OCCASIONAL PAPER 105

INDIVIDUAL TRANSFERABLE QUOTAS AND THE SOUTHERN BLUEFIN TUNA FISHERY

AUSTRALIAN
BUREAU OF AGRICULTURAL
AND RESOURCE ECONOMICS

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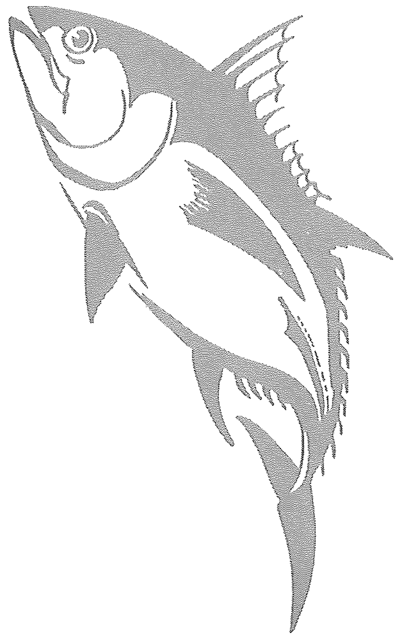
ECONOMIC IMPACT

PROJECT 62336

GERRY GEEN
AND MARK NAYAR



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Foreword

In the early 1980s the southern bluefin tuna fishery was believed to be biologically overexploited and heavily overcapitalised. An Australian government inquiry into the management of the fishery in 1983 recommended a substantial reduction in total catch and the introduction of a management regime based on the allocation of individual transferable quotas (ITQs) to fishermen as the best approaches to alleviating these problems.

As a result an ITQ system was introduced in the Australian southern bluefin tuna fishery in 1984. This was the first ITQ system to be used in an Australian fishery and was amongst the first in the world.

The changes in the economic performance of the fishery which have resulted from management by ITQs are analysed in this study. Because ITQs can potentially be used in some other fisheries, this analysis will contribute to the debate on the direction of fisheries management in Australia.

BRIAN FISHER
Executive Director

Australian Bureau of
Agricultural and Resource Economics

April 1989

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SUMMARY

Individual transferable catch quotas (ITQs) were allocated to fishermen in the Australian southern bluefin tuna fishery in 1984. The profitability of the industry increased substantially as a result. This is despite the total Australian catch being halved between 1984 and 1987 due to a decline in the abundance of southern bluefin tuna. The ITQ management system in the fishery was the first in Australia and was amongst the first in the world. Its introduction marked a radical departure from traditional management regimes based on limiting the number of boats allowed to operate and other controls on fishing inputs. These traditional methods were, both in Australia and elsewhere, often ineffective in controlling the growth of fishing effort and in generating sustainable long term benefits.

A lack of adequate property rights for fishermen over fish stocks has been identified as the major underlying cause of the overexploitation of marine fisheries. By giving fishermen more clearly defined long term property rights in the form of ITQs, incentives for fishermen to conserve the fish stock and to maximise their cost efficiency of harvesting are strengthened. Unprofitable fishermen who wish to leave the industry can sell their quotas to more efficient operators capable of earning a higher return on each tonne of fish caught. In this way the overall profitability of the industry can be improved. ITQs could be suitable for use in some other fisheries, so their success in improving the economic performance of the southern bluefin tuna fishery is likely to influence the future direction of fisheries management in Australia.

The impacts of the ITQ scheme on profitability in the fishery and on the structure of the fishing fleet were compared with the likely outcomes of alternative management programs. A mathematical model which draws together the major biological, physical and economic relationships in the fishery was used to assess the likely outcomes of various management alternatives.

In Australia, fishermen catch juvenile southern bluefin tuna, from one to eight years of age, which inhabit the coastal waters of southern Australia. The tuna spread eastwards and are fished sequentially in Western Australian, South Australian and, formerly, New South Wales waters. Pole and line boats and purse seiners are used by Australian fishermen to exploit the shoals of juvenile tuna which swim close to the surface of the water. Adult southern bluefin tuna are found in deeper, oceanic waters where they are exploited mainly by Japanese longline fishing boats.

Significant commercial exploitation of the stock of southern bluefin tuna began in the early 1950s with the development of the Japanese distant water longline fleet. Japanese catches grew rapidly, reaching a peak of 77 kt in 1961. Australian fishermen began coastal fishing for tuna in the mid-1950s. The catch of the Australian fleet increased slowly, to around 11 kt in 1980.

In 1979, Australian biologists warned that the fishery was fully exploited and, in 1981, that the size of the parent stock was apparently declining, threatening the recruitment of young fish to the harvestable stock. The parent stock was at that time estimated to be less than 30 per cent of its pre-exploitation size. In the years after this warning the Australian fishing effort continued to increase, and the catch almost doubled, reaching a peak of 21 kt in 1982.

To prevent any further growth in the Australian catch, in 1983 the Australian government introduced an interim quota of 21 kt.

The Japanese and New Zealand governments also agreed to limit the catches of their fleets to 29 kt and 1 kt, respectively. In the following year the Australian quota was cut to 14.5 kt, and ITQs were introduced. The Japanese agreed in 1985 to reduce their catch limit to 23 kt. At the time, biologists generally

Fishing methods used to catch southern bluefin tuna

There are three fishing methods employed in the Australian southern bluefin tuna fishery. These are trolling, pole and line, and purse seining. Longlining is used by the Japanese fleet to catch the larger, oceanic southern bluefin tuna.

Trolling

Trolling is a simple technique which involves slowly towing a small number of artificial lures behind a boat. Schools of fish are located and the lures towed repeatedly through them. Fish strike the lures, become hooked and are retrieved individually. Only small quantities of fish can be caught per day. This method is normally used by small multipurpose boats.

Pole and line

Pole and line is the most commonly used method for catching southern bluefin tuna in the Australian fishery. Boats using this method range from around 10 m to 30 m in length. When a school of southern bluefin tuna is located, live bait fish are thrown into the water to attract the fish to the boat, and to get the tuna feeding. The fishing gear consists of fibreglass poles, each equipped with a short length of line to which is attached an artificial lure. The lures are jigged near the surface of the water until a fish strikes. The poles may be operated manually or mechanically.

Purse seining

The purse seine fishing method relies on encircling schools of fish with a large net. The boat steams rapidly around the school paying out the net. The net hangs vertically in the water supported at the surface by floats. Once the school is encircled a wire running through rings along the lower edge of the net is hauled in. This closes the bottom of the net trapping the fish. The net is then gradually hauled on board the boat. This concentrates the fish into a small 'bag' alongside the boat. The fish are then scooped aboard using a lift net.

In the Australian southern bluefin tuna fishery, purse seiners operate cooperatively with pole and line boats. When a school of southern bluefin tuna is sighted the pole and line boat approaches it and starts fishing. While the school is feeding around the pole and line boat the purse seiner sets its net, encircling both the fish school and pole and line boat. When the purse net is closed the pole and line boat steams out over the top of the net, leaving the purse seiner to complete the fishing operation. The revenue from the sale of the fish is shared between the boats.

Longlining

When southern bluefin tuna mature they become more oceanic and tend to swim deeper in the water. They are, therefore, less susceptible to capture by the methods used in the Australian fishery, which are only effective for surface schooling fish. The longline fishing method is used by the Japanese to catch these larger fish. The fishing gear consists of a line, up to 40 km long, which is supported at intervals at the surface by large floats. Hanging from the main line, at 50–100 m intervals, are lengths of thinner line with baited books attached.

The baited line is left for a number of hours before being hauled in. Average catch rates for the Japanese fleet in the 1980s have ranged from 2 to 4 fish per thousand hooks set. Around 2500–3000 hooks per boat are set each day, resulting in catches of 5–12 fish. With an average weight of around 70 kg in 1988 each fish would have been worth, on average, $2500 on the sashimi market.

believed that these catch limits would allow the parent stock to recover.

In 1986, biologists became more concerned about the possibility that recruitment was declining and recommended that catches be further reduced. The Australian and Japanese industries agreed to reduce their catch limits to 11.5 kt and 19.5 kt, respectively, for three years starting in 1986. In return for acceptance of their reduction in catch, the Australian industry was paid 'compensation' by the Japanese, who expected to benefit from the Australian catch restraint.

The Japanese fleet was unable to catch its quota in 1986 or 1987, despite increasing its fishing effort. The reduction in the abundance of mature southern bluefin tuna, and indications that recruitment may have been declining since the late 1970s led biologists, in 1988, to advise that major reductions in catches were necessary to safeguard the reproductive capacity of the stock.

Fishery model

Substantial changes in fleet structure, operation and profitability have occurred since 1984, when ITQs replaced an interim management system based on aggregate quotas. Not all of these changes can be attributed to the ITQ system alone. The structure and performance of the fleet have been influenced by other factors which have little or nothing to do with the introduction of ITQs.

Irrespective of the form of management of the fishery, the reduction in the total Australian quota and losses sustained by New South Wales and South Australian operators over a number of years before 1984 would have resulted in boats leaving the fishery in both states.

To assess the economic effects of ITQs alone, these and other factors influencing fleet profitability need to be accounted for. Essentially, the question of what would have happened to the structure of the fleet, the amount of capital employed and profits if ITQs had not been introduced needs to be answered to provide a baseline against which the structure of the fleet and profitability under ITQs can be compared directly. The changes attributable to ITQs can then be assessed.

If ITQs had not been introduced in 1984 it is likely that the need to strictly limit catches of southern bluefin tuna would have resulted in a continuation of management by aggregate quota. Under this system the total catch of the fleet operating in each state was limited. The number of boats operating might have been unrestricted, as in 1983-84, or, alternatively, limitations on entry of new boats to the fishery might have been added to the aggregate quota.

The Bureau has used a mathematical model to assess the likely economic impacts of alternative management schemes. The model, which was developed by the Industries Assistance Commission for its 1983 inquiry and subsequently modified and updated by the Bureau, allows the likely behaviour over time of the fishing fleet and the fish stock to be simulated. To provide a consistent base for comparison of the economic effects of the management alternatives, the Australian fleet is modelled as catching the same total quota under both the aggregate quota and ITQ systems.

Aggregate quota management

Simulation of the fishery, using the model, indicates that if the aggregate quota scheme had continued to be used to manage the fishery (but with the total catch reduced from 21 kt to 14.3 kt), the fleet would have contracted in the south-eastern part of the fishery, where operators had been making substantial losses for several years, and the Western Australian fleet, which had remained profitable, would have expanded. This change in the structure of the fleet would have resulted in a large net outflow of capital from the fishery. This is because the reduction in the number of high valued south-eastern boats in the fishery would have more than outweighed the increase in capital employed in the Western Australian sector of the fleet.

Unrestricted boat entry and exit is assumed to eventually dissipate all potential resource rents. Resource rents are profits in excess of a 'normal' level for the industry which may arise as a result of management reducing the level of fishing effort in the fishery.

