OCCASIONAL PAPER 103

A POLICY MODEL OF THE NORTHERN PRAWN FISHERY

AUSTRALIAN
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AND SEAN PASCOE

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BUREAU OF AGRICULTURAL
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Foreword

The northern prawn fishery has been subject to management since the early 1970s in an attempt to control the expansion of effort and prevent the overexploitation of the resource. Many of the management policies developed over this period have proved to be ineffective in controlling effort. Moreover, the increasing cost of management and the need to avoid costly and ineffective measures will lead to increasing demands for analysis of the cost effectiveness of such policies.

In order to assess the effects of current and alternative management policies on both effort and profitability in the fishery, a mathematical programming model of the fishery was developed in the Bureau's Fisheries Economics Research Section. This report outlines the model and assesses the short and long term effects of the current and alternative management policies on the fishery.

ROBERT BAIN
Director

Australian Bureau of
Agricultural and Resource Economics

Canberra

January 1988

Acknowledgments

This report is the culmination of several years of investigation into the structure and economics of the northern prawn fishery. In particular, the study draws on the previous modelling experiences of Dave Collins and Debbie Brown of the Bureau's Fisheries Economics Research Section and on the data manipulation of Phil Stewart, currently in the Fisheries Section of the Bureau of Rural Science. The methodology for determining the fishing power coefficients was developed by Ken Brewer of the Bureau's Quantitative and Econometric Services Section. The authors would also like to thank Ian Somers of the CSIRO Division of Fisheries Research for his advice on the biological relationships used in the model and Frank Meany from the Australian Fisheries Service, Department of Primary Industries and Energy, for the provision of data and advice on the management of the fishery.

For the report itself, the authors wish to acknowledge the contributions of the referees — Ken Noble and Gerry Geen from the Bureau and Dave Wesney from the Australian Fisheries Service. Other useful comments were provided by Ray Trewin, Alistair Watson and Robert Bain, all from the Bureau. The report was edited by Naida Faulkner.

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CONTENTS

List of figures and tables

Map

Figures

Tables

SUMMARY

The northern prawn fishery is one of the largest fisheries in the Australian Fishing Zone, with an annual output valued at around $120m. The fishery is managed to overcome the economic and biological problems that would be created by the indiscriminate harvesting of this highly valuable resource, and this management has become increasingly complex as the level of regulation has increased in response to increasing fishing effort. This complexity is the consequence of the difficulty in achieving adequate control over catch and fishing effort when technology is constantly changing. Further, the management committee is made up of a number of competing groups that often have difficulty in reaching consensus on management changes. It is now generally agreed that the current fleet size is much larger than that needed to take the catch with maximum economic efficiency, and the management committee is pursuing a number of policies to reduce both capacity and effort in the fishery.

The results from the model developed in this paper indicate that most current policies are unlikely to provide long term net benefits to the industry, and some impose costs in the short term without a commensurate return. Alternative policies that address the common property problem more directly and provide for the better use of resources in the fishery are analysed. Further development of the model is envisaged to provide management with an ongoing framework for policy analysis.

Management of the northern prawn fishery has become increasingly complex as the level of regulation has increased. This regulation is aimed essentially at overcoming the economic problems created by many different operators competing for a common property resource. Unfortunately, much of the earlier regulation, though well intentioned, has proved ineffective and the fleet capacity has expanded well above that needed to take the catch with reasonable economic efficiency. The realisation of this resulted in both the industry and government agreeing on the need to reduce fleet capacity. Just what level of adjustment is either necessary or desirable has been the subject of some debate. Even greater debate has surrounded the choice of policy to achieve the adjustment.

Some of the difficulties of management are due to the lack of a framework within which biological, economic and physical relationships can be analysed. The implications of a specific regulation for the fishery can rarely be assessed adequately with existing *ad hoc* methods. The purpose of this paper, therefore, is to provide an analytical model which incorporates the most relevant information on the fishery and allows the effects of policy options to be quantified. As more information on the biology and economics of the fishery becomes available, the model can be further developed to provide industry and managers with improved insights into the implications of specific policies.

The fishery

There are five main species of prawn harvested, the most important of which are banana prawns (*Penaeus merguiensis*), brown tiger (*P. esculentus*) and grooved tiger (*P. semisulcatus*). Stocks of banana prawns are considered to be determined by environmental conditions, but tiger prawn stocks are also apparently influenced heavily by the pattern and level of fishing effort. The two prawn groups also differ in their aggregation habits, with banana prawns forming dense schools which allow substantial catches to be made in a single trawl. Because large catches can be made, the banana prawn catching season is very short (about six weeks), after which time the fleet moves on to the more dispersed tiger prawns. The tiger prawn species are the more valuable on a weight for weight basis, but the lower cost of catching banana prawns would normally make these the most profitable part of the catch.

The fleet currently consists of 246 active vessels of varying sizes, ages and efficiency. An additional nineteen entitlements to fish also exist but no vessels are attached to these at present. Capacity in the fleet is measured by a combination of engine and hull size known as class A units. There have been approximately 100 000 active class A units in the fishery for some years, but there are also about 15 000 inactive units which could add to the capacity of the fishery at any time.

This fleet fishes for 35 000–45 000 boat-days each year, depending on the economics of catching prawns. About 85 per cent of this time is spent targeting on tiger prawns. Because of increases in prawn catching efficiency over time, the effective effort applied to the prawn stocks has increased, notwithstanding the apparent containment of nominal effort.

Management of the fishery is concerned with promoting economic efficiency and conserving the stocks of prawns. To this end, a large number of controls exist on what waters may be fished and when, and who may fish and with what. Such controls are designed to overcome the inefficiencies inherent in the exploitation of a high valued common property resource. These inefficiencies include overcapitalisation, excessive levels of fishing effort and possibly lower levels of catch. Current controls consist of closures of waters at certain times, limits on the number of boats that may fish (and on the number of nets that each boat may tow), and a limit on the total capacity of the fleet (although not on any one boat). In addition, incentives exist which discourage replacement of boats by (possibly) more technically efficient ones.

The fishery model

The model combines the most important biological, economic and physical features of the fishery which impinge on, or are affected by, management decisions. Fleet characteristics incorporated include boat numbers, boat size, fishing power, fishing costs and hours fished. Variability in these parameters among boats was modelled by employing twelve distinct boat groups. Separate catch–effort relationships were calculated for banana and tiger prawns, with a distinction being made for the latter between the short and long run relationship. These characteristics were incorporated into a linear programming model which produces a solution to a maximisation or minimisation problem.

In the northern prawn fishery model the problem was specified as the maximisation of profit, effort or revenue depending on the scenario being analysed. Management policies were simulated by constraining fishing activity. For example, gear restrictions involved a reduction in fishing power, seasonal closures reduced the amount of time a boat could spend fishing, the boat replacement policy limited the extent of replacements by raising the cost of a new boat, and the Voluntary Adjustment Scheme reduced the number of class A units in the fishery.

Results

The model can provide quantitative analysis of a wide range of policy measures. All current policies were analysed, as well as some possible alternatives.

A key result was that the current target of 70 000 class A units in the fishery, if achieved, would not in itself lead to higher returns because effort can expand through increased fishing hours or adoption of more technically efficient capital. As a consequence, contributions to the Voluntary Adjustment Scheme are

unlikely to provide net benefits to the individuals who make them unless effort can be contained.

The Voluntary Adjustment Scheme fails to provide benefits because a reduction in class A units does not prevent effort increasing from other sources. Even if an economic surplus were generated, the gains would likely be small in relation to operators' contributions to the scheme. However, society would benefit in this instance from the fewer resources employed in the fishery.

A second important result is that other current policies to reduce effort both immediately and in the long term (gear restrictions and the boat replacement policy, respectively) raise fishing costs without necessarily providing compensating benefits. In the case of the boat replacement policy, boat numbers are kept higher than they would otherwise be in the long term because of the financial disincentive to rationalise operations. However, the retention of older, less efficient boats in the fishery inhibits the expansion of effort that could occur if these boast were replaced.

Gear restrictions reduce effort and catch but the beneficial effect on the stock (and the next year's availability of prawns) appears to be inadequate in relation to the cost incurred. Stock protection appears to be achieved at less cost by appropriate seasonal closures. In any case, the effectiveness of a given gear restriction is limited as improvements in technology and operators' skills eventually nullify its effect on effort.

The major underlying weakness of current policies in the northern prawn fishery is that none of them addresses the common property problem directly. This weakness is compounded by the current policies not being applied tightly enough. Equity considerations have resulted in too many class A units being issued as well as the relatively large number of surplus units held by the smaller boats.

Measures which allow circumvention cannot fulfil both the industry's and management's expectations of greater economic efficiency. More fundamental measures have a greater chance of success, and their operation and administration could be substantially simpler than the present array of measures.

A remote possibility is the use of individual transferable quotas which could provide an economic surplus (or rent) of around $38m. Most of this would be derived from the banana prawn fishery. Unfortunately, the erratic recruitment to this fishery may render this form of management infeasible without major improvements in the ability of the fishery managers to forecast stock levels.

An alternative which tackles the problem of excessive effort directly is a levy on effort. Effort would need to be measured by the aggregate expenditure on fishing to avoid substituting non-leviable items for leviable ones and eroding the levy base. The levy would comprise a percentage of total costs and encourage operators to reduce these costs. Those operators who applied the most financial effort would bear the greatest cost. The overall effect of an effort levy would be to reduce effort while allowing the remaining individual operators most of the freedoms of which the traditional policies necessarily deprive them.

Similarly, a levy on output would perform the same function, although its incidence would be different. Which of the two management options was preferred would depend on the respective enforcement problems, compliance rates and management costs.

The novelty of an effort levy should not prevent serious consideration being given to it. What is apparent is that most current policies have little chance of providing long term benefits, whatever their short term merits, and that the alternative outlined above would enable better use to be made of the prawn resources in the northern prawn fishery.

1. Introduction

The value of the annual domestic commercial harvest of fish resources from the Australian Fishing Zone is increasing rapidly and is currently over $650m. Approximately a fifth of this is derived from the northern prawn fishery. The economic conditions under which fisheries resources are harvested are substantially different from those facing most other industries in that, for the most part, complete private property rights to the resource do not exist. Individual operators do not have exclusive rights to the use of any particular stock or area, and the incentives for them to use the resource economically are therefore reduced.

It is axiomatic that when no individual operator faces the full consequences of his or her own actions some form of intervention may be desirable to prevent individuals or society bearing the costs incurred by others. In the case of fisheries, lack of intervention tends to result in the overexploitation of the stock (Waugh 1984). That is, a catch yielding higher net returns could be taken with substantially less effort than is expended in the overexploited fishery. A second feature of overexploitation is that long term catch levels themselves may be below those which could be achieved from a more controlled harvesting regime. Neither of these problems has been eliminated in the northern prawn fishery despite the best endeavours of fisheries managers.

Notwithstanding these problems, management in the fishery has had some achievements. The implementation of limited entry, unitisation, boat replacement policies, closed seasons and limits on the extent to which effort may expand have all contributed to the confidence that has encouraged the industry to develop. However, there is also the expectation that there are substantial economic gains still to be realised. This is exemplified by the management body's recent recommendation that physical capacity in the fishery needs to be reduced by 40 per cent by 1990.

One of the reasons for the current problems in the fishery probably lies in the politics of management: in an endeavour to accommodate the diverse interest groups within the fishery, decisions have perhaps been made which were not ideal, but at the time were possibly better than no decision at all.

Another reason is the lack of detailed knowledge on the many biological and economic relationships within the fishery, and the paucity of data on which to base decisions. All too often, attention is focused on only those immediate areas where the data suggest a problem exists, and little or no consideration is given to the wider ramifications of a proposed solution, because a logical framework in which to evaluate the effect of policy changes on the fishery as a whole is lacking. It was in response to this latter problem that this research was conceived and the model of the fishery developed.

The analytical framework presented in this paper takes the form of a linear programming model, which combines biological, economic and physical relationships. The integration of these different relationships into one model allows the effects of both outside factors (for example, changes in prawn prices) and policy options to be considered. Different policy options to meet a given objective can then be compared, and managers will be better armed to deal with any given problem. Ideally, the model will be developed further to allow it to be used directly by the managers themselves. It is, of course, essential that any potential users of the model are fully conversant with its scope and limitations if any results are to be properly interpreted, and this requires a continued interaction between the model builders and the model users.

2. Background

The northern prawn fishery is one of the largest Australian fisheries in both a physical and an economic sense. It extends across virtually all the waters of northern Australia, from Cape Londonderry in Western Australia, east to Cape York in Queensland, and covers an area of approximately 1 million square kilometres (see map). Annual output from the fishery has varied between 8.3 kt and 11.7 kt in the past five years, and in 1985-86 the gross value of production was around $120m.

2.1 The product

There are five main species of prawns harvested: banana (*Penaeus merguiensis*), brown tiger (*P. esculentus*), grooved tiger (*P. semisulcatus*), endeavour (*Metapenaeus endeavouri*) and king (*P. latisulcatus*). Banana prawns dominated the catch until 1978. Since then, increased exploitation of the tiger prawn fishery has resulted in the tiger prawn catch being higher than the catch of banana prawns, although the latter is highly variable. The other species are less important than either banana or tiger prawns, and together constitute about 20 per cent by weight of the annual catch.

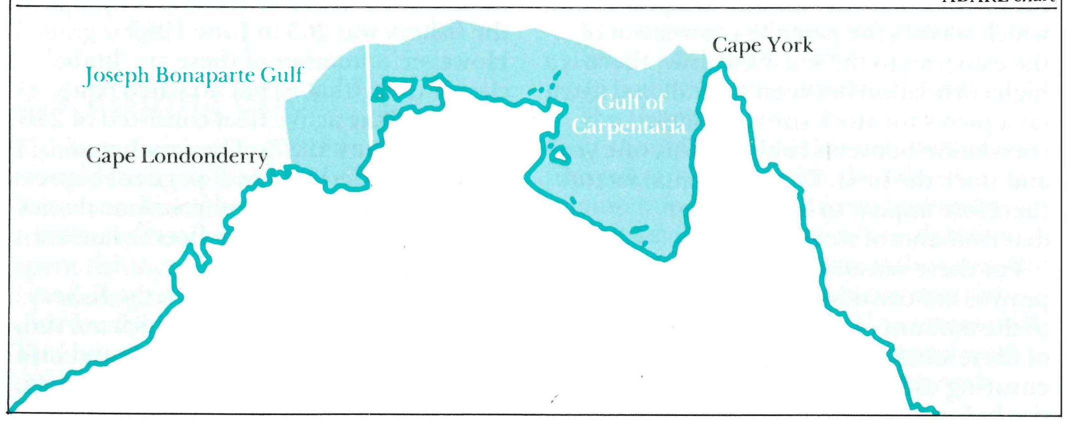
Differences among the species relate to both their marketability and their dispersion or density in the sea. Over 90 per cent of the catch is exported, principally to Japan, and it is generally accepted that we are price takers in the overseas prawn market. Price differentials for the various species therefore relate to perceived quality differences rather than to changes in Australian supply. In general, the tiger prawn species fetch the highest prices ($14.86/kg in 1985-86), followed by banana prawns ($9.51/kg), king ($8.11/kg) and endeavour ($7.29/kg).

2.2 Prawn stocks

An important biological feature of penaeid prawns is their short life span of just one to two years. Maintenance of the stock therefore depends on an adequate level of spawning in the previous year and subsequent recruitment to the fishery. Recruitment and the maintenance of the stock for most prawn fisheries was, until recently, not thought to be a source of concern (for example, Garcia 1983): each spawning female produces about a million eggs and, even with massive mortality due

Australian northern prawn fishery

ABARE chart



to predation or unfavourable environmental conditions, sufficient numbers were thought to be able to survive to form the next year's population. Fishing pressure in comparison with the natural dangers to the prawn population appeared relatively insignificant.

This, however, may be too optimistic a view for some species. A number of authorities have suggested that, for some prawns, there is a relationship between adult stock levels and subsequent recruitment (Penn and Caputi 1983; Gulland 1984) and fishing pressure can therefore affect the next year's stock. Penn and Caputi hypothesised from an analysis of data from the Exmouth Gulf tiger prawn fishery that a 50 per cent increase in fishing effort from a given base could reduce the spawning stock by 37 per cent, other things being equal.

