs are set too high or two low in the same frequency but are wrong by a larger margin).

Key results:

1) In all cases, strategies with two updates provided TACs that were closer to the 'real' catches than single update strategies that were in turn closer to achievable catches than strategies without update.

2) Across both TAC setting options (25$^{th}$ percentile and median) and irrespective of the precision and accuracy of the initial total catch estimate, update strategies that first update predicted catch after three weeks, provided TACs closest to the 'real' catches.

3) Improving the precision (by 20%) and accuracy of prior estimates of catch, lead to 20-40 per cent reduction in the standard deviation of the differences between TAC and catch. In other words, simulated stock assessment (a prior for total catch that is 20% more precise and 50% more accurate) has the potential to markedly reduce the magnitude of TAC setting errors. Where TACs were set to the 25$^{th}$ percentile of the predicted catch distribution, the improved prior for total catches made TACs closer to the 'true' catch by 15 per cent on average.

4) TACs set to the 25$^{th}$ percentile of the predicted catch distribution lead (by definition) to TACs that were on average much smaller than those set to the median. As indicated by the 95$^{th}$ percentiles (of Table 6) and the graphs (Figure 16 and Figure 17), TACs set to the 25$^{th}$ percentile of predicted catch are less likely to be set much larger than the catches that are available. The deviances away from the true catch levels were on average less variable where TACs were set to the median of predicted catch.

5) Updates in weeks 3 and 4 lead to a smaller variance between 'true' catch and the TACs that were set.

6) Initial TACs would need to be set to the 50$^{th}$ percentile of historical catches in order to update after three weeks (Table 7). Intial TACs set to the 25$^{th}$ percentile of historical catches would have restricted fishermen 1/4 of the time if updates occurred after the second week (historically, fishermen would already have achieved their quota 25% of the time before an update in week 2).

## Table 6. A summary of the performance of 20 TAC setting strategies.

| TAC setting | TAC update strategy | TAC - 'true' catch ($C^{sim}$) (tonnes) Mean | St. Dev. | 5% | 95% | P(>0) |
|---|---|---|---|---|---|---|
| **25%** | | | | | | |
| | 1.1a) update in wk 2 | -548 | 622 | -1686 | 346 | 0.189 |
| | 2.1a) update in wk 3 | -473 | 483 | -1413 | 166 | 0.147 |
| | 1.2a) update in wks 2 & 4 | -429 | 465 | -1339 | 173 | 0.154 |
| | 2.2a) update in wks 3 & 4 | -402 | 409 | -1190 | 143 | 0.136 |
| | 1.1b) SA: update in wk 2 | -477 | 421 | -1229 | 173 | 0.121 |
| | 2.1b) SA: update in wk 3 | -411 | 333 | -1036 | 60 | 0.082 |
| | 1.2b) SA: update in wks 2 & 4 | -372 | 347 | -1014 | 120 | 0.114 |
| | 2.2b) SA: update in wks 3 & 4 | -355 | 318 | -957 | 95 | 0.114 |
| | no update | -707 | 981 | -2366 | 877 | 0.250 |
| | SA: no update | -685 | 582 | -1633 | 301 | 0.130 |
| **50%** | | | | | | |
| | 1.1a) update in wk 2 | -45 | 603 | -1165 | 821 | 0.527 |
| | 2.1a) update in wk 3 | -49 | 448 | -929 | 523 | 0.535 |
| | 1.2a) update in wks 2 & 4 | -38 | 424 | -871 | 514 | 0.545 |
| | 2.2a) update in wks 3 & 4 | -45 | 378 | -778 | 462 | 0.515 |
| | 1.1b) SA: update in wk 2 | 26 | 382 | -678 | 608 | 0.570 |
| | 2.1b) SA: update in wk 3 | 15 | 287 | -532 | 405 | 0.587 |
| | 1.2b) SA: update in wks 2 & 4 | -8 | 304 | -578 | 416 | 0.548 |
| | 2.2b) SA: update in wks 3 & 4 | -18 | 288 | -544 | 400 | 0.521 |
| | no update | 0 | 981 | -1694 | 1550 | 0.500 |
| | SA: no update | 0 | 550 | -916 | 921 | 0.503 |

*25% and 50% refer to setting the TAC at the 25$^{th}$ percentile and the median of the distribution of predicted catch $C^{pred}$, updated by the simulated abundance indices. 'SA' (Stock Assessment) refers to strategies which involve an improved prior for predicted catch. 'P(>0)' is the probability that TAC-'true' catch is greater than zero.*

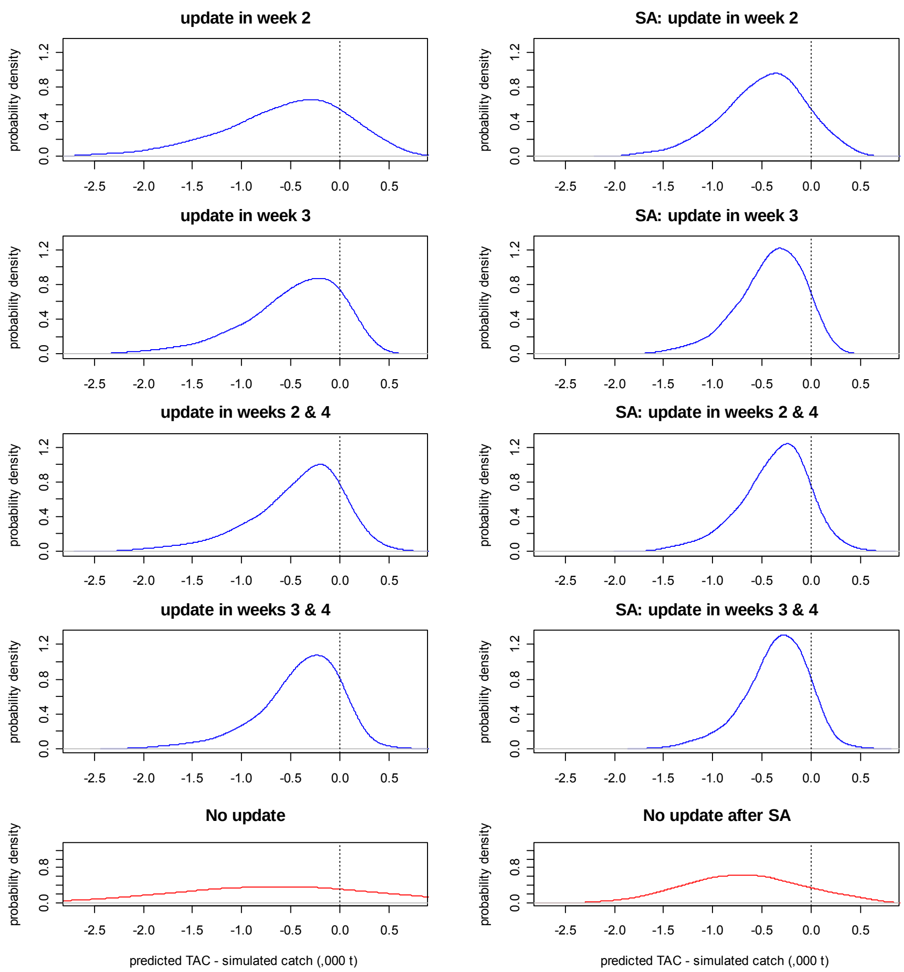


**Figure 16. TACs relative to available catch: TAC (set at the 25th percentile of estimated total catch) minus the 'true' catch (over 10,000 simulations).**

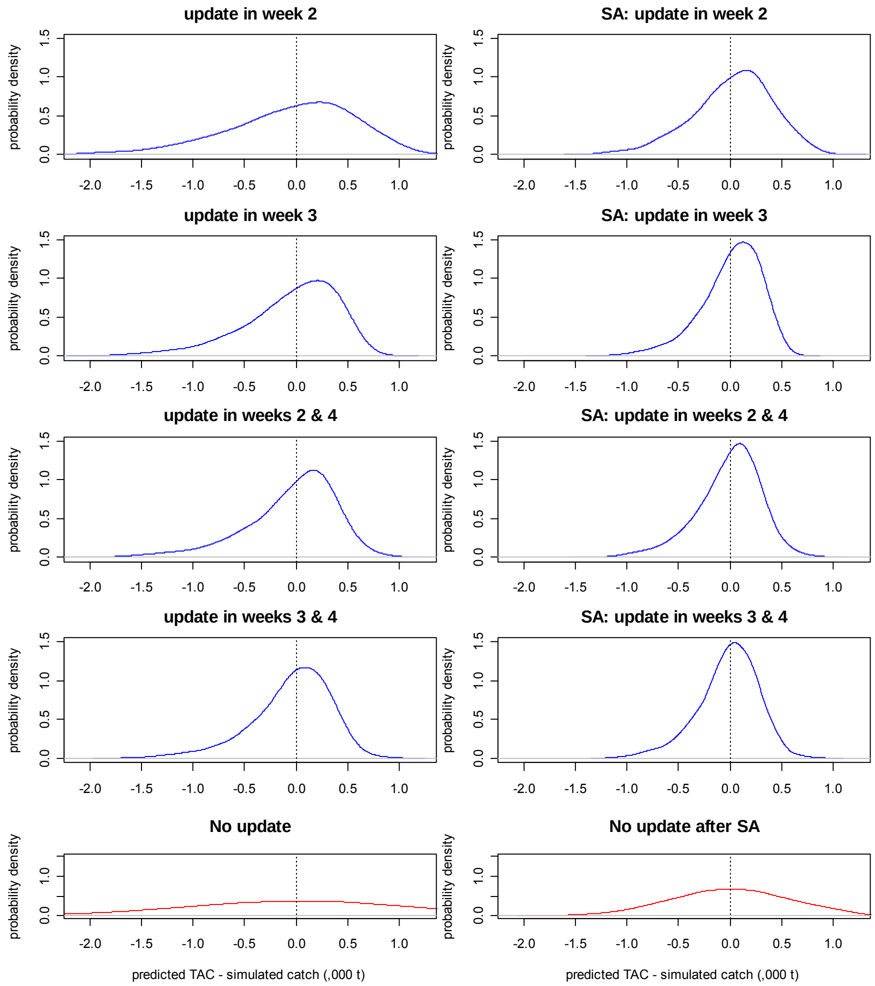


**Figure 17. TACs relative to available catch: TAC (set at the median percentile of estimated total catch) minus the 'true' catch (over 10,000 simulations).**

**Table 7. The implications of setting initial TACs to a percentile of historical catch**[15]

| Initial TAC | | % restricted catch by wk2 | % restricted catch by wk3 |
|---|---|---|---|
| **med** | **(3085 t)** | 0.00% | 16.16% |
| **low** | **(2214 t)** | 22.35% | 51.13% |

*'% restricted' refers the number of years in which catches were higher than the initial TAC level (the percentage of times fishermen would be waiting for an update). 'med' and 'low' refer to initial TACs set according to the median and 25th percentile of historical catches, respectively.*

[15] Similarly to the relationship between CPUE and total catch, the interpretation of these figures relies on the questionable assumption that fishing behaviour will not shift dramatically under output control.

#### *6.4.4.4. Discussion*

These analyses indicate that if a single mid-season update is to be implemented it should occur after three weeks and initial TACs should be set to moderately high levels (the median of historical catches for example) to prevent fishermen waiting for an update. If two updates can be employed, weeks 3 and 4 lead to TACs that are closer to the ‘real’ total catches and yields are, on average, higher. Beyond this finding, the decision over whether preseason stock assessment or the setting of TACs to low ($25^{th}$ percentile of predicted catch) or moderate levels (median) depends on further cost-benefit analysis.

The improved prior prediction (due to simulated stock assessment) of total season catches employed in this modelling lead to gains of between 71 and 47 tonnes where TACs are set to the $25^{th}$ percentile of predicted catch and 27 tonnes where TACs are set to the $50^{th}$ percentile of predicted catch. The cost of stock assessment and its potential for improving preseason estimates must be better known before it can be determined whether cost-effective gains can be achieved. Setting TACs according to the median of predicted catch reduced the size of errors in general since they were now centered closer to zero (**Table 6**). Clearly the benefit is that the occurrence of unrealised catch is less frequent. However, to know whether this a superior option to more precautionary TAC rules, relies on an evaluation of the costs of setting TACs above the level of catches that are available. While catches are likely to be better in good years, under such a strategy, in bad years, race-to-fish dynamics may be encouraged and biological risk increased.

