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MANAGEMENT POLICIES FOR THE SOUTH-EAST TRAWL FISHERY: AN ECONOMIC ANALYSIS

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Management of the south-east trawl fishery is currently based mainly on limited boat entry and a restrictive boat replacement policy. In recent times there has been a growing awareness in both government and industry that the management program is unable to curtail the growth of fishing effort and catches, endangering the economic and biological well-being of the fishery. A government/industry working group has identified four alternative long term management options. The aim of this study is to assess the likely economic effects on the industry of the introduction of each of the management options, and by so doing enable the management authority to rank the options from an economic perspective. A linear programming model, incorporating the main economic and physical features of the fishery, has been developed to assist this analysis.

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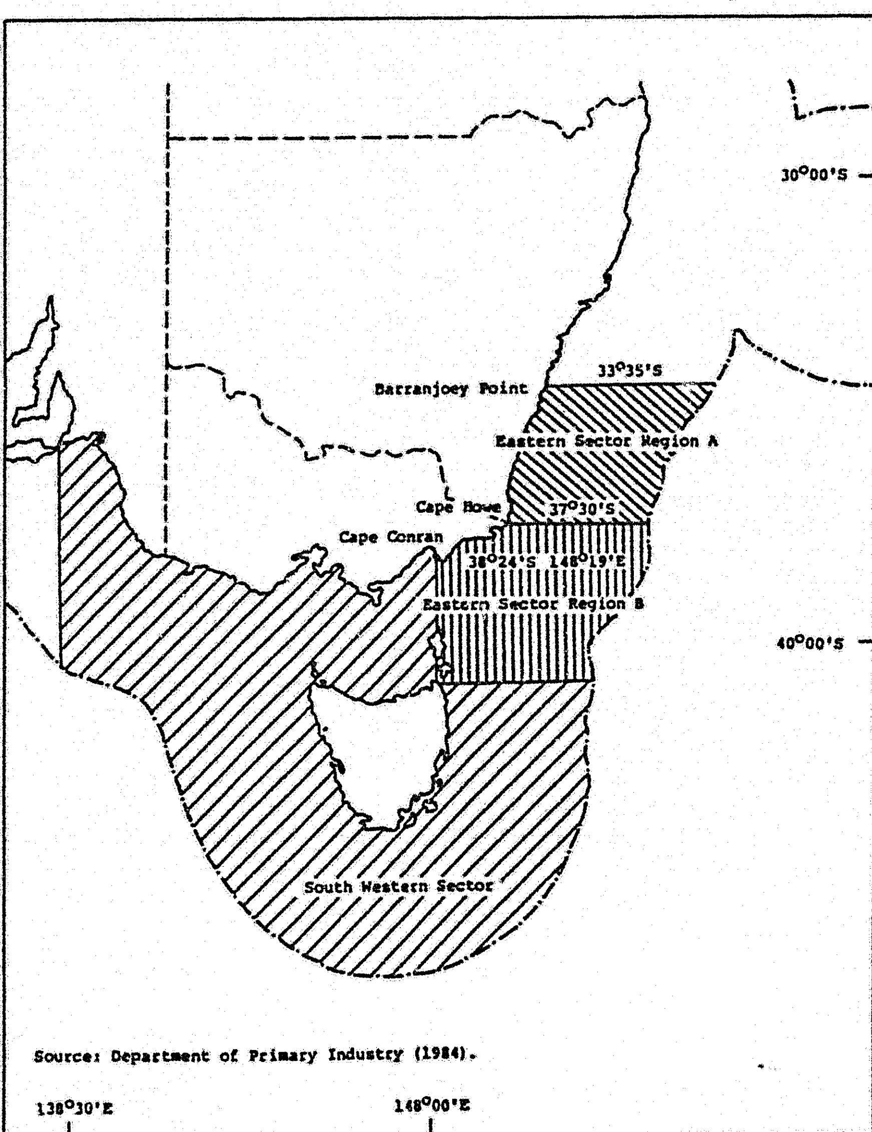
The south-east trawl fishery is a multi-species fishery with a long history of commercial fishing. It is situated off the south-east of Australia in waters under Commonwealth jurisdiction. The fishery extends from Barrenjoey Point, north of Sydney, around Tasmania and west to Cape Willoughby in South Australia, and is divided into two sectors for management purposes: an eastern sector and a south-west sector. The eastern sector is further subdivided into two regions. To operate throughout the fishery, fishermen need to have three endorsements on their licence, one for each sector (see map).

Boundaries of the South-East Trawl Fishery



Source: Department of Primary Industry (1984).

The main harvesting method is bottom trawling, although a small danish seine fleet operates mainly out of Lakes Entrance in Victoria. The fishery was first exploited in the early 1900s by steam-powered trawlers, operating out of Sydney. The second phase, which overlapped the first, commenced in 1936 with the entry of the first danish seine vessels into the fishery.

Since the mid-1960s there has been a revival and growth of the trawl fishery.

During the late 1970s and early 1980s many new vessels were constructed to operate in the fishery in response to improved profitability, due largely to the development of the fishery for gemfish off the New South Wales coast. Since the early 1980s there has been an expansion of fishing effort in the south-west sector of the fishery by vessels mainly based at Portland, Victoria. This expansion was stimulated by the development of the deep water fishery for blue grenadier, then later for orange roughy.

The current management scheme in the fishery, introduced in 1985, is based on limited boat entry into the fishery and a restrictive boat replacement policy aimed at reducing the physical fishing capacity of the fleet. Over the past few years there has been a growing awareness within industry and Government that the management arrangements currently in force are unable to curtail the growth of fishing effort and catches. The catch of gemfish has grown to a level which is believed to threaten the continued health of this fish stock. Concern that the gemfish stock could become depleted if catches continued to grow led the Commonwealth government in 1988 to limit the total annual catch of this species. In 1989 a total quota was also set on the catch from a stock of orange roughy located off the east coast of Tasmania. Although biologists are still uncertain about the size of the stock and the catches which it can sustain, the available evidence suggests that the species is very vulnerable to heavy fishing pressure and that a cautious approach to management is warranted.

The need to introduce supplementary catch controls on gemfish and orange roughy highlighted the inadequacies of the present input-based management system and prompted the formation of a joint government and industry working group to identify alternative long term management options for the fishery.

This study aims to assess the likely economic effects on the industry of the management options proposed by the working group.

Background

Prior to 1970, most operators fished inshore grounds on the continental shelf. By the early 1970s, trawlers started operating in the deeper waters of the upper continental slope off southern New South Wales, Victoria and Tasmania. Species landed from these deeper waters include gemfish, redfish, mirror dory, king dory, ling and blue grenadier. Gemfish has subsequently become the most important species in the eastern sector of the fishery in terms of both quantity and value. The bulk of the gemfish catch occurs during the mid winter spawning run off the coast of southern New South Wales.

Since 1985 a fishery for orange roughy has developed on the deep water grounds in the south-west sector of the fishery. These fish are found in dense aggregations at depths of around 800-1000m on the continental slope. The introduction of target fishing techniques resulted in the orange roughy catch rising to 8 kt in 1986-87.

South-east trawl catches are sold mainly on the Sydney and Melbourne fresh fish markets, although a substantial quantity of gemfish, blue grenadier and orange roughy are sold directly to processors.

Over seventy species of fish are currently being harvested from the fishery. The catches of the main species for each sector in 1986-87 are given in Table 1. The ten species chosen make up over 80 per cent of the total catch. The major species caught by danish seiners are flathead and whiting. These boats land around 60 per cent of the total flathead catch and around 95 per cent of the whiting catch. Gemfish and redfish are the major species caught in the eastern sector, while catches in the south-west sector are dominated by orange roughy, and to a lesser extent by blue grenadier and warehou.