It is now thought that the reproductive capacity of the tiger prawn population in the northern prawn fishery is vulnerable to fishing pressure at a certain time of the year (Somers 1987) and that stocks could be increased in future years if fishing effort were redirected to less critical times. The current mid-seasonal closure (June–July) aims at preserving the stock prior to the critical spawning period in August, September and October.

The case of banana prawns is, however, different. According to Rothlisberg, Staples and Crocos (1985), banana prawns have a more robust reproductive strategy involving two distinct major spawnings in a twelve-month period. In addition, stock levels appear to be closely related to summer monsoonal rainfall (Staples 1985), which washes the juvenile prawns out of the estuaries to the sea. Certainly, there is a high correlation between rainfall and catch (as a proxy for stock size) and little correlation between fishing effort one year and stock the next. Environmental factors therefore appear to be the major determinants of stock size.

For these reasons, stocks of banana prawns are considered to be independent of the amount of fishing, and management of these stocks is concerned solely with ensuring the prawns reach a reasonable size before capture. Nevertheless, Penn (1984) has noted their potential vulnerability to excessive fishing and the demise of the banana prawn fishery in the Exmouth Gulf is cited as an example of this by Penn and Caputi (1985).

The dispersion of the various species also displays some contrasts. On the one hand, banana prawns form dense schools at certain times of the year and large catches can be taken within a very short time (Meany 1987). Because large catches are possible the fleet catching capacity has increased and the banana prawn season has become shorter each year. Major commercial operators expect to take 80 per cent of their total banana prawn catch within 33 days of the start of the season (normally early to mid-April), and the season is generally conceded to last only six weeks.

After this, the fleet moves on to the other species which do not aggregate to the same extent as banana prawns. Catch rates for these species are therefore lower, but they do not decline to the same extent as the season progresses. Hence, the season for the tiger species (including other species as by-catch) has tended to get longer, and it now effectively extends from the end of the banana season in May to the end of November. However, a mid-seasonal closure has been introduced to conserve the spawning stock.

2.3 The fleet

To operate in the fishery, each boat requires what is known as a class B unit. This is in effect an entitlement to fish. The number of these entitlements to operate in the fishery was 265 in June 1987. However, a number of these are 'limbo' class B units (that is, not attached to a boat), and the active fleet consisted of 246 vessels (Meany 1987). The number of active boats declined by 6 per cent between 1984 and 1987, but numbers alone do not reflect the capacity of the fleet to harvest the resource.

Since 1984, boat capacity in the fishery has been measured in units which are the sum of engine power in kilowatts and hull size in cubic metres (underdeck volume). For the purposes of management, these

are called class A units. The average size of boat in the fishery has increased markedly this decade and currently is around 427 class A units. In the context of current management, boats are classified into two broad groups; those less than or equal to 375 class A units, and those above this size. The number of boats in the smaller size category has declined rapidly, while above this size, boat numbers have increased. The smaller boat group accounts for 37 per cent of the fleet now, as opposed to 60 per cent in 1981. The aggregate capacity of the active fleet, as measured by class A units, has been relatively constant for some years at around 100 000 units.

Class A units by themselves cannot measure all the technical changes in the fleet that change harvesting capacity. The introduction of satellite navigators, Kort nozzles, coloured echo sounders, sonar, and new trawling gear have all contributed to an increase in fishing power. Measuring the effect of all these technical innovations would be extremely difficult but it is clear they have contributed to a big increase in the technical efficiency of the fleet.

Boat ownership in the fishery is divided roughly equally between owner operators and companies that run fleets (BAE 1984). Some of these companies are vertically integrated with the ship building, processing and marketing sectors and are therefore responsible for the product from the time it is caught to the time it is sold on the export market. It is also generally true that the owner operators have the smaller boats, and many of them contract their catch to a processing or marketing company with which they compete at the fishing stage.

2.4 Fishing effort

Fishing effort is a simple term to cover the complex range of inputs used in a fishery. From a technical view, it depends on the number of boats employed, aggregate time spent fishing, and the individual harvesting capability and spatial distribution of the boats (Anderson 1977). More mundanely, it is usually measured as the total number of days or hours spent fishing.

According to Buckworth (1987), effective effort in the northern prawn fishery has ranged from 35 000 to 45 000 boat-days a year over the past five years, with 85 per cent of this effort being applied to the tiger prawn sector. Average effort per boat has, therefore, been around 150–190 days fishing a year. Excluding factors such as weather, there are two main constraints on the amount of time spent fishing: first, closed seasons, which result from fisheries management considerations and, second, economic circumstances, which determine whether an individual operator continues to fish. This latter constraint exists at all times and depends partly on the availability of prawns and their behavioural habits. For example, fishing is limited to about twelve hours a day, during daylight in the banana season and mainly at night when fishing is for the other species.

The adoption of new technologies mentioned earlier ensures that an hour or day spent fishing this year has a greater impact on fish stocks than a similar period a few years ago. Buckworth (1987) has estimated that the effective level of effort per unit of time has more than doubled since 1979 and has increased more than tenfold since 1970.

2.5 Management policies

The purpose of management in the fishery is to achieve economic objectives (Department of Primary Industry 1982). These objectives (as set out in the management plan) are:

- to conserve, and to reduce the fishing pressure on, the stocks of prawns in the area of the fishery; and
- to promote the economic efficiency of the fishery.

It should be noted that maintenance of the resource merely for the sake of maintaining the resource (a biological objective) is not the main consideration, and is achieved in any case if the economic bjective is met (and if non-commercial species are left unaffected by commercial operations). Most of the biological work currently undertaken in the fishery is directed at improved economic performance through a better understanding of the population dynamics.

Notwithstanding the emphasis on economic management in the fishery, the social implications of management policy have not been — and are unlikely to be — ignored. The maximisation of social welfare may involve some sacrifice of the narrowly defined economic gains should the economic solution result in a socially unacceptable rate and direction of adjustment. This is a social question, and the economist's role is limited to assessing the economic cost of various courses of action.

Management of the fishery revolves around the apparently simple questions of what areas may be fished and when, and who is allowed to fish and with what. In the early years of the development of the fishery (1971–75), management decisions were confined to the first two questions. As the number of vessels in the fishery has increased, and each boat has raised its fishing effort, attention has increasingly been given to the last two questions.

Unfortunately, many of the management prescriptions failed to achieve their purpose, and new regulations had to be added to reinforce or counter the problems created by earlier ones. Various authors have analysed the management regimes in force in the northern prawn fishery and have outlined their inadequacies (for example, Kailis 1982; MacLeod 1982; Haynes 1987; Meany 1987). That current policies have their weaknesses is shown by a recent assessment that the 'greatest threat' to the management system is a period of 'good profits in the fishery'. On the other hand, management would achieve some of its objectives of reducing capacity in the fishery if the fishery faced an economic crisis (Meany 1987)! A successful management scheme is one that maintains profitability in the fishery while ensuring an appropriate rate of adjustment.

The major handicap to the development of effective management, however, has been the lack of agreement between the interest groups who played a part in determining the policies. Commonwealth, state and Northern Territory rivalries over jurisdiction as well as interstate special interests have often resulted in decisions being made out of compromise rather than consensus (MacLeod 1982). Operators are reluctant to have ineffective regulations removed if these regulations have affected their investment decisions. As a consequence, new regulations have been superimposed onto existing regulations in an attempt to counter the deficiencies rather than implement a new regulation and remove the old.

2.6 Current management scheme

The present scheme is the outcome of seventeen years of intervention in the fishery, a chronology of which is presented in table 1. As such, the various regulations reflect a mixture of experience (scientific and managerial), expediency and experimentation.

The question of what waters may be fished and when is covered by the regulations on seasonal closures. Broadly speaking, all waters in the defined fishery can be fished, except in two periods. The first period includes the months of December, January, February, March and the first half of April. The purpose of this closure is to allow the banana prawn stock to grow to its most valuable size before exploitation. The second period is from late June to the end of July, the purpose of this closure being to provide some protection to tiger prawn stocks prior to spawning. In addition, daylight trawling is banned during August, September and October (even though very little was previously undertaken in these months at this time). The aim of this regulation is to further reduce fishing pressure on female tiger prawns which are thought to be more active than males during daylight.

The question of who may fish is determined by the limited number of class B units (entitlements to fish) available. Any newcomer wishing to operate in the fishery needs to purchase a class B unit for each vessel to be employed. While this ensures that the total number of vessels in the fishery does not increase, it cannot achieve a reduction. The latter

objective is pursued through a buy back scheme known as the Voluntary Adjustment Scheme (now funded entirely by operators, but originally established with a $3m government grant), which finances the purchase of units that are then lost to the fishery forever. An additional regulation forces operators to surrender a class B unit every time they replace their boat. Hence, boat replacement can only be undertaken after either purchasing another operator's class B unit or losing the entitlement to fish for a second vessel under the same ownership.

Controls on what an operator can use to catch fish cover two areas: the combined size of boat and engine, and the number of nets. Each operator is restricted to a size of boat determined by the number of class A units held (see section 2.3). If an operator wishes to replace a boat, as well as surrendering a class B unit, he or she has to surrender the number of class A units by which the new boat size exceeds 375 class A units. The operator would, therefore, have to acquire from someone else in the fishery substantially more class A units than he or she would require for the new boat alone. (In fact, because of historical allocations, the number of class A units now in existence exceeds that required for the present fleet by about 11 per cent.)

This policy of reducing the physical capital in the fishery is complemented by

1 Chronology of management in the northern prawn fishery

1966	Commercial exploitation of banana prawns by two boats.
1970	Over 200 boats operating in the fishery for at least part of the year.
1971	Record catch of banana prawns (8 kt).
	Seasonal closures to protect banana prawn stocks introduced.
1974	New record catch of banana prawns (11.7 kt) resulted in increased capitalisation in the fishery.
	Formation of the Northern Fisheries Committee.
1975	Report of the first working group on management — concluded that although there was a potential for overcapitalisation in the fishery, this, in itself, did not warrant intervention.
	Copes (1975) report recommended an immediate freeze on entry of further vessels into the fishery and differential access fees to the prawn substocks.
1976	Report of second working group — recommended limited entry and like-for-like boat replacement policy.
	Establishment of Northern Prawn Fishery Advisory Committee (NORPAC) formalised industry involvement in management.
1977	Interim management regime introduced in declared management zone, which consisted of limited entry, boat replacement policy and continuation of seasonal closures for banana prawns.
1980	Revision of interim management plan. New boat replacement policy introduced allowing like-for-like replacement for larger boats and increase to 21 m for smaller boats.
1982	Review of management plan requested by Northern Fisheries Commission specifying increased industry involvement in management process.
1984	Establishment of Northern Prawn Fishery Management Committee (NORMAC) with increased advisory powers.
1985	New management plan introduced including new boat replacement policy based on unitisation calculated on the basis of underdeck volume and engine power, a buyback scheme financed by a levy on industry and extension of the declared management zone.
1986	Forfeiture provisions of the boat replacement policy introduced, requiring surrender of some units on replacement.
1987	Seasonal closure and daytime restriction for tiger prawns; maximum of two nets at a time per boat.

the Voluntary Adjustment Scheme which also aims to buy class A units from operators. Like the class B units, these units cease to exist once purchased under the buy back scheme.

Restrictions also currently exist on the number of nets that can be used. This is a recent development and is designed to have an immediate impact on the amount of effective effort the fleet can exert on the spawning stock.

The cost of implementing and enforcing all industry regulations apart from the Voluntary Adjustment Scheme is shared between the industry and government. In 1986-87, the industry share was 44 per cent of the total cost of approximately $0.5m. It is envisaged that this share will increase in future in line with the application of the government's 'user pays' policy, although there has been increasing industry pressure to contain the costs of management. Each individual operator's share of the cost is determined by the number of class A units held. The class A unit is also used as the levy base for the Voluntary Adjustment Scheme, with a lower rate applying to boats smaller than or equal to 375 class A units. Contributions to the Scheme currently total just under $4m a year and considerably outweigh the other management costs.

3. The northern prawn fishery model

The model combines the most important biological, economic and physical features of the fishery which impinge on, or are affected by, management decisions. Its purpose is twofold. First, it is intended to provide analysis of current policies and to quantify their effects. This paper details that analysis. Management and the operations of the fishery, however, are dynamic and the second purpose of the model is to provide the fishery managers with an adaptable tool so that future policy directions can be determined even when some basic relationships change, or additions to our knowledge suggest that some modifications to the model are required. The model provides quantitative estimates of the effects of policies in terms of the changes in a number of variables.

The principal components of the model are shown in figure A. These fall into three distinct compartments — fleet characteristics, policy options and the catch–effort relationship. When combined, these compartments predict an outcome, the most important variables of which are the fleet size, its catch of the two groups of prawn species, the level of effort and the profitability of the fishery. The latter is also termed the economic surplus or rent and is a measure of the excess of returns over all costs (including the opportunity cost of capital). It is therefore less than the accounting concept of profit as used by individual operators.

Depending on the policy being analysed, the outcomes may be fed back into the fleet characteristics or policy compartments in order to simulate the next stage of the policy's effects. A distinction is also made between the long run and short run with parameters specific to each scenario being used as appropriate.

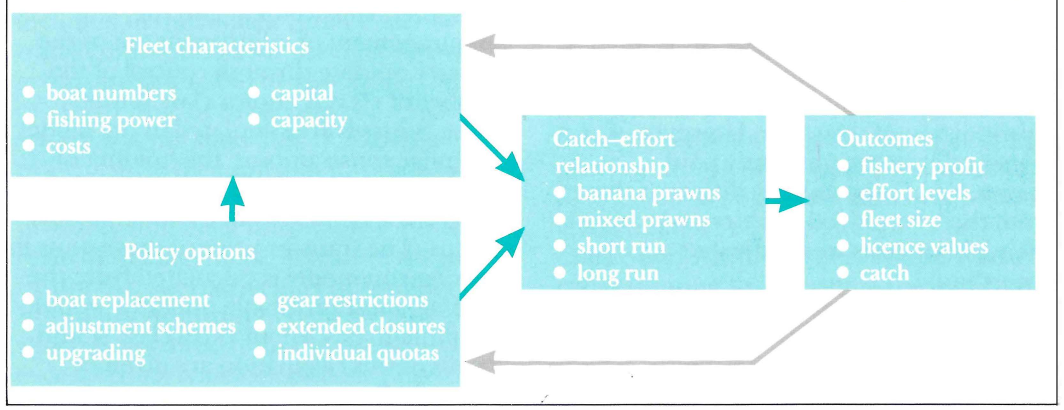
3.1 Fleet characteristics

The fishery contains vessels of different size, with different physical performance levels and different levels of profitability. The problem of individually representing these in the model is overcome by grouping all vessels into relatively homogeneous groups, based on a number of physical and economic criteria. The grouping is achieved through a clustering technique described in appendix C.

Because the regulations for smaller boats (less than or equal to 375 class A

A Diagrammatic representation of the northern prawn fishery model

ABARE chart



units) are different in some cases from those for bigger boats, separate grouping procedures for the two different broad boat sizes were undertaken. This ensured that management which differentiated on the basis of size of vessel alone could be simulated in the model. The variables which determined the 'best' split of the fleet into groups for the model were the number of hours trawled, the age of the vessel, its engine size and underdeck volume, and the main species targeted. Division of the fleet according to these characteristics produced twelve boat groups, of which two were in the small boat classification.

Cost information was obtained for representative boats in each group, from which variable costs, fixed costs and the value of capital investment per boat in 1985-86 were derived. A uniform rate of depreciation (15 per cent a year on a diminishing basis) was applied to all boats to reflect the expected average economic life of boats in the fishery. In addition, the historic capital cost was adjusted up by the index of prices for manufactured items to derive its cost in present day values. This overall approach overcomes the problem of different boats in the fishery being depreciated by different methods, often on an historical cost basis.

All interest payments incurred on a vessel were excluded since the distribution of ownership of the equity of a vessel is irrelevant to its economic use. Instead, the cost of capital was imputed from the updated capital value of the boat. The interest rate (opportunity cost) was assumed to be 10 per cent in real terms since this appears to be a generally acceptable rate of return (Clare 1982).

