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Optimal fisheries management instruments under biological uncertainty

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Individual transferable quotas (ITQs) have been identified as the preferred management tool for Commonwealth fisheries (Commonwealth of Australia 1989). This paper compares the effectiveness of ITQs as a management control with the current system of input controls in the northern prawn fishery using an integrated biological and economic model of the fishery, embedded in a stochastic optimisation framework to simulate optimal management of the fishery over any given planning horizon. The results indicate ITQs can be a successful management tool in the NPF, particularly in the presence of effort creep. However, the benefits from moving to an ITQ system are highly dependent on the rate at which the capital structure in the fishery is rationalised. Notwithstanding this result, other management strategies such as seasonal or area specific closures may also augment ITQs with additional benefits.

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Introduction

The classical problem in the management of a renewable resource is to balance current consumption use with investment in future production capacity. In an open access fishery everyone is allowed unlimited access to harvest as much fish by whatever means they choose. As there is no way to exclude incomers and there is no way of preventing existing operators from changing their level of harvesting effort, an individual cannot fully capture the benefits from their investment in maintaining larger stocks. Hence they will under invest and fish stocks and the long term economic returns to the fishery will be lower than socially optimal.

In order to overcome the problems associated with open access, fisheries management agencies have been established to control overexploitation and over–capacity (Kaufmann, Geen and Sen 1999). Whether through input controls or output controls, fishery management attempts to limit the harvesting of fish resources to a volume considered to be sustainable over the long term and maximising the economic returns to the fishery.

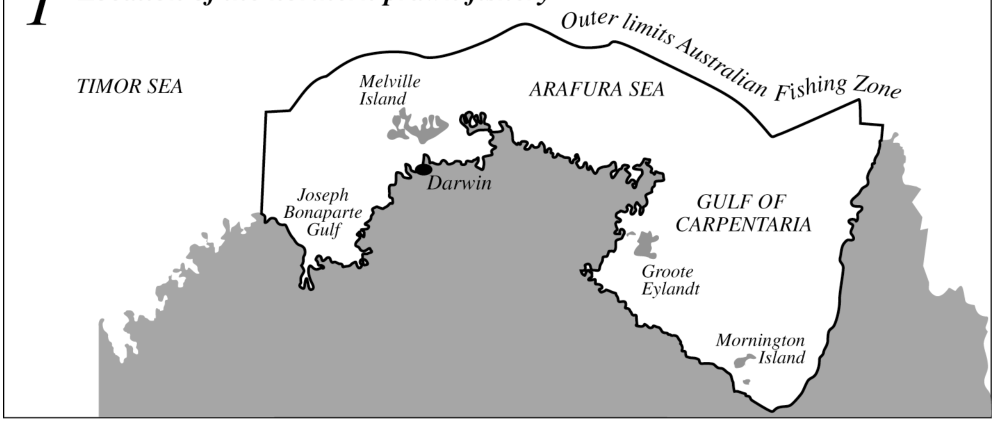
In 1989 a government policy statement on the management of Commonwealth fisheries stated the preferred management measure as one that allows market forces to operate (Commonwealth of Australia 1989). Specifically, the policy statement took the position that individual transferable quotas (ITQs) were the preferred management tool for Commonwealth fisheries. Further, fishery managers were required to demonstrate the superiority of other management controls over transferable quotas for a particular fishery in order to use other management tools.

This paper compares the effectiveness of a number of different management tools using an integrated biological and economic model of the northern prawn fishery embedded in a stochastic optimisation framework to simulate optimal management of the fishery over any given planning horizon.

Description of the NPF

The NPF is located in the Australian fishing zone between Cape Londonderry, Western Australia and Cape York, Queensland (figure 1). Covering an area of around one million square kilometres, the NPF is Australia’s largest fishery and one of its most valuable. The gross value of prawn production in this fishery in 1998-99 was estimated to be $111 million in nominal terms with a total harvest of around 8 000 tonnes (ABARE 2000a). Over 90 per cent of the catch is exported, with the principal market being Japan.