Management Policies

In July 1980 the Minister for Primary Industry announced that consideration was being given by state and Commonwealth governments to limiting the entry of boats into the south-east trawl fishery.

An interim management plan for the fishery was announced in May 1982 following an assessment that some limitation of effort was desirable. This plan did no more than warn operators that under any permanent management plan, new entrants to the fishery did not necessarily have any long term rights to fish. Existing operators were also advised against upgrading the capacity of their boats. At the same time, a task force was set up with the objective of determining, and recommending to the Minister for Primary Industry, an appropriate long term management plan.

A management plan based on limited boat entry into the fishery was introduced in 1985. In this plan, the fishery was split into two sectors, the eastern and the south-west, the former being divided into two regions with separate entry criteria for each. The division of the eastern sector was to take account of the concerns of Victorian fishermen regarding possible uncontrolled expansion of effort by New South Wales operators in waters adjacent to eastern Victoria.

TABLE 1

South-East Trawl Catch by Species and Sector:
October 1986 to September 1987

	Danish seiners	Eastern sector trawlers	Southwest sector trawlers	Total
	t	t	t	t
Flathead	1 341	956	31	2 328
Gemfish	1	4 068	264	4 333
Blue grenadier	0	468	1 383	1 851
Ling	0	569	168	737
Morwong	19	915	74	1 008
Orange roughy	0	1	8 103	8 104
Redfish	2	1 266	5	1 273
Squid	4	562	47	613
Warehou	1	422	567	990
Whiting	1 082	235	23	1 340
Other	111	2 772	607	3 490
Total	2 561	12 234	11 272	26 067

In 1986 a boat replacement policy was introduced to try to limit the expansion of fishing effort by licenced operators through the upgrading or replacement of their boats. Under the boat replacement policy, each boat is assigned a number of units of capacity based on the dimensions of the boat and the power of the main engine. Fishermen wishing to replace or upgrade their boats have to purchase additional units, corresponding to the increase in capacity of their boat, from operators leaving the industry or buying smaller replacement boats. In addition to units matching the capacity of the 'new' boat, extra units must be purchased and subsequently forfeited to the government. These units are removed from the fishery. In this way the total number of units employed in the fishery, and hence the physical capacity of the fleet, is reduced each time a boat is replaced or modified. The increase in the costs of upgrading and replacing boats under this policy also slows the growth of fishing effort by providing disincentives for fishermen to build more efficient boats.

Other input controls applying include a two-way freeze on the transfer of units between danish seiners and trawlers and restrictions on vessel size and mesh size.

As a result of strong demand for boat units from the south-west sector operators wishing to either build larger boats or upgrade existing boats to fish for orange roughy, ten boats were bought out of the eastern sector by the end of 1987. Although forfeitures reduced the total number of units employed in the fishery, fishing effort continued to increase. The main reason for this was that the boats which left the fishery were poor performers, putting in little fishing effort and taking small catches, whereas the boats to which their units were transferred became high-effort producers. Also, the boat replacement policy could do nothing to prevent operators simply increasing the amount of time they spent fishing.

Catches continued to increase, to levels which threatened to deplete certain fish stocks. In February 1987, an annual 20 kt total allowable catch of orange roughy was announced. In 1988, following scientific advice, the catch of gemfish during the spawning run off the east coast was limited to 3 kt.

The increase in fishing capacity and the development of target fishing have revealed the inability of the current management arrangements to contain fishing effort and catches. As a result, a working group was formed in 1988 to identify alternative long term management policies for the fishery.

The working group identified what it considered to be four feasible management options. Three were based on the existing system, with modifications such as differences in boat replacement policies between sectors, changes to sector boundaries, the selective use of non-transferable individual quotas and the introduction of a licence buy-back scheme. The other option is the introduction of individual transferable quotas on the major species, and the consequent scrapping of all input controls except minimum mesh sizes. The key features of each of these four management options are outlined in Table 2.

Although the working group examined some of the pros and cons of each option, it was unable to reach a conclusion as to which would be most effective in promoting the three-fold objective of management: the sustainable use of the fish resources, economic efficiency and social equity.

TABLE 2

Main Features of Proposed Management Options

Option 1	Option 2
More stringent 2-for-1 boat replacement policy across the whole fishery. Boats with dual endorsements can operate in both sectors.	Different boat replacement policy for each sector; 2-for-1 in west, current arrangements in east.
Individual non-transferable quotas on some species; orange roughy, blue grenadier, gemfish.	Individual non-transferable quotas on some species: orange roughy, blue grenadier, gemfish.
Possible buy-back of licences.	

Option 3	Option 4
Individual transferable quotas for all major species across the whole fishery.	Division into two fisheries along the eastern/south-west boundary. Boats must choose which side to fish on.
Disband input controls except minimum mesh size.	More stringent 2-for-1 boat replacement policy in eastern sector.
	Licence buy-back in eastern sector.

Recent developments in the fishery have been the allocation of the 1989 total allowable gemfish catch as individual transferable quotas, and the discovery in 1989 of a large spawning aggregation of orange roughy off the east coast of Tasmania. Within a few months of the discovery, catches reached approximately 14 kt. In August 1989 an annual total allowable catch of 15 kt for the stock off eastern Tasmania was introduced.

Modelling the Fishery

In order to examine the effects of the different management options, a model of the fishery was developed. This model draws together the key economic and physical features of the fishery. In the base model the economic and structural characteristics of the fishery as it existed in 1986-87 were simulated. The base model was then modified to allow for changing management, a variant of the model being constructed to simulate each management option. The model provided quantitative estimates of the relative effects of these management options on the important economic variables - notably profits, the amount of capital employed, boat numbers and catch levels - when all adjustment to the management option was complete: that is, when the fleet reached a stable structure.

However, because there is virtually no information on the biological relationships between stock size and annual recruitment for south-east trawl species, it was not possible to represent the response of these stocks to fishing pressure over time. Consequently, the relationships between catches and effort included in the model are based on observed catches and effort on a short run annual basis. An underlying assumption is that the size of fish stocks and their vulnerability to capture remain constant over the period during which the fleet adjusts to the management option. An analysis of the sensitivity of the model results to changes in stock sizes has been carried out.

The important elements of the model are shown in Figure 1. The fleet structure changes through boats upgrading, downgrading or leaving the fishery. The fleet produces effort that results in a quantity of targeted catch and associated by-catch. The total catch is sold to produce revenue. The costs of fishing, including an opportunity cost of capital, are deducted from this revenue to give profits. Management options affect the rate of exit through buy-back schemes, the rate of boat replacement and modification through boat replacement policies, and the quantity of fish caught via total catch limits allocated as either transferable or non-transferable quotas.

The model is specified as a linear programming problem in which the components described above appear as either activities or constraints. The purpose of the model was to simulate the operation of the four management options proposed by the working group. As the committee was interested in the longer term effects of the policies on adjustment and profitability of the fishery, an objective function of maximising profits less adjustment costs was used. The adjustment costs were deducted in the objective function to ensure that adjustment would take place only if its benefits exceeded its annualised cost.

The relationships and linkages in the model are discussed in relation to each key feature of the model. Variants of the base model are outlined in the description of the simulations.

Physical component

In 1986-87, the fishery comprised 148 active vessels of various sizes, with differing areas of operation, home ports, catches and effort levels. 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 that minimises the differences between boats within a group and maximises differences between groups.

Distinctions were made between three types of boats: danish seiners, eastern sector trawlers and south-west sector trawlers. The observable characteristics used to group the vessels include catches by species, effort (hours fished), boat size and home port. The main physical and operational characteristics for each boat type are detailed in Table 3.