The methods used in this analysis rely on important assumptions. For example, it is assumed that the correlations between observed catch-per-unit-effort and total catch reflect functional relationships; that they are not coincidental. Without a causative relationship among these observed variables, changes in CPUE will not lead to changes in total catch reflecting poor or no predictive ability. A further assumption is that these (hypothetical) functional relationships will persist under the shift to fishery managed by output controls. Output controls may alter the mechanics of the fishery sufficiently to change the temporal relationship between fishing efficiency and total catch, preventing the logical interpretation of historical relationships. A key concern about the approach outlined in this analysis is that it could encourage operators to strive for artificially high fishing efficiencies (or mis-reporting of catch and effort) in order to obtain higher TAC updates. Another critical management problem associated with the TAC rules used in this evaluation, is that they are not determined by established target and limit reference points. It may be necessary to establish proxies of Commonwealth Harvest Strategy reference points in order to implement a method such as this in management of banana prawns.

Despite the shortcomings described above, this analysis demonstrates how covariate data could be employed to update TACs at relatively low assessment cost (it is worth noting however, that the higher data requirements are likely to entail increased reporting costs). It is possible that CPUE reported over shorter time scales could be less susceptible to manipulation once output controls are implemented. Equally, where independent survey data are available, their relationship with total catch could be used in a simular way to the CPUE based method examined here. Where other covariates are found to improve the predictive power of mid-season updates they can be employed in a similar way. A key advantage of the Bayesian approach is that many sources of data (and other models) can be incorporated to update the same catch prediction. The merit of the Bayesian approach is that where precautionary TACs are set, their magnitude is determined by the fit of the model to the data. Where the fit is poor, model parameters are estimated with increased uncertainty and predicted distributions of catch are less precise leading to lower percentiles.

## 6.5. Other species

As with white banana prawns, there is no stock assessment that would support setting TACs on the remaining species in the NPF: red legged banana prawns, endeavour prawns, king prawns and the giant tiger prawn. The concern is that setting quota limits on the main target species may result in increased targeting on these species when the quota species are exhausted. Some form of constraint on the catch of other species if therefore likely to be needed. Equally, however, there is a concern that such constraints have the potential to significantly impact the catch of the main target species, if, for example a quota for a minor species, such as endeavour prawns, is reached and a vessel therefore has to leave the fishery before its quota for the major species, e.g. tiger prawns is taken. This, in turn, raises the concern of highgrading, which will require significant monitoring and enforcement to control.

### 6.5.1. Setting TACs for endeavour prawns

As shown in **Figure 18**, there is a significant catch of endeavour prawns during the second (tiger prawn) season[16], hence, although inter-annual variation in these catches is high, there is a real possibility of increased targeting at this time, particularly towards the end of the season. To guard against this, the option of setting a separate quota on endeavour prawns should be considered, along with the costs of monitoring and enforcing these limits.

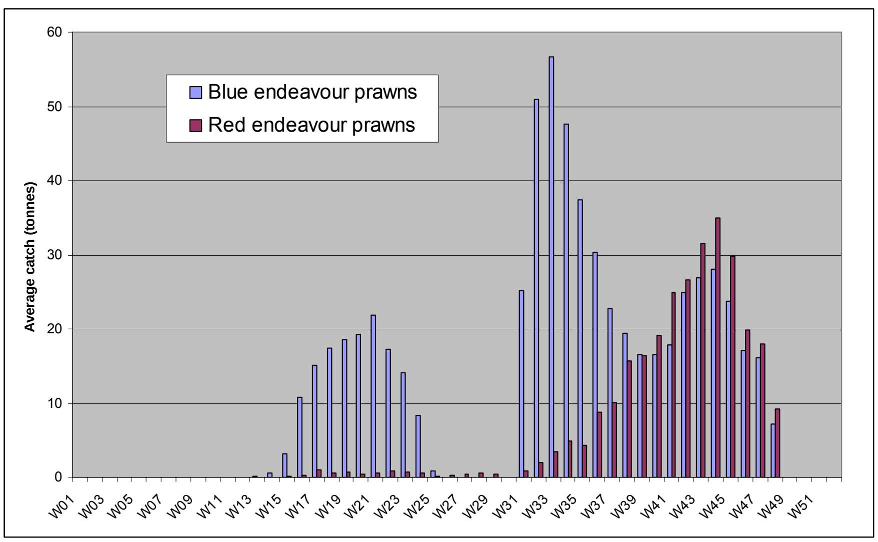


**Figure 18** **Average total catch per week (all vessels) of blue and red endeavour prawns over the period 1993 to 2005**

Lacking a stock assessment, we explored the option of using historical catch data – more specifically catch ratios - as a means of setting TACs for endeavour prawns. Endeavour prawns are largely caught as a bycatch of fishing operations targeting tiger prawns. **Figure**

[16] There has also been a significant catch of blue endeavour prawns during the first (banana prawn) season, but this is now much reduced due to the voluntary reduction of catches of tiger prawns in the first season.

**20** shows that the ratio of endeavour prawn catch to second tiger prawn catch has ranged between (roughly) 0.4 and 0.7. If the endeavour prawn TAC were based simply on an average ratio there is a risk that in some years, endeavour prawn quotas would be reached before tiger prawn quotas had been exhausted. Even allowing for differences between vessels and the opportunity for trading of quota to enable vessels with larger than average catches of endeavour prawns to continue fishing, the is a possibility that the tiger prawn season could effectively be ended early for some vessels due to high catches of endeavour prawns. This may, of course, be a necessary consequence of constraining the catch of endeavour prawns within conservation limits, however, presently there is no clear indication of what these limits are.

Taking these points into consideration, we have developed the structure of a potential TAC rule for endeavour prawns. This is to set the TAC to the smaller of either the historical maximum recorded annual catch of endeavours or the TAC for tiger prawns multiplied by some percentile of the historical ratio of endeavour prawn to tiger prawn catch. For demonstration purposes the 75th percentile could be used. Mathematically, this would be represented as follows (alternative percentiles could also be used (see **Figure 20**):

$$TAC^{e} = \min\left(TAC^{t}_{75}, \max\left(C^{e}_{y=1970:2006}\right)\right) \quad \textbf{(10)}$$

where $C^e_y$ is the catch of endeavour prawns in year *y* and

$$TAC^{t}_{75} = TAC^{t} \cdot \Delta^{et}_{75} \quad \textbf{(11)}$$

were $\Delta^{et}_{75}$ is the 75th percentile of the distribution of annual endeavour prawn catch / second season tiger prawn catch (**Figure 20**) and $TAC^t$ is the TAC that is set for tiger prawns in the second season. This rule would have the effect of constraining endeavour prawn catch within rough historical limits while minimising the chance that the TAC on endeavour prawns would restrict the catch of tiger prawns (this would have happened only once since 1990 according to **Figure 20**)..

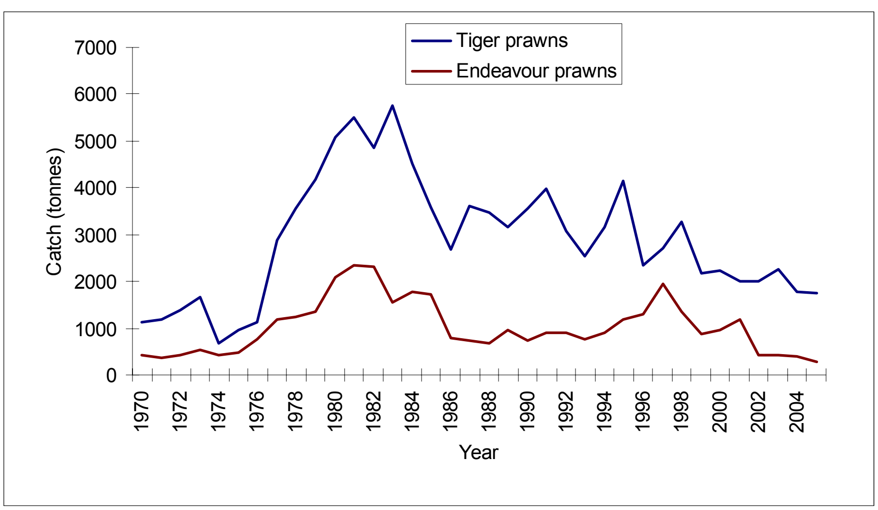


**Figure 19. The annual catches of tiger and endeavour prawns (red and blue species combined) and the ratio of endeavour catch divided by tiger catch.**

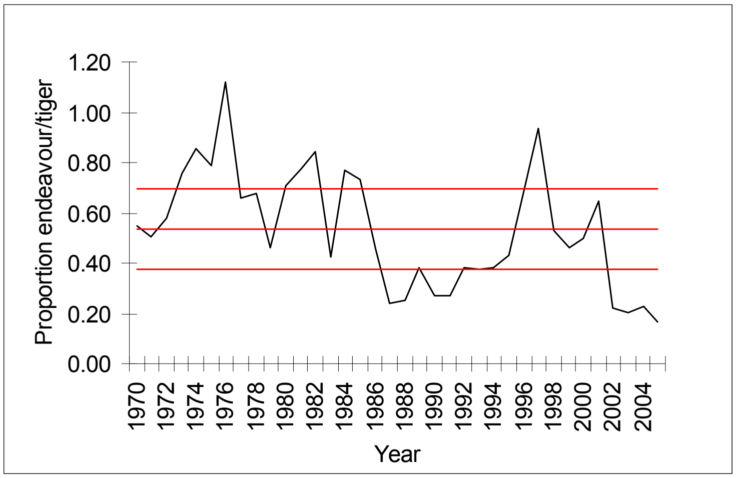


**Figure 20. The ratio of annual endeavour to second season tiger prawn catch from 1970-2005. The red horizontal lines represent the 25th, 50th and 75th percentiles.**

Regarding the apportionment of the endeavour prawn TAC between species, the ratio of catch of blue and red endeavour species has varied mostly between 0.2 and 0.7 (red/blue) (**Figure 22**). This ratio could be used to allocate separate TACs for the individual species. However, for practical purposes this should probably be used only as a target to be monitored, and the TAC should be set simply on the species group of endeavour prawns.

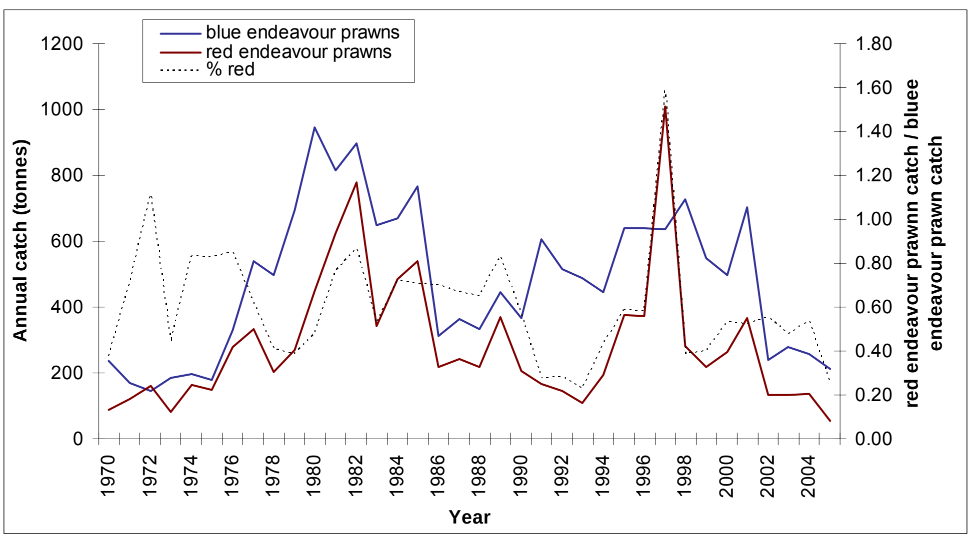


**Figure 21. The annual catches of blue and red endeavour prawns and the ratio of red endeavour prawns catch / blue endeavour prawn catch.**