1 *Location of the northern prawn fishery*



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 (*Fenneropenaeus merguiensis*) account for over 80 per cent of commercial landings from the NPF (Timcke, Harrison, Bell and Chapman 1999). The two tiger prawn species are the focus of the discussion in this paper.

Currently around 115 vessels are actively participating in the fishery. All vessels are purpose built twin gear otter trawls. Most boats in the fishery operate between 80 and 90 per cent 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 and Die 1999; Die and Bishop 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]

Management options

Input controls

The NPF is currently managed through a system of input controls. The timing and location of fishing effort have been restricted by season and area closures. The northern

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

prawn fishery 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. Reflecting the relatively large effect of random climatic events on spawning stocks, the choice of opening and closing dates have been reviewed a number of times. In addition to the principal season closures that are in effect for the entire northern prawn fishery, a number of region specific closures operate for either part of the year or permanently. Other input controls such as limited entry and gear restrictions are also used to account for increases in effective fishing effort brought about by the continued improvement of harvest technology.

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 as well as the 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 five per cent a year (Buckworth 1987; Taylor and Die 1999).

Output controls

An alternative management instrument that explicitly avoids the problem of effort creep is an output based system of quotas as used in the south east trawl fishery. An individual transferable quota (ITQ) system is a market based management option where ITQs are transferable property rights to harvest a specified quantity of fish. To ensure the sustainability of the stock, a total allowable catch (TAC) is set, with shares of this TAC allocated to fishing operators. A market in ITQs then enables operators to adjust the size of their fishing operations through the purchase, sale or lease of quota. In theory, it leads to a more efficient allocation of resources within the fishery. However there are a number of problems associated with a system of ITQs.

An ITQ system will not necessarily address the incentive to race to fish where there is a seasonal pattern in stock levels and catch per unit of effort (CPUE) changes. If stocks and CPUE fall throughout the season, individual operators have an incentive to fish early in the season. However, higher economic returns may be achieved if operators could agree to delay fishing, allowing prawns to be harvested at a larger size or at a time when prices are likely to be higher.

In addition, there is considerable uncertainty regarding the effect of fishing effort on tiger prawn stocks in the NPF and stock levels vary widely from season to season. If stock abundance is independent of fishing effort, or even if this relationship is very weak, then sustainable management of the stocks may be consistent with the harvest of all or a proportion of available biomass. Under these conditions it would be difficult to set a season specific TAC and a fixed quota may lead to a pattern of under and over fishing.

There are a number of problems associated with the management of the NPF using either effort or output controls exclusively. It is possible that the optimal management system for the fishery would involve some combination of both effort and output controls.

Modeling the fishery

Biological model

The objective of the model of the fishery 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 behavioural equations to represent fishing effort. Net economic returns are then calculated using estimated prices that reflect seasonality and fishing costs derived from surveys of the NPF fleet. A genetic algorithm (GA) was then used to determine a policy setting which maximises the net economic returns.

Linking surviving biomass to future recruits

Recruits to the fishery in the current year were modeled as a function of the surviving mature stocks from the previous year. The seasonal pattern for spawning for each of the tiger prawn species came from Crocos (1987a and 1987b). Data on recruits, *R*, and surviving stocks, *S*, were derived from the Wang and Die (1996) cohort model and fitted according to Ricker’s equation:

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

Residuals were normalised as a percentage of the predicted value and translated to be non–negative. The error structure was modeled using a log normal distribution, with standard parameters alpha and beta. The results are summarised in table 1.

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

Table 1: Parameters for stock–recruitment relationship

	Brown tiger prawns	Grooved tiger prawns
γ_1	15.6*	42.8*
γ_2	– 0.014*	– 0.048*
$\bar{R}^2$	0.31	0.48
Alpha	– 0.69	– 0.83
Beta	0.61	0.50
Minimum residual	0.49	0.38

* significant at the 5% level.