The fleet was disaggregated into thirteen groups: three danish seiner groups, seven eastern sector groups and three south-west sector groups. Boats that had endorsements but did not operate in the fishery in 1986-87 were incorporated into the model as 'potential' boats. These too were classified into groups as were the active boats.

FIGURE 1 - Model of South-East Trawl Fishery

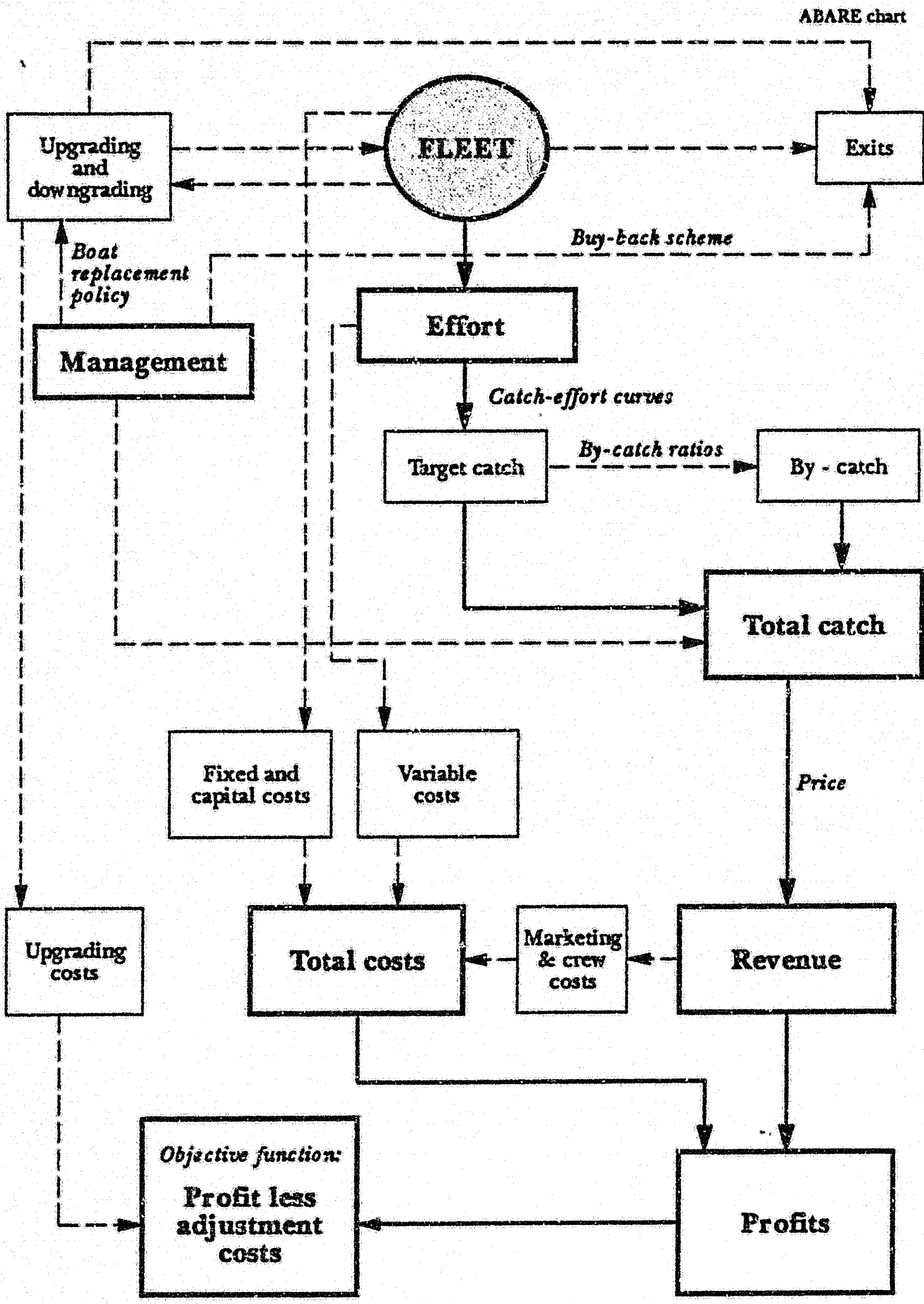


TABLE 3

Fishing Effort and Vessel Characteristics 1986-87 (average per boat)

Characteristic	Unit	Danish seiners	Eastern sector	South-west sector
Boat numbers	no.	25	83	40
Boat size	unit(a)	68	122	199
Effort	h	474	623	427
Catch	t	97.5	122.7	315.7

(a) As used under present boat replacement policy.
Source: Logbooks collected by the Australian Fisheries Service and the South East Trawl Boat Register.

Information on the physical characteristics of boats in each group was obtained from a number of sources. The number of hours fished by each boat in total and for each species in each sector were obtained from log book data. The maximum and minimum hours that a boat in a given group could fish were defined in the model as the 75th and 25th percentiles, respectively, of the amounts of time fished in 1986-87 by boats in that group. The maximum number of hours that a boat could fish for a particular species in a given sector was also the 75th percentile for that group for that species and sector.

Boats with different fishing capabilities have different impacts on the fish stocks for each hour spent fishing. For each boat group, these different fishing powers were calculated for each species for each sector.

Under the boat replacement policies each boat is assigned a number of units based on the underdeck volume of the boat and the power of the main engine. In the model, all boats in a group were assigned the average number of units held by boats in that group. These data were obtained from the central boat unit register.

The model allows boats to upgrade or downgrade to different groups. In order to upgrade, the boat must purchase extra units up to the number employed by boats in a higher group. A number of additional units, calculated as a proportion of the total units employed in the larger boat, are forfeited to the management authority. As the number of units in the fishery is limited, boats can upgrade only if other boats exit the fishery or downgrade, releasing sufficient units. In addition to the cost of units, a capital cost is also incurred on upgrading to a larger boat. The annualised difference between the capital cost of the 'old' and 'new' boat, plus the annualised cost of the required units, formed the adjustment cost in the model. 'Potential' boats could move into their counterpart active group at no cost.

Annual catch-to-effort relationships for the major fish species are important elements of the fishery model. The ten major species for which catch-effort relationships were estimated were flathead, gemfish, blue grenadier, ling, morwong, orange roughy, redfish, squid, warehou and whiting, which account for more than 80 per cent of the total south-east trawl catch.

To estimate the catch-effort relationships it was necessary to identify where and when fishermen actively target on particular species. A requirement of the south-east trawl logbook program is that fishermen nominate which species, if any, is targeted in each trawl shot. However, less than 40 per cent of operators have, to date, complied with this requirement. Consequently, these data were not used as the primary source of targeting information. The normal alternative method for extracting target information from logbook data relies on the assumption that the species which forms the greatest physical proportion of the catch is the target. However, this method can give a distorted picture of targeting behaviour, since it neglects shots which were targeted but unsuccessful and includes shots which unintentionally achieved a high catch of the given species.

To overcome these problems a method has been developed which focuses on the catch of the fleet fishing in a certain area and depth on a given day, rather than on the catches of individual boats. The overall pattern of fishing activity in each area, each day provides more insight into whether the fleet is targeting a particular species.

The derived 'rule' for deciding if targeting is occurring is as follows.

> If a single species comprises 60 per cent or more of the summed catch of all shots (which catch more than 100kg) taken in a particular depth range, area and day, then that species is assumed to be targeted by all shots made in that depth range, area and day irrespective of whether they were successful in catching the target species.