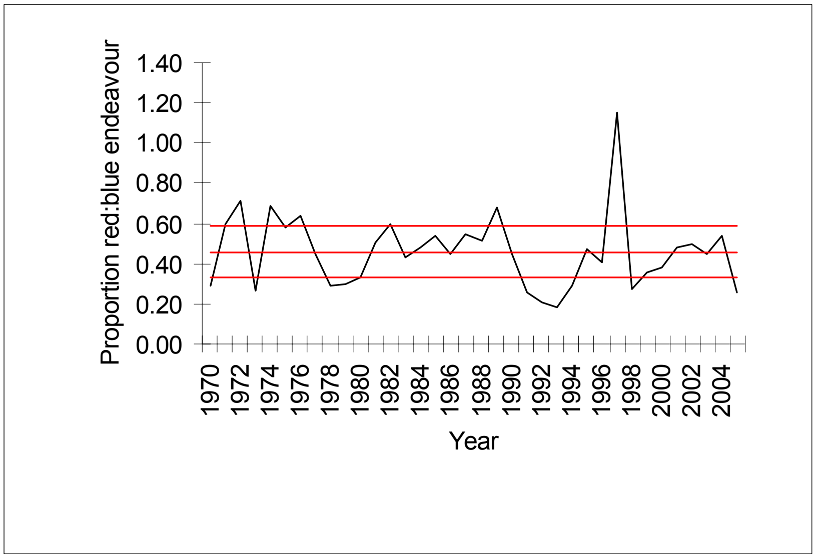


**Figure 22. The ratio of annual catch of red endeavour prawns to blue endeavour prawns from 1970-2005. The red horizontal lines represent the 25$^{th}$, 50$^{th}$ and 75$^{th}$ percentiles.**

The consequences of applying such an approach can be illustrated by considering how it would have performed based on historical catches. By setting a TAC to varying fractions of the observed annual tiger prawn catch, the differences with the observed endeavour prawn catches illustrate the potential problems with such an approach. Clearly this is somewhat confounded since the ratio is defined by the same historical catches. Nevertheless such an exercise demonstrates the trade-off between biological precaution and output that is determined by the level of the established catch ratio. By definition, higher percentiles of the catch ratio lead to higher endeavour TACs and fewer instances where historical catches may have been constrained (**Table 8**)

**Table 8. The affect of different TAC setting strategies on the catch of endeavours relative to historical levels. Average difference is the TAC minus the historical catch**

| | TAC setting strategy | | |
|---|---|---|---|
| | TAC 25 | TAC 50 | TAC 75 |
| ratio endeavour:tiger | 0.375 | 0.534 | 0.693 |
| average difference (t) | -253 | 71 | 390 |
| % years where TAC is greater than historical catch | 22% | 56% | 72% |

*TAC 25, TAC 50 and TAC 75 refer to a TACs set for endeavour prawns on the basis of the 25$^{th}$, 50$^{th}$ and 75$^{th}$ percentiles of the historical ratio of annual endeavour prawn to tiger prawn catches (endeavour prawn catch / tiger prawn catch)*

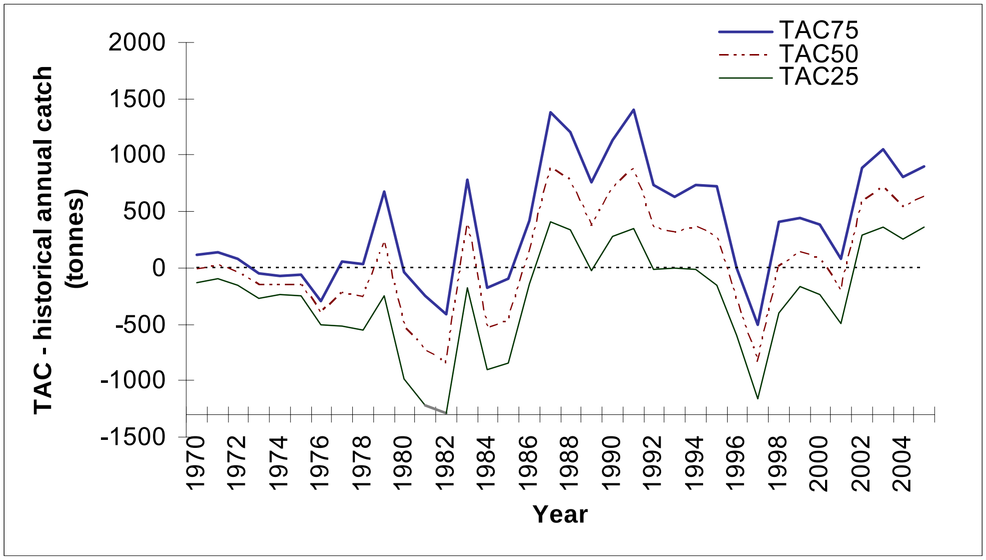


**Figure 23. The implications of setting TACs using different percentiles of the catch ratio of endeavour prawn catch / tiger prawn catch. TAC 75 represents the difference (TAC - historical catch) between historical catches of endeavours and the TAC set using the 75th percentile of the catch ratio (endeavour catch / tiger catch). TAC 50 and TAC 25 are derived from the median and 25th percentiles of the catch ratio. Where the lines exist above zero the TAC was higher than the observed catch, potentially increasing biological risk. Where the lines exist below zero TACs were lower and output may have been constrained.**

It is important to highlight that the use of historical data in this case may well be misleading since the functional relationships that exist between catches and subsequent stock sizes are not preserved. For example, reduced fishing power leading to 'restricted' catch (where TAC is less than an observed annual catch) may in reality, have lead to increases in stock sizes in following years and thus higher tiger and endeavour TACs. Similarly to white banana prawns, without an established population dynamics model it is difficult to determine the biological implications of exceeding levels of catch that may have been previously sustainable. Estimates of intrinsic rate of increase or the definition of a stock-recruit relationship are likely to be prerequisites for an informed risk assessment of increased levels of catch.

### 6.5.2. Assumptions and limitations of setting TACs according to historical catch ratios

It is important to note the assumptions of the method proposed above for setting TACs based on historical catch ratios. The method described assumes that the historical catches of both species of endeavour prawns and red-legged banana prawns have not severely affected long-term productivity. Specifically, that historical catches have not reduced the stock to levels that strongly affect recruitment.

An important additional assumption is that the descriptive catch ratios that are established reflect underlying causal relationships. For example, in setting the endeavour prawn TAC to the maximum historical annual catch in years of high tiger prawn TAC, the assumption is made that the underlying mechanisms leading to strong tiger prawns years also promote

strong endeavour prawn years. If not, the method could lead to TACs that are too high for endeavour prawns increasing risk to the stock and the long-term fishery.

Using historical catch ratios to set TACs is suggested here in the absence of established stock assessment methods to set more informed catch limits. Alongside such methods, it would be advisable to carefully monitor the annual catches for unprecedented species compositions. Mid-season spatio-temporal assessment of catch composition could also be used to better inform operators where high levels of by-catch are occurring. Geographic information systems (GIS) offer effective methods for illustrating such distributions and may help fishers to make more biologically precautionary choices.

## 6.5.3. Setting red legged banana prawn TACs

For setting a TAC, a similar approach to that suggested above for endeavour prawns could be used. However, much of the variability in the ratio of red to white banana prawn catch is driven by fluctuations in the catch of the latter (**Figure 24**). Also, unlike the situation with tiger prawns and endeavour prawns, fishers are well able to target red-legged banana prawns separately from white banana prawns, hence an entirely independent TAC could be set. It may therefore be more sensible to set TACs according to a fraction of historical catches, the variability of which is less than for the catch ratio (a CV of 0.32 compared with 0.47 in the case of $\Delta_{75}^{rw}$).

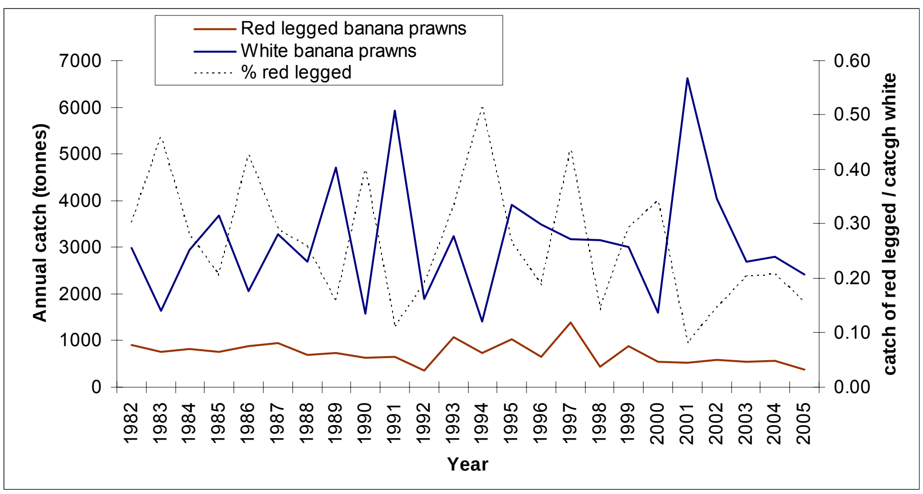


**Figure 24. The annual catches of red and white banana prawns and the ration of red legged banana prawn catch divided by white banana prawn catch.**

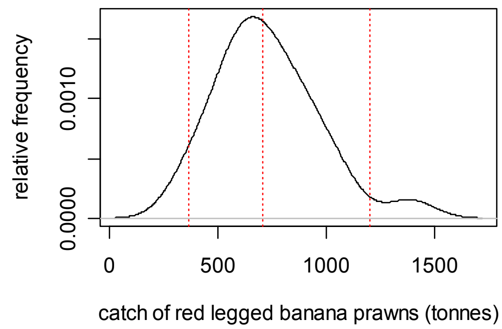


**Figure 25 The distribution of historical catches of red legged banana prawns. The vertical dotted lines represent the 2.5$^{th}$, 50$^{th}$ and 97.5$^{th}$ percentiles of historical catch.**

### 6.5.4. Setting TACs for the catch of white banana prawns in the second (tiger prawn) season

In the past, there has been a catch of white banana prawns in the second (tiger prawn) season. In the even that the option for setting TACs for banana prawns is taken up, this catch should be considered to be part of this TAC. However, if the mixed input/output control strategy is adopted (i.e. banana prawns will not be subject to a TAC in the first season) we recommend that there is still some means of constraining the catch of banana prawns during the second season. In the absence of a stock assessment, this TAC could be set in a similar way to that proposed for the first season (i.e. based simply on historical catch levels). However there may be more information with which to develop a better pre-second season estimate of total catch that could be used to set a more realistic TAC. For example, catches of banana prawns in the first season and the predicted (by stock assessment) exploitable biomass of tiger prawns in the second season may prove informative. These options have not been explored further at this stage.

The need for constraints of other species in the catch, including king prawns and giant tiger prawns has not been considered further at this stage, but the methods discussed above could form the basis of approaches to set TACs if needed. Equally, the use of basket quotas covering a number of species collectively should be considered. The catches of these and other species (e.g. squid and bugs) should be monitored closely during the early years of implementation of ITQs to see what effect there may be on the extent to which these are targeted as quotas are exhausted.

There are also existing gear-based measures in place to limit the bycatch of some non-target species (e.g. TEDs and BRDs), some of which are under environmental protection measures (e.g. turtles). Given the likelihood that there will be a change in gear regulations under an ITQ regime, the potential for using, incentive based mechanisms to encourage fishermen to innovate their own approaches to meeting bycatch targets should be explored.

# 7. Costs, benefits and operational considerations

## 7.1. The costs of ITE/ITQ management

In addition to the simple costs and benefits associated with fishing and sale of catches (presented in Section 5), moving from input to output controls may increase the need for fishery monitoring and control, particularly in relation to monitoring quota uptake and to avoid substantial problems associated with high-grading. Depending on the approach adopted, there may also be requirements for additional in-season monitoring, for instance of the species composition of catches. Assessment costs are likely to increase in the period prior to and following the implementation of ITQs as the assessment is modified to meet the needs of TAC and quota setting. There is also likely to be a longer term increase if the assessment is required to be re-run during the season to provide updates on stock status and advice on possible increases in TACs. Increased compliance monitoring may be required; in New Zealand fisheries, much of the enforcement consists of auditing of records and accounts. Offences are considered commercial fraud and met with firm penalties that may include fines, and confiscation of catch or fishing equipment (Annala, 1996). All of this may have cost implications for industry.

In terms of the available evidence, there are different estimates of the enforcement cost of an ITQ system. Arnason (2000) estimated the costs of fisheries enforcement in advanced fishing nations ranges from 2-15% of the gross value of landings. However, Icelandic Ministry of Fisheries reports that it only collects 0.4% of the total catch value to cover monitoring and enforcement costs. Icelandic fisheries are monitored by fishery observers. At any point of time, some observers are based aboard fishing vessels during actual fishing trips while others travel between the landing ports. Despite elaborate monitoring and enforcement, there are some violations of the various regulations. All together, however, these are seen as negligible (Runolfsson 1997). Finally, the Department of Fisheries (Western Australian) in 2006 estimated that it might cost $1 million to set up the ITQ system for Rock Lobster and from $ 2.5 to $3 million annually for the enforcement and management costs (the value of this fishery is approximately 4 times that of the NPF, $350 million AUD; Department of the Environment and Heritage, 2002).