Predicted effort and catch relationship

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. Weekly fishing effort, e, was expressed in terms of boat days fished and was split between each species. Weekly catch data, c, was expressed as the catch weight of prawns for each species.

The total fishing effort for both species of tiger prawns, e_{tot}, in week w, was estimated to be related to total effort and total catch in the previous week fished:

$$e_{tot,w} = \alpha_0 + \alpha_1 e_{tot,w-1} + \alpha_2 c_{tot,w-1} + \eta_{tot,w} \quad (2)$$

where $\eta_{tot,w}$ was the equation residual. In the first week fished immediately following a closure, effort and catch data from the most recently fished week were used.

The proportion of effort directed at brown tiger prawns, e_{tprop}, in week w, was estimated to be related to the week of the season, s, and the proportion of prawns caught in the previous week:

$$e_{tprop,w} = \alpha_0 \sin(\alpha_1 s) + \alpha_2 c_{tprop,w-1} + \eta_{tprop,w} \quad (3)$$

where $\eta_{tprop,w}$ was the equation residual. The proportion of effort directed at grooved tiger prawns, $e_{gprop,w}$, was then simply calculated as $(1 - e_{tprop,w})$.

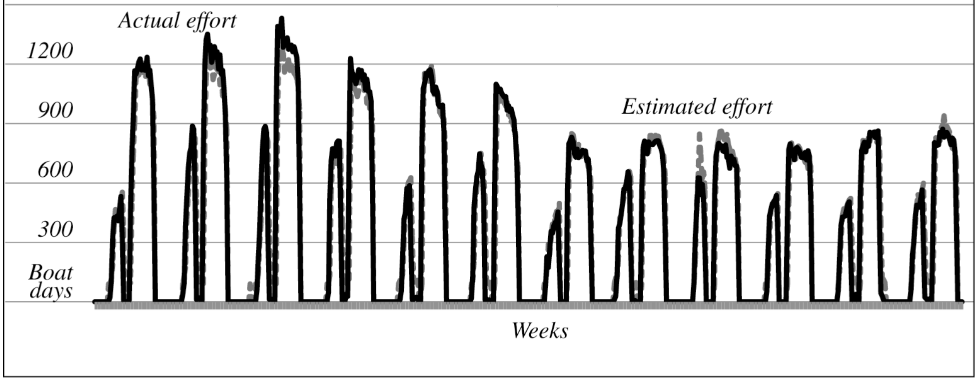
The weekly fishing effort for brown tiger prawns and grooved tiger prawns in boat days fished was then calculated as the product of total effort and the weekly effort proportions. Parameters for the effort equations are detailed in table 2. The fitted equations are plotted against historical effort data in figures 2 and 3.

Table 2: Estimated equations for fishing effort

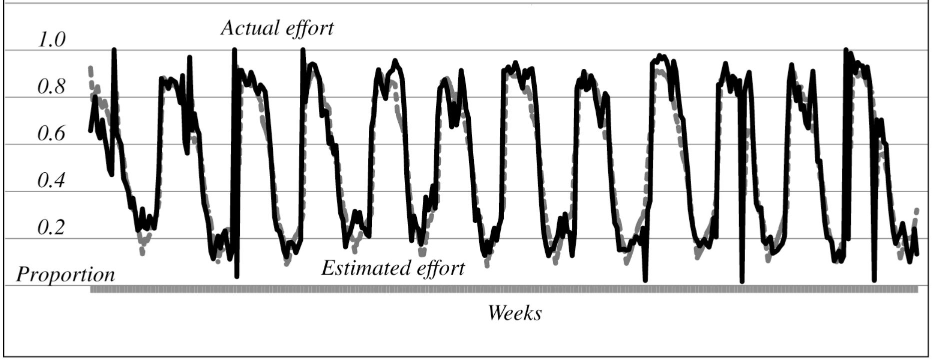
	Total effort equation (2)	Effort proportion equation (3)
α_0	90.21*	0.502*
α_1	0.72*	0.468*
α_2	0.001*	0.434*
$\bar{R}^2$	0.82	0.74

* significant at the 5% level.