If the aggregate quota scheme together with a limit on the number of boats permitted to operate in each state had been used to manage the fishery, model simulation suggests that only in Western Australia would the fleet have been able to earn resource rents, of around $1.6m a year. These rent earnings would probably not have been sustained. With individuals increasing their fishing effort to try to secure for themselves a larger share of these rents, the rents would be eroded through the greater costs of the increased fishing effort.

ITQ management

In contrast, if the Australian fleet catches 14.3 kt under the ITQ system it is estimated to be capable of generating around $6.5m of resource rents a year. Fewer boats are employed to take the catch, enabling industry operating costs to fall, and fishermen target larger, more valuable fish to supply to the Japanese sashimi (raw fish) market, an effect that can be partly attributed to the ITQ system.

The estimate of resource rent earnings was based on 1986-87 costs and prices and the assumption that the fleet catches a total of 14.3 kt of tuna. In fact, in 1986 Australian fishermen agreed to forgo the capture of 3 kt of their quota for three years in return for a compensation payment from the Japanese southern bluefin tuna industry. As this payment was greater than the profits the Australian industry could have expected to earn if they caught the 3 kt, it is likely that the resource rents actually earned by the fleet in 1986-87 were greater than the $6.5m estimated in this study.

The capital employed in the fleet under ITQs is estimated as being around $10m to $12m less than the amount which might have been employed under management based on aggregate quota. However, only about 30 per cent of the total capital which left the fishery following the introduction of ITQs can be positively attributed to the effects of the ITQ scheme alone. As already noted, the remainder would probably still have left the fishery under alternative management regimes.

The increase in catch rates per boat, which resulted from the reduction in the number of boats fishing, reduced the variable costs of fishing per tonne of tuna caught. The average cost of catching a tonne of tuna has fallen by around 25 per cent under ITQs compared with the alternative management schemes. The value of the catch is higher under ITQs because of the stronger incentives for fishermen to target larger fish in order to maximise their returns from their limited permissible catch. ITQs give fishermen greater confidence and security to search for larger fish, bypassing shoals of small fish on traditional inshore grounds, in the knowledge that they have the entire fishing season to catch their individual quotas.

The economic gains generated by the ITQ system are, of course, dependent on the maintenance of a healthy fish stock. Targeting larger fish by Australian fishermen reduces the total number of fish removed from the stock. Consequently, with ITQs more fish could be expected to survive through to spawning age.

The decline in the size of the parent stock, brought about by previous large catches, particularly of small fish in the early 1980s, may have reduced the level of recruitment of young fish to the stock. Although there is still a great deal of uncertainty about the relationship between the size of the parent stock and recruitment, there is mounting evidence to suggest that recruitment may already be declining and that major catch restraint is necessary to safeguard the reproductive capacity of the stock. Clearly, such restraint must be considered in an international context as potential gains from Australian catch reductions could be eroded by increased Japanese catches, and vice versa.

One means of achieving global restraint involves direct negotiation between the Australian and Japanese industries on catch reductions. The agreement reached in 1986, under which the Australian industry reduced its potential catch by 3 kt a year, was reached in this way. The Japanese industry, which paid Australian operators to reduce their catch, expected to benefit from increased catch rates, and thus lower fishing costs, as a result of an increased number of fish surviving to enter the older age classes. Importantly, it is the allocation of more clearly defined property rights in the form of ITQs that has facilitated this type of agreement, by encouraging collective action on the part of Australian fishermen.

Biologists warned in 1988 that Australian catch restraint alone would not, in the short term, be sufficient to avert a possible collapse of the stock and that Japanese catches of mature fish also needed to be further reduced. As a result the Australian, Japanese and New Zealand catch limits for 1988-89 have been administratively reduced to 6.25 kt, 8.8 kt and 0.45 kt, respectively. These limits are based on the current biological state of the stock and will be reviewed annually.

The continuing decline in the parent stock and the probable decline in recruitment to the stock mean that in the short term, even with reduced catch limits, catches could continue to decline. It is important to recognise that this deterioration in the state of the stock has resulted mainly from the large catches taken in the early 1980s and before. The growth in catches of small fish off South Australia and Western Australia in that period was particularly damaging.

Between 1984, when ITQs were introduced, and 1987 the number of southern bluefin tuna caught by the Australian fleet was more than halved, greatly relieving the fishing pressure on the stock. The positive effects of this are yet to flow through strongly to the parent stock and the further reductions in catches in 1988 were therefore necessary to conserve the stock.

The allocation of ITQs to Australian fishermen in the form of shares of a total allowable catch provided an efficient mechanism for government to adjust individual and total catches in response to biological advice on changes in stock size. A major advantage of ITQs over alternative management schemes is that they facilitate adjustment to changing circumstances in the fishery.

If catch limits, and thus individual quotas, are reduced, operators are faced with either purchasing extra quota to enable them to remain viable or selling or leasing their quota and leaving the fishery. The most profitable fishermen will purchase more quota so that their boats continue to operate at an efficient level, while the fishermen that choose to retire from the fishery will be compensated for so doing. The potential economic hardship resulting from catch reduction is thus mitigated by quota trading, and the industry is able to continue operating efficiently at the reduced catch level.

Despite substantial reductions in total catch and in the abundance of the stock, the Australian industry has prospered since the introduction of ITQs. Marked improvements in the productivity of the industry have increased profits. Fishermen are now able to operate flexibly and adjust efficiently to changes in catch limits.

In other fisheries currently managed by input controls, the introduction of ITQs would almost certainly lead to improvements in industry productivity. But the potential increase in fishermen's profits resulting from productivity growth could be eroded if the costs of managing the fishery were to increase under ITQs. If, for example, boats were widely dispersed along the coast or if there were a large number of possible marketing channels for fish, then enforcement costs might be greater for ITQs (or aggregate quotas) than for management using input controls.

However, if the improvements in productivity and profits in other fisheries following the introduction of ITQs were on a similar scale to those experienced in the southern bluefin tuna fishery, then even if ITQ management costs were higher fishermen could still be better off.

Clearly, the expected management costs under ITQs must be compared with the expected increase in fishermen's returns on a fishery by fishery basis.

1. Introduction

The common property nature of fisheries is the main cause of biological and economic overexploitation of fish resources. Without adequate private property rights, individuals have little incentive to conserve the fish stock when the benefits of so doing are likely to be derived by others. Similarly, efficient harvesting is discouraged when the full costs of individual production are not borne by the individual alone. Costs are imposed on others in the fishery because harvesting by any individual reduces the quantity of fish available to other operators, and increases boat or gear crowding on the fishing grounds.

Government intervention in common property fisheries is thus often necessary to conserve the resource and promote its more efficient exploitation. Limiting the number of boats permitted to operate has been the basis of the traditional approach to fisheries management in Australia.

Limited entry licensing does provide fishermen with some property rights in the fishery, but they are ill defined since they do not limit the amount of fish which the licence holder can catch. Consequently, fishermen have an incentive to increase their fishing effort in an attempt to increase their share of the total catch whenever an improvement in the profitability of the fishery occurs. However, their actions will raise the total costs of fishing and erode overall profits.

Fishery managers have often reacted by placing additional restrictions on the operations of fishermen to try to prevent effort from increasing. Fishermen have, however, proved adept at circumventing such restrictions, with the result that effort has often continued to increase, and at a higher unit cost.

In contrast to the inefficiencies imposed by input controls, the use of individual transferable catch quotas (ITQs) as the management system should foster economic efficiency. This is because fishermen are given a more clearly defined property right to a share of an annually determined total allowable catch from the fish stock.

Although fishermen may still compete to take their catches at the times when fishing costs are lowest or prices highest, the incentive to increase fishing effort with improvements in profitability is much reduced as a result of the allowable catches of individuals being limited to their quota holdings.

Since the individual quota rights are transferable, fishermen are encouraged to acquire more rights up to the quantity of fish that can be harvested most profitably by their boats, and in the longer term to adjust their enterprises to the most efficient scale (Pearse 1980). In this way the productivity of the industry should be improved.

Fishery managers can conserve the resource more effectively by the direct regulation of the total allowable catch, rather than by the indirect and uncertain method of attempting to restrict fishing effort using input controls.

It was the pressing need to reduce catches that led the Australian government to adopt controls on output as the principal management measure for the southern bluefin tuna fishery. An aggregate quota arrangement was implemented in the 1983-84 season as an interim measure. This was replaced in 1984-85 by an ITQ system following an Industries Assistance Commission inquiry into the management of the fishery, which concluded that the introduction of ITQs would promote economic efficiency and the conservation of the resource (Industries Assistance Commission 1984).

This was the first ITQ scheme to be introduced into an Australian fishery. It represented a radical departure from traditional fisheries management practices based mainly on limited entry and other controls on inputs. Because ITQs are a possible management option for a number of other fisheries, their success or otherwise in improving the economic performance of the southern bluefin tuna fishery is likely to influence the future direction of fisheries management in Australia.

The purpose of this study is, therefore, to assess how effective the ITQ scheme has been in improving the economic performance of the southern bluefin tuna fishery. Since there is no absolute measure of the worth of a management plan, the merits of ITQs in this fishery must be assessed in relation to the expected outcomes of alternative management programs. Although much has already been written on the theoretical merits of ITQs compared with other methods of managing fisheries (see, for example, Moloney and Pearse 1979), there have not been any empirical assessments of the economic performance of ITQ schemes actually in operation.

While there seems little doubt that the large scale restructuring of the fleet which followed the introduction of ITQs will have increased the productivity of the industry, the extent of these productivity gains is uncertain. Because fisheries management is costly, and because ITQ schemes tend to be more expensive, initially, than traditional schemes to administer and enforce, it is important that the expected benefits stemming from ITQs outweigh these increased management costs.

Management costs under the ITQ scheme are, however, likely to diminish over time as the number of operators in the fishery is reduced and with the growth of self-policing by fishermen of the quota restrictions. With the advent of the 'user pays' policy, under which fishermen will be expected to pay up to 90 per cent of fisheries management costs, it is also increasingly important that fishermen can see they are getting value for each dollar spent on management.

A bioeconomic model of the fishery has been used to simulate the expected flows of benefits and costs to southern bluefin tuna fishermen from fishing under the ITQ system and, for comparative purposes, under two other management regimes which were feasible alternatives to ITQs in 1984. The component of management costs being paid by Australian taxpayers, as well as any related costs or benefits resulting from the redeployment of the labour and capital which left the fishery, are also taken into account when assessing the net benefits of the ITQ scheme from a public perspective.

2. Background

Southern bluefin tuna, *Thunnus maccoyii* (Castlenau), are caught mainly by Australian and Japanese fishing fleets, with small quantities also being taken by fishermen from Taiwan, New Zealand, Korea, South Africa and Indonesia.

2.1 Resource base

The Australian fishery is based on the capture of juvenile fish, from one to eight years of age, which inhabit the coastal waters of southern Australia. The juvenile fish form large surface schools which are exploited by pole and line boats and purse seiners. (Brief descriptions of these and other fishing methods used to catch tuna are given in the boxed section on page 2.) The fish spread eastwards and are fished sequentially in Western Australian and South Australian waters and, formerly, New South Wales waters (see map).