Labour costs in the majority of cases were not a problem since the crew are paid a proportion of the catch. However, if owner operators apparently paid themselves a substantially different share from their employed counterparts, then their labour costs were adjusted accordingly.

Boats with different fishing capabilities have different impacts on the fish stocks for each hour spent fishing. These different fishing powers were calculated for each boat group for both groups of prawn species. Details of the calculations are provided in appendix D. Fishing power coefficients convert the actual number of hours fished to effective hours. It is the latter which determine catch levels. Limits on the number of hours each boat in each group can fish in a season were also incorporated. These figures were the average hours trawled per boat in 1985-86, a season longer than the current one because of the recent imposition of mid-year closures. Differences in the hours fished between boat groups reflect differences in fishing policy and organisation of the separate owners.

Finally, since major policy measures relate to the size of boats in class A units, the latter are also specified in the model. Details of data in the model relating to the boat groups can be found in appendix G.

3.2 Policies

Management provides the framework within which individual operators make their decisions. Without management, individual operators will act in such a way as to maximise their net returns; but because there is no incentive to take into account the effect of their actions on others operating in the fishery, any economic profit (rent) will be dissipated in the long term. By constraining the actions of operators, management may prevent effort increasing to this level, where rent is zero. The model, therefore, is set up to represent management policies as constraints on excessive fishing activity.

Policies relating to the upgrading of boats, their replacement and the encouragement of adjustment out of the industry operate through control of the number of class A and/or class B units. These controls are simulated in the model by similar constraints on the holding of these units, with appropriate distinction being made between small and large boat groups. The transfer price of these units in the long run model is calculated from the price the most profitable operator would be willing to pay for an extra class A unit. Details of this calculation are given in appendix E.

For the short term model, a given rate of boat replacement, which reflected the economic life of the vessels, was assumed. Under normal circumstances this would be about fifteen years, but the penalties associated with current boat replacement policies would probably extend this period considerably. The number of boats replaced each year was therefore assumed to be twelve, or 5 per cent of the fleet a year. It is recognised that the precise rate of replacement or upgrading will depend on many factors (for example, health, equity, age of operator) but these cannot be incorporated in an economic model.

Other policies are simulated more simply. Limited seasonal closures are represented in the model by a proportional reduction in the maximum number of hours a boat can fish. Some input substitution is assumed but not enough to eliminate the effects of the policy in terms of the aggregate application of effort. For this simulation, therefore, the maximum hours fished were reduced by 10 per cent.

Gear restrictions are modelled with straight reductions in the fishing power coefficients. For example, the recently introduced restriction on the number of nets is estimated to reduce fishing power immediately by 30 per cent. Again, substitution of other inputs to compensate for this enforced reduction will undoubtedly occur (for example, the use of heavier chains and greater engine power), so for this exercise it is assumed that the restriction effectively reduces fishing power by 20 per cent on a permanent basis.

Alternative policies have also been included in the model. Individual transferable quotas for the tiger prawn group are simulated by specifying the catch per boat of these prawns. A quota system was not modelled for banana prawns since the high and unpredictable variability in recruitment to this fishery probably renders it unsuitable for this form of management, at least in the near future. An alternative way of funding the Voluntary Adjustment Scheme (and one which bears directly on the problem of excess effort) is also modelled. This involves transferring the levy base from class A units to the effort expended, as measured by expenditure on inputs.

3.3 Catch–effort relationships

A basic catch–effort relationship is specified for each of the two groups of prawn species. Two further relationships are derived for banana prawns to represent more extreme environmental conditions than the average. The tiger prawn fishery comprises tiger, endeavour and king prawns. The latter two species are grouped with tiger prawns because they are essentially regarded as a by-catch. A long run sustainable catch–effort function and an infinite number of short run relationships was derived for the fishery encompassing these species. The precise short run function used in the model depends on the effort employed the previous year. The derivation of these relationships is explained in appendix B.

3.4 Model format

The model is specified as a linear programming problem in which the components described above appear as either activities or constraints. Given these activities and constraints, the model solves the problem of how the system changes if a given objective is to be met. The objective is normally the maximisation or minimisation of a value within the model. For example, the objective might be to maximise profit or catch, or to minimise costs or boat numbers. The particular objective chosen depends on the purpose of the analysis and the type of problem being encountered.

The use of linear programming models to solve resource allocation questions in fisheries is not uncommon. For example, previous linear programming studies have focused on the optimum numbers of boats, levels of effort or output for a fishery. Clarke and Kirkwood (1979) used linear programming to determine the optimum number of freezer or brine trawlers that should operate in the northern prawn fishery under specified conditions, while Murawski and Finn (1986) used the technique to determine optimal effort levels in a North American otter trawl fishery. Huppert and Squires (1987) performed a similar exercise in their analysis of the North American Pacific coast groundfish fishery. Problems of optimal output levels and the distribution of that output between different fleets or boats were tackled by both Meuriot and Gates (1983) and Sinclair (1985) — again for North American fisheries.

The present study goes a step further than most by measuring the effect of introducing additional management measures (that is, constraints) on both the levels of effort and output and the size of the fleet.

3.5 Simulations

The model provides solutions to both short and long term management scenarios. The long term outcome of any particular policy is, of course, much more marked than a short term result since far greater adjustment to economic signals is possible. Hence, there were some important areas of difference between the short and long term simulations undertaken.

In the short run, a distinction is made between fixed and variable costs while in the long term all costs were considered variable. The one exception to this was the opportunity cost of the boat's capital value, as only twelve boat types (each with a given capital value) was assumed in the model. To allow capital values to vary would have been equivalent to having different boats in the fishery from those on which the model is based. Other differences between the long and short run lie in the choice of catch–effort relationships, referred to above, and the rate of adjustment, which is more limited in the short term.

Three objective functions are used in the model. The maximisation of fishery rent is specified as the objective in those simulations where the assignment of property rights eliminates or substantially reduces the common property problem. It is used, for example, in the first set of simulations which represents the long run optimal fishing pattern when the entire fleet is managed as a single, profit maximising entity. This provides an estimate of the profit level which could be achieved if this form of management was considered appropriate. To the extent that crowding costs are reduced from present levels, profit levels can be even higher than this estimate indicates. However, any management costs would need to be deducted to arrive at the rent accruing to the operators.

The maximisation of effort is used as the objective function in the remaining long run simulations to reflect the lack of adequate property rights associated with both open access and limited entry management regimes. The open access simulation (when rent in the fishery is zero) is used as a baseline against which other solutions for various policies can be compared. The long run rent level produced by various management policies is constrained to be equal to or greater than zero to account for the possibility of successful, rent generating policies being introduced.

The third objective function used is the maximisation of gross revenue in the short run simulations. This is akin to the maximisation of effort used in the long run simulations, except that increases in effort without increases in output are prevented. It reflects the tendency in fisheries for output to increase beyond the level at which rents are maximised unless management can contain effort to the rent maximising level. While individual operators do not have this objective, their separate actions under a common property management regime effectively lead to this outcome for the fishery as a whole in the short term.

The solutions to the various objective functions depend on assumptions about technology, prices and costs remaining the same as in the base year. Not only is this unlikely to be the case but there is also some error associated with the figures used since they are derived from a sample of the fishery only. The robustness of the model is therefore tested routinely by specifying prices 20 per cent greater and less than the base figures in the first seven sets of simulations. In addition, cost parameters and the opportunity cost of capital were

initially varied from the base figures (1985-86 averages) by plus and minus 20 per cent. The results are given for all simulations in the first set of analyses but, because the effects of increasing prices and decreasing costs by the same proportion were similar, duplication was avoided by confining the sensitivity analyses to the price changes only, after the second set of simulations. Similarly, changes in the opportunity cost of capital did not affect results sufficiently to warrant further sensitivity analyses after the first set of simulations.

A full list of the simulations undertaken is provided in appendix F and results are given in tables 2 and 4 in chapter 4. Technological advance will undoubtedly improve the fishing power of boats in the fishery in the future but no estimate of the extent of this possible change was attempted. To the extent that fishing power does improve, the long run estimates of fleet size provided in this paper are inflated.

The linear programming model on its own cannot provide estimated values for all the variables in which management is interested. Subroutines were therefore developed outside the main model to calculate the values of some parameters which were then fed back into the main program. Parameters calculated in this way were the values of class A units and the short term catch–effort relationship for mixed prawns. A detailed mathematical specification of the linear programming model can be found in appendix A, while details of the subroutines for determining the value of the above parameters are provided in appendixes B and E.

3.6 Data

The data on costs were derived from operators' accounts for 1985-86, supplemented by information supplied directly by the operators. Price data for all the prawn species were obtained from a number of market sources, and a weighted average was calculated to reflect average prices over the year. The weighted price for the tiger group therefore includes the lower prices of the endeavour and king prawns as well as the higher prices for the tiger species.

Physical information on the boats for the base period was obtained partly from the operators themselves and partly from log books. Because the prawn catching year is a calendar one rather than a financial one, the log book data used covered the last half and first half of two separate seasons. The adjustment of this data is thought to be of minor importance in the context of the model as a whole, and does not affect the conclusions regarding the appropriateness of the different policies.

Data were not sought on the costs of administering particular management policies. The cost of management is a function of the policy being implemented, the size of the fleet, the area of operation and the sought-for compliance rate. The nature of the management authority may also affect costs (Haynes and Brown 1985; Lee 1987). While some estimate of the costs of management is clearly desirable to ensure that there are net benefits from any particular policy, such a question is beyond the scope of this paper. However, these costs could be incorporated easily into the model when they are available. Furthermore, the estimated fishery profit generated for each simulated policy will indicate the order of magnitude of management costs that could theoretically be tolerated before net benefits from the policy were eliminated.

4. Results of the model

The model is capable of generating results for a large number of policies, policy combinations and economic circumstances. However, the results presented here are restricted to a relatively narrow range of policy measures to ensure the main elements are not lost in too much detail. The policies analysed are the current range of measures, together with transferable quotas and an alternative form of levy to fund the Voluntary Adjustment Scheme.

Each policy or policy combination has both short and long term implications. The analysis has therefore been framed in terms of both these time periods.

The long term analysis is presented first. Interpretation of these results requires care since the model is not predicting what the state of the fishery will eventually be. Rather it is identifying the long term direction of the fishery given certain policies, current technology and prices. As such, the results are better compared with each other for assessing the effects of policy than being treated as absolute values on their own. Developments in fishing technology, in world prawn supply and demand, and the Australian economy will all influence the long term outcomes and the predictability of these outcomes declines the further ahead one looks. Nevertheless, given these provisos, the model does provide some indication of the extent of likely change if current conditions hold.

The short term analysis which then follows is based on potential changes in the fishery over the next one to two years. These are of more immediate interest to industry and managers since they indicate what may or may not be achievable within the near future. Since changes in the model parameters within this time period are likely to be less significant than in the long term, greater confidence can be placed in the absolute values generated.

The previous caveat still applies though: the relativities of the results are more important than any single figure.

One of the variables which is used is the rent or economic surplus (the returns in excess of 'normal' profits) generated. Under many policies no rent exists. This does not imply either that the industry as a whole is not making competitive returns on its capital and labour or that individual firms are not making rents. The existence of *industry* rents means that average returns are higher than competitive returns. However, not all *firms* will necessarily earn either rents or even competitive returns. This distinction between what an individual achieves and what the industry gains is important in understanding the following results.

4.1 Long run analysis

The long run analysis consisted of seventeen different simulations ranging from single ownership to various combinations of fishery management policies. Within the first seven simulations, different runs to represent different underlying assumptions (for example, different prawn price levels) were undertaken.

The results of the simulations are highlighted below with the full results detailed in table 2. A comparison of the first seven simulations under the base assumptions is presented in figure B.

Simulation 1: Private property regime

Theoretically, the economic efficiency problems arising from a common property resource can be overcome if the resource is allocated to a single (profit maximising) organisation having complete property rights to the resource. Under this regime, the single owner could organise fishing operations to achieve a profit maximising level of catch and effort, the rent generated reflecting the elimination of the common property problem.

The model results suggest that, with defined property rights, the maximum available catch of banana prawns is always taken, while the catch of tiger prawns (including by-catch) is substantially below present levels. The optimum fleet size under current (base) conditions is 78 vessels, with the average vessel size being just over 460 class A units. The total number of class A units in the fishery would be around 36 000 and each unit would have a value of around $3000. The rent generated would be around $38m.

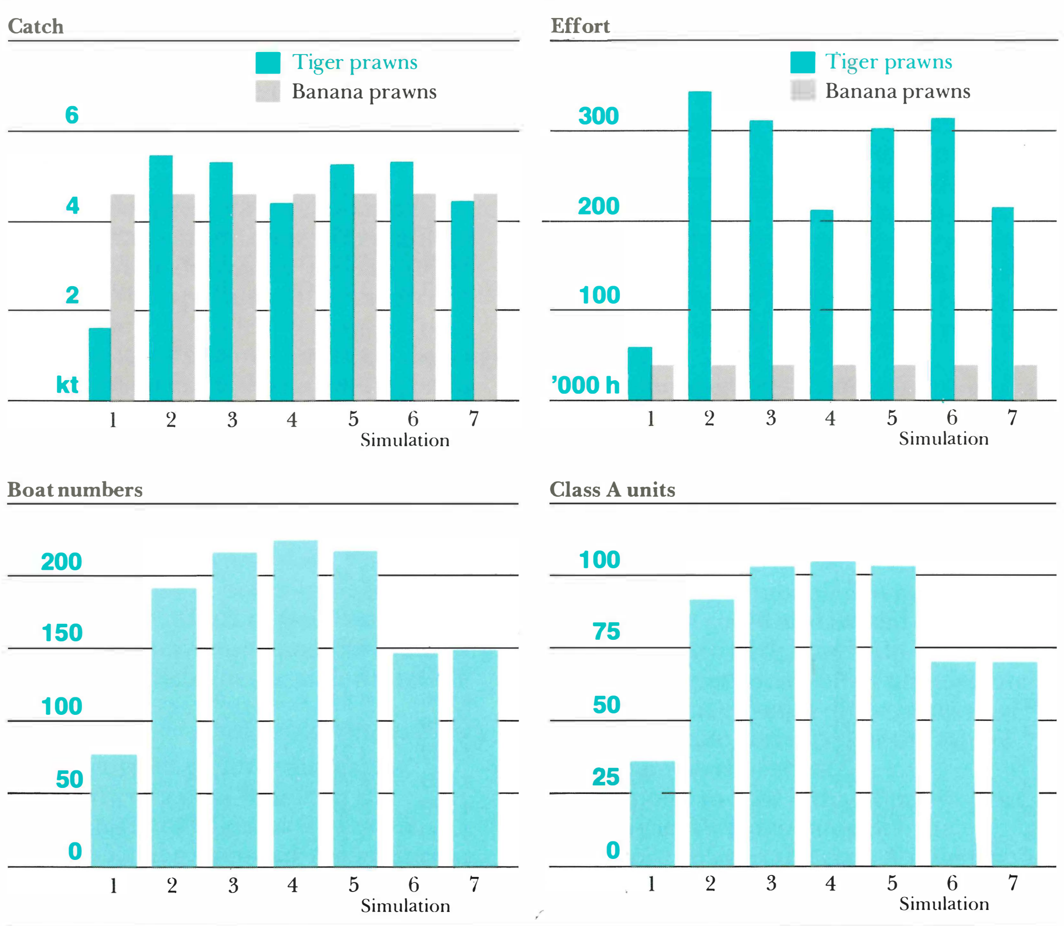
Varying the economic conditions as described earlier (that is, changing prices and costs) changes these figures: optimal fleet size then varies between 54 and 102 vessels, with the number of class A units varying between 24 000 and 48 000. Rents vary also (between $27m and $52m) but the value of a class A unit remains relatively stable at around $3000.

The results indicate that the optimum fleet size, and optimum levels of output and effort are sensitive to the price and cost data used. However, they also show that even with widely varying assumptions (runs b–g), the optimum size of fleet and number of class A units is substantially below both the current level and the immediate target of the Voluntary Adjustment Scheme.