2 ***Total fishing effort*** *Brown tiger prawns and grooved tiger prawns*



3 ***Proportion of effort directed at brown tiger prawns***



Based on the Wang and Die (1996) model of the fishery, catch is given, without species and time subscripts by:

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

where

$$m_f = effort \cdot \gamma_1 \cdot stock^{\gamma_2} \cdot catchability \tag{5}$$

and m_f is fishing mortality and m_{tot} is the sum of fishing and natural mortality. Estimates of natural mortality are those given in Wang and Die (1996).

After consultation with the northern prawn fishery assessment group (NPFAG), seasonal variation in the spawning biomass numbers were incorporated into the model based on Crocos (1987a and 1987b). The artificial seasonal pattern to estimates of catchability and cross–catchability specified by Wang and Die (1996) was removed and replaced with an estimate of average catchability and cross–catchability for the year.

Costs and returns

The gross revenue from fishing was calculated from the prawn catch and the export price. The majority of prawns from the northern prawn fishery are exported to Japan. Estimates for average annual prawn prices 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 prawns; (3) 9–12; (4) 13–15; and (5) more than 16.

The cost data used in the model were derived from ABARE surveys of the industry (ABARE 2000b). The costs were separated into packaging costs, fuel costs, crew costs and capital costs and are shown in table 3. 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. Capital costs are calculated as the sum of the depreciation rate and the real interest rate – to capture the opportunity cost of the investment – multiplied by the average capital value per vessel in the fishery. It was assumed that half the capital costs of each vessel could be attributed to fishing activities relating to tiger prawns.

Table 3: Costs associated with fishing

	Unit	Value
Packaging costs	$/kg	0.20
Fuel costs	$/day	770
Crew costs	% of revenue	0.27
Capital costs	$/vessel	127 716