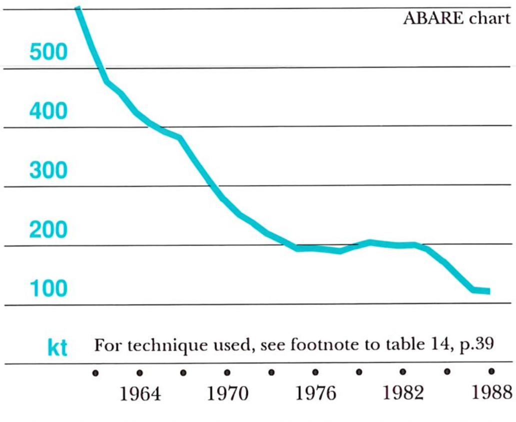
Adult fish, which may reach over twenty years of age, are found mainly in more oceanic waters and have an almost circumpolar distribution in the range 30–50° south. However, fish distribution does extend northwards toward Java and it is in these more northerly waters that the adult fish spawn (Hampton, Majkowski and Murphy 1984). The large, adult fish are targeted by a fleet of Japanese longliners operating mainly in the latitudes of the 'roaring forties'. Catches by the Japanese fleet reached a peak of 77 kt in 1960-61 but have since declined to 15 kt despite an increase in fishing effort (CSIRO 1988).

Although the Australian and Japanese fisheries are, for the most part, spatially and operationally distinct, they are interdependent, since southern bluefin tuna are believed to form a single stock in the southern hemisphere.

In 1979, Australian biologists warned that the fishery was fully exploited and that an increase in the Australian catch would be likely to reduce Japanese catches, and vice versa (Industries Assistance Commission 1984). In the early 1980s they stated that recruitment of young fish to the harvestable stock might be reduced if the apparent decline in the parent stock (spawning stock of fish aged eight years and more) were to be allowed to continue (see figure A for the estimated changes in the size of the parent stock over time). In the years immediately following this warning the Australian catch almost doubled to 21 kt while the Japanese catch declined only slightly (see table 1 for Australian and Japanese catches from 1952 onwards).

In 1983, a meeting of biologists from Australia, Japan and New Zealand, held in Shimuzu, Japan, issued a strong warning that the total catch of southern bluefin tuna should be urgently reduced with the aim of stabilising the size of the parent stock at its estimated 1980 level, which was thought to have provided a relatively constant level of recruitment to the stock. Below this 1980 level it was felt that there was a significant risk of recruitment declining. The biologists pointed out that the longer this reduction in total catch was delayed, the more severe would be the

A Estimates of the size of the parent stock



For technique used, see footnote to table 14, p.39

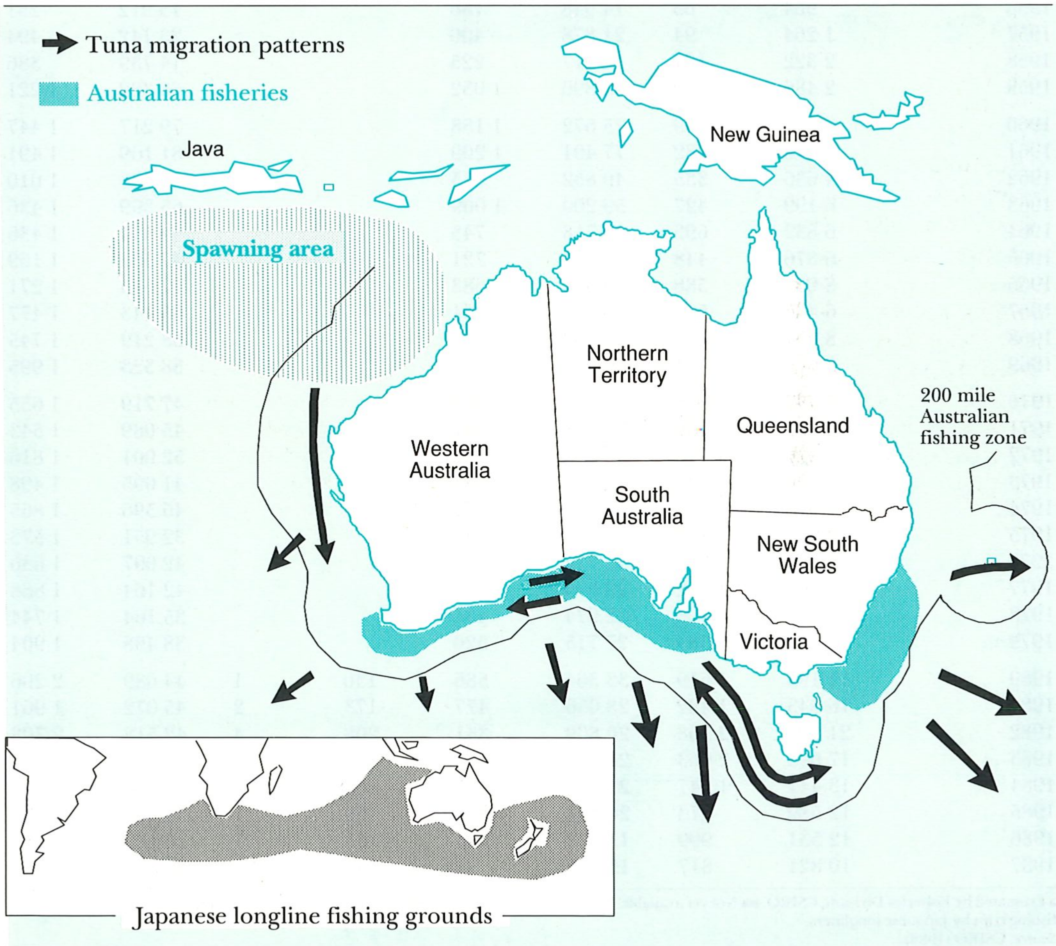
restrictions needed to allow the spawning stock to recover to the 1980 level (Majkowski and Caton 1984).

Immediately following this warning fishery managers from Australia, Japan and New Zealand undertook, as an interim measure, to prevent further growth in their southern bluefin tuna fisheries and to pursue discussions on international management (Caton 1985). It was agreed that the Australian and Japanese catches would be limited to 21 kt and 29 kt, respectively, for the 1983-84 season. The New Zealand catch limit was set at 1 kt.

The major concerns expressed by biologists about the state of the stock led the Australian government in 1984 to propose substantial reductions in both Australian and Japanese catch limits. This proposal was rejected by the Japanese who would not agree to any reduction in their catch (Caton 1985).

Because of the perceived risks of recruitment failure if global catches were not reduced the Australian government decided unilaterally to reduce the Australian catch to 14.5 kt despite the possibility that the benefits could be negated if the Japanese increased their fishing activity. Japanese boats were, however, excluded from fishing for the tuna within the Australian 200 mile zone in an attempt to reduce their catch. This was also imposed to prevent the inequitable situation arising whereby stringent management measures would be applied

Southern bluefin tuna fishery



to Australian fishermen while Japanese fishermen were allowed to catch unlimited quantities of the fish in Australian waters.

In 1985, Japan agreed to limit its catch to 23 kt and was consequently permitted to resume fishing for southern bluefin tuna in the Australian fishing zone.

An analysis of the expected long term impacts of various combinations of Japanese and Australian catches suggested that catches of 23 kt by Japan and 14.5 kt by Australia would result in the parent stock stabilising at around the 1980 level if recruitment to the stock was constant (Majkowski 1985). However, there was uncertainty about whether or not the parent stock, in its depleted state, had been able to sustain constant recruitment.

While most research had indicated that recruitment was relatively constant until

1 Catches of southern bluefin tuna

Year	Australia Weight	Australia No.	Japan Weight	Japan No.	New Zealand Weight	New Zealand No.	Total Weight	Total No.
	t	'000	t	'000	t	'000	t	'000
1952	264	17	556	6			820	23
1953	509	35	3 809	49			4 318	84
1954	424	35	2 183	27			2 607	62
1955	322	28	2 915	36			3 237	64
1956	964	65	14 948	186			15 912	251
1957	1 264	94	21 878	400			23 142	494
1958	2 322	161	12 417	225			14 739	386
1959	2 486	189	63 896	1 032			66 382	1 221
1960	3 545	259	75 672	1 188			79 217	1 447
1961	3 678	282	77 491	1 209			81 169	1 491
1962	4 636	335	40 852	675			45 488	1 010
1963	6 199	427	59 200	1 009			65 399	1 436
1964	6 832	693	42 718	743			49 550	1 436
1965	6 876	448	40 627	721			47 503	1 169
1966	8 008	588	39 607	683			47 615	1 271
1967	6 357	546	59 086	931			65 443	1 477
1968	8 737	917	49 482	828			58 219	1 745
1969	8 679	1 151	49 644	844			58 323	1 995
1970	7 097	956	40 622	699			47 719	1 655
1971	6 969	846	38 120	697			45 089	1 543
1972	12 397	1 010	39 604	806			52 001	1 816
1973	9 890	847	31 205	651			41 095	1 498
1974	12 672	1 193	33 924	672			46 596	1 865
1975	8 833	1 132	24 118	441			32 951	1 573
1976	8 383	996	33 714	634			42 097	1 630
1977	12 569	1 352	29 595	536			42 164	1 888
1978	12 190	1 293	22 974	451			35 164	1 744
1979	10 783	1 384	27 715	520			38 498	1 904
1980	11 195	1 619	33 364	586	130	1	44 689	2 206
1981	16 843	1 482	28 056	477	173	2	45 072	1 961
1982	21 501	2 368	20 809	331	208	4	42 518	2 703
1983	17 695	2 063	24 735	424	112	1	42 542	2 488
1984	13 411	1 447	23 323	365	86	1	36 820	1 813
1985	12 589	973	20 393	304	99	1	33 088	1 283
1986	12 531	999	15 522	213	83	1	28 136	1 213
1987	10 821	817	15 000 **a**	**na**	50	1	25 871	**na**

a Estimated by Fisheries Division, CSIRO. **na** Not yet available, as there is a delay in receiving most recent data because of the long duration of fishing trips by Japanese longliners.
Source: CSIRO (1988).

1980, some analyses presented at the 1987 international meeting of southern bluefin tuna biologists in Hobart suggested that the level of recruitment may have been declining since the late 1970s (CSIRO 1987). Unfortunately, the method used for assessing the size of the stock and recruitment can, at best, only indicate changes in recruitment six to seven years after they have occurred (Caton and Majkowski 1987). The method, known as virtual population or cohort analysis, is based on simulation of the effects of fishing and natural mortality on each age class of the fish as it passes through the fishery.

Even if recruitment to the Australian fishery was constant, it was apparent that the parent stock could be expected to decline in the short term. This is because the one and two year old age classes which were approaching sexual maturity and entry to the parental biomass had been depleted by heavy fishing in the early 1980s by the Western Australian and South Australian fleets.

