Flexible Seasonal Closures in the Northern Prawn Fishery

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Given high levels of uncertainty associated with fish stocks, predetermined access rights to the fishery may not deliver the most efficient outcome. Real time monitoring of the fishery could allow effort to be expanded or decreased in accordance with a set of performance indicators. The potential for using real time performance indicators in the Australian northern prawn fishery is examined in this paper using a stochastic optimal control model of the fishery. The results indicate that the benefits of using real time performance monitoring to control fishery access may be limited. However, this result may depend critically on the relationship between surviving stocks and future recruits to the fishery.

Keywords: prawns, fisheries access, stochastic control, genetic algorithm.

1 INTRODUCTION

1.1 Description of the Fishery

The northern prawn fishery (NPF) is located in the Australian fishing zone between Cape Londonderry, Western Australia and Cape York, Queensland (figure 1). Covering an area of around 1 million square kilometres, the NPF is Australia's largest fishery and one of its most valuable. For this fishery the gross value of prawn production in 1997-98 was estimated to be $116 million in nominal terms with a total harvest of around 8 500 tonnes (ABARE 1998). Over 90 percent of the catch is exported, with the principal market being Japan.

More than 50 species of prawn inhabit Australia's tropical northern coastline but brown tiger prawns (*Penaeus esculentus),* grooved tiger prawns (*P. semisulcatus*) and white banana prawns (*P. merguiensis*) account for over 80 per cent of commercial landings from the NPF. The two tiger prawn species are the focus of the discussion in this paper.

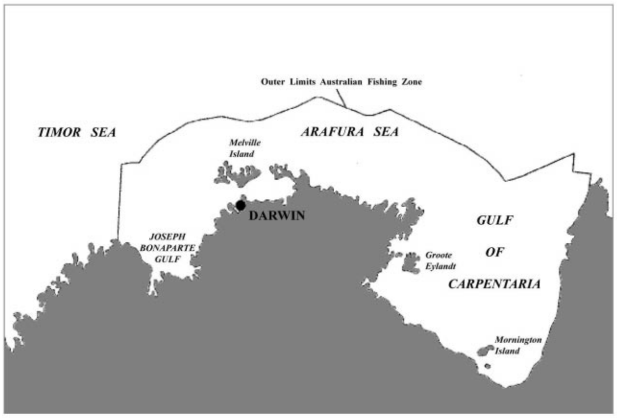

Figure 1: Location of the Northern Prawn Fishery

The lifecycle and habitat of tiger prawn stocks in the NPF is described in Crocos (1987a and 1987b). The timing and location of tiger prawn fishing largely reflects the physical availability and size of the species throughout the fishing season. At the start of the banana prawn season in April, fishing is almost exclusively in the east of the Gulf of Carpentaria, and the tiger prawn catch at this time is comprised mostly of brown tiger prawns. After three weeks almost all banana prawn fishing in the Gulf of Carpentaria has ceased and effort is directed toward brown tiger prawns around Mornington Island, in the south of the Gulf. During the tiger prawn season, which opens in early August, brown tiger prawns are targeted for the first few weeks, after which effort switches to grooved tiger prawns. This pattern of fishing effort and harvest has been relatively stable over the past five years (Timcke et al. 1999).

Currently, around 130 vessels are actively participating in the fishery. All vessels are purpose built twin gear otter trawls. The fleet is technologically advanced, employing modern packing and freezing capabilities and sophisticated electronic fishing aids such as colour echo sounders, satellite global positioning systems (GPS) and plotters. Most boats in the fishery operate between 80 and 90 percent of the time available for fishing with many unloading their catch and receiving supplies from mother ships.

Recent stock assessments have indicated that tiger prawn stocks are overfished (Taylor et al. 1999; Die et al. 1999). Tiger prawn landings began to decline in the second half of the 1980s and over the past decade have not recovered to levels of the early 1980s. Recent tiger prawn catches (2694 tonnes in 1997, 3250 tonnes in 1998 and 2986 tonnes in 1999) are well below the estimated maximum sustainable yield (MSY) of around 4000 tonnes per year.[1]

1.2 Management of the Fishery

The NPF is managed by the Australian Fisheries Management Authority (AFMA). The present management system is the result of a series of input controls and season and area closures. The experience of the NPF is typical of many limited–entry, input–control fisheries in Australia and overseas. Input controls alone, have failed to provide the necessary incentives required for a reduction in excess fishing capacity. The technological improvement of fishing inputs on individual vessels and substitution of regulated inputs with unconstrained inputs (effort creep) has significantly increased the fishing power of the fleet over recent years. Effort creep in the NPF has been estimated to be as high as 5 per cent a year (Buckworth 1987, Taylor et al. 1999). As a consequence, there have been ongoing reviews and adjustments to input and entry controls to reduce effective fishing effort.