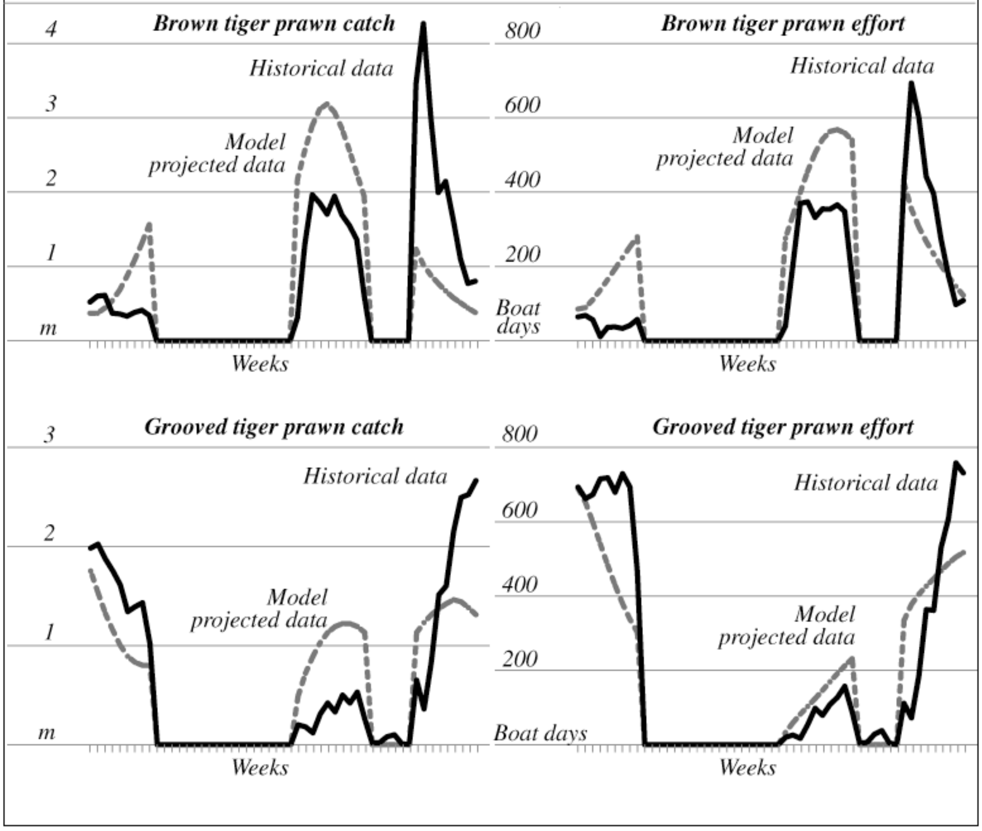
Historical validation

To assess the validity and accuracy of the model, weekly catch and effort predictions generated by the model were compared with data from Wang and Die (1996). Prediction errors were generated using Ricker's stock–recruitment relationship for catch and effort from one year forward projections between the year 1995 and 1997. The relative standard errors of the predictions are reported in table 4 and actual and predicted effort and catch for the 1997 biological year are shown in figure 4.

Table 4: Relative standard errors of catch and effort data, November 1994 – October 1997

	Brown tiger prawns	Grooved tiger prawns
Catch	0.042	0.028
Effort	0.033	0.020

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



Optimisation

The model is designed to maximise the net present value of the fishery given a set of management rules over any planning horizon. The objective of this analysis is to compare the relative effectiveness of seasonal closure rules with a system of ITQs as modeled by the determination of a total allowable catch (TAC).

Three different management tools are compared in this paper. In the first management system, the model determines the optimal timing and length, in whole weeks, of the mid–season closure as well as the final week of the fishing season.

In the second management system, the model determines the optimal TAC for the fishery and the season remains open with no mid–season closure until this limit is reached. In the third management system a mid–season closure is reintroduced and the model determines both the optimal TAC and the timing and length of the mid–season closure.

To compare the immediate impact of introducing ITQs as well as their effectiveness in the longer term, the capital structure – as reflected in the number of vessels in the fleet – is either held constant or allowed to vary. In the short term it is likely that despite a change in the management system, vessels will have zero opportunity cost of capital and stay in the fishery. Hence the introduction of a TAC and an ITQ system is unlikely to lead to rapid capital restructuring. However, in the longer term the fishery should adjust to an efficient capital structure as the cost of maintaining older vessels increases.

To compare the effectiveness of different management strategies in the presence of effort creep, an additional set of results are generated where effective fishing effort is allowed to increase by 2 per cent a year over the planning horizon.

Simulation design

The results generated from all simulations are based on a 30 year planning horizon to allow the model to reach equilibrium. In one set of simulations, the relationship between surviving prawn stocks and recruitment is purely deterministic. In the second set this relationship is stochastic. The initial conditions for the simulation were based on catch, effort and surviving biomass for the 1998 season.

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 Alemdar and Ozyildirim 1998; Beare, Bell and Harrison 1999; Beare, Bell and Fisher 1998; Birchenhall 1995; Ching–Tzong and Wen–Tsuan 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 pay–off 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 rules. 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 optimal 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 60 generations using 12 population strings. For the stochastic simulation, each string was evaluated over 20 trials, and assigned a fitness value equal to the average fitness over the trials. Following Goldberg, a cross–over rate of 0.6 was used and the mutation rate was set to 0.03.

Results

The results from the three management rules where effective effort is held constant over the 30 year planning horizon are presented in table 5. The optimal number of boats and length of the season are identical for both brown and grooved tiger prawns. The TAC represents the combined catch of both species of tiger prawns.