The measurement of the cost of monitoring and implementation in the NPF can only be approximate. Figures provided by Arnason (2000), based on a number of fisheries in Europe and North America, suggest a range of 1.5 to 10.8 million dollars in the NPF (based on gross revenue in the NPF of 72 million AUD in 2006). This range exceeds the current cost of monitoring and implementation provided by AFMA (2006), recently updated with 2006-07 compliance costs, estimated at $824, 711 AUD. There are some anomalies with the budget proposed by AFMA (2006), in terms of the comparison of current compliance costs to those estimated under an ITQ system. It is not clear, for example, why at-sea patrols and VMS monitoring would be more expensive under the current system, and especially so if multiple jurisdiction trips are required under a TAC system.

The main contentious point, however, is the salary cost that goes with observer converge and general quota monitoring. AFMA (2006) reports this cost at $196,994 AUD, apparently based on random inspections of mother ships and vessels during off-loads in port. While this is essential, it is often necessary to also have on-board observer coverage on existing vessels (or some part of the fleet) to also guard against highgrading and discarding, as well as to monitor and measure catch. Direct surveillance and on board monitoring varies from 2 to 8% of the value of catch in Arnason (2000), and comparable figures are casually reported

in the United States. Given a 50 boat fleet, and catch volume, comparable on-board costs in the NPF are approximated by a minimum of 1.4 million AUD per year for full observer coverage. This is considerably larger than the $194,994 AFMA (2006) estimate, and places the overall minimum costs of monitoring, enforcement and implementation (including all of the additional costs specified by the AFMA (2006) report) of ITQs in the NPF at about $2 million AUD per year (approximately $600 per vessel day). This is at the lower range of Arnason's (2000) study.

Thus if industry was to bear the brunt of management costs, excluding costs associated with research, it is likely that the appropriate costs for a TAE system would be the same as at present ($800,000 AUD) and approaching $2M AUD for a TAC system (a difference of $1.2M). It is difficult to estimate the additional management fees required for adopting a TAC system for banana prawns with in-season updates, but data requirements should not be much greater than are generally assumed to be required for the TAE system. Thus moving from a TAE to a TAC system for all prawns should generate additional profit from tiger prawns of $1.4M, a small loss from banana prawns (smaller than the $900,000 calculated above if in-season updates are implemented), and additional monitoring requirements of $1.2M. These calculations are summarised below.

| | | |
|---|---|---|
| Current cost of non-observer management of NPF | | $600,000 |
| Current cost of observers in NPF | | $200,000 |
| | (a) | $800,000 |
| Potential cost of non-observer management of a TAC ITQ | | $600,000 |
| Potential observer cost (100% coverage) in a TAC ITQ | | $1,400,000 |
| | (b) | $2,000,000 |
| Additional cost of moving to ITQ[17] () | (c = a-b) | $1,200,000 |
| Potential gain moving to TAC for tiger and retaining TAE for banana | (d) | $1,400,000 |
| Net gain for TAC for tiger and TAE for banana | (d – c) | $200,000 |
| Potential gain moving to TAC for tiger and banana prawns | (e) | $900,000 |
| Net gain for TAC for tiger and banana | (e – c) | -$300,000 |

In undertaking the above calculations, we have assumed that the total cost (non-observer and observer combined) of operating a TAC for both banana and tiger prawns, and the total cost for operating a combined system of TAE on banana prawns and TAC on tiger prawns, would be roughly equal. It is worth considering how a combined system might be operated. It may be sufficient to require minimum quota holdings in tiger prawns to fish banana prawns. The banana prawn fishery in the NPF has always been 'regulated' by effort reductions in the tiger prawn fishery in any case. On the other hand, the banana prawn and tiger prawn fisheries are effectively separated into the first and second seasons respectively. Running a combined TAE/TAC system would be easier if it was separated by season, but some of the efficiency gains expected of an exclusively TAC system would be lost and there may be

[17] assuming no additional cost of running a TAC/TAE system concurrently for the two types of prawns. In reality these might be lower because of lower observer costs on the TAE portion, but this could be offset by higher management costs associated with running a more complex system

additional monitoring costs associated with running two different and relatively complex management systems side-by-side.

Underlying our assumption of cost neutrality between a TAC-TAC and TAC-TAE system for banana and tiger prawns, therefore, is the consideration that a combined system would be more complex to operate, incurring greater non-observer management costs, but would save probably 30% of the observer costs (if 100% observer coverage was required only in the second season, for instance). There might be an additional bureaucratic cost to individual vessels/companies which we have not factored in.

While the above calculations indicate a small net cost of moving to TAC for all the fisheries, they do not consider the gains from no longer having to correct for effort creep nor the secondary (vessel) efficiency gains normally associated with ITQ systems. Furthermore, the level of observer coverage in these figures is very high (100%). Were it to be reduced, which would be quite possible in the later years of a TAC system, then observer costs might be reduced by up to 50%. This would mean that the additional cost of moving to ITQ would be $500,000, which would result in a net gain under either a TAC-TAE or TAC-TAC system (the gain.

Given the uncertainties in data, models and costs, we consider that all these gains and losses are effectively negligible. However, significant gains in efficiency and product quality would be likely to accompany implementation of an ITQ system on all prawns, if it was associated with the relaxation of some of the input controls (such as current restrictions on gear configuration). Some of the current conservation, management tools, such as the mid-winter closed season to protect spawning tiger prawns, would need to remain for conservation reasons.

These figures do not incorporate research costs. There is likely to be an initial cost associated with revising the assessment and TAC calculation methodology, but since in-season updates are suggested in this report to be based on simple catch rules, little additional research time is likely to be required beyond what is required under the present TAE system.

## 7.2. Eligibility and co-management

The prediction from simple models (together with recent experience in many fisheries worldwide) is that well-designed and well-implemented ITQ systems alter the fishery from a situation of vicious competition (“non-cooperative game”) to one of cooperation. With the opportunity for cooperation between the various components of the industry afforded by recent reductions in overall capacity and participation in the NPF, this is a significant reason to be optimistic about Australia’s new ITQ strategy.

The NPF industry is not homogenous and the economic and social drivers vary for different operators. Responses by operators to alternative means of implementing ITQs will vary, and this will be important in evaluating performance. In particular some vessels operate in different fisheries at different times of the year, while others currently work exclusively in the NPF. In recent years the number of vessels operating in the NPF has reduced significantly and is now approximately 50. Not only is such a small fleet more easily managed, but there is a greater opportunity of cooperation and agreement among operators. In the most recent seasons, a reduced tendency to fish heavily at the start of the banana prawn fishery and decreased fishing under extreme weather have been observed and attributed to a greater confidence of operators in achieving profitable harvest. It may be the case that a smaller industry that holds allocated quotas in greater security will ease the introduction of ITQs.

There would be a significant benefit in the NPF of eliminating the race to fish. This is particularly true in the banana prawn fishery where rapid and opportunistic exploitation of "boils" tends to impact on the quality and presentation of the shrimp product. A significant market premium could be realised if vessels operated in a way that enabled them to package and present prawns more effectively to the market. There is recent evidence that following the last round of re-structuring and reduction in the number of operators and vessels, the industry itself has begun to operate in a way that encourages improvements in production quality.

In competing with cheaper products from, for example, shrimp farming operations in southeast Asia, fisheries for wild prawn can benefit from management of the fishery that encourages the production of larger prawns that attract a premium price. Timing of the season in relation to recruitment events and growth rates is clearly important here. The opportunities for realising these benefits through the implementation of ITQs will be explored.

There is apparently universal agreement that the benefits to the fishery of having reduced the fleet size to approximately 50 boats should not be undone by allowing expansion of the number of vessels operating in the fishery under ITQs. If the B licensing scheme (currently under review by AFMA) were to change, it may be necessary to implement a form of minimum quota holding (MQH) requirement for taking part in the fishery to control vessel numbers.

## 7.3. Transferability of quota

Limitations on the transferability of quota are likely to undermine the opportunities for the industry to develop their own economic efficiencies, and may result in unexpected and undesirable effects in the quota trading market. It is recommended that there are no restrictions on transferability of quota. It is also important to ensure that there is a well-established mechanism (e.g., a brokerage service) for quota trading.

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# Appendix 1: ITQ Theory applied to short-lived species

The general theory of ITQs (Clark 2007) uses a general-production model, which is not entirely realistic for short-lived (or semelparous) species. Here we briefly discuss an ITQ model for a short-lived species such as the banana prawn.

Cohort biomass is given by

$$B(t)=N_0 e^{-(m+F)t} w(t) \qquad (1)$$

with the usual notation (time $t$ is measured in days). This reaches a peak at time $t_{\mathrm{MY}}$ given by

$$w'(t_{\mathrm{MY}}) = Mw(t_{\mathrm{MY}}) \qquad (2)$$

and management is at least partly designed to limit the fishing season to a neigbourhood of $t_{MY}$.

An individual vessel's daily catch rate by weight is

$$H(t) = qB(t) \qquad (3)$$

where $q$ is the vessel's daily catchability. The individual net revenue flow is

$$R(t) = p(t)H(t) - c \qquad (4)$$

where $p(t)$ is the dockside price of prawns at time $t$ and $c$ the daily cost of fishing.

Suppose now that the vessel has an annual catch quota $Q$. If the vessel fishes for the time interval $[t_1,t_2]$ its total catch by weight is

$$\int_{t_1}^{t_2} qB(t)dt \leq Q \qquad (5)$$

Net revenue for the year is

$$\int_{t_1}^{t_2} [p(t)qB(t)-c]dt \qquad (6)$$

The owner's optimization problem is thus

$$\underset{t_1,t_2}{\text{maximize}} \int_{t_1}^{t_2} [p(t)qB(t)-c]dt$$

$$\text{subject to} \int_{t_1}^{t_2} qB(t)dt \leq Q$$

By Lagrange multipliers we find that the optimal values of $t_1,t_2$ satisfy

$$p(t_1)-\frac{c}{qB(t_1)} = p(t_2)-\frac{c}{qB(t_2)} \qquad (7)$$

and $$\int_{t_1}^{t_2} qB(t)dt = Q$$

Eq. 7 has a satisfying intuitive explanation. The expression

$$V(t) = p(t)-\frac{c}{qB(t)} \qquad (8)$$

is easily shown to equal the net revenue per kg at time $t$ (because the time required to catch 1 kg is $1/qB(t)$. If effort were unlimited, the most profitable fishing strategy would be to catch the entire TAC in one day, $t=t^*$ where $t^*$ maximizes $V(t)$. When daily effort is limited, one should

concentrate one's fishing around $t^*$ in such a way that $V(t_1) = V(t_2)$, as in Eq. 7. Note that, if $p(t)$ is increasing with $t$, we have

$$t^* > t_{MY}$$

– the economic optimum is later than the biological optimum, to take advantage of higher prices for larger prawns.

The foregoing argument applies to individual decisions under individual quotas (transferability is not an issue here). But if we also formulate an overall (whole industry) optimization model, for a fleet of $N$ identical vessels, we obviously get exactly the same result:

$$\underset{t_1,t_2}{\text{maximize}}\, N\int_{t_1}^{t_2}[p(t)qB(t)-c]dt$$

$$\text{subject to } N\int_{t_1}^{t_2} qB(t)dt = \text{TAC}$$

This shows that *individual fishing quotas motivate fishermen to use the optimal fishing strategy*, which maximizes "rents" from the fishery.

But why are individual quotas needed to achieve this outcome? Can't the managers simply close the fishery until $t = t_1$, the optimal opening date (as with the opening dates for the first (banana prawn) and second (tiger prawn) seasons in the NPF)? To answer this question, one has to bring in bioeconomic factors under, say, TAC-based management. (Without TAC management the fishermen would start fishing as soon as $V(t) > 0$ and this would result in low, in fact near zero, seasonal net revenues.) Controlling the opening date to $t_1$ ensures that fishermen will make a profit. But, according to bioeconomic theory, profits will tend to attract more fishermen. If fleet size is limited by licensing, each fisherman will then be motivated to increase the fishing power ($q$) of his vessel. This is "effort creep," which can result in elimination of much of the potential profitability of the fishery. *Individual quotas provide a reduced incentive for effort creep* because less is gained by increasing one's fishing power, than would be under input controls, given a fixed enforceable quota share. While effort creep may continue under ITQs, it is not a concern for fishery management, and therefore need not be inhibited (while it may still need to be monitored for the purposes for interpretation of catch per unit effort data).