The value of 60 per cent of catch was used because it gave results which corresponded to apparent industry practice in relation to targeting in the fishery. Depth is divided into 50 m ranges, while each area is a half-degree grid square. In Figure 2 the estimated targeted catch of each of the major species is shown as a proportion of the total catch of the species.

Some supporting evidence for the validity of the targeting analysis was provided by a comparison, carried out by the Bureau of Rural Resources, of the nominated target data from logbooks with the output of the derived targeting rule. The high degree of similarity between the two sets of results can be seen in Figure 3.

Catch-effort curves were estimated for each of the main species from the cumulative catch and effort over the year for each sector (eastern, south-west and danish seine). The cumulative relationship was decomposed into linear segments, the steepest segments representing the periods of greatest catch per unit of effort. The catch-effort curve was constructed by joining segments, progressing from the steepest segment to the flattest segment, on the assumption that if the amount of effort which could be employed was limited, it would be used only in the periods of high fish abundance. If effort increased, it would have to be exerted in periods of lower fish abundance. All non-targeted (mixed species) shots were incorporated into two separate, inshore and offshore, aggregate catch and effort relationships.

The by-catch associated with the catch of a targeted species was estimated as a ratio of the targeted catch. In the model, for each tonne of a targeted species caught there is an associated quantity of by-catch. The average annual by-catch associated with each tonne of target species caught in 1986-87 is shown in Table 4. The composition of non-targeted (mixed) catch in 1986-87 can be seen in Table 5.

FIGURE 2 - Proportions of Catches Targeted

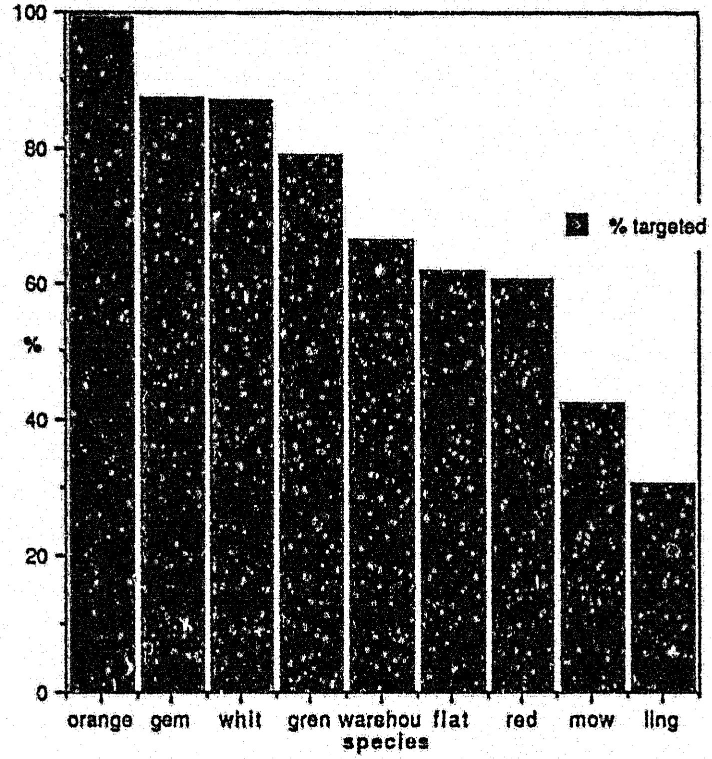
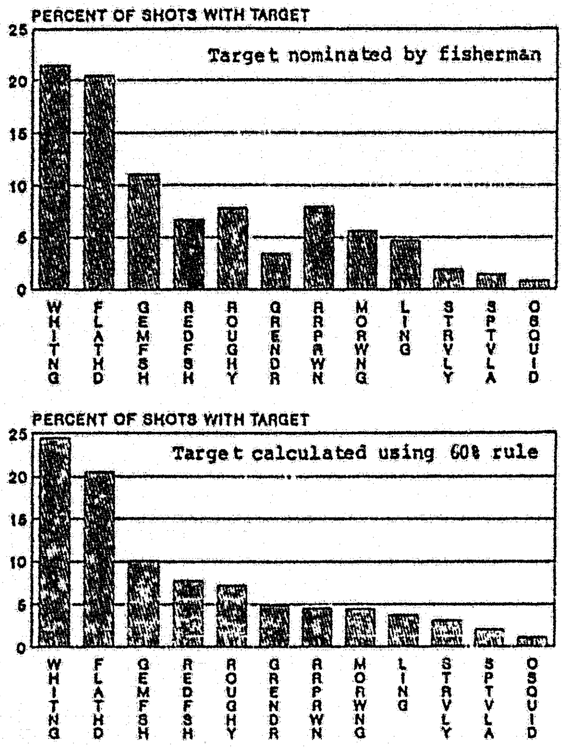


FIGURE 3 - Comparison of Nominated and Calculated Target Shots



Source: Fisheries Resources Branch, Bureau of Rural Resources.

TABLE 4

Annual Average By-catch Ratios
(kg/tonne target species)

Target species	Flat-head	Gemfish	Blue Grenadier	Ling	Morwong	Orange roughy	Red-fish	Squid	Warehou	Whiting	Other in-shore	Other off-shore
<u>Danish seiners</u>												
Flathead	-	-	-	-	-	-	-	-	33	39	-	-
Whiting	78	-	-	-	-	-	-	-	-	-	44	-
<u>Eastern boats</u>												
Flathead	-	-	-	-	122	-	-	39	-	-	205	-
Gemfish	-	-	16	14	-	-	-	-	-	-	-	78
Grenadier	-	51	-	70	-	-	-	-	-	-	-	83
Ling	-	20	73	-	-	-	-	-	-	-	-	221
Morwong	151	-	-	-	-	-	27	22	11	-	126	-
Redfish	52	12	-	-	17	-	-	-	-	-	168	-
Squid	16	-	-	37	-	-	11	-	-	-	142	-
Warehou	26	19	11	39	25	-	-	11	-	-	55	-
<u>South-west boats</u>												
Gemfish	11	-	28	-	-	-	-	17	17	-	-	109
Grenadier	-	22	-	24	-	-	-	-	30	-	-	50
Orange roughy	-	-	-	-	-	-	-	-	-	-	-	-
Warehou	-	-	15	11	-	-	-	13	-	-	-	117

Source: South-east trawl log book data, 1986-87.

TABLE 5

Composition of Non-targeted Catch

	Flat-head	Gem-fish	Blue grenadier	Ling	Mor-wong	Orange roughy	Red-fish	Squid	Warehou	Whiting	Other in-shore	Other off-shore
	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t
Danish seiners												
- Mixed inshore	417				19					427	137	
Eastern boats												
- Mixed inshore	181	16			145		113	54	36		455	
- Mixed offshore	13	154	71	138	10		46	58	10			500
Western boats												
- Mixed inshore	39	12	13		141			48	19		557	
- Mixed offshore	11	94	195	187		53		18	73			369

Source: South-east trawl log book data, 1986-87.

Economic component

Cost information was obtained from a financial survey of the fishery covering the years 1986-87 and 1987-88 (Geen, Brown and Pascoe 1989). For consistency with the catch and effort data from logbooks, information on costs and prices in 1986-87 was used in the model. Variable costs, fixed costs and capital costs for representative boats in each group were derived from these survey data. Crew costs were estimated as a proportion of gross revenue.

All interest payments incurred on a vessel were excluded, since the distribution of ownership of a vessel is irrelevant to its economic use. An opportunity cost of capital of 10 per cent in real terms was included to reflect the potential returns from forgone alternative investments (as in Haynes and Pascoe 1988).

Average fish prices were derived from both Sydney and Melbourne fish market data, Sydney prices being used for the eastern sector catch and Melbourne prices for danish seiner and south-west sector catches. Marketing charges were estimated for each sector based on data collected in the survey of the fishery.