With a decline in the parent stock the risk of recruitment failure increases. Because the commercial fishery could collapse if recruitment failed, in 1986 biologists recommended further reductions in catches, particularly of mature fish in the short term (Caton and Majkowski 1987). An agreement between the Australian and Japanese industries was reached whereby their combined catch would be reduced to 31 kt for three years starting in the 1986-87 season. The catch limits for the Australian and Japanese fleets under this agreement were 11.5 kt and 19.5 kt, respectively.

The Japanese catch in 1986 was, however, only 15.5 kt, some 4 kt less than their catch limit. The catch per unit effort for the fleet, measured in terms of the number of fish caught per 1000 hooks set, fell by 29 per cent compared with the previous year. In 1987 the Japanese catch remained at around the 15 kt level.

At the 1988 meeting of southern bluefin tuna biologists in Wellington all of the analyses presented indicated that the parent stock had fallen to a dangerously low level. A number of these analyses again suggested that recruitment had been declining since before 1980. The proposition that recruitment was declining is supported by other evidence, including the results of a 'tag and release' study of southern bluefin tuna in the Australian sector of the fishery (Eckert and Majkowski 1987). The high recovery rates of tagged fish indicate a higher than anticipated exploitation rate. The probable explanation for this high exploitation rate is that declining recruitment has reduced the total number of fish available for capture. The same conclusion can be reached from the observation that, despite substantial reductions in the catches of two and three year old fish since 1984, there has been no increase in the catches of four to six year old fish in southern Australian waters.

As at the 1987 meeting, all forward projections of the stock indicated a further decline in the size of the parent stock for at least the next few years. Beyond that period some simulations indicated that the parent stock could recover in size. Others, including one using a modified analytical approach, to try to account for changes in the spatial distribution of Japanese fishing effort, indicated that the parent stock would continue to decline.

The increased number of analyses projecting a long term decline in the parent stock, and the mounting evidence of declining recruitment, led scientists in 1988 to recommend major reductions in the global catch of southern bluefin tuna. As a result the Australian, Japanese and New Zealand catch limits for 1988-89 were reduced to 6.25 kt, 8.8 kt and 0.45 kt, respectively.

2.2 The fishery before ITQs

Although a tuna cannery was operating in New South Wales as early as 1936, the capture of southern bluefin tuna was only an opportunistic fishing activity until the 1950s (table 2). At this time the pole and line fishing technique was introduced from America, and quickly replaced the less efficient trolling method. The success of the pole and line fishing technique fuelled an expansion in the size of the fleet, which spread to South Australia from New South Wales.

In the 1960s and 1970s a small scale fishery developed off Western Australia, where a multipurpose fleet comprising relatively small boats, averaging around 11 m in length, operated throughout the year. The boats used mainly trolling gear, although the pole and line method was used by some boats when concentrations of fish had been located (Caton 1985). The New South Wales fleet was also multi-purpose, albeit with larger boats in the 15–20 m range capable of changing over to bottom trawling in the tuna off-season.

Because of the lack of alternative fishing opportunities in South Australia, the fleet that developed there was principally large purpose built pole and line boats (20 m or more).

Purse seiners were introduced into the fishery in the 1960s, but did not prove successful until the 1970s when they began to fish cooperatively with pole and line boats which held the shoal around them at the surface while the purse net was set. The fish catching efficiency of purse seiners operating in this manner gave rise to fears among fishery managers that the tuna stock might be adversely affected if additional purse seiners were allowed to

2 Management in the southern bluefin tuna fishery

1952	Targeted commercial exploitation of southern bluefin tuna by New South Wales and South Australian boats and Japanese longline fleet.
1961	Japanese fleet takes record catch of 77 kt.
1968	First commercial catches by Western Australian boats.
1971	Japanese industry introduces voluntary area closures to protect spawning fish and juveniles.
1974	Successful introduction of five purse seiners to the southern bluefin tuna fleet.
1975	Entry of additional purse seiners to the fishery prohibited. Purse seiners banned from fishing off Western Australia.
1976	'Freeze' on further entry of pole boats into the south-eastern sector of the fishery. Number of boats limited to 76.
1979	Australian biologists warn that fishery is fully exploited.
1981	Lifting of 'freeze' on entry of additional pole boats. Restriction on number of purse seiners maintained.
1982	Record Australian catch of 21 kt.
1983	Biologists warn that the global catch of southern bluefin tuna should be urgently reduced to arrest the decline in size of the spawning stock.
	Australia, Japan and New Zealand agree to prevent any further growth in catches. Catch limits are 21 kt, 29kt and 1 kt, respectively. Australia introduces a minimum landing size for southern bluefin tuna and area closures for purse seiners.
1984	Individual transferable quota system introduced into the Australian fishery. Australian quota reduced to 14.5 kt. Japanese refuse to reduce their catch. Japanese longliners prohibited from fishing for southern bluefin tuna in Australian waters (south of 34°S).
1985	Japanese agree to limit their global catch to 23.15kt and are readmitted to the Australian fishing zone around Tasmania.
	Southern Bluefin Tuna Management Advisory Committee formed.
1986	Biologists warn of the risks of recruitment failure if catches are not further reduced.
	Voluntary three year agreement reached between Australian and Japanese industries to limit the global catch to 31 kt. Catch limits for Australia and Japan are 11.5 kt and 19.5 kt, respectively, but the Japanese fleet catches only 15.5 kt.
1988	Biologists recommend major catch reductions. Catch limits are reduced to 6.25 kt for Australia, 8.8 kt for Japan and 0.45 kt for New Zealand.

3 Rates of return to capital [a]

Sector	1980-81 [b]	1981-82 [c]	1982-83 [c]	1983-84 [c]
	%	%	%	%
Western Australia				
Pole boats	9	6	13	4
New South Wales and South Australia				
Pole boats	13	–7	–16	–25
Purse seiners	–3	–4	–4	–5

a Returns are adjusted to full equity. That is, interest payments are deducted from costs. **b** Survey data. **c** Estimates based on reported changes in catches, prices and numbers of boats operating. Costs of fishing inputs are assumed to have risen in line with the consumer price index.

enter the fishery (Franklin 1987). As a result the further entry of purse seiners to the fishery was prohibited in 1975 and the purse seine fleet was banned from operating in Western Australian waters.

Concern about the effects of increasing fishing effort on the economic performance of the fishery led the Australian government in 1976 to implement a freeze on further entry of pole and line boats into the south-eastern sector of the fishery.

The security offered by the freeze, together with improving catches and prices, provided incentives for fishermen to replace or upgrade their boats. As a result, the fishing capacity of the fleet in South Australia and New South Wales increased dramatically during the late 1970s, perhaps trebling (Crough 1987). The Western Australian fleet also expanded substantially over the same period, there being no restrictions in that state on the entry of boats.

The freeze was lifted in 1981 as it was recognised that it had proved ineffective in containing the growth of fishing capacity.

Although the total catch of southern bluefin tuna was still increasing, the economic position of many operators in the fishery began to deteriorate markedly in the early 1980s. A survey was carried out by the Bureau covering the years 1980-81 and 1981-82. This showed that, although reasonable returns were being made by pole boats in 1980-81, the South Australian and New South Wales pole boats incurred losses in 1981-82 and the profit level of the Western Australian fleet was reduced (table 3). This downturn was caused primarily by a 30 per cent fall in tuna prices in that year (Bureau of Agricultural Economics 1986).

In 1982-83 the financial position of south-eastern operators is estimated to have again deteriorated, despite the total Australian catch reaching a record 21 kt. Although a substantial increase in catch was achieved in South Australia, the average catch per boat fell due to entry of boats after the freeze was lifted. In New South Wales, total catch was only 50 per cent of that taken in the previous year despite an increase in the number of boats fishing.

The Western Australian fleet continued to operate profitably, with increases in total catch counteracting the effects of increasing boat numbers. The profitability of the South Australian and New South Wales fleets fell mainly because of reductions in fish abundance resulting from the larger catches taken by Western Australian boats.

In 1983-84, the year before the introduction of the ITQ system, a limit of 21 kt was set on the total Australian catch as an interim management measure. However, because of reduced fish abundance off New South Wales, and restrictions placed on when and where purse seiners could operate, the total catch fell nearly 5 kt short of this limit. As a result, the financial performance of the south-eastern sector of the fleet deteriorated, creating considerable pressure for operators to adjust out of the fishery.

3. Introduction of ITQs

In 1983 the Industries Assistance Commission was requested by the Minister for Industry and Commerce to report on changes to the southern bluefin tuna fishery management program necessary to facilitate conservation of the resource and efficient development of the industry (Industries Assistance Commission 1984).

In their review of the interim management plan the Commission found that the three main characteristics of the plan — a total quota for the fleet of each state in the fishery, a minimum landing size for fish, and restrictions on purse seiners — all served to increase fishing costs.

Specifically, the total quotas were viewed as providing incentives for fishermen to 'rush to fish' in an attempt to increase their share of the total catch, thereby encouraging investment in larger, more powerful boats and leading to increased competition and further capitalisation in an industry already identified as being overcapitalised.

Minimum landing sizes for the fish were found to impose a cost on the industry by forcing fishermen to spend more time searching for schools of larger fish, or sorting and discarding fish to ensure they met the size limit.

Finally, because purse seining was assessed as being the most efficient method of catching southern bluefin tuna, in terms of the cost per tonne caught, restrictions on the use of this method would raise industry costs.

Simulations carried out by the Commission using a biological model of the dynamics of the stock, developed by CSIRO scientists (see Majkowski and Hampton 1983), demonstrated a likelihood of substantial further reductions in the size of the parent stock, and increased risk of recruitment failure, if the catch size and composition associated with the interim management plan were continued. The historically high level of total Australian catch and the failure of the minimum landing size to reduce the harvest of small fish significantly were the main factors causing the decline.

The Commission concluded that 'a continuation of a program styled on the interim management program would encourage fishermen to "rush to fish", would inhibit the harvesting of fish at least cost, and would maintain a level and composition of catch which would not only fail to maximise returns from the fishery but could encourage a stock collapse' (Industries Assistance Commission 1984, p. 29). Accordingly, the Commission recommended that the interim management program be replaced.

The principal management alternative which the Commission went on to evaluate was a scheme based on the assignment of ITQs. This was the management approach suggested by the Bureau in its submissions to the inquiry (Bureau of Agricultural Economics 1983, 1984), and also by the Australian Fisheries Service and the South Australian Department of Fisheries. Under these proposals, area restrictions, size limits on fish and limited entry arrangements would be abolished so that fishermen would be able to operate relatively freely subject to their individual quota entitlements.

The Commission believed that the removal of operational constraints would lower fishing costs. Trade in quota rights would also lower costs by enabling operators to adjust their quota holdings toward the catch level at which they could operate most efficiently. The use of ITQs was seen as offering better prospects for conserving the resource, because ITQs strengthen economic incentives for fishermen to target larger, more valuable fish to increase the returns from their limited permissible catches.
Improving the average size of fish in the

catch, and thus reducing the number of fish caught to fill the quota, would result in more fish surviving to enter the parent stock. This would lower the risk of recruitment failure (Industries Assistance Commission 1984).