Table 5: Numerical optimisation results, no effort creep

		Deterministic				Stochastic			
		Brown		Grooved		Brown		Grooved	
	unit	mean	*std dev*	mean	*std dev*	mean	*std dev*	mean	*std dev*
Seasonal closure rule									
Fixed capital structure									
Number of boats	no	115				115			
TAC	t	–				–			
Season length	wks	26				31			
Annual effort	days	8 706	*na*	10 718	*na*	10 804	*487*	12 810	*358*
Annual catch	t	2 416	*na*	2 003	*na*	3 280	*785*	3 088	*535*
Net returns*	$m	483	*na*	423	*na*	672	*74*	696	*57*
Flexible capital structure									
Number of boats	no	90				115			
TAC	t	–				–			
Season length	wks	31				31			
Annual effort	days	8 921	*na*	10 036	*na*	10 682	*312*	12 813	*272*
Annual catch	t	2 408	*na*	1 957	*na*	3 280	*773*	3 094	*528*
Net returns*	$m	489	*na*	423	*na*	669	*73*	699	*56*
TAC rule									
Fixed capital structure									
Number of boats	no	115				115			
TAC	t	3 812				5 838			
Season length	wks	23.8				32.8	*9.5*		
Annual effort	days	10 960	*na*	6 669	*na*	12 579	2 041	10 749	*3 899*
Annual catch	t	2 198	*na*	1 709	*na*	2 915	*658*	2 649	*411*
Net returns*	$m	426	*na*	366	*na*	579	*101*	588	*42*
Flexible capital structure									
Number of boats	no	62				68			
TAC	t	4 084				9 896			
Season length	wks	39.1				42.0	*0.1*		
Annual effort	days	8 852	*na*	7 977	*na*	10 196	314	9 601	301
Annual catch	t	2 334	*na*	1 836	*na*	3 156	*755*	2 881	471
Net returns*	$m	489	*na*	417	*na*	666	*77*	681	*51*
TAC with mid–season closure rule									
Fixed capital structure									
Number of boats	no	115				115			
TAC	t	7 651				9 891			
Season length	wks	28.0				31.0	*0.2*		
Annual effort	days	9 440	*na*	11 455	*na*	10 750	*478*	12 909	*341*
Annual catch	t	2 479	*na*	2 047	*na*	3 298	*773*	3 112	*523*
Net returns*	$m	480	*na*	423	*na*	669	*73*	699	*56*
Flexible capital structure									
Number of boats	no	86				108			
TAC	t	5 370				9 391			
Season length	wks	32.0				32.0	*0.3*		
Annual effort	days	8 968	*na*	9 799	*na*	10 697	*450*	12 445	*339*
Annual catch	t	2 419	*na*	1 957	*na*	3 282	*766*	3 086	*511*
Net returns*	$m	489	*na*	426	*na*	666	*74*	696	*55*

* net economic returns to the fishery over a 30 year planning horizon. *na* not applicable.

Fixed capital

Under deterministic steady state conditions when the capital structure of the fishery is held constant the seasonal closure rule outperforms both the TAC rule and the TAC with mid–season closure rule. With a fishing season of 26 weeks the net present value of the fishery over 30 years is around $906 million. The TAC rule performs the worst with a shorter fishing season and a net present value of around $792 million. When a mid–season closure is added to the TAC rule it performs almost as well as the seasonal closure rule. The optimal fishing season increases to 28 weeks and the net present value of the fishery over the 30 year planning horizon is only $3 million lower than that generated by the seasonal closure rule.

The improvement in performance of the TAC rule with the addition of a mid–season closure reflects the fact that a TAC based rule does not lead to the most efficient timing of fishing operations as occurs in the seasonal closure rule. The seasonal closure rule still outperforms the TAC with a mid–season closure because the initial conditions are not near equilibrium.

When the stock–recruitment relationship is uncertain under all three management options, the length of the fishing season increases and the net present value of the fishery increases. This reflects the right skewed distribution of the Ricker equation errors.

With a stochastic stock–recruitment relationship, the seasonal closure rule and the TAC with a mid–season closure rule generates equal highest returns to the fishery. The TAC rule is the poorest performing, with a net present value more than $200 million lower than the other two rules over the 30 year planning horizon. The two rules with a mid–season closure are the best performing because they are able to adjust the timing of fishing effort to when it is most profitable.