Simulations of Management Options

Simulations were carried out to allow a comparison of the relative effects of alternative management options on the fishery. The results of the simulations show the configuration and profitability of the fleet when its adjustment in response to the management option being modelled is complete. Thus, there is no explicit time horizon assumed in the model as the time taken to reach the steady state could, and most likely would, differ under each option.

Of the four management policies under consideration, three are based on the continued use of input restrictions as the primary controls. The other proposal is based on the introduction of individual transferable quotas throughout the fishery. The key features of each of the management options are given in Table 2.

Input controls

The input restrictions which have been modelled are boat replacement policies and licence buy-back with or without distinctions between sectors. Additional restrictions in the form of individual non-transferable quotas, imposed under the predominantly input-based options 1 and 2, were also simulated.

The aim of a boat replacement policy is to reduce or prevent the growth of fishing effort by restricting fleet adjustment. This is accomplished by imposing financial penalties on operators replacing or modifying their boats. If a boat is upgraded, extra units are needed, which can be purchased only from boats leaving the fishery or downgrading.

Under existing management arrangements units can be traded freely between trawlers throughout the fishery, though not between danish seiners and trawlers. The price of units is thus based on their expected value when employed in the most profitable sector of the industry. Over the past few years this has been the fleet fishing for orange roughy in the south-west sector. The traded price averaged around $3000 per unit in 1986-87. Because annual adjustment costs are an important feature of the model, the unit price must be converted into an annualised figure. As it stands, it represents that part of the boat's profits attributable to each unit of the boat's capacity over a number of years. Assuming that fishermen have a relatively short investment horizon of five years, and a high real discount rate of 20 per cent (incorporating a 10 per cent premium to reflect the high risk nature of the industry as in Haynes and Pascoe (1988) and Geen and Nayar (1989)), an annuity value of $1000 per unit has been estimated for inclusion in the model. As all changes in fleet structure occur instantaneously in the model, there is no dynamic variation in the price of units.

Under management options 2 and 4, boat units and licence endorsements are transferable only to other boats operating in the same sector. Clearly, this would affect the trading price for units in each sector. In the eastern sector, where the average profitability of boats is lower than in the south-west sector, the average price of units could be expected to fall. A maximum expected price for units in the eastern sector has been estimated by simulating the eastern sector operating efficiently with the optimal number of boats in the fleet, and dividing the resulting annual total profit by the number of units employed in that sector. This procedure gave an estimated annuity value of units of $290.

For the south-west sector the price of units should initially remain at the annualised $1000 level even if the fishery were divided. This is because the expected profits from fishing for orange roughy would continue to be the prime determinant of unit prices. Subsequently, as the division of the fishery into discrete sectors would reduce the number of units potentially available for trade, it would tend to put upward pressure on unit prices as supplies dwindle.

The most restrictive boat replacement policy modelled was the forfeiture of a licence when a boat is replaced or upgraded. This '2-for-1' boat replacement policy, proposed in option 1 for the whole fishery and in options 2 and 4 for various sectors (see Table 2), forces an operator wishing to upgrade to buy another operator out of the fishery to obtain the required additional licence. It was assumed that a boat would leave the fishery only if it were profitable for all its units and its endorsement to be purchased by other boats in the fishery. The average price of south-west licence endorsements in 1986-87 was around $150 000, which converts to an annuity value of $50 000 using the same time horizon and discount rate as noted earlier. Eastern sector endorsements in 1986-87 were valued at around $50 000, giving a annuity value of $16 666. The forfeiture of units, as previously described, also applies under this boat replacement policy.

A more direct means of reducing the fishing capacity of the fleet under input-based management schemes is via a licence buy-back scheme. The management authority purchases licences at the market price from fishermen wishing to leave the fishery. This activity was simulated by the model forcing a given number of boats (and their associated units) to leave the fishery. Danish seiners have been excluded from the buy-back, as it appears that separate management is envisaged for these boats under each of the input based options (SETMAC 1988).

<u>Output controls</u>

Two forms of output controls are included in the management options - individual transferable quotas and individual non-transferable quotas.

The assignment of individual non-transferable quotas was simulated by adjustments to the total allowable catch. Given non-transferability of quota, if a boat in a low quota group is upgraded to what would be a more efficient group, the total allowable catch cannot increase even though the catching power of the fleet may have increased. On the other hand, if a boat downgrades to a group with a lower historical catch of the species concerned, then the total allowable catch decreases. Similarly, if a boat leaves the fishery the total allowable catch decreases.

Individual non-transferable quotas were assumed to apply only to gemfish, blue grenadier and orange roughy (as inferred from the proposed management options). The gemfish catch was limited to 3 kt and the other two were limited to their 1986-87 catches.

Under a system of individual transferable quotas all input controls, except minimum mesh size restrictions, are eliminated. Without the impediment to fleet adjustment posed by a restrictive boat replacement policy, the fleet is able to rapidly restructure toward a more efficient size and configuration.

Individual quotas could not be explicitly transferred in the model. The effects of quota trading on adjustment were incorporated into the model indirectly. The maximum expected long run economic rent per tonne of catch of each major species, under an individual transferable quota system, was estimated from the optimal long run catch and input mix. This in turn was estimated by running the model with no impediments to adjustment and no adjustment costs. Using historical catch data for each boat group, the value of a boat's quota package was then estimated (assuming quotas are allocated on the basis of historical catches). If a boat with a low quota value upgraded to a group with a high quota value - that is, a group with a larger catch of the main species - then the annualised cost of purchasing the additional quota was added to the capital adjustment cost associated with upgrading the boat. Boats were free to leave the fishery as long as it was profitable for the remaining fleet to purchase the quota portfolios of the departing boats.

<u>Validation</u>

In order to assess the ability of the model to simulate the fishery under the various options, it was necessary to compare the output of the model to that of the fishery under known conditions. A variant of the model was constructed to simulate the management conditions of 1986-87, the year corresponding to the biological and economic data. The catches and effort levels estimated by the model were compared to the actual catches and effort levels in the fishery in that year (see Table 6).