The above provides a summary of the theory of IQs. There is by now an extensive data set in support of the predicted outcomes – at least for long-lived species. But there is no reason not to expect the theory to remain valid for short-lived species as well.

# Appendix 2 Intra seasonal TAC adjustment for short lived species

Most short-lived species experience wide fluctuations in annual recruitment. If the current year's recruitment is accurately known prior to the fishing season, TACs and hence ITQs can be determined accordingly.

More commonly, however, recruitment is highly unpredictable. Pre-season and within-season stock surveys may be used to estimate the current year's recruitment, but considerable uncertainty may persist right through the fishing season. How can TACs and ITQs be determined in this situation?

First, a prior distribution $f(x)$ for annual recruitment $x$ can be obtained from historical catch data, although even this may be problematic if recruitment cannot be accurately assessed from such data. We will assume here that $f(x)$ is known, however. Three possibilities can then be delineated:

**Case 1**. No seasonal updates;
**Case 2.** One pre-season update.
**Case 3**. One pre-season update plus one or more within-season updates.

Let us first consider the case of no updates. We assume that a large TAC will risk the collapse of the stocks from overfishing. Let

$$p_Q = \Pr\ (\text{collapse given TAC } Q) \tag{9}$$

For example, if $x_0$ is a limit point such that collapse is deemed highly likely if escapement falls below $x_0$, then $p_Q$ is given by

$$\begin{aligned} \Pr\ (\text{collapse} \mid \text{Q}) &= \Pr(x - Q < x_0) \\ &= \Pr(x < x_0 + Q) \\ &= \int_0^{x_0+Q} f(x)dx \end{aligned} \tag{10}$$

The economically optimal TAC $Q$ (which is the same every year, in this case) is determined bny maximizing the expected present value (EPV) of present and future catches:

$$\begin{aligned} \text{EPV} &= Q + \alpha(1-p_Q)[Q + \alpha(1-p_Q)[\cdots]\cdots] \\ &= Q[1 + \alpha(1-p_Q) + \alpha^2(1-p_Q)^2 + \cdots] \\ &= \frac{Q}{1-\alpha(1-p_Q)} \end{aligned}$$

where $\alpha = 1/(1+i)$ is the annual discount rate. Substituting and simplifying, we obtain

$$\text{EPV} = \frac{(1+i)Q}{i + p_Q} \tag{11}$$

This expression shows how risk and future discounting interact in determining the expected payoff EPV.

Specifically, we see that

$$EPV = \frac{1+i}{i}Q \quad \text{for small } Q$$

$$EPV = Q \text{ for large } Q$$

because $p_Q \to 0$ as $Q \to 0$ and $p_Q \to 1$ for large Q. What this says is that setting a small TAC, *Q* gives a sustainable yield of *Q* every year, the present value of such an annuity being equal to $Q(1+i)/i$ . On the other hand , setting a large TAC will wipe out the stock quickly, giving a total expected reward *Q*. Depending on the function $p_Q$, the optimal TAC would be some intermediate value $Q^*$.

(For pedagogical purposes the above calculation has been deliberately oversimplified. In fact the expected annual catch, given TAC *Q* , equals

$$\bar{H}_Q = E\{\min(Q,x)\} = \int_0^Q xf(x)dx + \int_Q^\infty Qf(x)dx \tag{12}$$

The corrected version of Eq. 11 is thus

$$\text{EPV} = \frac{(1+i)\bar{H}_Q}{i + p_Q} \tag{13}$$

and we have

$$EPV = \frac{1+i}{i}Q \quad \text{for small } Q$$
$$EPV = \bar{\chi} \quad \text{for large } Q \tag{14}$$

(a large TAC will give expected catch $\bar{x}$ and wipe out the stock in one year).) As before, the economically optimal TAC under the present assumption is the value *Q* that maximizes EPV, with no regard for the future. If *i* is small then a small TAC is preferable. Under minimal information (i.e., no updated stock estimates), only a strongly precautionary TAC can be justified under low discounting. In this respect it is worth noting that in the absence of ITQs fishermen tend to have high (even infinite) discount rates, whereas with ITQs they will have discount rates close to investment-market values.

*Pre-season updates*

The result of a pre-season stock survey would be an updated "posterior" distribution for the current year's sock level, $f_1(x)$. Standard Bayesian updating methods can be used to determine $f_1(x)$, which of course may still involve considerable uncertainty. Nevertheless the updated distribution $f_1(x)$ allows for an improved TAC – low when $f_1(x)$ indicates low abundance, and vice versa. Again, in an ITQ system fishermen will be motivated to support pre-season (and within-season) stack estimation programs, much more so than without ITQs.

*Within-season updates*

Fishermen's success rates (e.g., CPUE) early in the season can be a valuable source of information about the current stock size. Using this information can result in further updates $f_2(x)$, $f_3(x)$, etc. (Note also that under ITQs catch data should be more reliable than otherwise, because this is essential to the success of the ITQ program.) The TAC can then be progressively adjusted according to these updates. It will probably be a good idea to normally allow positive increments to the TAC, avoiding negative increments except under dire circumstances. Thus the initial TAC would be quite low, for example as determined from $f(x)$. In most years there would be subsequent positive adjustments to the TAC (and the ITQs).

## Appendix 3: Specifications of the tiger prawn operating model

The biological and fishery operating model used was designed to be a close as possible to that used to assess the resource, and which is detailed in Dichmont *et al.* (2003). It is a biomass/numbers delay-difference type model, but the main difference is that the model does not employ effort to define fishing mortality, but uses the ratio of the catch to the exploitable stock biomass to define the exploitation rate. The model itself runs on the "biological" year for Tiger prawns – from around week 40 in a standard year through to the end of December and then on until week 39 in the following calendar year, as it is this cycle which determines recruitment times and is easier to format in a population-model sense. The operating model is single stock, single species and single area in nature.

*Numbers and biomass dynamics*

The dynamics of the numbers of prawns are as follows:

$$N_{y,w+1} = N_{y,w}\pi_w^m(1-\pi_{y,w}^h) + \alpha_w R_y \qquad \text{(A3.1)}$$

where $\pi_w^m$ is the probability of survivorship of natural mortality, $\exp(-M_w)$; $\pi_{y,w}^h$ is the probability of being harvested (exploitation rate); $\alpha_w$ is the relative amount of weekly recruitment; $R_y$ is the recruitment, conditional on a stock-recruit relationship to be defined later. The harvest probability is calculated as follows:

$$\pi_{y,w}^h = \frac{C_{y,w}}{EB_{y,w}0.5(1+\pi_w^m)}, \qquad \text{(A3.2)}$$

where $C_{y,w}$ is the catch biomass, $EB_{y,w}$ is the (exploitable) stock biomass which is the total stock biomass multiplied by the availability coefficient by week, as used in Dichmont *et al.* (2003), and the correction factor in the denominator in the fraction in Eqn. (A3.2) is to adjust the biomass to its value in the middle of the week. The reason for using an additive adjustment in Eqn. (A3.2) to adjust the stock numbers to the middle of the week, and not a power law, i.e. $\pi_w^m$ to the power of a half, is to ensure a linear reduction in survivability of the stock numbers over the week. In this formulation, the probability of surviving to the middle of the week is exactly half way between 1 and $\pi_w^m$ .

The stock biomass dynamics obey the following equation:

$$B_{y,w+1} = \pi_w^m(1-\pi_{y,w}^h)\left[(1+\rho)B_{y,w} - \rho\left(B_{y,w-1}\pi_{w-1}^m(1-\pi_{y,w-1}^h) + w^{pr}\alpha_{w-1}R_y\right)\right] + w^r\alpha_w R_y, \qquad \text{(A3.3)}$$

where $w^{pr}$ and $w^r$ are the weights the week before and the week of recruitment, respectively.

*Stock-recruit relationship*

The spawning stock index, not the biomass, is calculated as follows:

$$S_y = \sum_w \beta_w N_{y,w} \frac{1+\pi_w^m}{2}\left(1-0.5\pi_{y,w}^h\right), \quad \text{(A3.4)}$$

where $\beta_w$ is the relative proportion of spawning in each week, and the last two brackets in Eqn. (A3.4) are to adjust the numbers to their values half-way through the week, again so as to mimic as much as possible the assumptions made in the assessment population dynamics model. Either a Ricker or Beverton-Holt model can be specified, where

$$R_y = \alpha S_{y-1} f\left(\beta, S_{y-1}\right) \exp\left(\varepsilon_y - \sigma_r^2/2\right), \quad \text{(A3.5)}$$

where $f(\beta, S_y) = \exp(-\beta S_y)$ or $f(\beta, S_y) = \left(\beta + S_y\right)^{-1}$ if the required stock-recruit model is Ricker of Beverton-Holt, respectively. For the given total stock-recruit variance, $\sigma_r^2$, the stochastic recruitment effect, $\varepsilon_y$, is modelled as an AR(1,1) process:

$$\varepsilon_y = \chi \varepsilon_{y-1} + \xi_y, \quad \text{(A3.6)}$$

with

$$\xi_y = N\left(0, (1-\chi^2)\sigma_r^2\right) \quad \text{(A3.7)}$$

and $\chi$ is the level of (lag-1) autocorrelation in the stochastic recruitment effects.

# Appendix 4: WinBUGS model for Simulating total catch and CPUE data and evaluating the performance of different TAC update strategies for white banana prawns