1.2.1 Quota Schemes

Alternative approaches to the implementation of input controls and the measurement of fishing effort have been proposed. One alternative management instrument which explicitly avoids the problem of effort creep is an output based system of individual transferable quotas (ITQs).

ITQs are transferable property rights to harvest a specified quantity of fish. While a market in ITQs can enable operators to minimise costs by adjusting the size of their fishing operations through the purchase, sale or lease of quota, managers must specify the total level of allowable catch (TAC). When managers face a high level of uncertainty regarding a sustainable or economically efficient TAC, the benefits of an ITQ system may be greatly reduced. For example, if managers make ongoing adjustment to the TAC to avoid the risks of over exploitation, the risks of such adjustment for operators' capital investments, including quota purchases, may limit the efficiency of the fleet. Alternatively, managers could purchase and sell quota within the season. This may add significantly to management costs, as the costs of purchasing quota when stocks are low are likely to be higher than the value of sales when stocks are high. However, allowing long term access through fixed annual quotas may lead to sustained lower or under exploitation of the fishery.

Variable Closures

In contrast to input controls and a quota system, season and area closures regulate the timing and location of fishing effort. The principal objectives of seasonal closures in the NPF have been to protect pre-spawning prawns, to allow prawns to grow to a more valuable market size before harvesting, thereby ensuring the production value of the fishery is as high as possible. In addition to the principal season closures that are in effect for the entire NPF, there are numerous region–specific closures that operate for either part of the year or permanently (see AFMA 1997 for a detailed listing). Most of these closures are designed to protect juvenile prawn stocks and the coastal marine environment.

The relatively short life span of prawns means that the timing of fishing effort in the NPF is critical from both a biological and financial point of view. The NPF season typically opens in early April each year and closes at the end of November with a mid-season closure from mid June to the end of July to protect pre-spawning tiger prawns. The end-of-year closure is designed to prevent catches of juvenile tiger prawns and to allow banana prawns to grow to a larger, more commercially valuable size.

The fixed season closures of recent years have been criticised by industry as inflexible. With fixed season opening and closing dates, there is certainty regarding the timing of fishing operations. However, large fluctuations in stocks between seasons imply that a flexible approach to determining the start and duration of the fishing season may be advantageous. With ongoing improvements in fishery data collection and knowledge of the biological development of stocks, closures that are responsive to the status of target stocks and the marine environment may be a feasible instrument for management in the NPF.

The choice of opening date for the northern prawn fishing season has been reviewed a number of times and a variety of dates within the March to May period found to be optimal (see for example: Somers 1985; Brown et al. 1995; Somers et al. 1997). Somers (1985) found substantial regional and annual variation in the optimal opening dates for the banana prawn fishery. Somers et al. (1997) extended the Somers (1985) model to include the tiger prawn fishery. They found that the optimal timing of the entire fishing season is sensitive to changes in recruitment timing and natural mortality. Improved estimates of prawn recruitment and mortality relationships (Wang et al. 1996) mean that it is now possible to determine the net benefits of increased recruitment through season closures. It is the strength and nature of this relationship that determine the costs and benefits of maintaining stocks for the following season.

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[1] Historical catch and effort data for the tiger prawn fishery is consistent with over-exploitation of stocks. However, another possible explanation is that recruitment has been affected adversely by as yet unidentified environmental factors (Taylor et al. 1999).

In order for the NPF fishery to move to a variable season opening date, sampling of stocks prior to the season opening would be necessary. Based on the size of prawns sampled and catch rates, the opening date for the fishery could be determined. The benefits of such a program are likely to depend on the cost and accuracy of the sampling.

Prior to 1994, opening dates for the NPF were flexible and determined by pre-season sampling. In 1994 the opening date for the fishery was fixed at 1 April, with the proviso that the season could be varied if exceptional monsoonal rainfall occurred in the Gulf of Carpentaria. The decision to fix the opening date recognised the high costs and logistical difficulties associated with pre-season sampling (Hill 1994).