3.1 ITQs recommended

The Commission recommended that a system of ITQs should be established as this would be the most direct means of pursuing the joint goals of stock conservation and industry efficiency. A detailed evaluation by the Commission of the likely impact of such an ITQ system was facilitated by the construction and use of a bioeconomic model of the fishery. Economic data collected by the Bureau on the performance of the Australian fleet in the 1980-81 and 1981-82 seasons (Bureau of Agricultural Economics 1983) were used in the fishery model.

Simulations were carried out to examine the effects on the parent stock and on the returns from the fishery of different levels of Australian and Japanese catches, and of various distributions of the Australian quota between states. The impacts of various possible quota distributions on catch and fleet compositions were also assessed.

The general conclusions from the Commission's analysis were that: the benefit of catch restraint by Australia could be eroded by increased Japanese catches; if the average size of fish in the Australian catch increased, the size of the Australian quota could be increased or, alternatively, by holding the quota constant the size of the parent stock could be increased; and an Australian quota in excess of 14 kt could place the parent stock at risk if more than 1 kt of it were caught in Western Australia (assuming a Japanese catch of 16 kt).

A simulation of the fleet structure under ITQs, with a total catch limit of almost 14 kt, indicated that the fleet size was likely to be substantially reduced and that there would be a shift away from the Western Australian inshore fishery. The projected composition of the fleet is given in table 4.

The Commission predicted, using the model, that trading prices for quota sold 'in perpetuity' would start at around $1140/t. This estimate was arrived at by discounting the projected average profits per tonne earned by the fleet at 20 per cent over a five year period. It was argued that 20 per cent was a realistic discount rate given the risks faced by southern bluefin tuna fishermen. The Commission also anticipated an increase in the average weight of fish caught and an acceleration of the trend toward supplying fish to the Japanese sashimi market.

An ITQ system was introduced into the fishery in October 1984. Individual quota entitlements were based on a percentage of the total allowable catch as determined annually by the Australian government. The eligibility of fishermen to receive entitlements was based on their dependence on and financial commitment to the fishery together with their history of involvement in the fishery (Franklin 1987). Allocation of quota shares to fishermen was based on catch history (75 per cent) and investment in the fishery (25 per cent).

Because of the urgent need to reduce fishing pressure on the stock of southern bluefin tuna, the total Australian catch quota for 1984-85 was reduced to 14.5 kt, from 21 kt in the previous year. Consequently, quotas granted to fishermen were also substantially less than their previous catches, averaging 40–60 per cent of their best catch in the qualifying period (Franklin 1987).

4 Projections of the composition of the fleet under ITQs [a]

Sector	Total quota holding	Projected number of boats
	t	no.
Western Australia		
Pole boats	1 000	13
South Australia		
Pole boats	6 450	16
Purse seiners	4 450	4
New South Wales		
Purse seiners	2 000	2
Total	13 900	35

a Model estimates of fleet composition when adjustment to the quota limits completed.
Source: Industries Assistance Commission (1984).

To try to increase the average size of fish caught in Western Australia, restrictions were placed on when and where the Western Australian fleet could operate.

3.2 Short run impact of ITQs

Because the allocations of quota were lower than their catches of previous years, many fishermen were faced with either purchasing more quota to make their continued operation economic, or selling up and leaving the fishery. The ITQ system facilitated adjustment by enabling departing fishermen to receive compensation for giving up their tuna fishing activities from the proceeds of the sale of their quotas to other fishermen.

Changes in fleet structure

The ensuing restructuring of the fleet was rapid. Most of the quota traded was purchased by South Australian fishermen, with the result that quota holdings in Western Australia and New South Wales at the end of 1985 were less than half of the initial allocations (table 5). The reported trading prices for quota in late 1984 were in the range $800/t to $1200/t (Franklin 1987), as predicted by the Industries Assistance Commission.

The departure of New South Wales operators is attributable to the impact of heavy losses in previous years and the decline in fish abundance off the New South Wales coast. Although around 500 t of quota is still held in New South Wales, virtually all of this quota is leased on an annual basis to South Australian fishermen.

5 Quota holdings [a]

State	1984-85	1985-86	1986-87	1987-88
	t	t	t	t
Western Australia	2 752	1 344	1 249	1 292
South Australia	9 272	12 186	12 563[b]	12 619[b]
New South Wales	2 022	901	520	495
Total	14 045	14 431	14 332	14 406

a Quota holding at the beginning of the quota year (October). **b** 3000 t of this South Australian quota is temporarily withdrawn as part of the Australian–Japanese industry to industry catch agreement.
Source: Australian Fisheries Service.

Most Western Australian fishermen elected to sell their quota entitlements and leave the fishery, even though Western Australian pole boats were the only boats in the fishery to apparently operate profitably in the two years immediately before the introduction of ITQs (table 2).

Although quotas allocated to fishermen were substantially less than their best previous catches, this factor is unlikely to have been the major reason why fishermen in Western Australia sold their quotas. For most Western Australian operators, fishing for southern bluefin tuna was one of several complementary fishing activities. Increased fishing effort in alternative fisheries could have been expected to compensate for any diminution in fishing opportunities in the southern bluefin tuna fishery. In fact many of the fishermen who sold their quotas continue to operate in these alternative fisheries.

The profit expectations of Western Australian fishermen were, however, probably diminished by the restrictions on the timing and location of their fishing activities, which were aimed at trying to increase the size of fish caught and by the implied threat of additional future restrictions if these did not have the desired effects (Caton 1985). Under these circumstances the offers made by South Australian fishermen for the purchase of Western Australian quotas are likely to have had more attraction than would have been the case in the absence of the operational restrictions.

The South Australian fishermen recognised the potential profits that could be earned by using their large boats to work further offshore to catch the larger fish needed to supply the lucrative Japanese sashimi market. The lack of alternative fishing opportunities for the large, specialised South Australian tuna boats, together with the consequent difficulties in selling these boats outside the fishery, was another factor which influenced South Australian operators to stay in the fishery. Because of their high equity in these large, capital intensive boats, which was around 75 per cent on average in 1981-82 (Bureau of Agricultural Economics 1986), South

Australian operators were more able than their Western Australia counterparts to finance the acquisition of the additional quota needed to improve the viability of their fishing enterprises.

The same pattern of quota transactions continued in 1986, although the rate of quota adjustment was much slower. By the beginning of the 1986-87 season most of the adjustment in quota holdings and in fleet structure (table 6) had taken place, with only marginal quota adjustments still occurring. Average prices of quota had by that time risen to $3200/t to $3500/t (Franklin 1987) indicating that the profitability of the fleet had improved.

The Western Australian fleet had contracted by 80 per cent to only 17 boats by 1986-87. The New South Wales fishery had effectively ceased, following its disastrous 1984-85 season. Conversely, the quota held by the South Australian sector of the fleet rose to 91 per cent of the total allowable catch, compared with the 66 per cent initially allocated.

The growth of catches in the Western Australian and South Australian inshore fisheries prior to the introduction of ITQs played a part in the collapse of the New South Wales fishery. The movement of southern bluefin tuna around the Australian coast from west to east results in the fish available off New South Wales being composed mainly of older age classes which have managed to survive Western Australian and South Australian fishing activities.

The increase in catches of small fish off Western Australia and South Australia in the early 1980s was therefore bound to reduce fish abundance off New South Wales in following years. Since 1984-85 there have been very few southern bluefin tuna of any age class caught off the New South Wales coast despite several attempts by contingents of the South Australian fleet to catch fish in that area.

Average size of fish caught

An important aim of the ITQ management plan has been to increase the average size of fish in the catch. As noted previously this is because catching larger fish means that a smaller number of fish need to be caught to fill a quota. This in turn should allow an increased number of fish to reach maturity and enter the parent stock.

As a result of the ITQ management program, the average size of fish in the Australian catch increased by around 11 per cent between 1983 and 1986. This improvement was the result of two factors — a reduction in the Western Australian share of the catch, and increased targeting by fishermen of larger fish. The increase in average size occurred despite the collapse of the New South Wales fishery, which was based mainly on fish larger than those caught in the South Australian and Western Australian sectors of the fishery.

6 Fleet structures and catches a

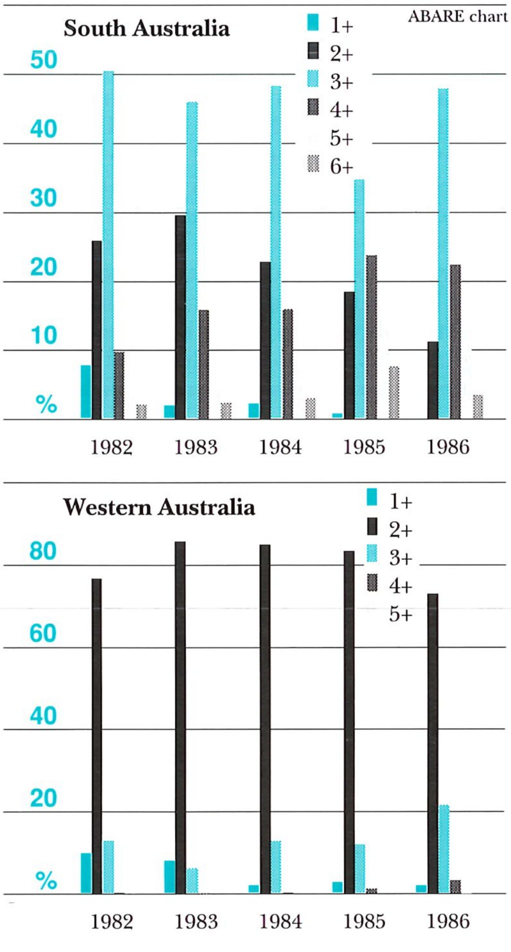
	1981-82		1982-83		1983-84		1984-85		1985-86		1986-87		1987-88	
Sector	Boats	Catch	Boats	Catch	Boats	Catch	Boats	Catch	Boats	Catch	Boats	Catch	Boats	Catch b
	no.	t	no.	t	no.	t	no.	t	no.	t	no.	t	no.	t
Western Australia														
Pole boats	68	3 816	74	5 478	84	4 516	49	2 190	26	1 337	17	1 321	17	1 189
South Australia														
Pole boats	26	5 887	46	8 585	39	5 638	17	7 126	15	7 312	14	6 113	14	5 982
Purse seiners	4	6 861	4	5 327	5	4 981	5	3 680	6	4 585	6	3 887	6	3 803
New South Wales														
Pole boats	11	2 284	12	1 249	5	654	5	458 c	0	0	0	0	0	0
Purse seiners	1	983	2	399	1	245	1	0	0	0	0	0	0	0
Total		19 831		21 038		16 034		13 454		13 234		11 321		10 974

a Boats actually fishing, rather than simply holding quota. **b** Provisional data. **c** Caught by a single New South Wales boat fishing off South Australia.
Source: Australian Fisheries Service.

Trade in individual quota entitlements resulted in a large transfer of quota holdings from Western Australia to South Australia. Because the catch in the South Australian fishery is predominantly of age classes older than are taken in Western Australia, the redistribution of quota had a direct effect on the average size of fish in the Australian catch.