WinBUGS models

```
# Model that fits linear model parameters to observed data and generates simulations
# units are in ,000 tonnes
Model{

# fit model to data
for(i in 1:15){
	for(j in 1:4){
		Cobs[i,j]~dlnorm(Cpred[i,j],cobstau[j])
		Cpred[i,j]<-log(a[j]*cpueobs[i,j]+b[j])
	}
}

Cmak~dnorm(2.976,cmaktau)I(1.000,6.000)  # generate some simulated catches
cmaktau<-1/(1.087*1.087)		# take the observed standard deviation and convert to a precision

for(j in 1:4){
	# simulated cpues given simulated catch
	cpuemak[j]<-max((Cmak-b[j])/a[j],0)

	# priors
	a[j]~dunif(0.5,6)
	b[j]~dunif(0,3.5)
	tau[j]<-1/(sd[j]*sd[j])
	sd[j]~dunif(0.05,1)
	cobstau[j]<-1/(cobssd[j]*cobssd[j])
	cobssd[j]~dunif(0.3,2)
}

} # End of model


# Model that takes simulations and fitted parameters and looks at different update strategies
# units are in ,000 tonnes
Model{

# the fitted parameters (slopes and intercepts) from a previous analysis of the 4 cpue vs catch relationships
mvn[1,1:2] ~ dmnorm(mean1[1:2],prec1[1:2 ,1:2])
mvn[2,1:2] ~ dmnorm(mean2[1:2],prec2[1:2 ,1:2])
mvn[3,1:2] ~ dmnorm(mean3[1:2],prec3[1:2 ,1:2])
mvn[4,1:2] ~ dmnorm(mean4[1:2],prec4[1:2 ,1:2])

for(j in 1:4){
	# priors
	a[j]<-mvn[j,1]
	b[j]<-mvn[j,2]

		a.cut[j]<-cut(a[j])
		b.cut[j]<-cut(b[j])
		cpuetau[j]~ dgamma(3.785518,0.008613854)

}

ctau<-1/(1.087*1.087)
ctauSA<-1/(0.8696*0.8696)
for(i in 1:10000){
```

```
meanSA[i]<-(Cmak[i]+2.976)/2
# mean of prior for catch (updated by SA)

# scenario 1:  low initial TAC, update after 2 weeks
C[i,1]~dnorm(2.976,ctau)I(1,6)          # prior for catch (based on historical catch)
cpuepred[i,1]<-log(max((C[i,1]-b.cut[1])/a.cut[1],0.01))  # 1st cpue, 1st scenario, 1st relationship
cpuemak[i,1]~dlnorm(cpuepred[i,1],cpuetau[1])

Cnoupdate[i]~dnorm(meanSA[i],ctau)I(1,6)
C[i,5]~dnorm(meanSA[i],ctau)I(1,6)
cpuepred[i,7]<-log(max((C[i,5]-b.cut[1])/a.cut[1],0.01)) # 1st cpue, 5th scenario, 1st relationship
        cpuemak[i,7]~dlnorm(cpuepred[i,7],cpuetau[1])

# scenario 2: moderate initial TAC, update after 3 weeks
C[i,2]~dnorm(2.976,ctau)I(1,6)          # prior for catch (based on historical catch)
cpuepred[i,2]<-log(max((C[i,2]-b.cut[2])/a.cut[2],0.01)) # 2nd cpue , 2nd scenario, 2nd relationship
cpuemak[i,2]~dlnorm(cpuepred[i,2],cpuetau[2])

C[i,6]~dnorm(meanSA[i],ctau)I(1,6)
cpuepred[i,8]<-log(max((C[i,6]-b.cut[2])/a.cut[2],0.01)) # 2nd cpue, 6th scenario, 2nd relationship
cpuemak[i,8]~dlnorm(cpuepred[i,8],cpuetau[2])

# scenario 3: low initial TAC, update after 2 & 4 weeks
C[i,3]~dnorm(2.976,ctau)I(1,6)          # prior for catch (based on historical catch)
# same as scenario 1 (need new data point (cpuemak[,1]=cpuemak[,3]))
cpuepred[i,3]<-log(max((C[i,3]-b.cut[1])/a.cut[1],0.01))  # 3rd cpue, 3rd scenario, 1st relationship
cpuemak[i,3]~dlnorm(cpuepred[i,3],cpuetau[1])

cpuepred[i,4]<-log(max((C[i,3]-b.cut[3])/a.cut[3],0.01))  # 4th cpue, 3rd scenario, 3rd relationship
cpuemak[i,4]~dlnorm(cpuepred[i,4],cpuetau[3])

C[i,7]~dnorm(meanSA[i],ctauSA)I(1,6)
cpuepred[i,9]<-log(max((C[i,7]-b.cut[1])/a.cut[1],0.01))  # 3rd cpue, 7th scenario, 9th prediction, 1st
                                                              relationship
cpuemak[i,9]~dlnorm(cpuepred[i,9],cpuetau[1])
cpuepred[i,10]<-log(max((C[i,7]-b.cut[3])/a.cut[3],0.01))  # 4th  cpue, 7th scenario, 10 th prediction,
                                                              3rd relationship
cpuemak[i,10]~dlnorm(cpuepred[i,10],cpuetau[3])

# scenario 4: med initial TAC, update after 3 & 4 weeks
C[i,4]~dnorm(2.976,ctau)I(1,6)  # prior for catch (based on historical catch)

# same as scenario 2 (need new data point - winbugs oddness)
cpuepred[i,5]<-log(max((C[i,4]-b.cut[2])/a.cut[2],0.01)) # 5th cpue, 4th scenario, 2nd
                                                              relationship
cpuemak[i,5]~dlnorm(cpuepred[i,5],cpuetau[2])

cpuepred[i,6]<-log(max((C[i,4]-b.cut[4])/a.cut[4],0.01)) # 6th cpue index, 4th scenario, 4th
                                                              relationship
cpuemak[i,6]~dlnorm(cpuepred[i,6],cpuetau[4])

C[i,8]~dnorm(meanSA[i],ctauSA)I(1,6)

cpuepred[i,11]<-log(max((C[i,8]-b.cut[2])/a.cut[2],0.01)) # 5th cpue, 4th scenario, 11th prediction,
                                                              2nd relationship
cpuemak[i,11]~dlnorm(cpuepred[i,11],cpuetau[2])

cpuepred[i,12]<-log(max((C[i,8]-b.cut[4])/a.cut[4],0.01)) # 6th cpue, 4th scenario, 12th prediction,
                                                              4th relationship
cpuemak[i,12]~dlnorm(cpuepred[i,12],cpuetau[4])
} }# End of model
```

# Appendix 5: Meetings held with NPF Industry Representatives

**Main issues raised at a meeting with NPF industry representatives in Cairns on 5th June 2007**

Present at the meeting

Noel Hoschke
Robert Hoschke
Peter Hoschke
Heather Taverner
Allen May
Norm James
Colin James
Max O'Halloran
Greg Albert
Brian Corbett
Brian Bencki
Graeme Parkes (MRAG)

The over arching view was that the participants at this meeting were not in favour of moving to ITQs. The recent buy-back was agreed on a vote. It was not something the industry group based in Cairns wanted to accept or be involved in; hence they did not feel obligated to accept ITQs as a result of this decision. They did not take part in the buy-back specifically because they wanted to remain in the fishery and now feel their further participation is threatened by ITQs.

Reductions in effort have been driven by the status of the tiger prawns. There needs to be a period of stability in the fishery (say 5 years) during which the efficacy of the current management regime could be properly evaluated before moving – or not – to another new system (i.e. ITQs)

If ITQ management is to be implemented it could potentially work for tiger prawns, but using it in the banana prawn fishery is expected to be very difficult due to the high, environmentally driven (rainfall essentially) variability in stock abundance – therefore how can the quota be set?

The bigger boats do better than the smaller boats on banana prawns due to the nature of the fishery (targeting temporary large concentrations of prawns (boils)); the smaller boats spend more time targeting tiger prawns. Some of the larger vessels more or less target banana prawns all the year round. Smaller vessels cannot to that because they cannot achieve the high catch rates of bananas in the boils that the larger boas towing larger gear can do.

There is a concern that if operators with only one boat do not receive sufficient quota allocation for their operation to be viable, their options will be limited compared to a company with more vessels, that have more flexibility in the way they fish. i.e. they will have two options: buy more quota or sell up. This might lead to consolidation. However, they do not want to leave the fishery. If they had wanted to leave the fishery, they would have already done so in the last re-structure.

Some participants had calculated how much quota they expected to be allocated based on their current effort unit allocation and an assumed TAC (same catch as last year) and they are concerned that this will be much less than their catch last year (perhaps half). This will effectively force them to sell their quota since it will not be enough to keep them in business.

The prospect of fluctuating TACs from one year to the next is also a source of concern. Large fluctuations will tend to undermine the value of the ITQs. Perhaps the magnitude of change from one year to the next could be limited? Their current range of catch of tiger prawns per vessel is about 22 to 25 tonnes per year.

There is a lack of confidence in the stock assessment and this might have implications for how operators fish the quota that is allocated to them. There is merit in the survey as a means of setting TAC levels, but the coverage should be increased, for example, it would be good to do some survey work in closed areas to confirm what is going on there.

There is interest in whether ITQs would be accompanied by a relaxation in the current season restrictions. In the tiger prawn fishery, operators do not target one species vs. another. Separating quotas by species would result in a significant surveillance problem. Quotas by area could not be enforced.

With respect to banana prawns, there is disagreement with the suggestion that recent reductions in the numbers of boats have not lead to overall reduction in the effective effort because of the searching element involved in the fishery. While a single boat can potentially fish for as long as two boats did previously, it is much less effective at covering the ground in a search pattern. Some of the small operators still use spotters (small planes or helicopters) but this method is not used as much as previously.

With respect to the control of the number of boats operating in the fishery, there was a view that the B licence should be retained. A minimum quota requirement to go fishing was another option.

The closure of the season to protect the tiger prawn spawning in June/July means this fishery is essentially lost – because the vessel q is so much higher at this time. Because the fishery is effort limited, some participants felt that they do not receive an effective credit in the second season that compensates for this.

The possibility of quotas on lesser species is also a concern. Endeavour and king prawns are not really targeted, but the endeavours in particular appear in some years in large numbers, hence a quota on them might lead to closure of the tiger season (for some vessels) because of the exhaustion of the quota. This raises the issue of dumping and highgrading.

There will be greater incentive for highgrading under ITQs. It already happens in the banana prawn fishery. The view was that on-board surveillance using cameras would not be an effective way of preventing highgrading, and the only way to counteract it would be through surveillance. Extending the season (e.g. by reducing the length of the closed season) might reduce the incentive for highgrading.

There was some discussion of the need to work the shrimp grounds (by trawling them) in order to keep them productive. Line fishing was an example where an individual vessel would work up and down a line and the CPUE would increase over a period of some days. The mechanism by which tie happens is thought to be attraction or aggregation of the prawns into the area of disturbance.

There was a discussion of the effects of moving from MSY to MEY and the current impacts of high fuel costs and the strong AU$ (weak US$), driving the target biomass higher than it might otherwise be. They prefer TACs to be set purely on the basis of biological criteria.

**Main issues raised and views expressed at a meeting with NPF industry representatives in Brisbane on 6th June 2007**

Present at the meeting:

George Raptis
Mike Obrien
Phil Robinson
Peter Shultz
Ron Earle
Annie Jarrett
Graeme Parkes (MRAG)

Some operators within the NPF fishery are used to working in ITQ based fisheries (e.g. redfish). They are used to the idea of leasing other quota to carry on fishing. One of the benefits of ITQs is the option to move quota between boats.

The variability of the banana prawn fishery was emphasized – Weipa was cited as an example. This area had shown a marked decline in catches for several years and was on the verge of closure, when it suddenly produced a bumper year.

The survey in February is not thought to cover sufficient ground to provide a reliable recruitment index for setting pre-season TACs.

The information from spotters is very unreliable in terms of predicting how good the banana prawn season is likely to be. Trying to use this as a predictor for season performance is likely to cause more problems than it solves.

There is concern about whether it will be possible to set quotas that are going to be commercially viable based on the current level of information. However, the stability in the fishery that might result from implementing quota management is potentially attractive.

The view was that the way to set quotas on banana prawns is to set a high quota above that which is expected to be caught and let the fishery be self managing (when the cpue drops, boats shift on to tiger prawns). There could still be a trigger point to end the season - much as there is now (a trigger to extend the season or not).

An overall quota of 3,500 tonnes of banana prawns is needed for the fishery to be viable.

The B licence should be retained as a means of controlling the total number of vessels in the fishery.

Smaller operators would like to target tiger prawns earlier in the season. Searching for banana prawn boils is difficult for them and consumes a lot of fuel. The non-targeting of trigger prawns in the first season is currently voluntary.

There was a preference among some participants at this meeting for allowing boats to catch banana prawns and tiger prawns at any time during the season – i.e. whenever they want to. This includes stopping the mid-season closure that costs vessel operators a lot of steaming time (i.e. to stop fishing and then start again later). They were interested to find out the effects of taking prawns at different times of the year – e.g. if you take more, smaller prawns, how does this impact the spawning stock and the overall available TAC?

Highgrading is likely to be a problem in the tiger prawn fishery. There needs to be a voluntary code about where and when to fish. The current race to fish in the banana prawn

fishery means that they do not produce an optimal product. The market wants packs of fixed weight and size of prawns, but the vessels need more time to prepare the catch in such packs.

There are difficulties in the fishery as it stands at the moment. Vessels are generally old (perhaps 30 years old) because operators cannot afford to replace them. Most of the captains are also old and three is little opportunity for young fishermen to learn the trade in the restricted fishing season. The situation needs to improve otherwise the fishery will not remain viable. Under the current conditions (fuel price, exchange rate etc.) the turnover per vessel is not enough.

The issue of the change in vessel operations under quota was discussed and the implications of this for the assessment described.

The compliance budget is very high, but there are very few infringements.

**Main issues raised and views expressed at a meeting with NPF industry representatives in Perth on 9th June 2007**

Present at the meeting:

David Carter
Martin Exel
Andy Prendergast
Ian Boot
John Palmer
Graeme Parkes (MRAG)

The boats operated by the Perth-based industry are primarily designed for the banana prawn fishery.

The industry in Perth is generally cooperative with the idea of introducing ITQs into the NPF. There is no need to re-visit the method of allocation of quotas – this is effectively pre-determined through the current system of effort quota.

There is concern about fishing opportunities under quota management being driven by the lowest common denominator under the precautionary approach. i.e. the most vulnerable component of the catch will constrain the catch of other species. A pure species allocation would be preferred, but it was recognised that there is no way to effectively manage this. The spatial model for species separation in tiger prawns might be an option, but the distribution varies significantly in time and space. There was interest in what is happening in the closed areas.

Regarding the options for setting TACs there is clearly a difference between the options for different species groups (mainly tigers and bananas), and the ways in which operators can work the two main seasons. For tiger prawns it is possible to put in more effort to reach the quota limit. For banana prawns the vessels are essentially limited by their refrigeration capacity. Once they reach this limit they cannot catch more prawns until the freezers are cleared.

There is concern over the extent to which quotas might vary from year to year. Large fluctuations would be hard to manage.

There was agreement that quota allocations should be fully tradable and/or leasable within seasons.

Regarding season length, starting the tiger prawn season earlier was not considered to be a viable option (spawning issue). The end of the season is largely driven by the fishery, in November the catches drop off in any event.