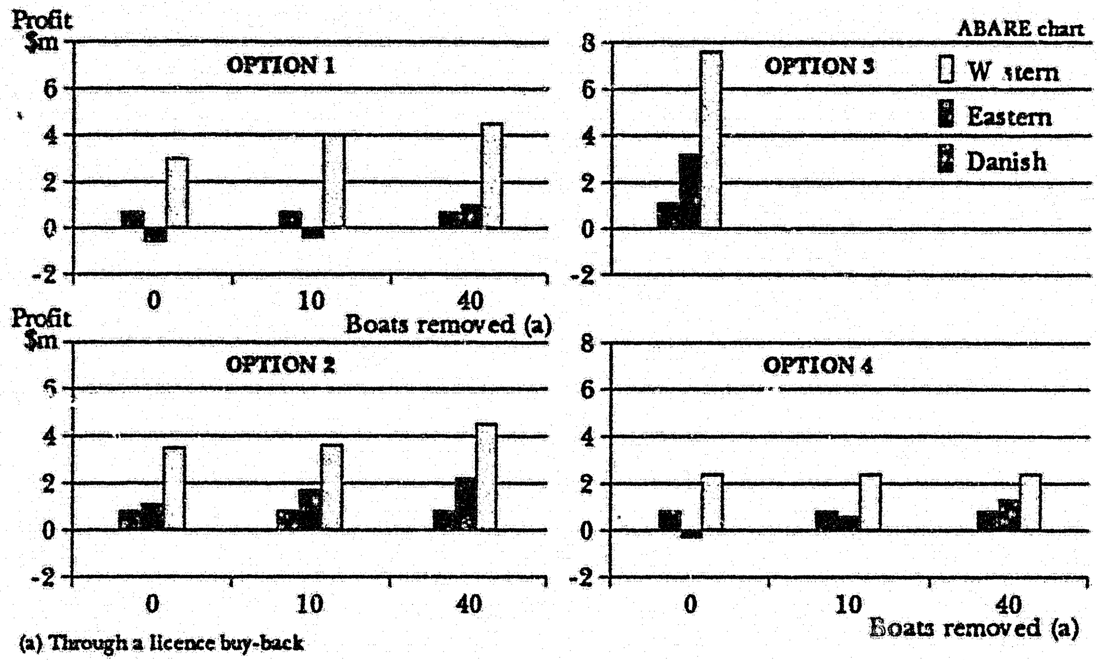
Although it would be desirable to assess the performance of the model over a number of years, the high degree of variability in stock size and the lack of information on the interrelationship between catch and subsequent recruitment precludes such a validation. Thus the validation against 1986-87 observed catch and effort data is a second best alternative. However, if the model were not able to replicate the observed behaviour in the fishery in the year in which it was based, then it would be unlikely to be a useful tool for analysing changes in the fishery. There is sufficient potential in the model for deviation from the observed catch and effort levels if the model were not specified correctly. Boats in the model have the potential to fish for greater or lesser amounts of time, in total and on individual species, than that which was observed. The catch and effort relationships were extrapolated to allow for increased fishing effort. From Table 6, it can be seen that the model is able to duplicate the actual catches and effort to a high degree of accuracy.

TABLE 6

Model Validation

Variable	Model	Actual 1986-87
Catch	kt	kt
Danish seiners		
Flathead	1.600	1.341
Whiting	1.111	1.082
Morwong	0.003	0.019
Other	0.125	0.119
Eastern sector trawlers		
Flathead	0.935	0.956
Gemfish	4.040	4.068
Blue grenadier	0.340	0.468
Ling	0.553	0.569
Morwong	0.898	0.915
Redfish	1.220	1.266
Squid	0.532	0.562
Warehou	0.401	0.422
Other	3.072	3.008
Southwest sector Trawlers		
Flathead	0.025	0.031
Gemfish	0.265	0.264
Blue grenadier	1.383	1.382
Ling	0.174	0.168
Morwong	0.052	0.074
Orange roughy	8.100	8.103
Redfish	0.000	0.005
Squid	0.039	0.047
Warehou	0.556	0.567
Whiting	0.000	0.023
Other	0.606	0.607
Effort	'000 h	'000 h
Danish seiners	12.662	12.013
Eastern sector	49.354	51.141
Southwest sector	9.757	11.128

FIGURE 4 - Simulation Results of Management Options



<u>Results</u>

The key results of the simulations are given in Table 7, and depicted in Figure 4. For each option except individual transferable quotas, results of three runs are given; one without a buy-back of li ences, one with a 10-licence buy-back, and one with a 40-licence buy-back.

From Table 7, it can be seen that option 3, based on the introduction of individual transferable quotas across the fishery, resulted in the highest profits being earned in each sector. In this simulation the fleet in the south-west sector is subject to the greatest structural adjustment. The number of boats contracts from 35 to 11, indicating the overcapacity of this fleet with respect to available fish resources in 1986-87. The profits of the fleet are estimated to more than double compared to the base case of 1986-87.

Under individual transferable quotas the number of boats fishing in the eastern sector fell by 35 per cent, from 83 to 54. The boats which leave are predominantly the largest and smallest operating in the sector, these being less efficient and less profitable than the intermediate sized boats. Reducing the number of boats and improving the average level of efficiency of the remaining boats would be likely to result in the profitability of the fleet almost doubling, from $1.7m to $3.2m a year.

Under individual transferable quotas the number of danish seiners falls by 36 per cent, from 25 to 16. The amount of capital employed decreases by about one third, while the profitability increases by 57 per cent compared to the base case.

Under the management options based on input controls the stricter the boat replacement policy, the slower the rate of adjustment towards the most efficient and profitable fleet configuration. In the options which include a

TABLE 7

Simulation Results

Management option	Eastern sector			South-west sector			Danish seiners		
	Boats	Capital	Profits	Boats	Capital	Profits	Boats	Capital	Profits
	no.	$m	$m	no.	$m	$m	no.	$m	$m
Benchmark(a)	83	14	1.7	40	29	3.5	25	3	0.7
Option 1									
0 buy-back	83	22	-0.6	40	29	3.0	25	3	0.7
10 buy-back	83	22	-0.4	30	29	4.0			
40 buy-back(b)	59	16	1.0	24	23	4.5			
Option 2									
0 buy-back	83	13	1.1	35	27	3.5	25	3	0.8
10 buy-back	75	12	1.7	35	27	3.6			
40 buy-back	51	9	2.2	24	23	4.5			
Option 3	54	9	3.2	11	9	7.6	16	2	1.1
Option 4									
0 buy-back	83	22	-0.3	40	29	2.4	25	3	0.8
10 buy-back	73	19	0.6	40	29	2.4			
40 buy-back	43	13	1.3	40	29	2.4			

(a) Based on the measured profitability of the industry in 1986-87, but with the catch of gemfish reduced from 4 kt to 3 kt in the eastern sector. (b) When more than 32 boats are removed, total profits are reduced.

'2-for-1' boat replacement policy in the eastern sector (options 1 and 4), no adjustment takes place as the costs of upgrading outweigh the benefits. Adjustment does occur with a '2-for-1' boat replacement policy in the southwest sector as the benefits of reducing boat numbers there are substantial.

In the eastern sector, maintaining the existing boat replacement policy (option 2) is estimated to result in greater levels of profits than occur with the stricter boat replacement policies. By removing 10 boats through a buy-back scheme profits are estimated to increase to over 50 per cent of those expected under individual transferable quotas. The removal of more than 10 boats results in a less than proportional improvement in profitability. In option 2, the improved profitability in the eastern sector as a result of removing ten boats attracts two of the smaller boats from the south-west sector to move to the eastern sector.

With transferability of boat units between the eastern and south-west sectors, the price of units is determined by the profitability of the orange roughy fishery in the south-west. The relatively high price of units promotes adjustment in terms of providing incentive for eastern sector operators to sell their units and leave the industry. However, the high unit price makes it uneconomic for eastern sector fishermen to improve the efficiency of their operations by upgrading or replacing their boats. Under these circumstances, the fleet would become gradually less efficient. If, on the other hand, the fishery is divided into two discrete parts, between which units cannot be transferred, then the price of units in the eastern sector may fall by around 70 per cent to reflect the lower profitability there. The lower unit price would facilitate adjustment towards a more efficient eastern sector fleet.

Splitting the fishery into two separate fisheries, however, may have a detrimental effect on adjustment in the southwest sector if input based management is also maintained there. Forcing boats to fish on only one side of the line or the other (option 4) results in more effort being employed in the south-west sector, as the south-west boats that also fished in the eastern sector redirect their effort solely to the more profitable southwest sector. The effect of this is that profits are reduced to their lowest level relative to the other simulations.

The sensitivity of these results to changing stock sizes was tested. A 25 per cent increase in the abundance of all species compared to 1986-87 has little impact on the relative performance of the management options for danish seiners and eastern boats. In the western sector, a stricter boat replacement policy (option 2) prevents boats from adjusting to take advantage of the higher stock levels. As a result, option 2 changes from being the second best option to the worst for the western sector. A reduction of 25 per cent in the abundance of all fish stocks has no impact on the relative rankings of the management options.