Further analysis indicates that on average a single owner faced with the

B Long term effects of current management policies

ABARE chart



existing fleet and existing fishing time for each boat would be unable to generate a rent. In fact, substantial losses would be accrued until 43 vessels had left the fishery and the number of class A units had been reduced to around 83 000. This takes account only of income earned in the northern prawn fishery. The greater the income earned elsewhere (for example, on the east coast) the larger is the optimum size of fleet in the northern prawn fishery because some of the effort associated with

2 Results of long run simulations

Simulation number	Boat numbers	Class A units	Effort		Catch		Annual rent	VAS Value of purchases	
			Banana	Tiger	Banana	Tiger		class A units	class A units
		'000	'000 h	'000 h	t	t	$m	$	'000
1a	78	36	41	60	4 629	1 635	38	3 140	
b	102	48	41	120	4 629	2 953	52	3 277	
c	54	24	41	–	4 629	–	27	3 288	
d	54	24	41	–	4 629	–	34	3 288	
e	102	48	41	120	4 629	2 953	45	2 789	
f	78	36	41	60	4 629	1 635	37	3 106	
g	78	36	41	60	4 629	1 635	38	3 164	
2a	192	92	41	344	4 629	5 470	0	0	
b	222	106	41	419	4 629	5 495	0	0	
c	153	73	41	248	4 629	4 828	0	0	
d	162	77	41	269	4 629	5 030	0	0	
e	227	109	41	432	4 629	5 463	0	0	
3a	217	103	41	312	4 629	5 328	0	0	
b	217	103	41	375	4 629	5 536	0	0	
c	227	105	41	216	4 629	4 474	0	0	
4a	225	105	41	213	4 629	4 431	0	0	
b	217	103	41	282	4 629	5 129	0	0	
c	224	105	41	136	4 629	3 258	0	0	
5a	217	103	41	304	4 629	5 283	0	0	
b	219	103	41	345	4 629	5 475	6	165	
c	226	105	41	215	4 629	4 462	0	0	
6a	147	70	41	315	4 629	5 344	5	205	27
b	165	70	26	339	3 822	5 454	15	628	30
c	150	70	41	235	4 629	4 687	0	0	29
7a	149	70	41	217	4 617	4 483	5	201	28
b	165	70	25	238	3 797	4 725	14	615	30
c	150	70	41	148	4 629	3 463	0	0	30
8a	225	105	41	213	4 629	4 433	0	0	–
9a	148	70	41	306	4 629	5 294	6	255	28
10a	148	70	41	237	4 629	4 711	0	0	28
11a	190	91	41	249	4 629	4 840	0	0	–
12a	190	91	41	249	4 629	4 840	0	0	–
13a	148	70	41	237	4 629	4 711	0	0	37
14a	148	70	41	237	4 629	4 716	0	0	37
15a	190	91	41	345	4 629	5 471	0	0	–
16a	148	70	41	237	4 629	4 716	0	0	37
17a	172	70	41	326	4 629	5 404	0	0	37

a Base assumptions. **b** Prices increased by 20 per cent. **c** Prices decreased by 20 per cent. **d** Costs increased by 20 per cent. **e** Costs decreased by 20 per cent. **f** Capital cost increased by 20 per cent. **g** Capital cost decreased by 20 per cent.

this fleet capacity will be expended elsewhere.

Simulation 2: Open access

By definition, rents are competed away to zero and class A units have no value under open access conditions. Catches of banana prawns remain at their maximum, as they do in virtually all the simulations, while catches of tiger prawns approach or go beyond the maximum sustainable yield. The latter occurs when higher output prices encourage more effort into the fishery and output declines from its maximum. The number of boats likely to operate in the fishery in the long term under open access conditions is 192, with the range being between 153 and 227 depending on the price assumptions.

This size fleet (192 vessels) would have the class A equivalent capacity of 92 000 units. The higher price scenario would raise this to 106 000 units, while the lower price would see it fall to 73 000 units. This lower price scenario (2c in table 2) is also equivalent to a management regime based on a landings tax, and demonstrates that a reduction in fleet size, capacity and effort is attainable even under an open access type of management. With a landings tax, the industry earns normal competitive returns while the tax (in this case about $20m) is the equivalent of a resource rental.

These results show there is a wide range of boat numbers and sizes, and levels of effort which provide no rent at all. However, the imposition of constraints on fishing activities can produce rents even when the number of class A units is relatively high. The effects of such constraints are given below. The current boat replacement policy is considered first, and then the effects of gear restrictions, reduced season length and the Voluntary Adjustment Scheme are superimposed.

Simulation 3: Boat replacement policy

The current policy requires the forfeiture of a class B unit on the replacement of a boat as well as the purchase and subsequent forfeiture of a number of class A units if the new boat is above a certain size. There is therefore a financial penalty associated with the movement toward a larger boat size. Not surprisingly, this retards the rate of adjustment. Although the price operators will be willing to pay for the units will depend on expected future rents in the fishery, the supply of units will depend not only on their price, but also on factors such as the market for used boats or the profitability of alternative fisheries. These factors then will also affect the rate of adjustment.

In the very long run, the boat replacement policy is not sustainable since units cannot be forfeited indefinitely if the industry is to remain. For the purpose of this paper, the analysis is taken to the point where boat replacement is just profitable, taking into account the cost of buying the extra units and the extra net returns possible from moving to a different sized boat (see appendix E).

In general, there is little difference in catches and rents generated under the boat replacement policy and the open access situation, as can be seen in figure B. However, more boats and more class A units are retained in the fishery under the boat replacement policy than under open access — a reflection of the adjustment difficulties that the former policy imposes. However, under open access, extra boats may enter the fishery in periodic boom years and these are subsequently reluctant to leave.

Boat numbers and fleet capacity are currently above the long run equilibrium and the boat replacement policy slows down the rate of adjustment toward this level. However, the boat replacement policy also reduces the rate at which additional effort is introduced through the new technology embodied in new vessels. In passing, it could also be said that the mere existence of this and other policies raises the expectations of unit holders that some rents may eventually be generated. This would also serve to slow the rate of adjustment in the industry.

One point to note is that if prawn prices fall sufficiently (simulation 3c), the number of vessels (and class A units) in the fishery can be larger than at higher price levels. The financial penalty associated with replacement by a larger boat can induce operators to replace their boats with vessels which suffer a smaller replacement penalty (that is, boats smaller than or equal to 375 class A units).

Simulations 4 and 5: Gear restrictions and seasonal closures

The imposition of limits on certain inputs is intended to restrict effort in a fishery. Whether such policies are successful depends on the extent to which substitution of one input for another is possible, the available capacity in the fishery prior to the restriction, and the severity of the restriction itself. The effects of these policies can be compared by referring to figure B.

The reduction in fishing power through gear restrictions (simulation 4), if sustainable, reduces effort on the tiger prawn species considerably and likewise reduces the catch. Catches and effective effort on the banana prawns are unaffected. Boat numbers and class A units are slightly higher than without the policy because of the reduced incentives to invest in boats with the potentially high fishing powers. The reduction in season length (simulation 5) has virtually no effect on catch, effort exerted or size of fleet. Both policies fail to generate any rent because in the long run they will not result in a sustainable reduction of effort.

Under lower price conditions (see table 2), the same general outcomes occur, except that in the case of gear restrictions (simulation 4) there are more extreme reductions in effort on the tiger species, with a consequently lower catch. The fleet size remains approximately the same and no rents exist. When the price is higher by 20 per cent, the model predicts some rent generation with seasonal closures (simulation 5) because of the physical limitation on the hours fished per vessel, even though the fleet size is not substantially different from that under a lower price regime.

Simulations 6 and 7: The Voluntary Adjustment Scheme

The long run objective of the Voluntary Adjustment Scheme is to reduce the number of class A units in the fishery to 70 000 by the process of buying out existing operators. Associated with this target is an expected decline in effort of some 30 per cent. The effect of successfully achieving this objective in conjunction with the boat replacement policy (simulation 6) and then with the addition of gear restrictions and a reduced season length (simulation 7) is highlighted in figure B. These simulations ignore the cost of financing the Voluntary Adjustment Scheme, since this cost is historic once the target fleet size is achieved. That is, the model examines the expected level of activity in the fishery once the target has been achieved and the costs associated with the adjustment have already been incurred.

The simple reduction in the number of class A units, under the base price condition, generates annual rents of just under $5m. Catches of banana prawns are maintained at high levels, while the level of output of tiger prawns varies with the existence of gear restrictions and seasonal closures. Catches of tiger prawns are 20 per cent higher without the restrictions than with them. Boat numbers are reduced to just under 150 under both scenarios.

The value of the class A units left in the fishery, given an annual rent of about $5m, would be of the order of $200 each. This contrasts with the current price of around $450. The implications of this are discussed in chapter 5.

The reduction to 70 000 in the number of class A units does not of itself guarantee the achievement of positive rents. Under the lower price regime analysed, the catch of tiger prawns (and the effort applied) would fall substantially and no rent would exist. On the other hand, with a higher price a higher rent is achievable. The model suggests an annual rent of $14m to $15m is achievable, when prices are 20 per cent above the base level. The value of a class A unit would in this instance be of the order of $600.

Simulations 8–17: Other combinations of policies

The above policies (gear restrictions, shorter fishing season, boat replacement and the adjustment scheme) can, of course, be combined in a greater number of ways than has been demonstrated here. The results of all these combinations (at base prices) are given in table 2 and a summary of an analysis of all these results is provided in table 3.

Regression analysis is used to determine the effect of each policy (in all policy combinations) on a number of variables. It is essential to remember that the analysis includes the assumption that the Voluntary Adjustment Scheme can successfully reduce the number of class A units to 70 000, as this has a bearing on the interpretation of the results. Table 3 shows the statistically significant effects of policies on selected variables. The negative effect of a successful Voluntary Adjustment Scheme on boat numbers and numbers of class A units requires no comment since this is the purpose of the scheme. However, the lack of effect on catch and effective effort should be noted.

The effect of the Voluntary Adjustment Scheme on rent was positive but this result should be interpreted with caution because this regression has very poor explanatory power. The same comment applies to rent and the boat replacement policy. In addition, the latter has significant 'positive' effects on boat numbers and capacity, the reverse of what is intended by the policy makers, since the penalties associated with replacement of boats discourage rationalisation of the fleet structure.

Gear restrictions have a negative effect on catch and effective effort only, while shorter seasons (of the size described earlier) have no effect whatsoever. The importance of a shorter season on top of existing closures would depend on the abundance of the stock at the time of closure. This is considered in chapter 5.

Individual transferable quotas

A separate simulation of the effect of individual transferable quotas was not necessary. The assignation of catch quotas to individuals, by overcoming many of the common property features of the fishery, would be expected to give the sort of results reported for the private property regime. The rent would, of course, be lower by the extent of the management costs incurred on the administration of the quota system. While these costs may be substantial they are unlikely to approach anywhere near the level of rent potentially available. For example, annual costs of administering the Southern Bluefin Tuna Quota Scheme are about $700 000 for about 45 boats over an area as extensive as the northern prawn fishery.

If similar costs per boat are applicable in the northern prawn fishery then the management cost would be in the range of $2m to $3m and would still provide considerable rents from the fishery. Although these costs may not be strictly comparable due to the increased potential for northern prawn operators to evade controls, the costs would need to be much higher to outweigh the possible rents. However, notwithstanding this conclusion, individual quotas may not be the ideal answer to the management problem.

Of the $38m rent attainable under private ownership conditions (and so potentially achievable under a quota

3 Overall effect of policies on selected variables

	Policy			
Variable	Boat replacement	Gear restriction	Shorter seasons	Voluntary Adjustment Scheme
Boat numbers	+	*	*	–
Class A units ('000)	+	*	*	–
Catch of mixed prawns (t)	*	–	*	*
Effort on mixed prawns ('000)	*	–	*	*
Rent ($m)	(+)	(*)	(*)	(+)

+ indicates significant positive interaction. — indicates significant negative interaction. * indicates no significant interaction. ( ) indicates poor regression fit.

system) over 90 per cent is generated by the banana prawn fishery. Yet the banana prawn fishery is the one least suited to a quota system since its recruitment and output is extremely variable and, at present, it does not lend itself to accurate forecasts of available catch.

4.2 Short run analysis

The short run analysis comprised eight different simulations representing the range of management policies in the fishery. In the short term, fishing will continue as long as the gross margin (revenue minus variable costs) is positive. Profits (gross margin minus fixed costs) may be negative in the short run. In fact, in all the short run simulations discussed below, profits for the fishery as a whole were negative. The gross margins and key variable values for each simulation at the base assumptions are presented in table 4.

Simulations 18–22: Current policies

The incremental effects of current policies on output, effort and gross margins are shown in figure C. The first simulation (18) shows the effect of limiting fishing rights to the original 246 vessels during a season from mid-April to the end of November. Superimposing the present policy on boat replacement and upgrading (simulation 19) produces, not surprisingly, virtually no change in the fishery. Catch and effort are unaffected, while the slight increase in the gross margin is due to the assumption that twelve boats are replaced by more efficient ones. The increase in gross margin is therefore not related to the boat replacement policy.

The introduction of a shorter fishing season than existed in 1986 (simulation 20) likewise has no effect on output or effort because the existing capacity of the fleet is more than sufficient to take the catch in a shorter time. The increase in gross margin occurs only because some limited upgrading occurs and the set of boats replaced is different from the set of boats replaced in the previous simulations because of the changed environment. If the delayed harvest results in larger prawns on average being caught, then higher prawn prices will add to the gross margin.

The addition of gear restrictions (21) on top of these other policies has a major effect on output and margins. Assuming that a 20 per cent reduction in fishing power is enforced for the season, the catch could fall by about 6 per cent. Although the number of effective hours trawled will also fall, the actual number of hours will increase to compensate for the decline in fishing power. Gross margins fall by about $10m under this scenario.

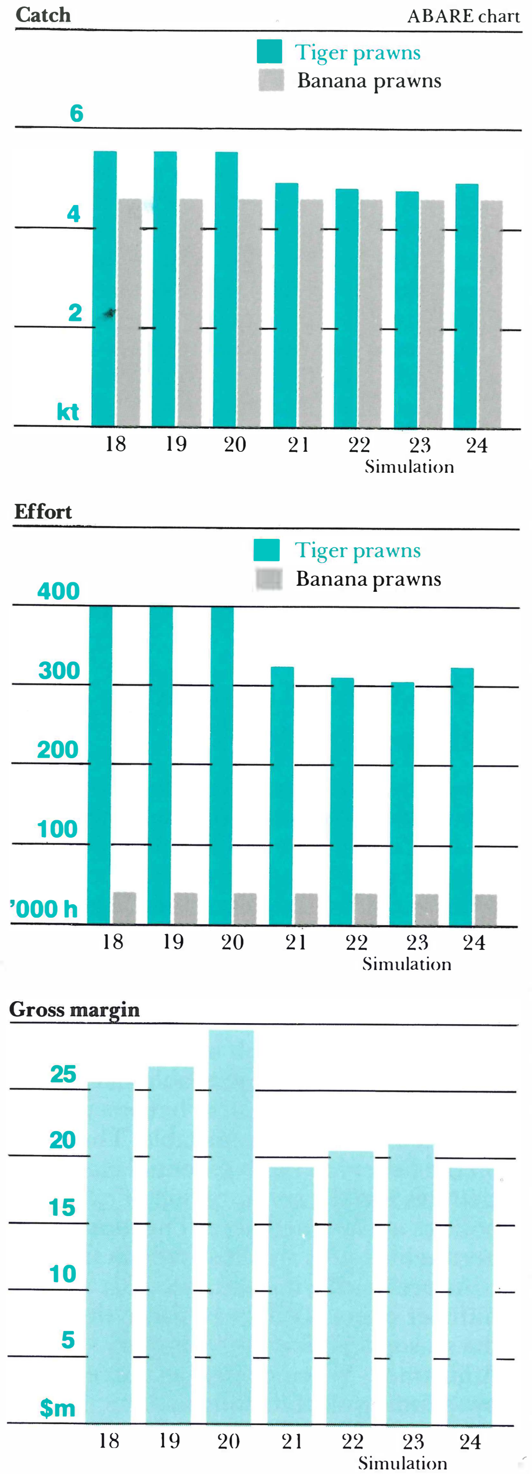
The point of gear restrictions is to reduce fishing intensity on the tiger prawn stocks to allow them to recover. To this extent, this short run analysis does not include any benefits from higher stock levels in a subsequent year. However, the

4 Results of short run simulations at base assumptions

			Effective effort		Catch		Gross margin	
Simulation number	Boat numbers	Class A units	Banana	Tiger	Banana	Tiger	Total	Less VAS levy
		'000	'000 h	'000 h	t	t	$m	$m
18	246	114.6	41	400	4 629	5 526	25.7	
19	246	113.7	41	400	4 629	5 526	26.9	
20	246	113.3	41	400	4 629	5 526	29.8	
21	246	113.2	41	325	4 629	4 919	19.4	
22	232	105.4	41	312	4 629	4 808	20.6	16.7
23	232	105.4	41	308	4 629	4 773	21.2	17.4
24	234	99.7	41	325	4 629	4 919	19.4	
25(i)	213	97.4	41	313	5 928	5 107		34.2
(ii)	213	97.4	41	313	4 629	5 107		21.9
(iii)	213	97.4	41	313	2 400	5 107		1.1

(i) 'Good' year for banana prawns. (ii) 'Average' year for banana prawns. (iii) 'Poor' year for banana prawns.