The substantially higher prices that could be achieved by supplying the Japanese sashimi market rather than the local or export canning markets provided significant economic incentive for fishermen to target larger fish. An important requirement of the Japanese sashimi market is for fish of greater than 15 kg weight, which prior to 1984 comprised only about 13 per cent of the Australian catch.

B Composition of the fish catch, by age class



The assignment of individual quotas gave fishermen the confidence and security to target larger fish, bypassing schools of small fish on traditional inshore grounds, in the knowledge that they had the entire fishing season in which to catch their individual quotas. Most of the South Australian fleet began to fish further offshore, in the waters above the edge of the continental shelf in the middle Great Australian Bight area. An increasing number of Western Australian fishermen also started fishing further offshore in the Bight, in conjunction with the South Australian fleet.

The associated changes in the size composition of the South Australian and Western Australian catches over the period 1982–86 are depicted in figure B. The proportion of fish greater than 15 kg weight in the total catch (fish aged four years and more) steadily increased to 35 per cent, while the amount of fish being exported to the sashimi market increased from around 2600 t in 1983-84 to over 4500 t in 1986-87.

Although there was already a trend toward supplying this market, the changeover to ITQs certainly accentuated it by providing fishermen with greater incentives to maximise the value of their now limited catch.

The trend of increasing average size of fish in the Australian catch was reversed in the 1987-88 season. Although fishermen attempted to target larger fish on offshore grounds as in previous years, few schools were located (Caton 1988). After extensive searching the fleet moved closer inshore to fill their quotas with the more abundant younger fish. The scarcity of large fish was almost certainly the result of the large catches of juvenile fish taken in the early 1980s by the South Australian and Western Australian fleets prior to the introduction of ITQs.

4. Modelling the fishery

Substantial changes in fleet structure, operation and profitability have occurred since the 1983-84 season. These changes cannot be attributed solely to the effects of the ITQ system. Fleet structure and performance have also been influenced by factors which have little or nothing to do with the introduction of ITQs. For example, the reduction in the total Australian quota, and the impact of the heavy losses sustained by New South Wales and South Australian operators over a number of years before 1984 would have almost certainly resulted in a contraction in the size of the southern bluefin tuna fleet in both states, irrespective of the form of management of the fishery.

Essentially, the question of what would have happened to fleet structure, the amount of capital employed and profits if ITQs had not been introduced needs to be answered to provide a base against which fleet structure and profitability under ITQs can be compared directly. The changes attributable to ITQs alone can then be assessed.

If ITQs had not been introduced in 1984, the need to strictly limit catches of southern bluefin tuna would almost certainly have resulted in a continuation of management by aggregate quota. Regulation of the fishery by input controls could not be relied on to bring about the required reduction in catch.

Under an aggregate quota system, such as that which operated under the interim management plan, the total catch of the fleet of each state is limited. The number of boats operating might be unrestricted, as in the 1983-84 season, or alternatively limited entry arrangements might be superimposed on the aggregate quota system, restricting boat numbers in each sector of the fishery.

A simulation model provides a framework for the assessment of the economic impact of each management scenario. The model incorporates the major biological, physical and economic relationships in the fishery. The model is based on the one developed by the Industries Assistance Commission in 1983 to examine the economic and biological effects of different management policies on the fishery. The model has been modified by the Bureau to take into account the way the fleet adjusts over time. The model has also been updated to reflect more recent conditions in the fishery. Biological data were obtained from CSIRO, and economic data were obtained from logbooks and discussions with fishermen.

The purpose in using the model is to estimate the flow of economic returns and costs, the amount of capital employed and changes in the size of the fish stock in response to alternative management regimes applied to the fishery. This is achieved by simulating the behaviour of the fishing fleet and the fish stock over time.

To identify the likely future trends in the size of the parent stock under ITQs, simulations featuring declining recruitment were carried out. Constant recruitment was assumed when examining the relative effects of alternative management schemes on the economic variables of interest (fleet size, capital employment and profitability). This is because with constant recruitment the parent stock and the structure of the fleet eventually stabilise under each management alternative. If declining recruitment were used, a stable state would not be reached so the choice of time period for comparing the alternative management schemes would be arbitrary, and thus inconclusive.

A brief description of the structure of the model is given below; the mathematical specifications are detailed in the appendix. The data used in the model are also reported in the appendix.

4.1 Structure of the model

A schematic representation of the model is given in figure C. The model has three major components: biological, physical and economic. For all the aggregate quota simulations (including both unrestricted and limited entry scenarios), data relating to the operation of the fleet under the aggregate quota scheme in force in 1983-84 were initially used in the model. These simulations, in common with those carried out for the fishery under ITQs, commence in the 1983-84 season and run for twenty years.

The sets of parameter values for the first three years of the ITQ simulations were chosen to reflect the observed operations of the fleet over that period. The parameters for subsequent years were based on the 1986-87 values, but varied with the size of the fish stock and boat numbers. The values of the major variables — boat numbers, profits and losses and fish numbers — were calculated for each year of all simulations.

The relationships and linkages in the model are discussed below in relation to each component of the model.

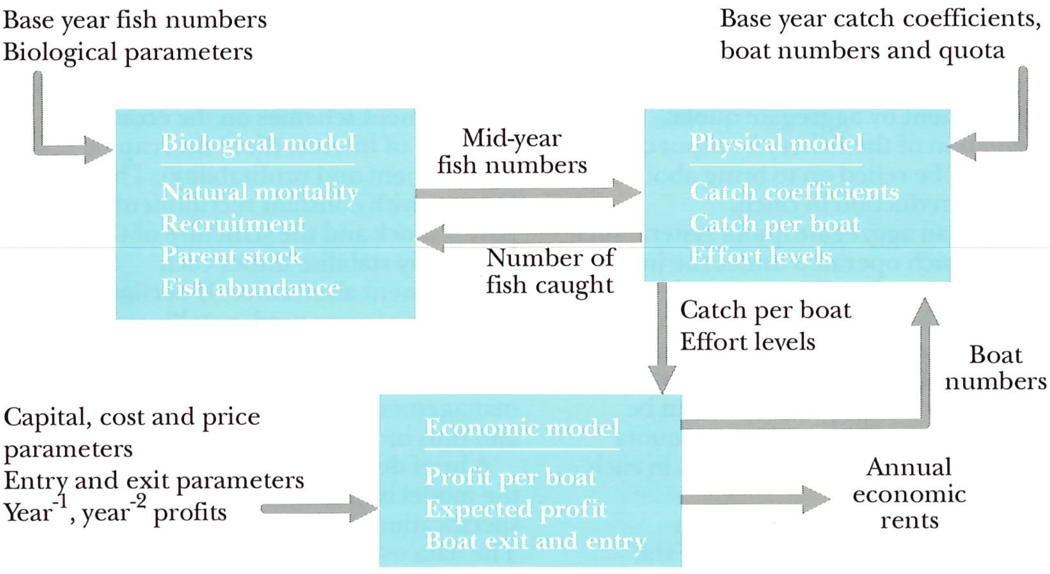
Biological

The fish stock was divided into nineteen age classes. Starting fish numbers in each age class for the base year of the simulation were derived from CSIRO estimates. Each year a proportion of each age class is lost to fishing and through natural mortality. The rate of natural mortality was assumed to be the same for all age classes in all years (as in the analyses of Hampton and Hearn 1987). Fishing mortality, and hence catch in any year, varies across age classes according to the pattern of fishing activities.

The total catch was assumed to be taken instantaneously at the midpoint of each year. The stock is augmented each year by recruitment to the youngest age class. The model can be run under the assumption of either constant or declining recruitment. Under the constant recruitment assumption, the size of the parent stock has no effect on the recruitment rate. The alternative assumption, as adopted by scientists at the 1988 scientific meeting, is that the recruitment rate declines linearly with the size of the parent stock when the size of the parent stock falls below a critical level (CSIRO 1988).

C Model of the southern bluefin tuna fishery

ABARE chart



Physical

There were four types of fishing boats included in the model: Western Australian pole boats, South Australian pole boats, South Australian purse seiners and Japanese longliners. Associated with each type of boat is a set of nineteen catch coefficients, corresponding to the number of age classes of southern bluefin tuna. The coefficients are estimates of the proportions of each age class harvested by the average boat of each type in the base year.

The initial set of catch coefficients used to model the fleet under aggregate quotas was derived from data on numbers of fish harvested and estimated stock size in 1983-84. For subsequent years these catch coefficients are modified in response to changes in the number of boats operating, as affected by the economic component of the model.

A decline in boat numbers from one year to the next increases the catch per unit effort of remaining boats, thereby increasing their catch coefficients. An increase in boat numbers has the opposite effect. The catch coefficients were assumed to be inversely proportional to boat numbers. This presupposes that total catch is insensitive to changes in fishing effort over a fairly wide range of fishing effort. This is characteristic of heavily exploited fisheries in which boat crowding reduces the effectiveness of the fishing effort expended by each boat. Figure D depicts the assumed short run relationship between catch and effort in the fishery.

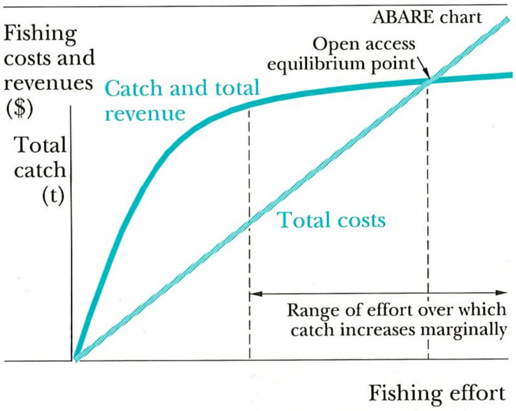
The catch of each boat is calculated as the product of fish abundance, catch coefficients and fishing effort, subject to the assumption that the total catch of each class of boat equals either their aggregate catch quota or the sum of their individual quotas. In effect, the yield per boat is predetermined by the quota and the number of boats in the fishery, thus leaving effort to vary in response to changes in fish abundance.

The fishing effort which may be exerted by any individual boat is, however, constrained to stay within 20 per cent of the average level per boat applied in the base year. This is in accordance with a previous estimate of the ability of operators to increase their fishing effort in the fishery (Industries Assistance Commission 1984).

Economic

The economic component of the model simulates the movement of boats into and out of the various sectors of the fleet in response to expectations of profits. Boat profits are taken as the difference between total revenues and total costs. Revenues are calculated by multiplying the catch in tonnes by the price received for the fish. Costs are broken up into fixed and variable components. Labour is paid a share of the gross returns from fishing.

D Simplified short run relations between effort and catch, and costs and revenues



The decision to enter or leave a fishery operating under an aggregate quota system, which allows unrestricted boat access, is based on expected profits rather than the profits of the current year alone. Fishermen's profit expectations are influenced by a number of factors including recent profitability in the fishery and anticipated changes in quota, costs of fishing inputs and fish prices.