Flexible capital

Allowing the level of capital to adjust, as reflected in the number of vessels in the fishery, enables the modeled TAC based management rules to represent the longer term capital adjustment of a properly functioning quota market. The current management of the NPF with seasonal closures also includes a policy of limited entry and effort controls. For capital to move out of the fishery under the seasonal closure rule adjustment to these additional effort controls would be required.

When the capital structure is allowed to vary the number of vessels in the fishery declines and the length of the fishing season increases correspondingly. The differences in the economic performance of the three rules are reduced with this additional flexibility.

When the stock–recruitment relationship is known with certainty, the TAC with a mid–season closure rule performs the best. The TAC rule, which was the poorest performing rule when the capital structure was held fixed, improves significantly with a large reduction in the number of vessels in the fishery. Under deterministic conditions there is only a $9 million decrease in the returns to the fishery under a TAC rule relative to a TAC with a mid–season closure rule over the planning horizon.

When the stock–recruitment relationship is uncertain the seasonal closure rule outperforms both the TAC rule and the TAC with a mid–season closure rule. Fluctuations in the stock–recruitment relationship can result in either over or under fishing with a TAC based rule, reducing its economic performance relative to a seasonal closure rule.

With an optimal capital structure, the economic value of a mid–season closure is significantly reduced. The gains from the mid–season closure, which alter the timing of fishing effort, are offset by the required increase in capital to fish over a shorter season.

These findings suggest that if the northern prawn fishery was to adopt a management system based on a TAC rule, in the short term – when capital is unable to adjust – there would be considerable value in keeping a mid–season closure. However, in the longer term the value of the mid–season closure would be diminished as the level of capital in the fishery adjusts.

Effort creep

There are a number of ways effort creep can occur. It can be the result of technological innovation, for example, the introduction of GPS and plotter systems, or it can be generated by the substitution of unrestricted inputs for restricted inputs that can increase the costs of fishing if they are less efficient.

To simulate increases in effective fishing effort over time, effort creep was incorporated into the model by allowing a two per cent increase in maximum effort in boat days. In response to any increase in fishing effort, effort based costs such as fuel increased correspondingly. The model was not reoptimised, instead the equilibrium levels of effort, catch and revenue were determined given the increase in maximum effort under the management rule that was optimal when there was no effort creep. This set of simulations provide insight into the impact of effort creep when the managers of the fishery do not take into account anticipated increases in effective effort. If the fishery managers were to anticipate a given level of effort creep and set their management strategies accordingly then the model would need to be reoptimised and different results would be generated.

When effort creep is introduced into the simulations the TAC based management strategies are unaffected. While the race to fish incentive may lead to suboptimal capitalisation of vessels in the fishery under a TAC, increases in effective effort have no impact on the overall level of catch set by a TAC. In contrast, increases in effective effort under a seasonal closure rule leads to increases in effort and effort related costs beyond any additional increase in catch (table 6).

Under a seasonal closure rule, when effort creep increases effective effort by two per cent a year over the 30 year planning horizon overall effort increases and the net economic returns to the fishery decline relative to a no effort creep scenario.

Under both deterministic and stochastic conditions, when the capital structure of the fishery is held constant, effort creep reduces the net economic returns of the seasonal closure rule and the TAC with a mid–season closure becomes the best management strategy. The seasonal closure rule is able to outperform the TAC only rule because of the value in economic returns associated with keeping a mid–season closure when capital is unable to adjust.

When the capital structure of the fishery is allowed to adjust and the value of the mid–season closure is reduced. When the stock–recruitment relationship is known with certainty, the two TAC based management strategies are superior to the seasonal closure rule. However, when the stock–recruitment relationship is stochastic the TAC rule is the worst performing because of the under or over fishing that occurs when the TAC is held constant but the level of stocks vary from year to year.

The relatively better performance of the TAC based management rules over the input based management rule in the presence of effort creep may be understated in these results. If increases in effective effort are able to reduce the costs of fishing, then the net economic returns to the fishery under a TAC based system may be even higher.