C Short term effects of current management policies



improvement of next year's stock levels can presumably be attained by far less inefficient methods than reducing fishing power. For example, an extended seasonal closure alone, strategically timed, should protect spawning stock, and would not result in the same increase in actual hours trawled.

The Voluntary Adjustment Scheme is not expected to have much short term impact on the fishery, and this is reflected in the results. It is here assumed that the money raised in levies is used entirely to purchase class A and B units at the current market price. If this is achieved, approximately fourteen boats and 8000 class A units would disappear from the fishery. There would be an associated marginal decline in effort and output relative to simulation 21. Although gross margins (excluding the levy) would increase, the net result of financing the Voluntary Adjustment Scheme would be a decline in gross margins.

Simulations 23 and 24: Alternative policies

A problem with the existing Voluntary Adjustment Scheme is that it does not address directly the problem of excessive effort causing rents to be dissipated. Long term structural adjustment under the Voluntary Adjustment Scheme would have a better chance of success if it also restrained effort. A simple way to achieve this (in theory, at least) is to alter the levy base from class A units to effort. This would be an improvement in two ways.

First, the fund would be financed by operators in proportion to the effort applied. Those operators applying the most effort, and contributing most to the problem, would finance most of the adjustment. This is a better 'user pays' basis than the present system which relates cost approximately to physical size of the major input, though the present scheme had the same general philosophy.

Second, there is a direct incentive to reduce effort if its cost is now greater. In economic terms, a levy on effort internalises within a firm the cost which the firm's effort imposes on other operators or firms.

The most appropriate levy on effort is one which embraces all inputs into the fishing process. Including all inputs in the leviable base avoids the problem of operators substituting non-leviable items for leviable ones and eroding the levy base. It also avoids the distortion in resource use that occurs when the price of one input is raised artificially above the price of another. The only levy base which satisfies all these criteria is the total cost of fishing. In other words, the levy needs to be a proportion of the total cost of operations and could be collected by the normal taxation system at the end of each financial year. In the base year, a levy of 2.75 per cent of total costs would provide the same Voluntary Adjustment Scheme income as the current (1987-88) class A unit levies ($40/unit for boats with more than 375 class A units; $20/unit for those with less) — that is $3.88m. The effect of using this new levy base (simulation 23) is shown in figure C.

The new levy base, because it raises directly the cost of effort, results in less effort and lower output of the tiger prawn species. However, the reduction in costs due to decreased effort is greater than the loss of revenue, and the industry gross margin is higher than that achieved in simulation 22. Thus, this levy base can contribute to the achievement of both long and short term objectives of reducing effort.

An effort levy is a policy tool in its own right and does not have to be linked with others. It could, for example, replace existing restrictions on boat replacement or upgradings and gear, and eliminate the need for an adjustment scheme. An effort levy of 24 per cent (simulation 24) would provide the same level of industry profitability that current policies give (compare simulations 21 and 24 in table 4 and figure C) while releasing individuals from many of the constraints that currently govern their business activity.

The long term effect of such an effort levy can be seen in the results for simulation 2d (table 2) where an open access fishery was exposed to a 20 per cent increase in costs. The fleet structure is rationalised, effort on the tiger species is reduced and yet profitability for the industry as a whole is unchanged. On a per boat basis, therefore, profit levels are substantially higher.

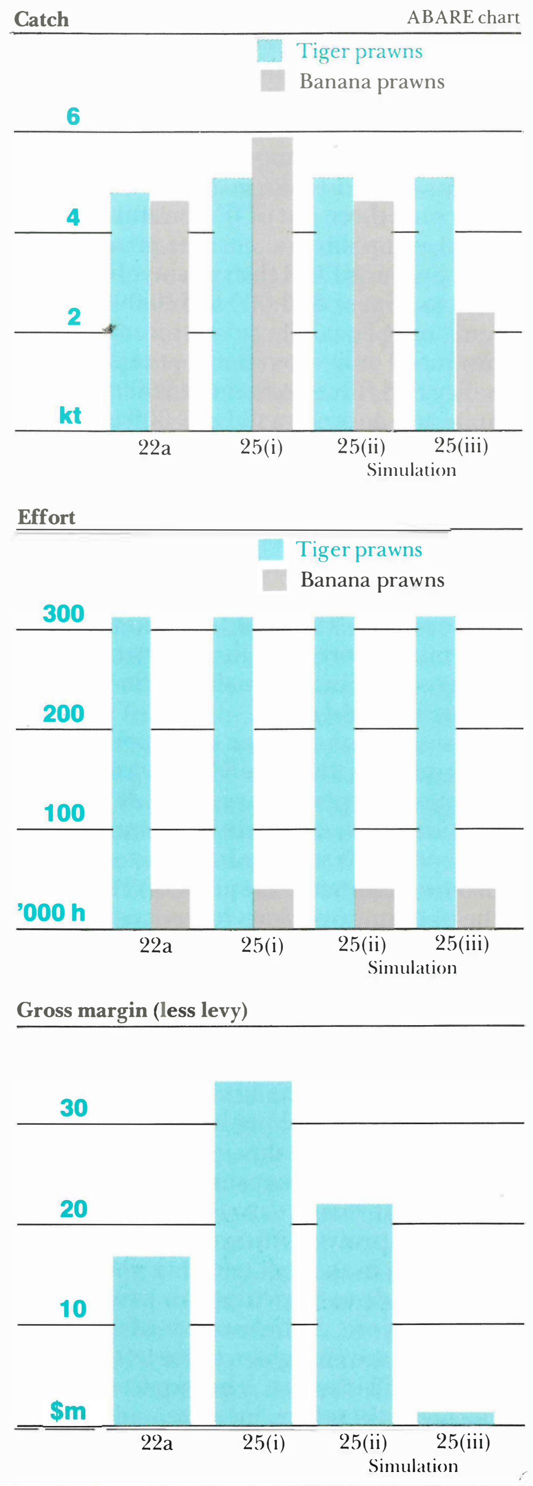
A second policy alternative is the introduction of individual transferable catch quotas, although the feasibility of this is questionable, in the light of the variable banana prawn stock. This was modelled by allocating quotas of the tiger species (based on historical catch levels) to individual vessels. Forcing vessels to catch their quota gave an infeasible solution since the constraint that returns should exceed variable costs could not be met. The inference is that once any quota is allocated, trade in quota would ensue, with some operators choosing to leave the tiger prawn fishery, at the least. In fact, the model indicated that when a certain level of quota had been transferred, not only would revenue exceed variable costs but rents would be generated of a similar order of magnitude to that predicted under the long term analysis (about $2.5m for the tiger species).

4.3 Current policies: further outlook

The above simulations refer to a single time period (one season). The fishery, though, is dynamic and the effects of reduced effort in a base year will be reflected in higher potential catches the following year (simulation 25). The stock–recruitment model given in appendix B suggests that the reduction in effort on tiger prawns to 325 000 effective hours in the base year will result in approximately a 6 per cent increase in available catch the second year. In the case of banana prawns, the catch level is unpredictable. The effect on the fishery of these potential biological changes and the continuation of existing policies is examined here. The most pertinent results are illustrated in figure D.

As previously, it is assumed that a fixed number of boats will be replaced during the season and that the Voluntary Adjustment Scheme operates successfully by spending all of its funds on the purchase of class A and B units, at the same price as in the previous year. This

D Second year effects of current policies and varying banana prawn availability



scenario therefore represents perhaps a 'best possible' outcome: in practice, purchases of A units could be as difficult as they have been historically, and boat replacements less frequent because of the financial penalty involved.

Given the above assumptions, the only difference that the size of the banana catch makes to the results is in the size of the gross margin. Effort, fleet size and the number of class A units are unaffected by the choice of banana prawn catch levels. (It should be pointed out that this would not necessarily be the case if banana prawn availability fell below the 'low' level assumed for the model.)

The main interest in these results is in how the second year compares to the first. Boat numbers have, of course, been assumed to decline. The combined effect of the forfeitures under the boat replacement policy and the purchases under the Voluntary Adjustment Scheme is to reduce boat numbers from 232 to 213. Similarly, the number of class A units declines by 8000, with 1500 of this due to the boat replacement policy. Effort in the banana prawn fishery is unchanged, while that in the tiger prawn fishery actually increases, though not significantly. The fishery gross margin less levy improves by approximately $5m (for an average banana season) reflecting the higher catch of tiger prawns. This higher catch of tiger prawns is the 'reward' for introducing gear restrictions the previous year, and sustaining considerably higher fishing costs.

Whether this increase in fishing costs was worthwhile can be judged from the simulation results presented in table 4. Gross margin levels for the fishery as a whole can be compared for the range of policies in the base year (simulations 20–22) and the second year (simulation 25). The increase in output and gross margin in this second year is equal to only half the cost imposed by gear restrictions. A similar picture exists on a per vessel comparison: output increases, but margins decline compared with the pre-gear restriction scenario. Clearly, the cost of achieving stock protection via gear restrictions is considerable.

5. Discussion and conclusions

The model is based on certain cost assumptions and catch–effort relationships. Costs, of course, can and will change over time, and biological research will no doubt expand our knowledge of stock levels, recruitment and the effect of fishing effort. Management, however, has to be based on available knowledge and the model is an attempt to incorporate what is known at present about the fishery (that is, the fleet, the stock and the economic environment) into a single analytical framework. A strength of the model is that changes in any of the features of the fishery can easily be incorporated.

The choice of policy will depend on management objectives. Since it has been explicitly stated by the managerial body that economic objectives are the justification for management in the northern prawn fishery, these objectives have been given priority in this paper. Therefore, only changes in fleet size and structure, catch levels, effort and financial performance have been considered. The social implications of any changes are not unimportant but are outside the ambit of this paper. Similarly, other objectives such as maximising export revenue earnings should not take precedence over the broad economic objective which maximises the economic returns from the fishery.

A key measure of the returns to resources is the level of rent generated. An open access fishery generates no rent in the long run, and one measure of the success of management is the extent to which it produces rent. Another measure is the extent to which yields are sustained or increased.

The annual rent theoretically obtainable from the northern prawn fishery is around $38m, or almost $0.5m for each boat remaining in the fishery at the optimal level of effort. Most current policies, however, are unlikely to produce any rent at all. At any time, some operators will be making better returns than others so that some individuals may be making good profits and others losses.

In only three out of fifteen simulations of current policies at current prices was a rent produced and the sum involved was $5m to $6m or $30 000 to $40 000 for each remaining boat. These rents were produced only when the boat replacement policy had forced out about 9000 class A units and approximately 27 000 units were removed under the Voluntary Adjustment Scheme. These rents are subject to a number of assumptions. First, it is assumed the Voluntary Adjustment Scheme can successfully reduce the number of class A units to 70 000. On the basis of past performance, this could take many years and much more than the $3.9m currently being subscribed annually to the Voluntary Adjustment Scheme.

Using a discount rate of 20 per cent (see appendix E), even the $16 000 current average levy per boat would only just be considered an adequate investment, from the operator's standpoint, if it started to produce annual net returns of $40 000 to the operator five years hence *and* operators had a *ten* year time horizon. With the shorter time horizon assumed in this paper, the investment appears unattractive. In any case, since only 5000 active class A units were purchased in two and a half years, the likelihood of 27 000 to 36 000 units vanishing in the next five years is extremely slim, especially if the disposal of a commensurately larger number of vessels through commercial channels proves difficult. Disposal has not been easy in the past (although efforts are being made to overcome this problem). Furthermore, as the number of units declines, the charge on those left in the fishery will increase. The expected cost per boat will, therefore, increase and the expected returns will recede further into the future.

The indicative future values of class A units under current policies may well be less than the present values. The basic explanation for this is that current expectations for the fishery are beyond those that current management policies can deliver. Additionally, the existence of the Voluntary Adjustment Scheme creates an extra level of (temporary) demand for class A units which cannot be sustained in the long term.

A second assumption in this analysis is that fishing power does not increase beyond today's level. But today's state of the art is tomorrow's antique and the future effective power of vessels may well be such that an even smaller fleet is needed to harvest the resource efficiently. The existence of such fishing power would allow even greater substitution between inputs to overcome any restrictions that management may impose. The target of 70 000 class A units would become irrelevant in a fishery of the future.

This is not to say that the Voluntary Adjustment Scheme is without virtue from society's point of view. If substitution of one input for another is limited at some stage in the future, and a rent can be generated (as the model indicates), the removal of resources from the fishery may provide some economic benefits to society. The resources that leave the fishery (whether they be capital or labour) can generally earn returns elsewhere, while those that remain in the fishery accrue greater returns than previously earned. Consequently, the policy does have the potential to result in increased returns to these resources from society's viewpoint.

If the current Voluntary Adjustment Scheme provides little prospect of economic benefits, what about the alternatives? The boat replacement policy and gear restrictions force inefficiencies on to individual operators with the intention of providing industrywide benefits. However, the results from the model suggest that few benefits will be realised. Both policies, if they are retained and are effective, reduce catch and effort but increase operational costs. While no rents are generated, both policies could have the effect of shifting costs sufficiently to ensure that the new equilibrium of the fishery is at a higher level of output and lower level of effort than without the policies. Although this might ease pressure on the prawn stock, it does not contribute to the economic objective of management, that is, to increase profitability.

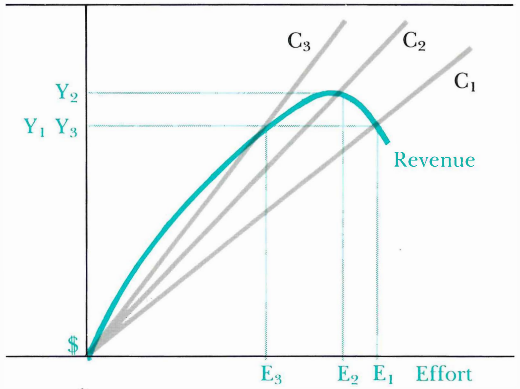
In figure E, for example, cost increasing policies could move the fishery cost curve from C_1 to C_2 and output from Y_1 to Y_2, and decrease effort from E_1 to E_2. However, the model suggests that the long run equilibrium without management would be closer to Y_2 and E_2, and that imposing costs on this equilibrium would reduce catch as well as effort (see cost curve C_3 in the diagram).

It is worth considering to what extent output would have fallen without the gear restrictions. If effective effort had continued at the level prior to the imposition of gear restrictions (400 000 hours on the tiger prawns), the stock recruitment model in appendix B suggests that recruitment would have fallen no further. Indeed, effort would have to be substantially above this level before the spawning stock was further reduced. The absence of gear restrictions, therefore, while giving a lower output in the second year, provides net savings to the industry when cost savings are taken into account.