Discussion

Under the management regime existing in 1986-87 all sectors of the fishery were overcapitalised, and therefore were less profitable than they could otherwise have been. The results of the model simulations indicate the supremacy of individual transferable quotas over input controls in improving the economic performance of the industry. However these results ignore the costs of management under the different options. The costs associated with administration and enforcement of individual transferable quotas are likely to be higher than for input based schemes. A further difficulty of quota management is the problem relating to bycatch management. As seen in table 4, most of the target species are also caught at certain times of the year as bycatch of other target species. Balancing quota allocations may prove difficult under these circumstances and lead to bycatch species being dumped. This potential dumping problem is, however, also present and probably more acute under the input based options which feature individual non-transferable quotas on key species.

However, the potential benefits of the individual transferable quota system are high also, particularly in the south-west sector. Individual transferable quotas seem well suited to this part of the fishery for several reasons. The aggregating nature of some of the key fish stocks allows more effective targeting by fishermen thereby reducing the potential bycatch/dumping problems. The need to set total quotas in this sector has already been demonstrated because of the large catches resulting from target fishing, which if uncontrolled, may deplete stocks. The corporate structure and vertical integration of operators in the south-west sector may also make them more inclined towards increased stability and predictability in landings.

As noted previously the results of the model indicate that the profitability of the eastern sector would double under individual transferable quotas. However, this improvement is from a low base. The absolute increase in profits, around $1.5m per annum, does not provide a large margin to allow substantial net benefits to be derived when the costs of individual transferable quota management are accounted for. The large number of species and the large quantity of non-targeted (mixed) catches is likely to make balancing catches and quotas more difficult in the eastern sector than in the south-west. The dispersion of the fleet, and the numerous landing sites and marketing channels are also likely to increase enforcement costs.

Recent advice from biologists, however, indicates that the catches of gemfish and redfish need to be substantially reduced and that the catches of some other key species need to be contained. The fishery for gemfish is already managed by individual transferable quotas, and it is possible that total allowable catches will have to be set for other species to prevent catches from increasing, particularly in view of the reduced fishing opportunities for gemfish. If total allowable catches have to be set on a number of species on the east coast the associated costs of administration and enforcement may be comparable with those of an individual transferable quota system while the potential benefits would be much lower.

The experience in New Zealand, following the introduction of their widespread ITQ system, was that while establishment costs of the monitoring system were substantial, the ongoing management costs are very similar (in real terms) to the costs of managing the previous input based system (M. Lack, personal communication, 1.9.89).

The modest improvement in total danish seine profits under individual transferable quotas does not warrant their introduction in that sector of the fleet alone. The key issue for danish seiners is the preservation of the flathead stock which is also fished by eastern trawlers. If this stock becomes subject to quota control then individual transferable quotas may be the best approach to allocating this resource between danish seiners and trawlers.

If an individual transferable quota system is adopted for the fishery as a whole or for any sector of the fishery, further economic research should be undertaken on the issues relating to bycatch management and total quota setting under uncertainty.

APPENDIX A

Mathematical Specification of the Model

Notation

Subscripts

i,j	refers to the species of fish caught.
k	refers to the sector (1 = danish seiners, 2 = eastern sector and 3 = south-west sector).
l,m	refers to the boat groups (1 to 3 are danish seiners, 4 to 10 fish predominantly in the eastern sector, 11 to 13 fish predominantly in the south-west sector, 14 to 16 are 'potential' danish seiners, 17 to 23 are 'potential' eastern boats and 24 to 26 are 'potential' south-west sector boats).
n	refers to points on the catch-effort relationship curve.

Variables

P	the fishery profit (less adjustment costs)
P_k	the profit in sector k
R	the fishery revenue
R_k	the revenue in sector k
C	the fishery total costs
C_k	the total costs in sector k
V	the fishery total variable costs
V_k	the total variable costs in sector k
L	the fishery crew costs
L_k	the crew costs in sector k
M	the fishery marketing costs
M_k	the marketing costs in sector k
F	the fishery total fixed costs
F_k	the total fixed costs in sector k
K	the fishery capital costs
K_k	the capital costs in sector k
X_l	the number of boats in group l
H_{ikl}	the number of hours fished for species i in sector k by boats in group l
E_k	the total number of hours fished in sector k
E_{kl}	the total number of hours fished in sector k by boats in group l
E_{ik}^*	the number of effective hours fished for species i in sector k
W_{ikn}	the weight assigned to point n on the catch-effort relationship curve for species i in sector k

T_{ik}	the total targeted catch of species i in sector k
B_{ik}	the total bycatch of species i in sector k
Q_{ik}	the total catch of species i in sector k
S_l	the number of boats in group l that exit the fishery
Z_l	the number of boats in group l that sell their endorsements to the buy-back scheme
U	the total number of units in the fishery
U_k	the total number of units in sector k
A_{lm}	the number of boats in group l that upgrade (or downgrade) to group m (for l not equal to m)
D_k	the total number of endorsements for sector k sold
G_k	the total number of endorsements for sector k bought
N	the total number of units forfeited
O	the total number of units sold to the buy-back scheme
Y_k	the total number of units sold to other operators in sector k
Z_k	the total number of units bought by other operators in sector k

Parameters

m_k	the marketing charge in sector k (%)
c_k	the proportion of revenue paid to the crew in sector k (%)
h_l	the maximum hours that a boat in group l can fish (h)
l_l	the minimum hours that a boat in group l can fish (h)
s_{ikl}	the maximum hours that a boat in group l can fish for species i in sector k (h)
u_l	the number of units used by a boat in group l (units/boat)
f_l	the fixed cost of operating a boat in group l ($/boat)
k_l	the capital cost of operating a boat in group l ($/boat)
v_l	the variable cost of operating a boat in group l ($/hour)
e_{ikl}	the fishing power of a boat in group l relating to species i in sector k
t_{ik}	the total allowable catch of species i in sector k (kt)
a_{ikn}	the level of effort at point n on the catch-effort relationship curve for species i in sector k (h)
q_{ikn}	the targeted catch at point n on the catch-effort relationship curve for species i in sector k (kt)
b_{ijk}	the bycatch of species i associated with one tonne of targeted catch of species j in sector k (t)
p_{ik}	the price of species i in sector k ($/kt)
d_k	the annualised value of an endorsement in sector k ($)
y_k	the annualised value of a unit in sector k ($)

r_{lm}	the number of units released by boats in group l downgrading to group m, where $r_{lm} > 0$ if $u_l > u_m$ else $r_{lm} = 0$ (units/boat)
g_{lm}	the number of units required by boats in group l to upgrade to group m (including units to be forfeited), where $g_{lm} > 0$ if $u_l < (u_m + x_{lm})$ else $g_{lm} = 0$ (units/boat)
x_{lm}	the number of units forfeited when upgrading or downgrading from group l to group m (units/boat)
w_{iklm}	the catch of species i in sector k forgone by boats in group l downgrading to group m (kt), where $w_{iklm} > 0$ if initial catch of species i by group m is less than that of group l
i_{lm}	the annualised cost of upgrading (or downgrading) from group l to group m ($)
o	the opportunity cost of capital (%)
n_l	the initial (1986-87) number of boats in group l
z	the total number of endorsements in the fishery (1986-87)
j	the total number of units in the fishery (1986-87)
j_k	the total number of units in sector k (1986-87)
α	the number of boats sold to the buy-back scheme

Objective function

(1) $\max P = \Sigma_k P_k - \Sigma_l \Sigma_m i_{lm} A_{lm} - \Sigma_k d_k G_k - \Sigma_k y_k Z_k$

Constraints

Associated with the objective function is a series of constraints that represent limitations on the amount of profit 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.