To vary the mid-season and end of season closing dates, it may be possible to analyse logbook data on volume of catch by size composition for the current season to ascertain both the abundance of stocks and the maturity of prawns in the catch. The primary source of information on the status of stocks in the NPF is daily catch and effort logbook data. Currently, catch/effort logbooks are completed manually by vessel skippers and data on catches only becomes available to fishery managers after a delay of several weeks.[2]

The position of the individual boats fishing in the NPF is presently monitored in real time using a global positioning system. The development of electronic logbooks may not impose prohibitive costs.[3] Fishers could use a message terminal on board the vessel to complete an electronic version of the relevant logbook, and then forward the logbook data via the transceiver used to transmit positional data.

One condition for the effective adjustment of season closures based on real time catch and effort data is that stock abundance can be accurately predicted. That is, if catch and effort information provides some indication of the state of tiger prawn stocks, then the exploitation of stocks may be controlled during the season by an adjustment to season closing dates. Timcke et al. (1999) showed that within five weeks of the start of the tiger prawn season the annual tiger prawn catch could be estimated to within 5 per cent of the actual total catch. This suggests that if catch data were available in real time it would be feasible, at least once the tiger prawn season had started, to set an optimal closing date for the fishery.
A second, more general condition for an effective closure scheme is that the closure of the fishery at one site location and time does not lead to a significant reallocation of effort to other locations and or periods. Given that the intensity of fishing effort is relatively constant throughout the season (Timcke et al. 1999), season closures are unlikely to shift effort from one part of the year into another. A change to the end of season closure to protect grooved tiger prawn stocks, for example, is unlikely to result in an increase in effort earlier in the season with a consequential impact on brown tiger prawn stocks.

2 MODELING THE FISHERY

The objective of the modeling exercise was to represent the existing, as opposed to the ideal structure of the fishery, and the response in fishing effort to policy instruments introduced under conditions of uncertainty regarding recruitment stocks. The model draws upon an existing biological model of the fishery and overlays this with statistically estimated behavioral equations to represent fishing effort. Economic returns are then calculated using estimated market relationships that reflect the seasonality of prawn prices and fishing costs derived from surveys of the NPF fishing fleet. A genetic algorithm (GA) was then used to determine optimal policy setting.

2.1 Biological Model

Stocks of both brown and grooved tiger prawns are assessed annually using the cohort model described by Wang et al. (1996). Assessments are based on weekly catch and nominal effort (days fished) log book data for the two tiger prawn species. Actual catch data are not recorded on a species specific basis. Catch samples were used to determine the proportion of brown and grooved tiger prawns at different locations. Log book data was then disaggregated to the species level based on the recorded location of the catch. The observed catch data were fitted to the estimated catch from a population model to provide estimates of annual recruitment and spawning stock. These estimates were then used to estimate equilibrium yield as a function of effective fishing effort (actual fishing mortality). The population model is age-structured and includes natural growth and mortality, catchability and seasonality in patterns of spawning and recruitment.

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[2] For 1996, 1997 and 1998, AFMA reported that they received a record for every fishing day from every trawler in the NPF. The quality of data provided in the NPF is regarded as exceptionally high (Taylor et al. 1999).

[3] Under AFMA's guidelines for the implementation of an Integrated Electronic Data Management System, industry is required to meet the full cost of electronic logbook hardware and 50% of other costs.

2.1.1 Linking Surviving Mature Biomass to Future Recruits

Recruits to the fishery in the current year were modeled as a function of the surviving mature stocks (over 26 weeks in age) from the previous year. Data on recruits, *R*, and surviving stocks, *S*, were derived from the Wang et al. (1996) cohort model and fitted according to Ricker's equation:

$$R_t = \gamma_1 S_{t-1} e^{\left(\gamma_2 S_{t-1}\right)} \qquad (1)$$

Residuals were normalised as a percentage of the predicted value. For the purpose of stochastic simulation the error structure was modeled using a gamma distribution, with standard parameters alpha and beta. The residuals were translated to a non-negative domain using the minimum residual value. The results are summarised in table 1.

Table 1: Parameters for stocks to recruits relationship

Parameters	Brown Tigers	Grooved Tigers
γ_1	18.1*	13.7*
γ_2	-0.016*	-0.016*
R^2	0.33	0.48
Alpha	3.11	6.15
Beta	0.19	0.09.
Minimum residual	0.50	0.44

* significant at the 5% level.