The effect of additional seasonal closures is more complex. On their own, as effort reducing policies, they would be ineffective because they are aimed at

E Long run effects of cost on output and effort

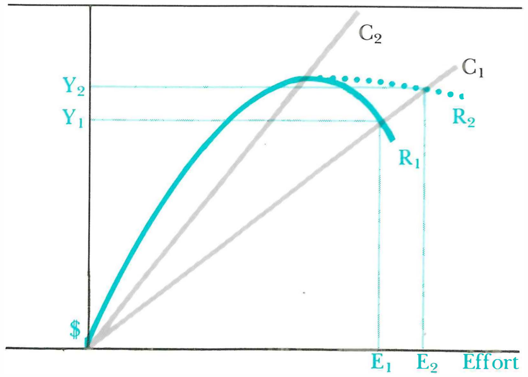
ABARE chart



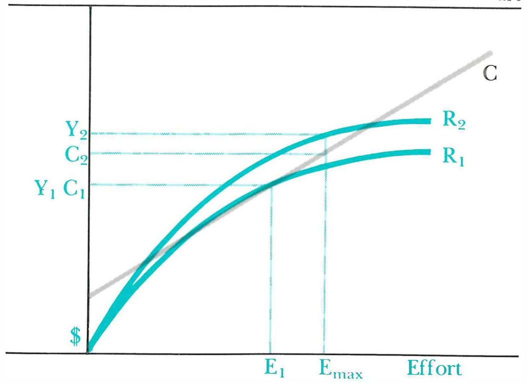
limiting only one input in the fishery (time per boat). The numbers of boats and their associated fishing powers are more than enough to compensate for any reasonable reduction in the length of the fishing season, and catch and effort remain largely unaffected. Aggregate effort will still be determined by individual decisions which eliminate the potential rent in the fishery.

Nevertheless, a seasonal closure aimed at the protection of spawning stock (rather than the containment of aggregate effort) may be an appropriate policy. Protection of the spawning stock to ensure maximum recruitment levels to the fishery will alter the shape of the sustainable yield curve (and therefore sustainable revenue) from R_1 to R_2, as shown in figure F. If the cost curve relevant to the industry is C_1, then output will increase, as will effort. No long term rents will be generated but the industry will be just as efficient while at a larger size in terms of output.

F Long run effect of seasonal closure to protect spawning stock ABARE chart



G Short run effect of seasonal closure to protect spawning stock ABARE chart



In the short term, some rents could well be made before the industry adjusted to the new yield–effort relationship. This is illustrated in figure G, where an increase in recruitment results in a higher yield for any given level of effort. The short term physical capacity of the fleet *may* be insufficient to eliminate rents (shown by the difference between Y_2 and C_2). However, such short term rents are unlikely to exist in the northern prawn fishery because of the existing excess capacity.

Given a cost–effort relationship similar to C_2 in figure F, a seasonal closure of the type under discussion would have no long term effect. The short term effect of the closure should only be to reinforce the individual operator's decision to reduce effort in view of the lack of profitability in the fishery. Consequently, economic forces would regulate effort to ensure recruitment reverted to its maximum. A closure, though, may enable this position to be reached sooner rather than later, with consequent gains to the industry.

5.1 Whither policy?

Current policies in the northern prawn fishery offer little prospect of achieving the goals of the operators and managers in the fishery. Apart from a specific closure to protect spawning stocks, these policies impose costs either directly on efficient operation (boat replacement policy, gear restrictions) or indirectly in the pursuit of possible future gains (the Voluntary Adjustment Scheme). Shortening the fishing period by a non-specific closure similarly has no effect on effort because of the availability of underutilised fishing capacity in the fleet. If the closure were severe enough, it could result in increased costs in other areas as operators 'tooled up' to counter reduced fishing time.

Why then do both long and short term prospects fall short of the obvious hopes of the industry? The answer lies in the nature of the measures themselves. None of them fully addresses the fundamental problem of property rights in the fishery, which is the rationale for management. Granted that these measures are those traditionally used by fishery managers, it should not be forgotten that traditional management also spends much of its time concerned with short term crises, as the history of the northern prawn fishery demonstrates.

Two alternative policies were analysed using the northern prawn fishery model, and both offer some prospect of real economic gains being achieved. A levy on effort to fund the Voluntary Adjustment Scheme has an immediate impact on effort levels, while still meeting industry objectives of attempting to reduce the fleet size. Of course, an effort levy could also be used as a policy instrument on its own and this is probably more desirable than linking it with existing policies.

The ramifications and implications of introducing such a radical measure are beyond the scope of this paper. Suffice it to say that such a measure appears to have the attraction of being flexible and administratively simple (via a percentage charge on tax deductible fishing costs) and it could eliminate most of the other (costly) regulations which govern fishing activity. Such a simple measure would also reduce the cost of management by eliminating much present management activity.

The second measure which could theoretically overcome the common property problem of fisheries is the use of individual quotas. Again, examination of the detail associated with the introduction of quotas is not within the scope of this paper. Instead, some generalisations only are possible.

Most economic gains could come from a quota system on the banana prawn fishery, once it is possible for catches to be accurately predicted. With current knowledge, however, such a course appears infeasible. The tiger prawn fishery is more stable and if biologists can predict recruitment and potential catches with some degree of confidence, then individual quotas are certainly worth examining. Work such as that carried out by CSIRO in the Western Gulf of Carpentaria (on which the biological model in this paper is based) would therefore need to be undertaken for the entire northern prawn fishery.

Should such a quota system be technically feasible the economics of administration need to be considered. The potential annual rent on the tiger prawn species is not large (about $2.5m at base price levels) and this has to more than cover any extra research and management costs that an individual quota system may require. A further consideration indicated by the model would be the immediate transfer of quota within the fishery following its allocation. In itself this is not a problem since each operator has a choice of whether to remain in the fishery or accept compensation for leaving. After all, this is exactly what the Voluntary Adjustment Scheme aims to achieve. A problem, as always with quota systems, would lie in the choice of criteria for allocating quota in the first place.

5.2 Caveats

The results from the model are ultimately dependent on the relationships and the data used. While the most recent and accurate information available was sought, it is always possible that the complete picture is not revealed through the data. For example, if output is greater than published information suggests or costs are actually lower than tax accounts indicate, then the orders of magnitude given in this paper for different variables are likely to be inaccurate.

An attempt was made to overcome this problem by undertaking price sensitivity analyses on a large number of simulations. As the results in table 2 indicate, while the absolute values change with changes in assumed returns, the broad conclusions outlined above generally do not. An important exception relates to the position of the industry cost curve. Higher catch levels and/or lower costs than those used in the model could place the cost curve to the right of maximum sustainable yield (in the region of E_1 in figure E). In this case, increasing effort results in declining long run catch levels.

The model is a highly simplified representation of what actually occurs. Not everything can be modelled satisfactorily. The present model has one particular weakness due to time and data constraints: some boats in the northern prawn fishery also operate outside the area (on the east coast, for example), and this activity is not yet incorporated in the model. The implications of this is that fishing costs used in the model may be overestimated as some of the costs may actually be incurred outside the fishery. Consequently, the potential rents from management may be underestimated. Incorporating the other fishing activity presents little problem, but obtaining the data to quantify it does. Further research is required to overcome this problem.

The results contained in this paper are only the first step in the use of the model. Further development, including the incorporation of the other fishing activities mentioned above, is anticipated. The existence of the model — and the knowledge of its potential uses — should encourage many involved in the industry to provide further assistance. Ultimately, the model is expected to be a tool for management and its value will increase the greater is that input.

Appendix A Mathematical specification of the model

The model of the northern prawn fishery comprises a series of variants, each simulating a particular management policy or a combination of management policies. The model is formulated to maximise the value of a specified variable in the fishery subject to the biological, economic and management constraints that exist. Both long and short run outcomes are simulated. Major assumptions for the long and short run simulations are outlined below:

Long run

- Yield is sustainable — hence, in the tiger prawn fishery, marginal returns to extra effort beyond maximum sustainable yield are negative.
- Boat numbers are unrestricted (subject to the number of entitlements).
- Fleet configuration is unrestricted (subject to the existing or assumed number of class A units).
- All costs are variable (except the opportunity cost of the capital value of the vessel, which is fixed for each group).
- A maximum is placed on number of fishing hours per boat.

Short run

- Yield is not assumed sustainable — hence marginal returns to effort are always positive, though diminishing.
- Boat numbers are determined by initial number, number of boat replacements and purchases under the Voluntary Adjustment Scheme.
- Fleet configuration is determined by initial configuration and changes allowed under the Voluntary Adjustment Scheme and boat replacement policy.
- Financial penalties are incurred on upgrading of a boat (capital costs plus purchase of units).
- Specified costs are fixed.
- Number of hours fished is restricted by a minimum and a maximum value (to ensure all boats in the solution are active).

The specifications of the objective functions for individual policy scenarios are given below, together with the model constraints.

Notation

Subscripts

i refers to the species fished, where $i = 1$ is banana prawns and $i = 2$ is tiger prawns (including by-catch species).

j,k refer to the boat groups, where j (or k) $= 1, 2$ are the 'small' boats (≤ 375 class A units) and j (or k) $= 3, 4, \ldots, 12$ are the 'large' boats (> 375 class A units).

a refers to class A units.

b refers to class B units.

n refers to points on the catch–effort relationship curve.

Variables

X_j the number of boats in group j.

H_{ij} the number of hours trawled for species i by boat group j.

Q_i the total catch of species i (t).

K the total capital in the fishery ($).

T_a the quantity of class A units traded.

T_b the quantity of class B units traded.

E_i the total effort expended on fishing for species i (effective hours).

W_{in} the weight assigned to point n on the catch–effort relationship curve for species i.

R_{kj} the number of boats entering group j from group k by either replacement or upgrading (short run only), $k \neq j$.

S_j the number of boats in group j that sell their endorsements.

A_a the number of class A units sold to the Voluntary Adjustment Scheme.

A_b the number of class B units sold to the Voluntary Adjustment Scheme.

U_j the number of class A units held by boat group j.

F the total Voluntary Adjustment Scheme fund ($).

Parameters

- p_i the price of species i (\$/t).
- c_j the long run variable cost of a boat in group j (\$/h).
- v_j the short run variable cost of a boat in group j (\$/h).
- f_j the short run fixed cost of a boat in group j (\$/boat).
- o the opportunity cost of capital (%).
- x_j the initial number of boats in group j.
- e_{ij} the fishing power of a boat in group j relating to species i.
- w_a the price of class A units (\$/unit).
- w_b the price of class B units (\$/unit).
- t_j the maximum number of hours available for a boat in group j to fish (h/boat).
- s_j the minimum number of hours available for a boat in group j to fish (h/boat).
- d_j the maximum number of hours available for a boat in group j to fish for banana prawns (h/boat).
- l_{in} the level of effort at point n on the catch–effort relationship curve for species i (h).
- q_{in} the catch at point n on the catch–effort relationship curve for species i (t).
- u_j the average number of class A units held by a boat in group j (units/boat).
- k_j the average capital value of a boat in group j (\$/boat).
- g_{kj} the number of class A units forfeited when upgrading (or replacing) a boat from group k to group j ($g_{kj} = 0$ for $j = 1, 2$).
- r_{kj} the number of class A units released by downgrading from group k to group j, where $r_{kj} > 0$ *if* $u_k > u_j$ else $r_{kj} = 0$.
- h_{kj} the number of class A units required to upgrade from group k to group j, where $h_{kj} > 0$ if $u_k > u_j$ else $h_{kj} = 0$.
- y_j the levy on the number of class A units held by a boat in group j (\$/unit).
- z the levy on total costs in the fishery (%).

Objective functions

In the model, four different objective functions were employed for the different simulations. These functions are:

(1) Maximise rent (long run) $= \Sigma_i p_i Q_i - \Sigma_i \Sigma_j c_j H_{ij} - oK$

(2) Maximise rent (short run) $= \Sigma_i p_i Q_i - \Sigma_i \Sigma_j v_j H_{ij} - \Sigma_j f_j X_j - oK$

(3) Maximise effort $= \Sigma_i \Sigma_j e_{ij} H_{ij}$

(4) Maximise revenue $= \Sigma_i p_i Q_i - w_a T_a - w_b T_b$

Objective functions (1) and (3) were both used in long run simulations of the fishery, the former under conditions of single ownership and transferable quotas, while the latter objective function was used to analyse open access, boat replacement policies, seasonal closures, gear restrictions and the Voluntary Adjustment Scheme.

Objective functions (2) and (4) were both used in the short run simulations. The policies examined were the same as for objective functions (1) and (3), respectively.

Constraints

Associated with the objective function is a series of constraints that represent limitations on the amount of profit, effort or revenue that can be obtained. The constraints in the model either set limits on activities or reconcile the activities to simulate actual behaviour. These constraints are defined below.

Constraints common to all simulations

(5) $\Sigma_i H_{ij} - t_j X_j \leq 0$ for each boat group j

(6) $\Sigma_i H_{ij} - s_j X_j \geq 0$ for each boat group j

(7) $H_{1j} - d_j X_j \leq 0$ for each boat group j

(8) $\Sigma_j e_{ij} H_{ij} - E_i = 0$ for each species i

(9) $\Sigma_j X_j \leq 265$

(10) $\Sigma_j u_j X_j \leq 114\ 640$

(11) $-X_j - S_j + \Sigma_k R_{kj} - \Sigma_k R_{jk} = -x_j$ for each boat group j

(12) $\Sigma_j k_j X_j - K = 0.$

Constraints (5) and (6) set the maximum and minimum hours a boat group can fish for prawns. Constraint (7) limits the number of hours a boat group can fish for banana prawns. Equation (8) defines the total effective effort expended on species i.

Constraints (9) and (10) limit the number of class B and class A units respectively. Equation (11) determines the number of boats in group j after adjustment. Equation (12) defines the total capital in the fishery.

Linearisation of catch–effort relationship

The catch–effort relationship outlined in appendix B is a non-linear function. To incorporate this relationship into the linear programming framework, the function was decomposed into a series of linear segments between 25 points on the curve. Catch, given a level of effort, can be estimated as a weighted combination of, at most, two adjacent points on the curve, or at a particular point on the curve. The linearisation is included in the model as:

(13) $E_i - \Sigma_n l_{in} W_{in} = 0$ for each species i

(14) $Q_i - \Sigma_n q_{in} W_{in} = 0$ for each species i

(15) $\Sigma_n W_{in} = 1$ for each species i.

Equation (13) equates effort to the weighted points on the curve. Equation (14) determines the catch associated with the weighted points on the curve. Equation (15) ensures that the weights sum to 1. This technique of separable programming is a standard technique of incorporating non-linear functions into linear programming models. Further details can be found in Wagner (1975).

Constraints requiring returns to cover costs

(16a) $\Sigma_i p_i Q_i - \Sigma_i \Sigma_j c_j H_{ij} - oK \geq 0$

(16b) $\Sigma_i p_i Q_i - \Sigma_i \Sigma_j v_j H_{ij} \geq 0.$

Constraint (16a) is used in the long run simulations to ensure that returns cover all costs. Constraint (16b) is used in the short run simulations and requires that returns cover variable costs.

Constraints relevant to the boat replacement policy

(17) $\Sigma_j u_j X_j + \Sigma_k \Sigma_j g_{kj} R_{kj} = 114\ 640$

(18) $\Sigma_k \Sigma_j R_{kj} - T_b = 0$

(19) $\Sigma_k \Sigma_j R_{kj} - \Sigma_j S_j = 0$

(20) $\Sigma_j X_j + \Sigma_j S_j = 265$

(21) $\Sigma_k \Sigma_j h_{kj} R_{kj} - T_a = 0$

(22) $\Sigma_k \Sigma_j h_{kj} R_{kj} - \Sigma_k \Sigma_j r_{kj} R_{kj} - \Sigma_j u_j S_j = 0.$

Equation (17) constrains the remaining class A units after forfeiture following replacement. Equations (18), (19) and (20) reconcile the number of class B units that are forfeited and traded following replacement. Equation (21) determines the number of class A units purchased and equation (22) reconciles purchases of class A units with release of class A units through either sale or downgrading.