These findings suggest that under certain conditions TAC based management strategies can perform as well as the current system of seasonal closures. In addition, TAC based rules are capable of avoiding the increases in effort and effort related costs associated with effort creep.

However, the performance of TAC based rules are sensitive to assumptions regarding the ability of capital in the fishery to adjust. In the short term, where capital is fixed, there is considerable value in maintaining a mid–season closure to ensure the optimal timing of fishing effort. In the longer term however, when capital is allowed to adjust, the value of a mid–season closure diminishes because the increased revenue generated by changing the timing of fishing effort is more than offset by the increased capital costs associated with having more vessels in the fishery over a fishing season of shorter length.

Table 6: Numerical optimisation results, 2% effort creep

		Deterministic				Stochastic			
		Brown		Grooved		Brown		Grooved	
	unit	mean	*std dev*	mean	*std dev*	mean	*std dev*	mean	*std dev*
Seasonal closure rule									
Fixed capital structure									
Number of boats	no	115				115			
TAC	t	–				–			
Season length	wks	26				31			
Annual effort	days	9 788	*na*	12 159	*na*	12 586	*1 118*	15 011	*989*
Annual catch	t	2 488	*na*	2 039	*na*	3 361	*903*	3 157	*634*
Net returns*	$m	480	*na*	408	*na*	663	*78*	684	*60*
Flexible capital structure									
Number of boats	no	90				114			
TAC	t	–				–			
Season length	wks	31				31			
Annual effort	days	10 583	*na*	11 963	*na*	12 490	*1 137*	15 149	986
Annual catch	t	2 483	*na*	1 994	*na*	3 384	*903*	3 186	633
Net returns*	$m	483	*na*	411	*na*	666	*77*	687	*60*

* net economic returns to the fishery over a 30 year planning horizon. *na* not applicable.

Discussion

The simulation results demonstrate the ability of an ITQ based management system to generate greater economic returns to a fishery such as the northern prawn fishery faced with a problem of continual increase in fishing capacity (effort creep). Despite the continued review of input controls, advances in technology have increased effective fishing effort in the NPF. It is likely that further adjustments to management arrangements will be required in the future.

While ITQs explicitly avoid the problem of effort creep there are likely to be a number of potential difficulties associated with the implementation of quotas in the NPF. The short lived nature of prawns and the variability of stocks between seasons is likely to be a particular impediment to the effective use of ITQs in the northern prawn fishery.

Optimal TACs in the NPF are likely to vary between seasons because of the relatively large effect of random climatic events on spawning stocks. However, there is very little information on stock abundance prior to the start of the fishing season on which to base a TAC. Setting an average TAC, across seasons, is likely to be suboptimal. Depending on the relationship between remaining stocks at the end of a season and recruitment in the following year, harvests may be too high in a year of low abundance. Correspondingly, opportunities for increased harvest may be lost in seasons of high abundance.

Any management system used in the northern prawn fishery will need to manage banana prawns as well as tiger prawns. Given the current biological understanding of banana prawns in the NPF, a TAC is likely to be infeasible (Timcke, Harrison, Bell and Chapman 1999). This is because it remains largely undetermined whether recruitment of white banana prawns is affected by fishing effort.

Concluding remarks

Despite the 1989 government policy statement that ITQs are the preferred management tool for Commonwealth fisheries, in practice the individual characteristics of a fishery are an important consideration when determining the suitability of an ITQ management system (Copes 1986; Rose 1997). For example, the highly seasonal nature of Japanese prawn prices may have a significant influence on the performance of different management tools in the northern prawn fishery.

A number of different input, effort and output controls can be used to manage Commonwealth fisheries. In the northern prawn fishery the variability in prawn stocks between seasons is likely to reduce the effectiveness of a quota system. Other non–quota management tools, either on their own or in conjunction with a quota system, may be more suited to maximise economic returns in this fishery.

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