The estimated gamma distribution for both stocks is right skewed in level terms. The stochastic mean level of recruits is greater than the deterministic mean.

2.2 Predicted Effort/Catch Relationships

Estimates for weekly fishing effort for brown and grooved tiger prawns were based on weekly, species specific catch and effort data for the fishery for the period January 1987 to December 1998. Fishing effort, *e*, is expressed as total boat days fished and is split between each species. Catch data, c_{it}, is the total catch weight of prawns of species *i* in week *t* in kilograms.

The weekly fishing effort for brown tiger prawns (2) and grooved tiger prawns (3) was estimated to be related to effort in the corresponding week of the previous two years and catch of each species over the past four weeks:

$$e_{1t} = \alpha_{01} + \alpha_{11} e_{1,t-53} + \alpha_{12} e_{1,t-106} + \alpha_{13} \sum_{j=1}^{4} c_{1,t-j} + \alpha_{14} \sum_{j=1}^{4} c_{2,t-j} + \eta_{1t} \qquad (2)$$

$$e_{2t} = \alpha_{02} + \alpha_{21} e_{2,t-53} + \alpha_{22} e_{2,t-106} + \alpha_{23} \sum_{j=1}^{4} c_{1,t-j} + \alpha_{24} \sum_{j=1}^{4} c_{2,t-j} + \eta_{2t} \qquad (3)$$

where η_{it} are equation residuals. The effort equations, estimated as a system, are detailed in table 2. The fitted equations provide a reasonable representation of the historical effort data (figures 2 and 3).

Table 2: Estimated equations for fishing effort by species

Variables	e_1 equation (brown tigers)	e_2 equation (grooved tigers)
$e_{i,t-53}$	0.52699*	0.30915*
$e_{i,t-106}$	0.27498*	0.39549*
$\sum c_1$	0.27277E-03*	-0.31456E-05
$\sum c_2$	-0.85917E-04*	0.44543E-03*
R^2	0.83	0.93
constant	4.47202	-0.37647

* significant at the 5% level.

Catch is given, without species and time subscripts by:

$$catch = m_f \cdot stock \cdot \frac{1 - \exp\left(-m_{tot}\right)}{m_{tot}} \qquad (4)$$

where

$$m_f = e \cdot catchability \qquad (5)$$

and m_f is fishing mortality and m_{tot} is the sum of fishing and natural mortality Natural mortality and catchability are those given in Wang et al. (1996).