Constraints relevant to the Voluntary Adjustment Scheme

(23) $\Sigma_j u_j X_j \leq 70\ 000$ (long run only)

(24) $\Sigma_j u_j X_j + \Sigma_k \Sigma_j g_{kj} R_{kj} + A_a = 114\ 640$

(25) $\Sigma_j X_j + \Sigma_j S_j + A_b = 265$

(26) $\Sigma_k \Sigma_j h_{kj} R_{kj} + A_a - \Sigma_k \Sigma_j r_{kj} R_{kj} - \Sigma_j u_j S_j = 0$

(27) $w_a A_a + w_b A_b - F = 0$

(28a) $\Sigma_j y_j U_j - F = 0$

(28b) $z(\Sigma_i \Sigma_j v_j H_{ij} + \Sigma_j f_j X_j) - F = 0.$

Constraint (23) limits the number of class A units to the long run Voluntary Adjustment Scheme objective. Equations (24) and (25) reconcile the number of class A and class B units after forfeiture and sales to the Scheme. Equation (26) reconciles purchases and sales of class A units. Equation (27) limits the purchases of class A and class B units by the amount of funds available (given for year 1). Equations (28a) and (28b) determine the amount of Scheme funds available in subsequent years through either a levy on class A units or a levy on total costs. Only one of these last two constraints is employed in the model at any one time.

Appendix B Catch–effort relationship

The model contains two fundamental relationships linking effort and catch, one for each of the two groups of prawn species (bananas and tigers). The groups differ in a number of important ways and this necessitates their different treatment. In the first place, because of the schooling habits of banana prawns, catch rates are higher and the season much shorter than for the tiger prawns. Furthermore, a far higher proportion of the recruits to the banana prawn fishery is caught. Finally, it is believed that recruitment to the banana prawn fishery in one year is independent of the fishery effort the previous year (see chapter 2.1). For tiger prawns, the amount of fishing effort can affect the numbers available to be caught the following year. The short term (within a single season) relationship for tiger prawns will therefore be different from the long term (sustainable) relationship. These relationships for both groups of prawns are considered below.

Tiger prawns

Catch is a function of the recruitment to the fishery and the amount of effort applied. It is assumed that the catchability of the stock and the natural mortality rates remain constant. A function used by biologists is the dynamic pool model (Pitcher and Hart 1982) which has a number of variants. Somers (CSIRO, personal communication, July 1987) suggests the following variant for the purpose of this model:

$$Q_t = \bar{w} N_t \, qE_t \, (1 - e^{-(qE_t + m)}) / (qE_t + m)$$

where Q_t is the catch in year t (in kg); $\bar{w}$ is the average weight of each prawn caught (in kg); N_t is the recruitment to the fishery in year t (number); q is the catchability coefficient; E_t is the effort applied in year t (hours); and m is the natural mortality coefficient.

With recruitment to the fishery fixed for a given season, output increases with input (effort) up to the point of total exploitation at a diminishing marginal rate. For tiger prawns, the exploitation rate was taken to be 50 per cent (Somers 1987) — that is, 50 per cent of the available stock is removed by fishing. The maximum catch in any given season is therefore $0.5(\bar{w}N_t)$.

The maximum catch in a season when recruitment was at the maximum of the carrying capacity of the environment was taken to be the average of the two highest yielding years (1980 and 1981). This was 7 kt. The maximum effort going into the fishery (at which level half the recruits are caught) was taken to be the average of the annual effort levels in these years (400 000 hours). Given Q_t and E_t, with $\bar{w}$, q and m constant, N_t can then be calculated. In turn this can be held constant while E_t is varied to produce the short term catch–effort relationship shown in figure H. Parameter values are given in table 5.

The high levels of output shown in figure H (at around 6–7 kt) may not be sustainable in the long term if recruitment to the fishery in the following season is thereby affected. Although no published estimates of the stock–recruitment relationship for the northern prawn fishery as a whole are available, data do

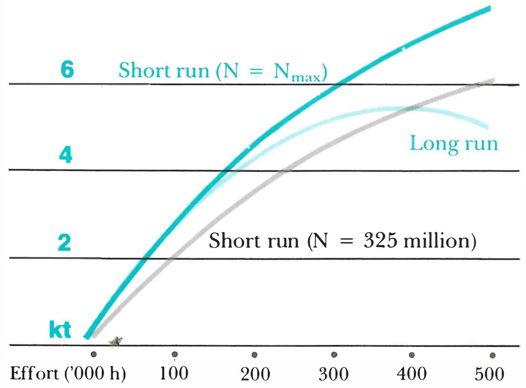
5 Parameter values used in calculations

Parameter	Tiger	Banana	Unit	Source
$\bar{w}$	0.034		kg	a
q	0.00000518	0.0000524		b
m	2.0	0.3		c
x	0.5	0.8		c
N_t	324.9		million	d
Stock	11 046.6	5 786.2	t	a

a Calculated from CSIRO sample data on weight and numbers caught in 1985. **b** Derived from the following function: $x = (qE_t/(qE_t + m))(1 - e^{-(qE_t + m)})$, where x is the exploitation rate. **c** I. Somers (personal communication). **d** Derived from assumed maximum annual catch. **e** Stock = wN_t.

H Catch–effort relationships in the tiger prawn fishery

ABARE chart



exist for a part of the fishery. In the absence of total fishery data, these have been used to proxy the stock–recruitment relationship. The data used comprise pre-August fishing effort, recruitment and a spawning stock index for grooved and brown tiger prawns in the western Gulf of Carpentaria for the years 1970 to 1985 (Somers 1987).

Both spawning stock and recruitment functions fit a Ricker curve (I. Somers, CSIRO, personal communication, 1987). The basic data were first transformed to bring them to units comparable to the main model and the following stock–recruitment relationships were determined:

$$I_t = 2.0077 \, N_t e^{-0.000001414 E_t}$$

$$N_{t+1} = 1.43751 \, I_t e^{-0.001331 I_t}$$

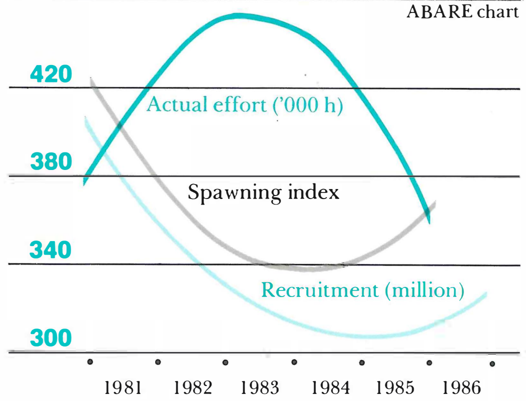
where I_t is the index of spawning stock in year t; N_t is the recruitment to the fishery at the beginning of year t (in millions); and E_t is the total effort expended in the fishery (in hours).

Output is sustainable in the long term only if the output in one year does not reduce recruitment in the following year. The long term catch–effort relationship can therefore be calculated from the above by specifying $N_t = N_{t+1}$. This long term catch–effort relationship is shown in figure H and is the relationship used in the long run simulations. The ratio of pre-August effort (which affects the spawning stock) to total effort was assumed to be that which occurred in 1985-86 (that is, 0.5). Variations from this ratio can be incorporated if necessary.

The same stock–recruitment relationships are also used to determine the annual catch–effort relationships used in the short run model simulations. Recruitment in the base year (1986) was estimated from the effort, derived recruitment levels and spawning index of the preceding six years. Recruitment at the start of this period was assumed to be at the maximum of the environmental carrying capacity, and was estimated to have declined to three-quarters of this level by 1984. Changes in these parameters are shown in figure I.

I Recruitment, spawning index and effort in the tiger prawn fishery

ABARE chart



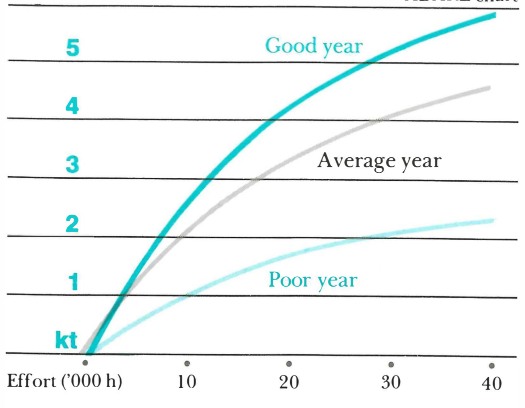
The predicted recruitment level for the base year (325 million) gives the short run catch–effort relationship shown in figure H. Somers points out that the stock–recruitment relationship calculated may not be fully reversible. If this is the case, then the catch–effort relationships calculated may be too optimistic.

Banana prawns

Since fishing effort and catch are not thought to affect recruitment to this fishery, the differentiation between what is achievable in the short and long term is irrelevant. The banana prawn production function is determined by the very high exploitation rate (x = 80 per cent) and environmental conditions.

J **Catch–effort relationships in the banana prawn fishery**

ABARE chart



For the long run simulations, average environmental conditions are assumed, with the extremes either side of the average cancelling each other out. Maximum catch in the average year is assumed to be 4629 t which can be taken with just over 40 000 hours of effort. This maximum catch was the average catch in the fishery in the period 1971–85. The recent inclusion of Joseph Bonaparte Gulf in the northern prawn fishery may raise actual catch levels but this may be offset by a lower exploitation rate.

In the short term, two alternative catch–effort relationships are calculated to represent more extreme (that is poor and good) environmental conditions. With the same level of effort as previously the maximum catch in a 'good' year is assumed to be 5928 t (the average of the four highest yielding years in the period 1971–85). Similarly, the maximum catch in a 'poor' year is assumed to be 2440 t (the average of the four poorest years in the period).

Each catch–effort relationship is calculated by the same method as used for the tiger prawn species (the first equation). Stock levels ($\bar{w}N_t$) for each year are determined by the exploitation rate and the maximum attainable catch that year. The three relationships are shown in figure J.

Appendix C Determinants of boat groups

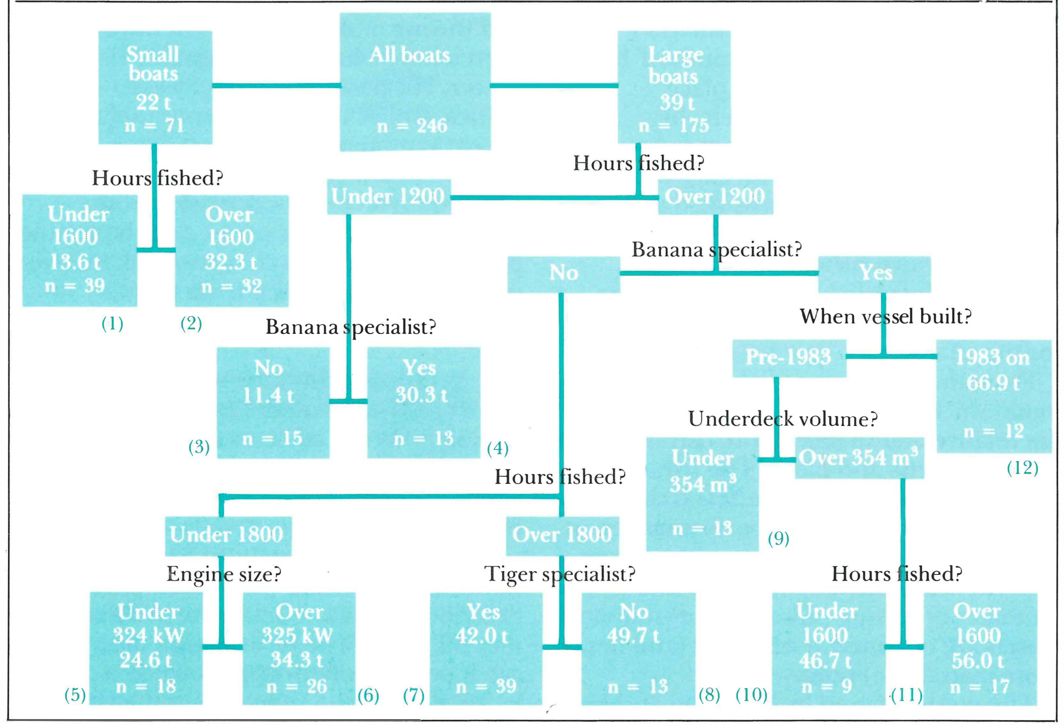
The fleet was separated into a number of relatively homogeneous groups based on the observable characteristics of individual vessels. These characteristics were derived from log books and included catch by species, hours fished per season, under-deck volume, engine size and age of vessel. Further characteristics were generated from this data to define vessels as specialists in the capture of particular species.

The grouping was achieved through a clustering technique (Weighted Automatic Interaction Detector) which successively splits the parent group so that the ratio of between-group variance to that within groups is ultimately maximised. The program is not bound by its initial choice of groups: if a split of a parent group into 'daughter' groups fails to improve the homogeneity of the groups sufficiently, the program re-forms the parent group and splits off another group showing the next largest variability. In the final solution, each new split of the population increases the homogeneity of the groups, but naturally the size of each group decreases. The final number of groups is subjectively determined according to the needs (and resources) of the project.

The determination of groups for the model is shown in figure K. The diagram shows for each group the average catch per boat (in tonnes), the variable which determined the formation of that group and the number of vessels per group. The diagram as a whole shows how each daughter group is related to its parent, and ultimately to the whole population.

K **Determinants of boat groups**

ABARE chart



Appendix D Fishing power

Different boats have different capacities to harvest fishery resources. This lack of homogeneity clearly needs to be taken into account in any modelling exercise which simulates economic activity. Fishing power can be defined thus: when two boats fish in the same place, at the same time, for the same species, their catches per unit time will be proportional to their fishing powers for that species. It is thus a relative measure: a dimensionless number whereby the performance of any boat can be compared with others. Actual catch rates vary with the abundance of the resource from one area of the fishery to another and from one day or month to the next. A vessel's fishing power is its relative harvesting capacity per unit of time, independent of the abundance of the stock. The actual catch rate is determined also by resource abundance.

Fishing power is inherently difficult to measure. A number of methods exist for calculating fishing powers. Gulland's method compares pairs of 'standard' boats fishing at the same time and place (Gulland 1956). Unfortunately, his method also requires each boat to have fished at the same time with each other boat in the sample, and missing data have to be generated by interpolation. In the northern prawn fishery, with a large number of boats fishing over a vast area, this requirement presents major problems for the analysis.

From the estimates of fishing power of 'standard' boats, Gulland then estimates the relative abundance of the fish stock at a particular time and place. The fishing power of 'non-standard' vessels is then calculated based on their performances on these fishing grounds. Thus, not only are hypothetical data generated but the estimates of fishing power of non-standard vessels are obtained at a further (and hence more inaccurate) remove.

The methods used by Beverton and Holt (1957) involved the direct comparison of a vessel's fishing performance with all others in a given place and time. Even indirect comparisons were used. For example, the performance of vessel 2 is estimated in relation to vessel 1; the performance of vessel 3 is estimated in relation to vessel 2, and hence to vessel 1; and a whole chain of ratios ('perhaps thousands') is derived to arrive at an estimated fishing power of vessel n in relation to vessel 1. In fact, Beverton and Holt used four methods to link up the fishing performances of vessels in slightly different ways and took the arithmetic mean of the answers to give their final estimate.

Their work was taken one step further by Robson (1966), who showed that a slight modification to one of their methods resulted in a more efficient estimation than any of the others. Using logarithms (like Gulland) to eliminate the correlation between the variance of the fishing power and the mean, Robson used multiple regression techniques to estimate fishing power. His particular model was sufficiently flexible to incorporate factors other than catch rates where these were thought to affect fishing power. Again, this method involves the calculation of the fishing power of one vessel, and the fishing powers of vessels that have not fished in its company are estimated from their performance compared with those that have.

Regression techniques were also used by Stark (1971). His model estimated the fishing power of all boats simultaneously, taking into account time and location, which are represented as a polynomial expression.

The technique employed here uses the same information as the models previously described but approaches the problem more directly. The information used is the catch per unit of effort per boat in a given location at a given time. The model is an

iterative one in which a vessel's fishing power is estimated as its performance relative to all other vessels fishing in the same time and place, multiplied by the sum of the fishing powers of all vessels involved. Repeating this for all the days that each vessel fishes and taking an arithmetic mean will give a second estimate of fishing power which is then fed back into the model for the second iteration, and so on. Ultimately, the iterations are stopped when successive estimates of fishing power do not materially change.

The initial estimate of fishing power that is necessary for running the model can be quite arbitrary but the number of iterations is reduced if a parameter thought to be correlated with fishing power is used. Since both engine size and gross tonnage have been shown to be correlated with fishing power (Gulland 1956; Beverton and Holt 1957), a proxy for these (class A units) was used in the first iteration of the model.