However, because costs, prices and total quota are held constant throughout the simulations, fishermen are assumed to decide whether to remain in the fishery on the basis of their future expectations, which are based on current year and previous profits earned.

Their expected profit is thus taken as a weighted sum of the current and two previous years' profits. Greatest weight is given to current profits, and least to that earned two years previously. The expected real profit rate is then compared with a real rate of return of 10 per cent on capital invested, which is taken to be the opportunity cost of capital (as in Haynes and Pascoe 1988). A 10 per cent return on capital is assumed to be a normal return in the fishery.

The rate of boat entry or exit varies according to the difference between these two figures, and is constrained to not exceed the average rates actually observed in the three years prior to the introduction of ITQs. This mechanism ensures that, in the long run, given constant real prices and costs, the number of boats will stabilise, as average profits earned in each sector of the fishery approach normal levels.

4.2 Simulations

Simulations were carried out to allow comparisons to be made of the fishery under aggregate quota based schemes and ITQs.

Management by aggregate quota

Unrestricted entry. The system modelled in this simulation was essentially that which was in force in the fishery during 1983-84. The key element of this regime was a total Australian allowable catch, divided among the three states that had fleets operating in the fishery (New South Wales, South Australia and Western Australia).

The allocation to each state's fleet was based on previous catches. In the simulation, the quota allocation to each state was also based on historical catch, but modified to account for the reduction in the total allowable Australian catch and the virtual cessation of tuna fishing in New South Wales from 1984-85 to the present.

The main supplementary regulations in the 1983-84 management system included a limit on the number of purse seiners and their total catch, a prohibition of these boats from Western Australian waters and some inshore areas in South Australia where small fish were known to congregate, and a restriction on the minimum size of fish that could be landed.

Because the catch coefficients of the fleet were based on 1983-84 data, all of these restrictions were included implicitly in the simulation insofar as they affected the operation of the fleet in that year. It was, therefore, assumed that overall fishing patterns would not have been markedly different over the time span of the simulation from those which occurred in 1983-84.

Although catches were constrained under these management arrangements, the numbers of pole boats operating in each sector of the fishery were not, though the limit on the permissible number of purse seiners was maintained. Boats moved in and out of the fishery, depending on the operators' expectations of profitability. Boats entered the fishery whenever greater than normal profits were being earned by current operators and, conversely, left the fishery when profits dipped below normal levels. The outcome of unrestricted boat access is that all remaining boats earn normal profits in the fishery.

Boat profits may, however, be above or below normal for short periods because boats cannot enter or leave a fishery instantaneously. Operators may enjoy greater than normal profits for a period until additional boats are built or refitted to enter the fishery. Similarly, losses may be made for a number of years before boats will leave. The time taken for boats to leave the fishery is modelled as being greater than that taken for boats to enter, due to the limited alternative fishing opportunities and the difficulties inherent in selling specialised boats outside the fishery for which they were designed.

Under an aggregate quota system there would be less incentive for fishermen to target larger, more valuable fish. In the often short time before the total quota was filled, searching for larger fish on offshore grounds would take time which could be spent fishing for more certain, larger catches of small fish. The risk of being unable to locate larger fish, while forgoing the capture of small fish, would clearly reduce the incentive for fishermen to venture offshore.

Therefore, if aggregate quotas rather than ITQs had continued as the management system, the growth in sales of southern bluefin tuna to the Japanese sashimi market would probably have been less than that which occurred under the ITQ system. The average prices received for southern bluefin tuna under an aggregate quota could, therefore, be expected to be somewhat lower than those received under the ITQ system. How much lower is, of course, debatable.

A conservative view, based on estimated rates of sales growth to the sashimi market before and after ITQs, would be that 50 per cent of the actual increase in sashimi sales under ITQs would have occurred with an aggregate quota. In the aggregate quota simulations the average prices for southern bluefin tuna were estimated on this basis as being around 8 per cent lower than the prices under ITQs. The average prices for the first three years of the simulation (1983-84 to 1986-87) were set in proportion to the prices actually received under the ITQ system. From 1986-87 onwards the price was held constant.

The average fixed and variable components of fishing costs for each boat type were estimated, based on the costs identified in a Bureau survey of the fishery covering the years 1980-81 and 1981-82. Although recent costs data are available (for the 1986-87 season), these data reflect the major changes in fishing patterns that have taken place since the introduction of ITQs.

The fishing patterns, and hence costs, in 1981-82, under open access to the fishery are likely to more closely resemble those that would have emerged under aggregate quota management. The 1981-82 costs, updated to account for changes in the costs of fishing inputs, were therefore used. The consumer price index was used to deflate all cost categories, with the exception of fuel, which is the subject of a separate index.

Information regarding the structure of the fleet and aggregated catches by boat type and state for the three years preceding the introduction of ITQs is presented in table 6. This information was obtained from fishermen's logbooks. The quotas of each state's fishery were set in the model on the basis of the relative catches of each sector of the fleet in the 1983-84 season.

Limited entry. With an aggregate quota system the entry of boats to the fishery might have been subject to restrictions. In a simulation carried out to allow for this possibility an upper limit was set on the number of boats allowed to operate in each sector of the fishery. The limits correspond to the number of boats in each sector allocated individual quotas in 1984. This assumes that the process which would determine whether or not boats were granted access rights would be the same as that used for allocating ITQs.

Thus, if an operator is granted an individual quota, this is taken to be synonymous with being granted access rights to the fishery under limited entry, both allocation processes being based on operators proving historical participation and their financial dependence on the fishery.

The same costs are used as in the simulation of the aggregate quota management system. This is because the number of boats which would be initially fishing under the limited entry scheme would correspond to the number that were operating under the previous open access conditions. Costs of fishing would, therefore, probably not have changed significantly from those experienced with open access to the fishery.

Apart from the restriction on boat numbers, this simulation is identical to the one described for unrestricted entry with management by aggregate quota.

A licence buy-back scheme was not simulated even though it is possible that such a scheme would have been instituted to try to reduce boat numbers and fishing effort, and increase fishery profitability under limited entry arrangements. The effectiveness of a buy-back scheme depends critically on the remaining operators not increasing their fishing effort in response to any increase in profitability in the fishery. If they are able to do so, the extra profits generated by the removal of boats will be quickly eroded by the increase in the variable costs of fishing.

A Bureau study of the northern prawn fishery concluded that the buy-back scheme in place there was unlikely to result in significant long term gains to the industry because of the potential for remaining operators to increase their effort (Haynes and Pascoe 1988).

In 1983 the Industries Assistance Commission estimated that operators in the southern bluefin tuna fishery were able to increase their fishing effort by around 20 per cent within a year. Even if additional restrictions on the use of fishing inputs were introduced, effort would probably still increase as a result of improvements in fishing technology and in operators' skills. By reducing the flexibility with which fishermen operate, the input restrictions also impose long term costs on the industry. Thus, the benefits from a buy-back scheme would be steadily eroded, and industry profitability would fall toward the level which would be expected under limited entry alone.

Management by ITQs

The fleet is modelled as catching its full allocated quota (14.3 kt) in each year. (In 1986-87 the Australian government held the balance of the national quota of 14.5 kt.) This is despite the fact that the catch was limited to 11.5 kt in 1986-87 and 1987-88 under the agreement with the Japanese. Since the purpose of the model is to compare the economic effects of ITQ and aggregate quota management schemes, it is important that the total catch simulated under the alternative schemes is the same. The total catch under both ITQ and aggregate quota schemes is thus taken to be 14.3 kt each year.

A separate simulation of the fishery under ITQs has been carried out using the actual catches by the Australian and Japanese fleets in 1986-87 (11.5 kt and 15 kt, respectively) and assuming recruitment is declining, to identify prospects for the fish stock if these catches were to be continued. The results of this simulation are reported in section 5.3.

Data relating to the 1986-87 costs of fishing, prices received for southern bluefin tuna from various outlets, and capital values of boats were obtained from South Australian fishermen. Changes in the costs of the South Australian fleet since the 1981-82 economic survey of the fishery carried out by the Bureau were identified, and the same proportional changes applied to 1981-82 costs data on Western Australian pole boats.

From a level of $988/t (in 1986-87 dollars) received during the 1983-84 season, the average price received by Australian fishermen for southern bluefin tuna across all market outlets rose to $2000/t in 1986-87. Most of this improvement occurred as a result of the diversion of an increasing amount of fish away from canneries toward the much higher paying Japanese sashimi market.

Fishing costs per tonne of fish caught have fallen substantially under the ITQ system, but because of the increase in average catch per boat resulting from the consolidation of quota holdings, and the change in fishing patterns, total costs per boat (in 1986-87 dollars) have risen above pre-ITQ levels.

Instead of fishing on grounds a few hours from home ports, operators are now steaming two days or more to get to distant grounds on the edge of the continental shelf. Variable costs of production, particularly fuel costs, have therefore increased.

Fixed costs of production are also higher under ITQs than they would be under an aggregate quota system, because of the introduction of the 'user pays' principle for government services under which fishermen are required to pay a proportion (44 per cent in 1986-87) of the costs of managing the fishery. Because ITQ schemes tend initially to be more expensive to administer than the alternative schemes considered in this paper, and because there are usually fewer boats over which to spread the costs, the management levy paid by each fisherman under ITQs is larger than with alternative schemes.

Total management costs under the ITQ system were $600 000 in 1986-87, compared with an estimated cost of $400 000 for management of an aggregate quota scheme. This estimate is based on evidence presented to the 1983 inquiry on the expected costs of managing the aggregate quota scheme then in place (Industries Assistance Commission 1984).

The interest payments on borrowings made to finance the acquisition of quota have added to the fixed costs of most operators who have remained in the fishery. Although this cost clearly affects individual profitability, it is of no consequence in assessing the economic performance of the fishery. It is the returns being made on the resources employed in the fishery that are important.

Interest payments reflect only the distribution of ownership of these resources. The estimated returns are therefore adjusted to full equity. That is, interest payments on quota purchases or on the boat itself are omitted from costs. The interest component of costs has, however, been replaced by a measure of the opportunity cost of capital, taken to be 10 per cent of the value of capital employed in the boats.

The capital value of quota is not included since from a public perspective it has no opportunity cost. This is because the value of quota simply represents the expected earnings from catching the quota. In contrast, the value of the boat reflects the opportunity costs of the resources employed in its construction. These resources, unlike a quota, could otherwise have been productively employed elsewhere in the economy.

5. Results

5.1 Aggregate quota

The key results of the simulations concern the number of boats that would have comprised the fleet when it finally reached a stable state under the regime of aggregate quota. This steady state fleet can then be compared with that for the ITQ scheme, and the difference between them attributed to the effects of ITQs.

Unrestricted entry

The underlying assumption for aggregate quota management is that the unrestricted entry or exit of boats will ultimately result in the dissipation of all potential resource rents in the fishery (see, for example, Anderson 1986). Resource rents are profits in excess of a normal return for the industry that arise as a result of management reducing the amount of effort exerted in the fishery.