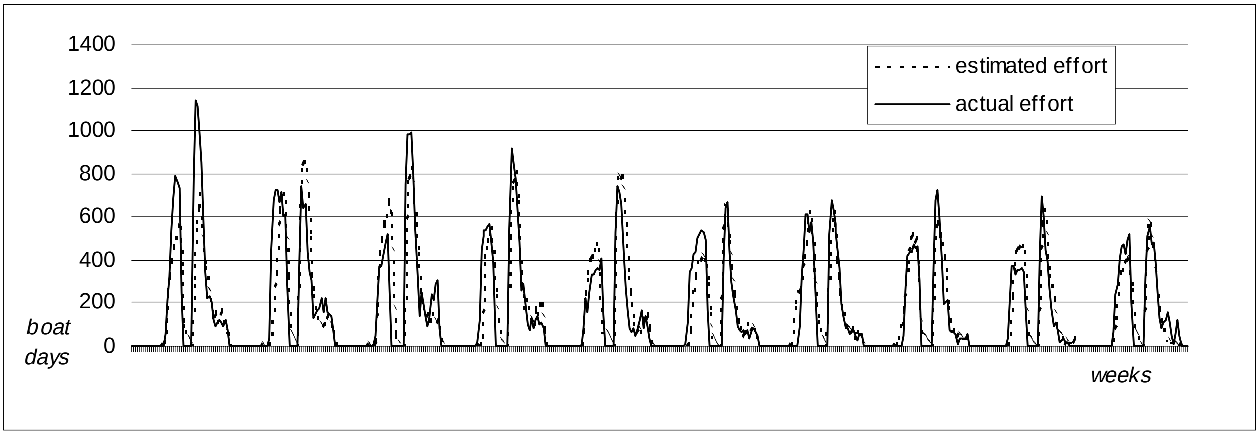


Figure 2: Fishing effort for brown tiger prawns

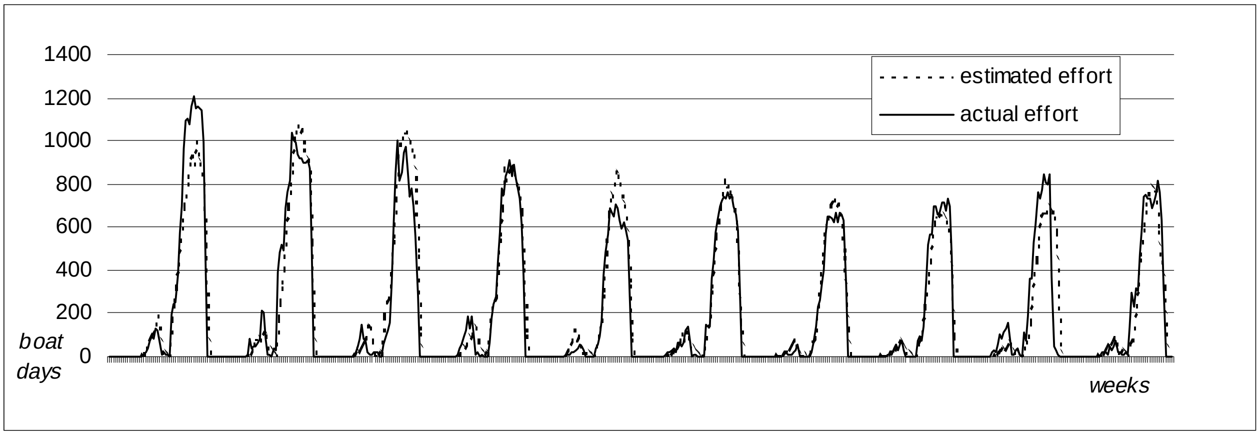


Figure 3: Fishing effort for grooved tiger prawns

2.3 Costs and Returns

The gross revenue from fishing was estimated as the product of the number of prawns caught and the export price obtained. The majority of prawns from the northern prawn fishery are exported to Japan and Japanese prawn prices are highly seasonal. Estimates for the weekly price of prawns were based on historical data for the primary wholesale price of tiger prawns received outside the Tokyo central market from June 1990 to September 1999. In terms of price received by suppliers, there is no distinction between brown and grooved tiger prawns. Prawns are categorised into one of five grades and sold in 1.5 kilogram lots, with the number of prawns in a lot determining the grade of the lot. The largest prawns attract the highest wholesale prices. Prawn grades considered are: (1) under 6 prawns; (2) 6-8; (3) 9-12; (4) 13-15; and (5) more than 16.

For each grade, the weekly tiger prawn price was determined as:

$$p_{gt} = \beta_0 + \sum_{g=1}^{5} \sum_{k=1}^{2} \beta_{gk} \, p_{g,t-k} + \varepsilon_{gt} \qquad \textit{for } g = 1 \textit{ to } 5 \quad (6)$$

where g is the grade of prawn, k is the number of lagged price terms included and ε_g is the equation residual. Inclusion of higher order autoregressive terms was considered and rejected. The estimated equations are detailed in table 3.

Variable	P1 equation	P2 equation	P3 equation	P4 equation	P5 equation
$P1_{t-1}$	0.6786*	-0.0380	-0.0477	-0.0212	0.0005
$P1_{t-2}$	0.2529*	0.0169	0.0408	0.0014	-0.0082
$P2_{t-1}$	0.2549*	1.0877*	0.1158	0.0037	-0.0429
$P2_{t-2}$	-0.1984*	-0.0903	-0.0993	0.0171	0.0236
$P3_{t-1}$	0.0945*	0.0353	0.6448*	0.1001*	0.0682*
$P3_{t-2}$	-0.0228	-0.0214	0.3218*	-0.0742*	-0.0338
$P4_{t-1}$	-0.1595*	-0.0887	0.1776*	0.8986*	0.0598
$P4_{t-2}$	0.0849	0.0718	-0.2090*	0.0161	-0.0705
$P5_{t-1}$	0.1288	0.0353	0.0985	0.0465	0.9482*
$P5_{t-2}$	-0.0841	0.0012	-0.0656	0.0175	0.0394
constant	-50.5640	10.8285	85.7813*	9.6285	53.9050*
SE(e_t)	96.432	76.102	98.135	76.693	60.825
R^2	0.9690	0.9802	0.9345	0.9715	0.9778
LLF	-2802.70	-2691.66	-2810.91	-2695.29	-2586.57

* Significant at the 10 % level.