There is insufficient funding to do effective surveys, i.e. to get sufficient coverage. In the participants' view, the February survey does not really cover the area of the banana prawn fishery very well. It focuses mainly on tiger prawns. Also it is not much use in an adaptive sense because, for example in a case where it indicated a large recruitment of banana prawns and the TAC were to be increased, it takes too long to mobilise the fleet to make effective use of it in the coming season. The June/July survey is most useful for directing effort as opposed to setting quotas.

There needs to be a reduction in the race to fish in the banana prawn season – perhaps driven by the setting of catch quotas. If they had more time to fish, they could do more with the product to add value. What is caught in the first hour of fishing on a boil is best, then the

quality drops off. A good example was the fishing in Fog Bay in 2006. There were 3 boats fishing and there was sufficient for all, with no race to fish. All of the catch was processed into 5kg boxes. Abolition of brine tanks would stop vessels from being able to handle very large catches in a short period of time, and force a more measured and controlled approach to catching.

There was some discussion over whether quotas by themselves would be sufficient to remove the incentive for the race to fish. In the participants view, a meaningful quota on banana prawns would do this and bring the associated benefit of better quality. There are things the industry can do internally to reduce the race to fish and ITQs would tend to support this.

The cpue-based trigger for extending the banana season is generally regarded as a good management mechanism, although the current cpue trigger level (500kg/day per vessel average) may be too low. Also, the way in which the average cpue is calculated may need to be looked at, because at the moment it could all come from one area.

The imposition of ITQs opens up the opportunity to review the entire way the fishery is exploited. For example with the two main spawnings of tiger prawns each year, it is possible to get larger tiger prawns in the first season. ITQs might enable vessels to target what they want when they want.

For tiger prawns, the prime market period is at the same time as the peak part of the season in August-September. For banana prawns, although they are caught primarily in April and May, the market at this time is not particularly good. The prime market is again in September.

The red legged banana prawn fishery in the Joseph Bonaparte Gulf is a special case – essentially a separate fishery. There is an opportunity for the fishery to allow the prawns to grow to a bigger (and more valuable) product.

In general the fishery would benefit from strategies that enable fishers to catch bigger, better quality prawns so they can produce a product that is larger than cultured prawns. A later opening for the banana prawn season (e.g. May) might be an option.

The performance of spotter aircraft in supporting the banana prawn fishery is variable, but the fishers cannot afford to try to operate without them; this would be too great a risk. Some parts of the banana prawn fishery can be reasonably predicted from the rainfall – particularly Karumba.

The participants were keen to have a management system that does not allow the fleet size to start to grow again. This can be achieved through minimum quota holdings – a vessel operator must hold a minimum percentage of the total quota for each vessel that actively fishes. Another option would be to retain the B licence.

There is an expectation that there will be some quota holders who do not have B licences, because there are currently some holders of SFRs who do not have B licences.

The main highgrading issue was expected to be in catching small banana prawns, which might later be dumped in favour of larger prawns. One way to avoid this is through the use of square meshed panels to reduce the catch of small prawns.

There were contrasting views about whether highgrading would be a problem in the tiger prawn fishery.

E-logbooks (near-real time reporting) would help to show whether highgrading is taking place.

The main concerns at present are:

1. the cost of management through TACs and quotas
2. the level of TAC
3. has ITQ management worked in any fishery comparable to the NPF?

There are many things the industry can do better in the fishery, such as a more measured approach to catching banana prawns to improve the quality and consistency of the product (this is already happening to some extent), but it is not clear that a move to ITQ management will help this.

# Appendix 6: Report of the NORMAC ITQ Workshop 5th July 2007

**Assessment of alternative approaches to implementing Individual Transferable Quotas (ITQs) in the Northern Prawn Fishery (NPF) and identification of the impacts on the fishery of those approaches.**

**NORMAC, Brisbane. July 2007**

**Report of the meeting**

## Introduction

The meeting was undertaken in a spirit of cooperation and participation. All attendees contributed their experience and opinion in a constructive way either in the plenary meeting or group debates. All discussions among attendees were balanced and respectful, providing high quality information to the project team.

The discussion of ITQs and options for TAC implementation was structured primarily under species group headings (tiger prawns, banana prawns and endeavour prawns). In this report of the meeting we present these discussions and conclusions under each species group and then provide a summary of general issues that applied to all species groups.

## Tiger prawns

Generally, the group recognised that the current stock assessment method captures the stock dynamics of tiger prawns well and offers a relatively reliable pre-season estimate of current levels of exploitable biomass (noting that the analysis is retrospective and not configured to the setting of TACs). Assuming the modelling can be successfully modified to output controls, it is possible that a method based on these population dynamics could be used to set TACs according to Commonwealth harvest strategy target and limit reference points.

## Species specific TACs

The group recognised that a single species group TAC could be restrictive because they would have to be tailored to the poorest performing stock (most probably brown tiger prawns). However there was a consensus that species-specific TACs were unnecessarily complex. Most agreed that *implicit* species-specific TACs could be implemented by altering the distribution of fishing, whilst adhering to a single group TAC.

The most simple and popular option was using alterations to the start date of the second season to offer protection for brown tigers (the stock considered to be doing less well at present). Under circumstances where stock assessment found such an approach to be ineffective, the next best option was believed to be temporal weighting of quotas to discourage fishing at times when a single species might be more susceptible (note such a mechanism could also be used to protect grooved tigers where necessary). There were however concerns about how such as system would work and whether it would encourage race-to-fish fleet dynamics at times when quota weightings were low.

Other more complicated methods such as a spatio-temporal weighting were discussed. Whilst they are more considerate of the population dynamics and distribution of tiger prawns and could lead to less restrictive quotas, most thought such a solution to be overly complex and the resulting time-space matrix hard to interpret. The majority of attendees believed the variable start date and weighting options described above to be superior to explicit species-specific TACs. The principle concern over species-specific TAC options was the quantitative interpretation of tiger catches in terms of the two major component species. Considering that it is extremely hard to distinguish between grooved and brown tiger prawns, catches by area and time would have to be interpreted by fishermen and managers according to an established (spatio-temporally disaggregated) ratio of the two species. It was stated that the uncertainty over this ratio would be prohibitively large and that it could become difficult for fishermen to make sound decisions over where and when to go fishing to meet their quota in the most efficient way; essentially, that management complexity would stand in the way of fishing efficiency. The group recognised that species-specific stock assessments are necessary and considered species-specific TACs to be an area for investigation when there is evidence from stock assessment that species group TAC options are not performing satisfactorily.

**Frequency of TAC updates**

The group recognised that there is a trade-off between the cost of assessment and the benefits that can be obtained from regular updates in TAC (*i.e*. increased catch levels in good years and/or greater biological precaution). However, a lack of reliable quantitative information about both the cost of stock assessment and the gains from different update strategies, made the discussions about TAC update schedules uncertain and largely hypothetical. Despite this, the group managed to qualitatively eliminate various options of fine and coarse temporal resolution.

Given the level of precision and accuracy achieved by the current stock assessment method, all participants believed any kind of mid-season update to be an unnecessary cost given the expected benefits. Concerns over mid-season instability in the market value of the fishing rights were also voiced. The result is that an annual TAC represents the finest temporal resolution for update that should be subject to analysis. Given that the current stock status is believed to be lower than the target reference point of MEY, it was suggested that an annual update could be implemented until the stock approaches a higher, more stable level where it may be cost-effective to alter TACs less frequently. The longest duration of a TAC discussed was a two-year quota, confining our analysis to just two variants of TAC update.

The participants were confident that were important changes in the stock to occur, they could be identified by stock assessment and suitable action taken.

**Banana prawns**
**Setting pre-season TACs**

The stock assessment of banana prawns is currently under development. Until a reliable stock assessment method can be established, the basis for setting preseason quotas, if used, is likely to be historical catches. The level of this preseason TAC relative to historical catches is likely to be determined by (1) the desired balance between biological precaution and race-to-fish incentive / yield, and (2) whether there is to be a within-season update and if so, the duration of time before update. Historically, catches of banana prawns have been highly variable and relatively unrestricted. Where no mid-season update is to occur, TACs set according to some percentile of the historical catches will be too high in some years and too low in others to an extent that is determined by the very large variability illustrated by previous annual catches. The group concluded that were the banana fishery to move to ITQ management, within-season updates could increase TACs substantially in good years but lead to unrealised quota in bad years.

### Mid-season updates

In the absence of a formal stock assessment method, the historical relationship between fishing efficiency (measure by catch-per-unit-effort or CPUE) and total annual catch could be used to increase quotas mid-season. A Bayesian statistical approach to updating prior knowledge over total catch, was considered by the group to be an avenue worth investigating. Some participants questioned whether CPUE versus annual catch relationships established under input controls, could be applied logically in the update of TACs under output control. It was suggested that the interpretation of CPUE from a finer temporal scale (such as catch per hour of fishing) would require fewer assumptions in the shift to output control. Industry members raised the point that were such a system implemented, it could promote either misreporting of CPUE or 'race-to-fish' dynamics with the objective to receive a larger mid-season update.

Regarding the mid-season update option, it was recognised that only increases in TAC could be implemented in order to avoid promoting 'race-to-fish' dynamics. The relative level of the pre-season TAC would be determined by the period of time before update. Two scenarios were suggested: (1) a relatively low initial pre-season TAC followed by a (relatively uncertain) update after the first two weeks of the banana season or (2) a moderate pre-season TAC followed by a (somewhat more precise) update after the first three weeks.

Since much of the banana catch occurs within the first two to three weeks, any update would have to occur early and on the basis of relatively little information. All operators agreed that it was important that the fleet not reach its quota before the update, which could lead to either waiting at sea or pre-emptive fishing before the update. Such a scenario could be prevented by setting relatively high preseason TACs. The practical and economic costs of such a strategy were well recognised; it could promote a 'race-to-fish' in poor years. However, the biological cost is less well known. Many industry members expressed a view that certain operators would strive to achieve their allotted quota (it might be viewed as a target) even under uneconomic conditions. Similar behaviour has been observed by industry under the current system, with operators continuing to fish at the end of the season despite very poor catch rates. Without a reliable stock assessment (in particular an established stock-recruit relationship), it is hard to evaluate how uncharacteristically high levels of exploitation could affect the stock, specifically whether it could lead to recruitment over-fishing.

Given the lack of information on research costs, the group found it difficult to discuss whether a second mid-season update would be necessary. It was concluded that the 2$^{nd}$ and 3$^{rd}$ week updates be considered the primary subject of investigation. A possible additional update in week 4, could also subject to secondary analysis.

### Stock assessment

The quantitative team pointed out that stock assessment methods could offer increases in precision that may lead to increases in quota that on average, outweigh the research costs entailed. It was agreed that greater research into assessment and the cost-benefits of preseason stock assessment would be necessary before they could be considered.

### Input versus output control

The issue of input versus output controls arose repeatedly during the banana prawn discussion. All attendees agreed with the results of Professor Kompas' presentation; that unlike the tiger prawn fishery, ITQ management of banana prawns may not incur economic advantages over the current input controls. This is due to the relative environmental uncertainty associated with banana prawns, indicating that an input control instrument would generate both higher profits on average and less variance in profitability. The majority of the group concluded that the 'base case' scenario for the NPF should include the input control of banana prawns, at the very least until the ITQ management of tigers is established.

### Multi-species TACs

The group agreed that setting quotas in the second season may be necessary to prevent overexploitation of bananas when tiger quotas are reached. This reasoning formed the basis for a popular management strategy of input controls of the first season and output controls in the second. In certain areas, individual species of bananas may require quotas. In particular, the group felt that a separate quota for red leg banana prawns in the JBG management area would be necessary

### Endeavour prawns

There was discussion regarding the base-case scenario for the management of endeavours. While many believed that no TAC should be set initially, others felt that a precautionary TAC was required to prevent greater targeting of endeavours once tiger quotas were met. Given the current lack of an established stock assessment method for endeavours, a possible solution would be to set endeavour TACs to a fraction of the tiger prawn TAC. However, several attendees maintained that such an approach would be inconsiderate of the dynamic relationship between the tiger prawn and endeavour prawn stocks. Proponents of the spatio-temporal weighting of tiger prawn quota pointed out that this method could be used to protect both endeavour prawns and banana prawns in the second season.

In general, opinion was mixed on whether operators would start to target endeavour prawns after the tiger prawn quota was realised. The important point was made that in practice different operators would meet their quotas at varying times. It follows that while the theoretical arguments for quotas on non-tiger prawn species in the second season are largely valid, it is difficult to predict fishing dynamics and know whether they are necessary. These points were distilled into two options for investigation: either no quota control of endeavour prawns in the second season or quota control as a fraction of the tiger prawn TAC.