Accounting equations common to all simulations

These equations provide summary information on the performance of the fishery under the various simulations.

(2) $P_k = R_k - C_k$ for each sector k

(3) $R_k = \Sigma_i p_{ik} Q_{ik}$ for each sector k

(4) $C_k = F_k + V_k + oK_k + L_k + M_k$ for each sector k

(5) $F_k = \Sigma_l f_l X_l$
$l=1,2,3$ when $k=1$;
$l=4,\ldots,10$ when $k=2$;
$l=11,12,13$ when $k=3$

(6) $V_k = \Sigma_l v_l E_{lk}$
$l=1,2,3$ when $k=1$;
$l=4,\ldots,10$ when $k=2$;
$l=11,12,13$ when $k=3$

(7) $K_k = \Sigma_l k_l X_l$
$l = 1,2,3$ when $k = 1$;
$l = 4,\ldots,10$ when $k = 2$;
$l = 11,12,13$ when $k = 3$

(8) $L_k = c_k R_k$ for each sector k

(9) $M_k = m_k R_k$ for each sector k

Equation 2 calculates the profit in sector k. Equation 3 calculates the total revenue in sector k. Equation 4 calculates the total costs in sector k. Equations 5 to 9 calculate the total fixed costs, total variable costs, total capital costs, total crew costs and total marketing costs respectively in sector k.

<u>Constraints relating to hours fished common to all simulations</u>

(10) $\Sigma_k E_{lk} - h_l X_l \leq 0$ for each boat group l

(11) $\Sigma_k E_{kl} - l_l X_l \geq 0$ for each boat group l

(12) $E_{kl} - \Sigma_i H_{ikl} = 0$ for each boat group l and sector k

(13) $H_{ikl} - s_{ikl} X_l \leq 0$ for each species i, boat group l and sector k

(14) $E_{ik}^* - \Sigma_l e_{ikl} H_{ikl} = 0$ for each species i in each sector k

Constraints 10 and 11 limit the maximum and the minimum number of hours respectively that each boat may fish in the fishery. Equation 12 determines the total number of hours fished by a boat in group l in sector k. Constraint 13 limits the number of hours a boat in group l can fish for a species i in sector k. Equation 14 determines the amount of effective effort expended on species i in sector k.

<u>Boat and unit reconciliation equations common to all simulations</u>

(15) $\Sigma_l X_l + \Sigma_l S_l = z$

(16) $\Sigma_l u_l X_l = j$

(17) $-X_l - S_l + \Sigma_m A_{ml} - \Sigma_m A_{lm} = -n_l$ for each boat group l

(18) $\Sigma_l \Sigma_m g_{lm} A_{lm} - \Sigma_l \Sigma_m r_{lm} A_{lm} - \Sigma_l u_l S_l = 0$

Equation 15 ensures that all boats are accounted for while equation 16 ensures that all units are accounted for. Equation 17 determines the number of boats in group l after adjustment. Equation 18 reconciles units released through downgrading or exiting the fishery with units used through upgrading.

<u>Linearisation of the catch-effort relationship (common to all simulations)</u>

The catch and effort relationships used in the model are non-linear functions. To incorporate these relationships into the linear programming framework, the functions were decomposed into a series of linear segments between points on the curves. 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:

(19) $E_{ik}^* - \Sigma_n a_{ikn} W_{ikn} = 0$ for each species i in sector k

(20) $T_{ik} - \Sigma_n q_{ikn} W_{ikn} = 0$ for each species i in sector k

(21) $\Sigma_n W_{ikn} = 1$ for each species i in sector k

Equation 19 equates effort to the weighted points on the curve. Equation 20 determines the targeted catch associated with the weighted points on the curve. Equation 21 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).

By-catch and total catch equations common to all simulations

(22) $B_{ik} - \Sigma_j b_{ikj} T_{jk} = 0$ for each species i in sector k

(23) $Q_{ik} - B_{ik} - T_{ik} = 0$ for each species i in sector k

Equation 22 determines the total bycatch of species i as a function of the quantities of the targeted species j. Equation 23 determines the total catch of species i as a sum of the targeted catch and by-catch of species i.

<u>Constraints relating to boat replacement policies</u>

(24) $\Sigma_l u_l X_l + \Sigma_l \Sigma_m x_{lm} A_{lm} = j$

(25) $\Sigma_l \Sigma_m A_{lm} - \Sigma_l S_l \quad 0$

(26) $\Sigma_l \Sigma_m x_{lm} A_{lm} - N = 0$

Equation 24 replaces Equation 16 and allows for units to be forfeited. Equation 25 applies in simulations where a '2-for-1' boat replacement policy is in place. The equation ensures that for every boat replacement (upgrading or downgrading), another boat must leave the fishery to allow the forfeiture of an endorsement. Equation 26 determines the number of units forfeited.

<u>Constraint relating to non-transferable quotas</u>

(27) $Q_{ik} + \Sigma_l \Sigma_m w_{iklm} A_{lm} \leq t_{ik}$ for specific species i and sector k

Constraint 27 limits the total catch of species i to the total allowable catch less non-transferable quota forgone by boats upgrading or downgrading to groups with lower historic involvement with that species in that sector. It is assumed that the lower historic involvement is a reflection of a lower ability to catch that species.

Constraints relating to simulations involving separate fisheries

(28) $D_k - G_k = 0$ for $k = 2,3$

(29) $D_2 - \sum_{l=4}^{10} S_l = 0$

(30) $D_3 - \sum_{l=11}^{13} S_l = 0$

(31) $G_2 - \sum_{l=12}^{13} \sum_{m=4}^{10} A_{lm} = 0$

(32) $G_3 - \sum_{l=4}^{10} \sum_{m=11}^{13} A_{lm} = 0$

(33) $\Sigma_l U_{lk} X_l + \Sigma_l \Sigma_m x_{lm} A_{lm} = j_k$

(34) $\Sigma_l \Sigma_m A_{lm} - \Sigma_l S_{lk} \leq 0$

Where a boat that predominantly operates in one sector wishes to move to another sector, it is necessary to purchase the appropriate endorsement to fish in that sector. Endorsements can only be bought from other operators who exit the fishery. It is assumed also that an operator will only exit the fishery if another is willing to purchase the boat's endorsement. Equation 28 ensures that endorsements sold in one sector through voluntary exit are purchased by boats upgrading or downgrading into that sector from the other sector. Equations 29 and 30 refer to boats exiting the eastern and south-west sectors respectively. Equation 31 determines the number of boats moving from the south-west sector to the eastern sector (excluding group 11 which have a dual endorsement). Equation 32 determines the number of boats moving from the eastern sector to the south-west sector. Equation 33 replaces Equation 24 (with boat replacement) and reconciles units within a sector. Equation 34 replaces Equation 25 (with '2-for-1' boat replacement policy) and ensures that sufficient boats leave a given sector to allow other boats to upgrade or downgrade in that sector.

Equations relating to the buy-back scheme (with boat replacement policy)

(35) $\Sigma_l u_l X_l + \Sigma_l \Sigma_m x_{lm} A_{lm} + 0 = j$

(36) $0 - \Sigma_l x_l Z_l = 0$

(37) $\Sigma_l X_l + \Sigma_l S_l + \Sigma_l Z_l = z$

(38) $\Sigma_l Z_l = \alpha$

Equation 35 replaces Equation 16 and reconciles the number of units in the fishery. Equation 36 determines the number of units associated with boats selling to the buy-back scheme. Equation 37 replaces Equation 15 and reconciles the number of boats in the fishery. Equation 38 sets the number of boats that the buy-back scheme will remove from the fishery.

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