Table 3: Estimated equations for prawn prices by grade

The cost data used in the model were derived from ABARE surveys of the industry. Capital costs were excluded from the model so estimates of the costs associated with fishing are based on operating costs.

The operating costs were separated into packaging costs, fuel costs and crew costs and are shown in table 4. Packaging costs are dependent on the weight of the catch. Fuel costs are estimated as a function of effort in terms of boat days and reflect both the price of fuel in the region and the geographic spread of fishing effort. Crew costs are estimated as a fixed percentage of catch revenue.

Table 4: Operating costs associated with fishing

	Unit	Value
Packaging costs	$/kg	0.50
Fuel costs	$/day	850
Crew costs	% of revenue	0.26

2.4 Historical Validation

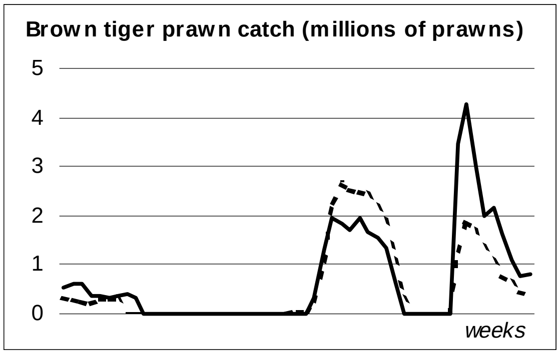
To assess the validity and accuracy of the model, weekly catch and effort predictions generated by the model were compared with data from Wang et al. (1996). Prediction errors were generated for catch and effort from one year forward projections between the years 1995 to 1997. The relative standard errors of the predictions are reported in table 5 and actual and predicted effort and catch for the 1997 biological year are shown in figure 4.

Table 5: Relative standard errors of catch and effort data, November 1994 – October 1997

	Brown tigers	Grooved tigers
Catch	0.074	0.046
Effort	0.019	0.033

2.5 Optimisation

The objective of this analysis is to examine the relative effectiveness of alternative seasonal closure rules. The first is a fixed closing date. The second is a real time rule based on observable indicators of the current status of the fishery (a performance rule).



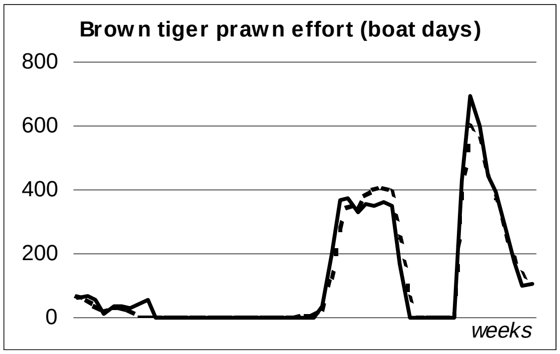


Figure 4. Continued on page 7

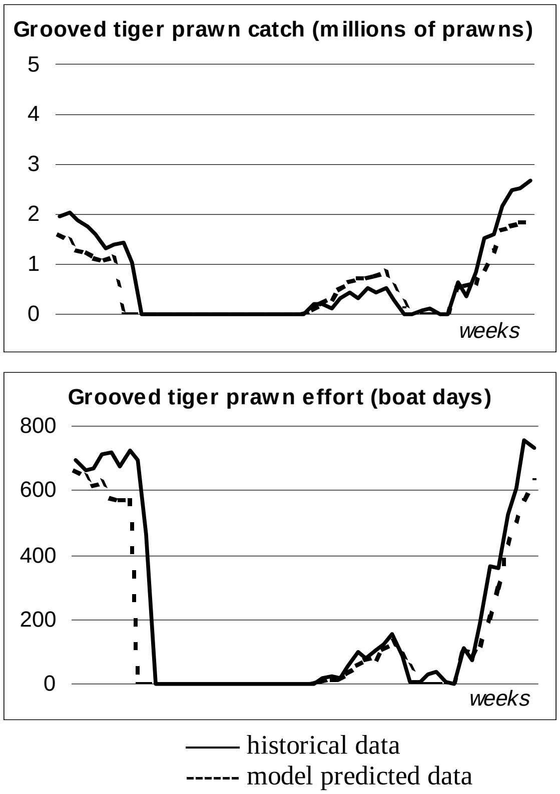


Figure 4: Comparison of model predicted weekly catch and effort with historical data, November 1996 to October 1997

2.5.1 Indicators

Ideally, indicators used in closure rules should be objectively and accurately measurable at any point in time. Most indicators will be subject to measurement error which may be systematic in some cases (for example, under-reporting). However, even an ideal set of indicators is unlikely to provide full information on the state of the fishery because uncertainty will always be a key aspect of fisheries management.