Mathematically, the fishing power model, for $t = 1, 2, \ldots, n_i$, can be expressed:

$$e_{(m+1)i} = (\Sigma_t(q_{it}\, \Sigma_j e_{mj} / \Sigma_j q_{jt}))/n_i$$

where m starts at zero and is successively increased by one until $e_{(m+1)i} = e_{mi}$ where e_{mi} is the fishing power of vessel i in iteration m, where $e_{0i} = u_i$; e_{mj} is the fishing power of vessel j in iteration m which fished in the same location as vessel i on day t; u_i is an index of class A units held by vessel i; q_{it} is the catch per unit of effort of vessel i on day t; q_{jt} is the catch per unit of effort of vessel j which fished in the same location as vessel i on day t; and n_i is the number of days on which vessel i fished.

Time, location and catch per unit of effort of the fishing vessel were obtained from log books. Locations were the fourteen statistical regions of the fishery as used by CSIRO.

In order to ensure equivalence between the hours of effort used in the production function and the hours of effective effort determined from the fishing powers, the latter were standardised by dividing by their weighted average. Since the weighting factor was the hours of effort, the nominal hours in the production function are equivalent to effective hours.

Separate fishing powers were calculated for vessels involved in the two prawn groups. The correlation between class A units and fishing power on the tiger species was fairly high at 0.74. However, in the banana prawn fishery there appeared to be little relationship between class A rating and fishing power ($r = 0.38$), indicating that other factors are more important than size and engine power in this fishery. There was a similarly low correlation ($r = 0.38$) between the fishing powers of vessels targeting on each species, suggesting that distinct boat types or boat management are needed for each fishery.

Variation in the fishing power of individual boats was considerably larger in the banana prawn fishery than in the tiger prawn fishery. In the latter, fishing powers ranged from 0.28 to 2.39, while in the banana prawn fishery they ranged from 0.01 to 4.32.

Appendix E Value of class A and B units in the northern prawn fishery

Units (whether class A or class B) have a value only insofar as they allow their owners access to the rents of the fishery. (Class C units also exist but they are of minor importance and their inclusion in the model would only serve to confuse an already complex issue.) Their value therefore reflects the stream of rents which their owners expect to earn over a period of years. (Rents are defined as the surplus remaining from revenues after all costs, including the opportunity cost of capital, have been met.)

For the purpose of translating this stream of rents into values of units, an appropriate time horizon and discount rate need to be determined. It is believed that operators generally have a short time horizon and a high discount rate, partly at least because of the risks (physical and financial) and uncertainty that fishing involves. A previous exercise carried out at the Industries Assistance Commission (Hagan and Henry 1986) on the values of southern bluefin tuna quota used a five-year time horizon and a 20 per cent discount rate. In that model, the predicted quota value was very close to the actual value. Because the parameters chosen by the Commission accord with intuitive knowledge of the fishery, and because they were apparently good predictors of quota values, the same parameters have been used here.

The value of all units together is given by the following function:

$$V = I((1+r)^t - 1)/(r(1+r)^t)$$

where V is the total value of all units; I is the annual rent (or economic surplus); r is the discount rate; and t is the time horizon.

A problem with the northern prawn fishery is that two distinct types of unit exist, and ownership of both is essential for continued operations in the fishery. The division of the total value of units between the two classes is a function of their supply and demand, and, as would be expected, generally the same factors affect both classes of unit. The only differences in the availability and demand for the two classes of unit arise from the various management regulations:

- the need to acquire class A units when a boat is upgraded;
- the need to surrender both one class B unit when a boat is replaced and as many class A units by which the replacement boat exceeds the base boat size of 375 class A units; and
- the original imbalance in the numbers of units created under the management scheme.

Two points need to be observed about the surrender provisions outlined above. First, the policy to surrender one class B unit on the replacement of a boat is clearly not sustainable in the long term. With boat replacement needing to occur, for example, every fifteen years and the average age of boat currently being about seven years, the size of the fleet theoretically would halve by 1994 and be a quarter of its present size by 2009, and so on.

In practice, boat replacement would be delayed beyond the otherwise economic optimum and the decline would occur more slowly. But the continued use of older boats and the costs associated with them (let alone the trend to no boats in the fishery) would inevitably lead to a repeal of the surrender provisions on these units. This has already been recognised by the management authorities who hope to remove all restrictions on boat numbers and class B units eventually (Meany 1987).

The second point is that the policy on the surrender of class A units is also likely to have only a limited life. The retention of these provisions would lead to a boat size of only 375 class A units in the very long term. At some point, therefore, these provisions will also vanish, although

control on the physical capacity of the fleet could still be maintained by keeping the other provisions relating to class A units.

Given these scenarios, it is assumed that only class A units will have any long term value, since they alone are likely to be the limiting factor on operations in the fishery. In the short term, however, both classes of unit will attract some value, although the price paid for class B units should be tempered by the knowledge of their lack of long term value if management policy proceeds on the lines indicated above.

The relative demand for class A as opposed to class B units will depend on the extent to which operators wish to upgrade boats or replace them. Each of these activities places different demands on the unit market. For example, assuming new and upgraded boats will be of an approximate optimum size under current conditions, the demand for the different units will be greater if the boats are to be replaced than if they are to be upgraded. This is due to the forfeiture provision in the boat replacement policy.

For the short run analysis, it was assumed that current prices are the best indicators of supply and demand for units. Presumably, as the number of surplus units declines, relative prices of the two types of units will alter to reflect divergencies in the actual ratio of units from a perceived optimum. Current prices of class A units are around \$450 each, with a B unit fetching \$20 000.

Prices of class A units for the long run simulations involving the boat replacement policy were determined from hypothetical supply and demand relationships. A series of prices was assumed in the boat replacement model, and the number purchased at each price level was determined by separate runs of the model. On the assumption that the buyers and sellers of units were potentially the same individuals (that is, existing operators), the same data can be used to estimate willingness to sell. As price increases, the number of units operators wish to purchase decreases. But, similarly, the operators' willingness to sell increases because they can now be better off by not holding the units.

The annualised cost in the long term of class A units was calculated to be approximately \$450 by this method. This is equivalent to a value of about \$1350. These values were used to determine the extent of adjustment under the boat replacement policy only. Once this adjustment was determined, the model was re-run without the above cost being imposed to determine effort levels, catch and rent. Similarly, no annual cost was assumed in the analysis of the Voluntary Adjustment Scheme: any levies paid to achieve a reduction in the number of units to 70 000 were regarded as historic costs and not relevant to the rent in the fishery once the adjustment was achieved.

Appendix F List of simulations and regression results

6 List of simulations

Simulation number	Time horizon	Objective function	Activities	Specific constraints	Policies analysed	Comments
1	Long run	Maximise profit	Fishing	None	Single ownership	All costs, except capital, variable Gives maximum rent attainable under any conditions
2	As (1)	Maximise effort	Fishing	Rent = 0	No management	All costs, except capital, variable Simulates open access fishery
3	As (1)	As (2)	Fishing Buying/selling class A units	Class A units limited Rent ≥ 0	Boat replacement	All costs variable except capital Cost of A units determined in submodel
4	As (1)	As (2)	As (3)	Fishing power coefficients reduced by 20 per cent Others as in (3)	Gear restrictions Boat replacement	Current gear restrictions are intended to reduce power by 30 per cent: some substitution assumed
5	As (1)	As (2)	As (3)	Hours fished per boat reduced by 10 per cent Others as in (3)	Seasonal closure Boat replacement	Assumes closure has no effect on spawning stock since operative catch–effort relationship is sustainable Current closure reduces season by 20 per cent: some substitution assumed
6	Long run	Maximise effort	Fishing Buying/selling class A units Reducing numbers of class A units	As (3) Class A units limited to 70 000	Boat replacement Voluntary Adjustment Scheme (VAS)	All costs variable except capital Cost of A units determined in submodel and recycled into LP Assumes VAS reduces numbers of class A units to 70 000

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6 List of simulations (continued)

Simulation number	Time horizon	Objective function	Activities	Specific constraints	Policies analysed	Comments
7	As (6)	As (6)	As (6)	Rent ≥ 0 Class A units limited to 70 000 Fishing power coefficients reduced by 20 per cent Hours fished per boat reduced by 10 per cent	Boat replacement Gear restrictions Seasonal closure VAS	As (4), (5) and (6) Assumes permanent reduction in fishing power and hours fished
8	As (6)	As (6)	Fishing Buying/selling class A units	As (3), (4) and (5)	Boat replacement Gear restrictions Seasonal closure	As (3), (4) and (5)
9	As (6)	As (6)	As (6)	As (5), (6)	Boat replacement Seasonal closure VAS	As (5), (6)
10	As (6)	As (6)	As (6)	As (4), (6)	Boat replacement Gear restrictions VAS	As (4), (6)
11	As (6)	As (6)	Fishing	As (4)	Gear restrictions	As (4)
12	Long run	Maximise effort	Fishing	As (4), (6)	Gear restrictions Seasonal closure	As (4), (5)
13	As (12)	As (12)	Fishing Reducing numbers of class A units	As (4), (6)	Gear restrictions VAS	As (4) Assumes VAS reduces number of class A units to 70 000
14	As (12)	As (12)	As (13)	As (4), (5) and (6)	Gear restrictions Seasonal closure VAS	As (5), (13)
15	As (12)	As (12)	Fishing	As (5)	Seasonal closure	As (5)
16	As (12)	As (12)	Fishing Reducing numbers of class A units	As (5), (6)	Seasonal closure VAS	As (5) As (17)
17	As (12)	As (12)	As (16)	As (6)	VAS	Assumes VAS reduces number of class A units to 70 000

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6 List of simulations (continued)

Simulation number	Time horizon	Objective function	Activities	Specific constraints	Policies analysed	Comments
18	Short run	Maximise revenue	Fishing	Total revenue exceeds variable costs All boats fish Restrictions on hours fished relaxed Boat numbers and size fixed	Limited entry	Management restricts boat numbers and length of season only
19	Short run	Maximise revenue	Fishing Buying/selling class A units	Total revenue exceeds variable costs Restrictions on hours fished relaxed Penalties on upgrading/ replacement Number of replacements = 12; maximum number of upgradings = 25	Boat replacement Upgrading	Assumes boats will be upgraded if net revenue can be increased
20	As (19)	As (19)	As (19)	As (19) Maximum hours fished per boat reduced by 10 per cent	Boat replacement Upgrading Seasonal closure	
21	As (19)	As (19)	As (19)	As (20) Fishing power reduced by 20 per cent	Boat replacement Upgrading Seasonal closure Gear restrictions	
22	As (19)	As (19)	As (19) VAS	As (21)	Boat replacement Upgrading Seasonal closure Gear restrictions VAS	Assumes all VAS income used to purchase class A units at $450 each
23	Short run	Maximise revenue	As (21)	As (22) Gross margin held to that in (21) All costs increased by 2.75 per cent to cover VAS contribution	Boat replacement Upgrading Seasonal closure Gear restrictions VAS Effort levy	Alternative method of funding VAS

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6 List of simulations (continued)

Simulation number	Time horizon	Objective function	Activities	Specific constraints	Policies analysed	Comments
24	As (23)	As (23)	As (18)	As (18) Number of boats declines by 12 Gross margin as in (21)	Effort levy	Alternative policy to current array of management tools
25	Short run (second year)	Maximise revenue	As (22)	As (22)	As (22)	

7 Results of regressing all policy combinations on selected fishery variables

		Policy				
Variable	Constant	Boat replacement	Gear restriction	Shorter season	Voluntary Adjustment Scheme	R^2
Boat numbers	201.60 (28.20)	+12.25 (1.92)	–1.00 (0.16)	–3.00 (0.47)	–54.75 (8.58)	0.83
Class A units ('000)	94.30 (43.30)	+6.38 (3.28)	+0.38 (0.19)	–0.13 (0.06)	–27.63 (14.19)	0.93
Catch of mixed prawns (t)	5 449.90 (49.80)	–108.00 (1.04)	–642.75 (6.17)	–125.00 (1.20)	–89.25 (0.86)	0.71
Effect on mixed prawns ('000 h)	332.90 (23.46)	–13.38 (1.05)	–79.63 (6.27)	–15.63 (1.23)	14.63 (1.15)	0.72
Rent ($m)	–1.00 (1.03)	+2.00 (2.29)	–0.75 (0.86)	+0.75 (0.86)	+2.00 (2.29)	0.35

Figures in parentheses are the *t*-statistics for each coefficient.

Appendix G Data used in the model

8 Group data: averages per boat

Group no.	Class A units	Fishing power: Banana	Fishing power: Tiger	Fishing hours a	Variable costs	Fixed costs	Capital value	Boat numbers b
					$/h	$'000	$'000	no.
1	257	0.55	0.84	975	137	180	186	39
2	291	0.43	0.78	2 129	140	80	191	32
3	544	0.55	0.82	635	265	176	191	15
4	534	1.58	1.56	784	295	268	344	13
5	383	0.28	0.85	1 467	220	176	191	18
6	541	1.59	1.25	1 451	274	234	157	26
7	492	0.69	1.21	2 077	210	289	312	39
8	448	1.75	0.98	1 980	222	206	197	13
9	419	1.03	0.96	1 456	196	211	189	13
10	567	1.42	1.39	1 266	247	260	198	9
11	513	1.15	1.19	1 823	227	235	234	17
12	580	1.12	1.22	1 619	287	322	568	12

a Maximum hours in the banana prawn fishery limited to 432. **b** Distribution of fleet as given in 1985-86 log book data, updated to July 1987.

9 Catch–effort relationship: banana prawns

Effort	Catch: Average (short and long run)	Catch: Good year (short run)	Catch: Poor year (short run)	Effort	Catch: Average (short and long run)	Catch: Good year (short run)	Catch: Poor year (short run)
'000 h	t	t	t	'000 h	t	t	t
4	950	1 217	501	30	4 112	5 265	2 167
8	1 730	2 215	912	31	4 171	5 342	2 199
12	2 370	3 035	1 249	32	4 228	5 415	2 229
16	2 896	3 709	1 527	33	4 283	5 485	2 257
18	3 124	4 000	1 647	34	4 335	5 551	2 285
20	3 330	4 264	1 755	35	4 384	5 615	2 311
22	3 517	4 504	1 854	36	4 432	5 675	2 336
24	3 688	4 723	1 944	37	4 477	5 733	2 360
25	3 767	4 824	1 986	38	4 520	5 788	2 383
26	3 843	4 921	2 025	39	4 561	5 841	2 404
27	3 915	5 013	2 063	40	4 601	5 892	2 425
28	3 983	5 101	2 100	40.8	4 629	5 928	2 440
29	4 049	5 185	2 134				

10 Catch–effort relationship: tiger prawns

Effort	Catch: Sustainable	Catch: Base year (short run) a
'000 h	t	t
40	1 128	923
60	1 635	1 339
80	2 110	1 727
100	2 546	2 090
120	2 953	2 430
140	3 323	2 748
160	3 665	3 046
180	3 981	3 326
200	4 263	3 590
220	4 522	3 837
230	4 637	3 956
240	4 747	4 070
250	4 850	4 182
260	4 945	4 290
270	5 035	4 395
280	5 115	4 498
290	5 191	4 597
300	5 257	4 693
310	5 318	4 787
320	5 374	4 879
330	5 422	4 967
340	5 458	5 054
350	5 486	5 138
360	5 509	5 220
370	5 528	5 300
380	5 543	5 377
390	5 554	5 453
400	5 544	5 526
450	5 418	5 526
500	5 089	5 526

a Recruitment to fishery = 325 million.

11 Effort, recruitment and spawning index: tiger prawns

Year	Effort	Spawning index	Recruitment
	'000 h		m
1980	386.4	423	411.7
1981	417.5	385	346.0
1982	440.0	357	332.0
1983	460.7	334	319.0
1984	430.3	336	308.0
1985	364.0	371	309.0
1986			325.0

Source: Effort derived from Buckworth (1987). Spawning index and recruitment levels derived from model given in appendix B.

12 Price data

Simulation	Bananas	Tigers
	$/t	$/t
Base price	9 510	12 540
High price	11 412	15 048
Low price	7 608	10 032

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