### General discussion

### High-grading

The group agreed that the implementation of ITQs increased the risk of high-grading but stressed that most fishermen strive for better fishing practices. Members of industry stated that to a small extent, high-grading already occurs in the current fishery under input controls. Opinions differed on whether a sufficient price differential exists among grades of prawns to make additional fishing profitable and support important increases in high-grading. In light of the uncertainty over this problem, a range of management options were discussed, including monitoring, enforcement of zero dead discards, observer coverage, comparing size composition of catches among vessels, penalties for discarding, making crew members contribute to the cost of fishing and additional quotas for small, crushed or broken prawns.

Some participants felt that changes to the 'culture' of the industry would be as effective as any of the options described above. Increased cooperation among operators and improvements in organisation were cited as key objectives. For example, it was suggested that operators could report areas where small prawns were being caught and make this information readily available to all fishers therefore reducing the need for high-grading.

### Transhipment

The risk of unregulated transhipment was thought by many to be relatively low. Vessel monitoring systems were believed to offer the best protection against unregulated transhipment operations. The incentives for foreign transhipment are also believed to be low given the relatively low price of prawns on the East Asian markets. The possibility of illegal landings (*e.g*. offloading at fuel stops) was brought up but most thought that these operations could not be kept secret for long. While overall, the risks from transhipment were thought insignificant compared with those of high-grading some attendees maintained that that the remoteness of the fishery could still provide excellent opportunities for unregulated transhipment, and hence misreporting of catch.

### 'Race to fish' incentives

All attendees from industry stated that the 'race to fish' could not be eliminated from the NPF altogether despite relatively restrictive quotas. These dynamics were believed to be more likely in the banana prawn fishery where historically, fishermen have used high fishing intensity to maximise catches. Setting TACs too high, allowing TACs to be reduced and/or allowing the end of the season to be brought forward were cited as likely circumstances under which output control could provide race-to-fish incentives. Similarly to high-grading, the group concluded that co-management, greater industry cooperation and organisation could dramatically reduce the incentive to 'race-to-fish'.

### Introducing ITQs to the NPF

In general, the group understood the potential benefits of moving to a quota system but expressed some reluctance to move away from a current system, the properties of which are not yet understood, and the benefits of which may not yet have been fully realised. Many attendees were interested to see how the fishery performs under the current system given the relatively recent fleet reduction to 52 boats. The discussion of how to introduce TACs reflected this with more participants preferring relatively conservative options entailing a more gradual introduction of TAC.

The group preferred to use a phased approach, starting with tiger prawns, given that these are the species group best suited to a shift to ITQs. If endeavour prawns and/or banana prawns are targeted during the tiger prawn season, leading to potential overexploitation, second season TACs could be implemented for these species. After a sufficient number of years to assess the impact of ITQ management on the tiger fishery, and subject to a thorough cost-benefit analysis, ITQs management of the banana prawn fishery could then be considered. It was also argued by most in the group that a full cost-benefit analysis of the move to ITQs in the NPF should be performed before its introduction, even before its application to tiger prawns.

**The consequences of a hybrid input-output control based management approach.**

The group was concerned that it would be hard to foresee the consequences of two types of management: ITQs for tiger prawns and ITEs for banana prawns. Among their concerns were: over exploitation of red leg banana prawns in the JBG management area, the production of two separate capital bases, species group specialisation, difficulties with trading among tiger and banana quota, difficulty in trading quota and/ for gear units and uncertain management costs. It was concluded that further analysis of the potential implications of hybrid management be investigated. Two principle questions are: Should all species groups fished in the second season be subject to quotas? Do the disadvantages of a hybrid approach support a shift in banana management to quotas?

**Costs of implementing ITQs**

The cost to industry of shifting from input to output controls was a reoccurring discussion point throughout the meeting. Even approximate costs could not be calculated because they are determined by factors such as the required level of enforcement, reporting and stock assessment which are uncertain. Cost concerns were magnified by the relatively high current cost of fishing (largely due to inflated fuel prices) and the remoteness of the fishery. A range of additional costs were identified: surveillance, enforcement, data reporting, effort monitoring, stock assessment and research. Until figures can be calculated for these costs, the economic analysis of the shift to ITQs is missing a central component. Equally, the potential benefits to the banana prawn fishery of increased economic efficiency remain uncertain and could go some way to addressing such costs. Recommendations were made for other case studies that might provide information on the additional costs of ITQ management, such as Australia's South East Fishery. It was also agreed that AFMA would provide details of an earlier report on the costs of implementing ITQs in the NPF, and the economist on the MRAG project team will update this information as much as possible.

**Other recommendations to the project team**

Stock assessment scientists recommended the South African anchovy fishery as an important case study for reference on the introduction of ITQs to short lived species. They also maintained that effort creep should be monitored under ITQs in order to properly interpret fishery dependent data.

Industry members brought up the issue of quota overruns. In particular they were interested in mechanisms by which flexibility can be built into the quota system (for example the deduction of up to 5% of quota from the TAC in the following year).

**Summary of options for analysis**

| Species group | Base Case | Alternatives | | |
|---|---|---|---|---|
| Tiger Prawns | [**1**] Annual species group TAC. Variable start of the tiger prawn fishing season | [**1.1**] Two-year TAC<br>[**1.2**] Explicit multi-species TACs | | |
| Banana Prawns | [**2**] No Change in management | *(first season)* | one update | two updates |
| | | low initial TAC | [**2.1**] after wk 2 | [**2.3**] after wks 2 and 4 |
| | | moderate initial TAC | [**2.2**] after wk 3 | [**2.4**] after wks 3 and 4 |
| | | [**2.5**] Second season output controls | | |
| Endeavour Prawns | [**3**] No quotas implemented in the short term | [**3.1**] Quotas based on a (variable) proportion of tiger prawn TAC | | |

## Appendix

### A1. List of Attendees

MRAG/ NORMAC ITQ Workshop
5th July 2007
Brisbane

**Consultants:** Tom Carruthers, Richard Hillary, Tom Kompas

**Attendees**

| | |
|---|---|
| Stuart Richey | NORMAC Chair |
| Annie Jarrett | NORMAC EO |
| Nick Rayns | AFMA/ NORMAC |
| Cathy Dichmont | CSIRO/NORMAC |
| Eddie Hegerl | NORMAC |
| Ian Knuckey | NPRAG CHAIR |
| Jim Gillespie | NORMAC / QDPI |
| David Carter | MAC Member/ industry |
| George Raptis | MAC member/ industry |
| Norm Peovitis | MAC member/ industry |
| Greg Albert | MAC member/ industry |
| Ean Casey | MAC member/ industry |
| Ron Earle | MAC adviser/ industry |
| Mike O'Brien | MAC adviser/ industry |
| Ian Boot | MAC adviser/ industry |
| Max O'Halloran | MAC adviser/ industry |
| Andy Prendegast | MAC adviser/ industry |
| Martin Exel | Industry |
| Noel Hoschke | Industry |
| Vic binding | Industry |
| Brian Corbett | Industry |
| John Palmer | Industry |
| Graham Ruby | Industry |
| Peter Schultz | Industry |
| Yimin Ye | CSIRO |
| Sean Pascoe | CSIRO |
| Andy Bodsworth | AFMA |
| Wade Whitelaw | AFMA |
| Norm Hall | NPRAG |
| Ian Cartwright | AFMA Board member |

### A2. Agenda / Discussion topics

**NORMAC, Brisbane. July 2007.**

**Timetable**

| | |
|---|---|
| 8.45 – 8.50 | Welcome & Introductions (NORMAC Chairman) |
| 8.50 - 10.30 | Plenary Session - MRAG Presentation |
| 10.30 - 10.50 | Morning Tea |
| 10.50 - 12.45 | Working Group Sessions to discuss specific issues raised in the MRAG Presentation |
| 12.45-1.30 | Lunch |
| 1.30 - 3.00 | Working groups to report on key questions (synthesis of WG outcomes by WG leaders) / Open session to clarify issues raised by WGs |
| 3.00 - 3.30 | Afternoon Tea |
| 3.30 - 4.30 | Plenary Session / discussion on Issues arising from Working Group Discussion |
| 4.30 - 5.30 | Synthesis of Outcomes from Workshop (MRAG ) - agreement on steps forward |

**Discussion Topics**

**1 Tiger Prawns**

1.1 Given that species group TACs may restrict the catches of species that are doing relatively well, are species-specific TACs necessary?
1.2 How could species-specific TACs be implemented (*e.g.* Interpreting catches from sub-areas with established tiger species composition)?
1.3 What frequency of TAC update is necessary (*e.g.* once every two years, annually, or annually with mid-season update)?
1.4 On mid-season updates: are there any clear justifications for a certain number of updates, and when in the season should they occur?

**2 Banana Prawns**

2.1 How should initial TACs be set for banana prawns? *E.g*. low (precautionary)/ med/ high (relatively unrestricted output).
2.2 How many, if any, mid-season updates are desirable given that they are likely to increase catches in good years but entail increased management?
2.3 Despite high uncertainty over stock dynamics, stock assessment may improve the precision of preseason estimates of exploitable biomass. Would such improvements justify the additional research, data reporting and assessment costs?
2.4 Is there a need for species-specific TACs and how could they be implemented?

**3 Endeavour prawns**

3.1 How could TACs be set for endeavours (*e.g.* by stock assessment or as a fraction of Tiger TAC)?
3.2 Similarly to tigers and bananas, would species specific TACs be necessary and how could they be implemented?
3.3 If tigers were subject to output control, could this promote increased targeting of endeavours?

## 4 Other issues

4.1 To what extend might high-grading be a problem for each species group?
4.2 How might high-grading be prevented (*e.g.* observer coverage, monitoring of size composition of catch)?
4.3 Given that vessel monitoring systems are available, is transhipment an issue?
4.4 Under what circumstance could TAC management create 'race to fish' fleet dynamics?
4.5 How could co-management and industry cooperation reduce a tendency for over capitalisation and 'race to fish' dynamics?
4.6 How should ITQ management be introduced (*e.g.* phasing in one species group at a time)?
4.7 What might be the consequences of mixed management methods? For example, where the tiger prawn fishery was managed by output controls and the banana prawn fishery by (similar to today) input controls.
4.8 Would the additional costs of surveillance, enforcement, data reporting, monitoring of effort etc. that may be required to implement ITQs be prohibitive for some or all operators?

# A3. Presentations

**Dr Tom Carruthers.**
**Background to the meeting.**

- Project aims and objectives
- Purpose of the workshop
- Background to the tiger prawn fishery and review of management and potential problems in the shift to ITQ management such as multi-species issues and TAC update strategies.
- Background to the banana prawn fishery and review of current thinking on the shift to ITQ management.
- Overview of the endeavour prawn fishery, and review of TAC setting options in the light of limited stock assessment.
- General areas for discussion and feedback: high grading, transhipment, race-to-fish incentives, management costs, the transition to ITQs, monitoring effort creep.

**Quantitative methods under investigation for the evaluation of the ITQ management of banana prawns.**

- Setting initial TACs on the basis of historical catches
- Updated TACs according to relationships between weekly historical catch-per-unit-effort and total yearly catches (assuming an implicit model)
- The advantages / disadvantages of mid-season updates.
- Assumptions of the method.
- The uncertain biological outcome of allocating a TAC higher than the catches that can be achieved.

**Dr Richard Hillary.**
**Quantitative methods applied to tiger prawns**

- The tiger prawn operating model
- Setting TAC

- Harvest control rules
- Initial conditions
- Simulating stock assessment: the incorporation of assessment error
- Comparing TACs set under perfect and imperfect knowledge
- The performance of annual TACS
- Multi-species issues: combined TACs
- Summary of the modelling to be undertaken

**A/Professor Tom Kompas.**
**An economic evaluation of the shift from ITE to ITQ management in the northern prawn fishery.**

- Economic theory behind ITQs
- The tiger and banana prawn fisheries under ITE management
- Variability in fishing efficiency versus stock size
- The economic implications of ITQ management of the tiger prawn fishery
- The economic implications of ITQ management of the banana prawn fishery
- Assumptions of the modelling
- Uncertainty over the economic benefits of ITQs
- Uncertainty in the costs of the shift to ITQ management

## A4. Background papers

**G. Parkes.** Assessment of options for implementing ITQs in the banana prawn fishery: setting TACs.

**T. Kompas.** Individual transferable quotas, instrument choice and profitability, and the cost of ITQ enforcement in the Northern prawn fishery.

**R. Hillary.** Assessment of options for implementing ITQs in the Tiger prawn fishery: setting TACs