The indicator considered here is total catch per unit effort (CPUE). The CPUE rule was implemented using the combined total of brown and grooved tiger catch as boats do not presently record separate catch by these species.

Within the fishery model the relationship between CPUE and catch may be specified in a number of ways. When catch is in fixed proportion to the level of effort and stocks, CPUE is equivalent to a measure of current stocks. Hence, it is reasonable to expect that a CPUE closure rule under these conditions will perform relatively well, especially in the presence of uncertainty regarding biological parameters affecting the fishery. This uncertainty includes, initial stock conditions and recruitment relationships.

When CPUE is increasingly subject to random or other unexplained sources of variation, the reliability of CPUE in a closure rule indicator declines. The use of a performance based closure rule under these conditions may still be advantageous in that it allows greater harvest during periods of abundance and reduced harvest when stocks are low. However, random variation in the CPUE measure may lead to premature closing of, or unwarranted extensions to, the fishing season which may adversely affect both returns and fish stocks.

The lack of reliability of point in time measures may be partially overcome by the use of moving averages. However, as the length of the moving average increases, the measure can become an increasingly poor predictor of the current state of the fishery. This introduces the need to consider an optimal window over which the performance indicator is constructed.

2.5.2 Simulation Design

As discussed previously, the NPF is currently subject to opening, mid-season and final season closure rules, as well as regional closures. The results presented here are restricted to the determination of an optimal final season closure rule, either at a fixed point in time in each season or when a *k* period moving average measure of CPUE falls below an optimal tolerance level (*tol*).

$$\sum_{s=t-k}^{t} \frac{cpue_s}{k} \le tol \qquad (7)$$

The two closure alternatives are compared under three scenarios. In the first scenario, the relationships between (1) surviving prawn stocks and recruitment; and (2) predicted effort and predicted catch, are purely deterministic. In the second scenario the relationship between stocks and recruitment is stochastic while the relationship between predicted effort and predicted catch is deterministic. That is, where there is a reasonably good performance measure under uncertain conditions. Finally, in the third scenario both relationships are uncertain, with the proportion of stocks caught per unit of effort allowed to vary uniformly by 20 percent. The genetic algorithm discussed below is easily adapted in the stochastic simulations to select the size of the window to compute the average CPUE value as well as the critical value.

The initial conditions for the simulation were based on catch, effort and surviving biomass for the 1997 and 1998 seasons.

2.5.3 Use of Genetic Algorithms

A genetic algorithm (GA) is a search technique that has been successfully applied to problems with complex dynamic structures that cannot be easily handled with traditional analytical methods. The GA approach was first developed by Holland (1975) and has subsequently been widely employed in economics and finance research as a flexible and adaptive search algorithm (see for example: Alemdar et al. 1998; Beare et al. 1999; Beare et al. 1998; Birchenhall 1995; Ching-Tzong et al. 1997). The approach provides a globally robust search mechanism with which to optimise over a decision process involving uncertainty in the form of a lack of a priori knowledge, unclear feedback of information to decision makers and a time varying payoff function.

A GA performs a multi-directional search by maintaining a population of individual strategies, each with a potential solution vector for the problem. An objective function is employed to discriminate between fit and unfit solutions. The population undergoes a simulated evolution such that at each generation, the relatively fit solutions reproduce while the relatively unfit solutions die out of the population. During a single reproductive cycle, fit strategies are selected to form a pool of candidate strategies, some of which undergo cross over and mutation in order to generate a new population. Cross-over combines the features of two parent strategies to form two similar offspring by swapping corresponding segments of the parents. This is equivalent to an exchange of information between different potential solutions. Mutation introduces additional variability into the population by arbitrarily altering a strategy by a random change.

In determining the optimal harvest strategy each GA strategy or string contains a possible setting of the decision rule or rules for closing the fishery. The length of each string corresponds to the number of parameters to be estimated. Those strings that give a relatively high net revenue are given greater weight in the formation of the next generation of strings. After a number of generations, the solution may converge, with the best individual strings representing the optimum solution.

The genetic search algorithm was implemented in MatLab using the approach described in Goldberg (1989). Given the computational time required, a small sample strategy was adopted. The search was conducted over 50 generations using 20 population strings. For the stochastic simulations, each string was evaluated over 15 trials, and assigned a fitness value equal to the average fitness over the trials. Following Goldberg, a cross-over rate of 0.6 and mutation rate of 0.001 was used.

3 RESULTS

The results from the two closure rules under various levels of uncertainty are presented in table 6.

Under deterministic steady state conditions, an optimal closure date and an optimal CPUE based closure rule are equivalent management instruments. The small differences observed between the two options in the model simulation are due to the fact that the model begins from a disequilibrium position of below average spawning stocks.

With the introduction of stochastic recruitment relationships, effort and catch levels are higher reflecting the right skewed distribution of the Ricker equation errors. Under the closure date regime, the optimal season length is expanded to exploit the additional stocks which result in high recruitment years, when compared to the deterministic optimisation. The season length expands and contracts with the level of stocks under the CPUE closure rule. However, the optimal season length is unchanged, on average, using the CPUE based closure rule, when compared to the deterministic optimisation. This reflects the estimated Ricker recruitment relationships. While there is a greater probability of a large increase in recruitment than a large decline, the marginal value of surviving stocks increases as populations decline. Hence, the benefits of reducing effort when stocks are low balance the benefits of expanding effort when stocks are high. Nevertheless, the net benefits of the CPUE based rule are relatively small. Over the 15 year horizon, net revenue increases by about $18m.

With the introduction of a 20 per cent uniform variation in catch for a given level of stocks, there is no significant change in the optimal closure date regime. For the CPUE closure date rule, the optimal length for the moving average was four weeks. On average, the optimal seasonal length is reduced when compared to the previous optimisations. The difference in net revenue between the optimal closure date and the CPUE closure rules declines to about $4m. This reflects the reduced reliability of the CPUE performance measure as an indicator of the status of fish stocks.

The recruitment relationships in the model allow stocks to recover quickly regardless of the fishing pressure placed on the prawn populations. This is potentially a key assumption in any assessment of both the biological and economic sustainability of the fishery. If, for example, reductions in stock levels below critical levels results in longer term impacts on the fishery, the benefits of limiting access based on real time monitoring of fish stock may be much more substantial.

4 CONCLUSIONS

The uncertainty associated with surviving stocks and future recruitments reduces the effectiveness of most management options for the NPF. Variable closure rules, based on real time monitoring rules, may allow managers to preserve stocks when they appear to be low and exploit stocks during abundant seasons. However, the subsequent impact of reduced current catch on future stocks is highly variable.

As a consequence, the benefits of establishing access rights based on real time performance measures may be limited. However, within the biological framework of the model, the impacts of exploitation are readily reversible. If over exploitation results in sustained damage to the reproductive capacity of prawn stocks, the value of real time monitoring could be substantially higher.

Table 6: Numerical optimisation results

		Optimal Closure Date				Optimal CPUE Closure Rule			
		Brown		Grooved		Brown		Grooved	
	unit	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Deterministic									
Season	wks	14	*na*	14	*na*	14	*na*	14	*na*
Effort **a**	days	6447	*na*	4207	*na*	6528	*na*	4254	*na*
Catch	m	62.0	*na*	36.0	*na*	62.0	*na*	36.3	*na*
Revenue	$m	13.5	*na*	9.9	*na*	13.5	*na*	10.1	*na*
Stochastic 1									
Season	wks	16	*na*	16	*na*	13.9	0.7	13.9	0.7
Effort **a**	days	6917	1409	5231	881	7143	1614	5499	1236
Catch	m	69	29	45	13	70.9	31.5	46.9	15.6
Revenue	$m	15.2	7.4	12.5	4.0	15.7	7.8	13.2	5.0
Stochastic 2									
Season	wks	16	*na*	16	*na*	13.4	0.2	13.4	0.2
Effort **a**	days	6919	1413	5229	881	6942	1616	5333	1007
Catch	m	68	30	45	13	69.0	31.4	45.6	14.2
Revenue	$m	15.2	7.5	12.5	4.0	15.3	7.9	12.7	4.4

a effort measured in boat days.

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