In the simulation the fleet under aggregate quotas takes around ten years to reach a stable state. The likely changes in boat numbers in the South Australian and Western Australian sectors of the fleet during this period are shown in figure E. Only South Australian and Western Australian fleets are represented because the New South Wales fleet became uneconomic and ceased to operate in 1984-85 due mainly to declining fish numbers off the New South Wales coast.

A similar reduction in fish abundance was experienced by the South Australian operators. But with the greater numbers of fish still available for capture, the effects on the South Australian fleet were less dramatic, though still pronounced. Catch per unit effort for each boat is reduced in the simulation, pushing fishing costs up and forcing operators into loss. This results in a rapid exit of boats in the first four years of the simulation, until the resulting improvement in individual catch rates, together with increases in the price of southern bluefin tuna, restores the profitability of the remaining boats.

The fleet does not immediately settle at a steady state because of the effects of modelling entry and exit of operators as being partly dependent on the profitability of the previous two years. This results in more boats initially entering or leaving the fishery than are necessary to enable the fleet to again earn normal levels of profit. The South Australian pole boat fleet finally stabilises at 22 boats, 17 less than in the base year 1983-84.

In common with the pole boat fleet, South Australian purse seiners incur losses in the initial years of the simulation. However, because purse seiners have few alternative fishing opportunities, the rate of exit is slow and only one of the five original purse seiners leaves the fleet. The increase in tuna prices, together with the departure of one purse seiner, allows the profits of the remainder of the purse seine fleet to return to normal levels.

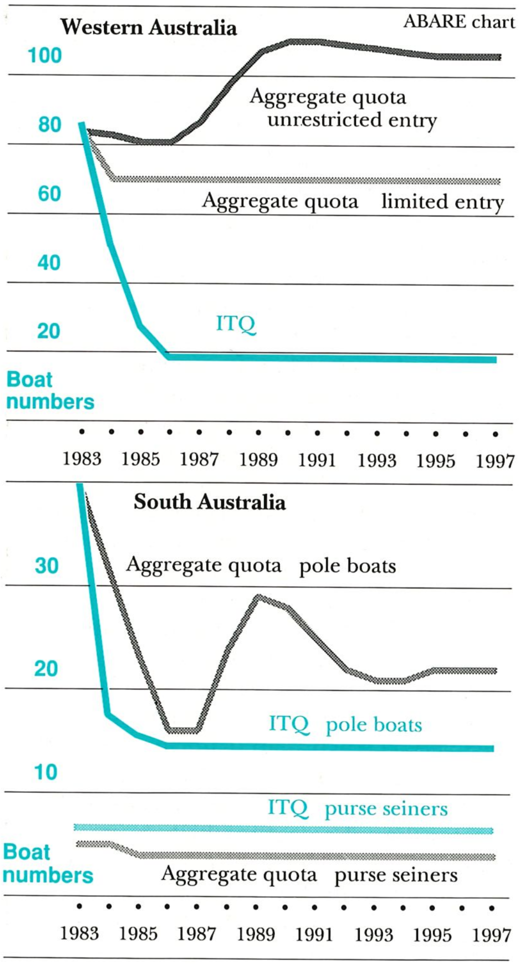
The eventual departure of 17 pole boats and one purse seiner from the South Australian fleet and 5 pole boats and one purse seiner from New South Wales would have reduced the amount of capital employed in those sectors of the fishery by an estimated $23m compared with 1983-84. This estimate makes allowance for the fact that some of these boats would have also operated in other fisheries on a seasonal basis, and that not all the capital employed in them can be considered as being specific to southern bluefin tuna. The capital costs have therefore been apportioned on the basis of the estimated proportion of time spent fishing for southern bluefin tuna.

In contrast with the disappearance of the New South Wales fleet and the decline in fleet size in South Australia, the number of boats operating in Western Australia under aggregate quota management increases from 84 in 1983-84 to a stable

106 in the mid-1990s in the simulation (see figure E). Although a slight reduction in fleet size might have occurred in the early years, the increases in average price of southern bluefin tuna in 1985-86 and 1986-87 would probably have prompted the rapid entry of boats to the Western Australian fishery.

Despite the 26 per cent increase in boat numbers in Western Australia, the total capital employed in this fleet is estimated to increase by only about $1.8m. This is because the boats used are relatively small, averaging around 11 m in length, and have a correspondingly modest capital value. They also operate in a number of other fisheries so that their total capital is not solely attributable to fishing for the tuna.

E Simulated changes in boat numbers under different management schemes



The total amount of capital which could be expected to be employed in the fishery as a whole when the number of boats stabilises is therefore estimated at $42m, over $21m less than that employed in the 1983-84 season, before the introduction of ITQs. So, even if there had been no change in the management regime in the fishery from 1983-84 onwards — an aggregate quota regime being maintained — many of the boats in New South Wales and South Australia would probably have left the fishery, and the total capital employed might have fallen by as much as 30 per cent compared with 1983-84. This process may have taken around ten years before a stable fleet was achieved, all other influences being constant.

Limited entry

Because boat numbers fall in both New South Wales and South Australia, the limited entry restrictions have no effect on the eventual size of the fleet in these sectors of the fishery. Thus, the fleet trajectory in South Australia under the unrestricted aggregate quota scheme shown in figure E also applies to this simulation. Only in Western Australia, where the fleet is able to operate profitably, do the restrictions on boat numbers come into effect.

In the simulation of an unrestricted aggregate quota, boat numbers in Western Australia increase to 106 in response to the resource rents being earned. With the restrictions on boat entry the existing fleet of 70 is modelled as continuing to enjoy these rents, totalling around $1.6m a year. Individual operators would, however, be likely to increase their fishing effort to try to secure for themselves a larger share of these rents. In consequence, rent levels would be steadily eroded.

5.2 ITQs

Because most remaining Western Australian pole boats devote a considerably greater proportion of their time to fishing for southern bluefin tuna under ITQs than they did with the previous aggregate quota (J. Sutton, Western Australian Fisheries Department, personal communication, November 1987), their total capital is considered as being directed at southern bluefin tuna. The total capital employed in the fishery under the ITQ management scheme in 1986-87 (and onwards in the simulation) is estimated at around $31m, with over 90 per cent of this being in the South Australian fleet.

The amount of capital employed in the fishery under ITQs is therefore around $10m less than that which might have been employed under an aggregate quota with limited entry scheme under steady state conditions, and some $12m less than under a continuation of the unrestricted aggregate quota regime. Only about 30 per cent of the total $33m loss of capital from the fishery following the introduction of ITQs can be thus attributed to the effects of the ITQ scheme. The remainder would probably have left the fishery anyway if alternative management regimes had been used instead of ITQs.

The reduction in the number of boats operating under ITQs has had a positive effect on the profitability of the remaining fleet. The average catches per boat in Western Australia and South Australia are estimated to be 67 per cent and 28 per cent higher, respectively, than they might have been under the aggregate quota with limited entry system, and 90 per cent higher in Western Australia than they might have been under a continuation of the previous aggregate quota.

These increases in catch rates are proportionately greater than the reductions in boat numbers in each state, suggesting that the remaining fishermen are those who had higher than average catch rates under the previous management scheme. This is consistent with the theory that trade in quotas will result in more efficient fishermen remaining in the fishery.

These increases in catch rate serve to reduce the variable costs of fishing per tonne of tuna caught. Changes in the level of effort of each boat also have a major influence on the variable costs of fishing. The level of fishing effort by individual boats in South Australia could be expected to be around 20 per cent lower under ITQs than it might be under the aggregate quota system while still catching the same tonnage of fish. This is because of a relative increase in the abundance of fish in South Australia under the ITQ scheme, due to lower Western Australian catches.

The average level of fishing effort of the Western Australian boats would probably be about the same under both ITQ and aggregate quota schemes, but under an aggregate quota with limited entry scheme it could increase somewhat when boat numbers are prevented from increasing.

The net effect of the changes in catch rates and effort levels is to reduce the average cost of catching a tonne of tuna by 23–28 per cent compared with the likely production costs under the aggregate quota based management schemes.

With increased gross returns from fishing and decreased fishing costs per tonne, economic rents of around $10m a year (at 1986-87 costs and prices) could be earned from the fishery under ITQs if the fleet catches its full quota. However, not all economic rents earned by fishermen result from management of the fishery. Some rents are attributable to the fishing and management skills of fishermen.

Highly skilled fishermen can earn ‘highliner’ or intramarginal rents under both open access to the fishery and under management (Anderson 1986). Resource rents on the other hand arise only as a result of fishery management. Using a method described by Anderson (1988) and detailed in the boxed section opposite, highliner rents are estimated to comprise about 36 per cent of total economic rents in the fishery. The resource rent resulting from the ITQ system is therefore estimated at around $6.5m a year.

This estimate is, however, probably lower than the actual resource rents earned by the fleet in 1986-87. This is because the compensation payment received by Australian fishermen from the Japanese industry, in return for not catching 3 kt of their quota, was probably greater than the profits which Australian fishermen could have expected to earn if they had caught the extra 3 kt.

Because labour is paid a share of the gross returns from fishing, the increases in average price received for southern bluefin tuna and in catch per boat, and the consequent increase in gross returns, may have allowed the skippers and crews to share temporarily in the rents being earned in the fishery. However, the average share of the gross returns paid to the skipper and crew has fallen from 30 per cent in 1981-82 (Bureau of Agricultural Economics 1986) to around 15 per cent in 1986-87. This reduction has probably eliminated any potential rents to labour.

The key results of the simulation of management by ITQs, together with those for the simulations of the aggregate quota with no entry restrictions and the aggregate quota with limited entry scenarios, are presented in table 7 on the following page.

Components of economic rent in the Australian southern bluefin tuna fishery

Economic rents are profits in excess of a 'normal' return on capital employed, given the particular risk characteristics of the fishery. What constitutes a 'normal' return in the fishery is debatable. In this study it has been assumed to be a 10 per cent real rate of return on capital.

Not all economic rents earned by fishermen result from fishery management. Some are attributable to their fishing and management skills. Highly skilled fishermen can earn 'highliner' or intramarginal rents under both open access to the fishery and under management (Anderson 1986).

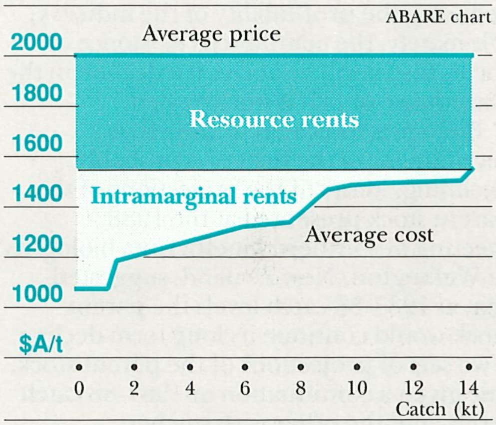
Resource rents, on the other hand, can only arise as a result of fishery management. Resource rents are generated when management reduces the level of fishing effort in the fishery. This can be achieved by introducing a system of ITQs. As the less efficient operators sell their quotas and leave the fishery, the catch rates, and hence returns per unit effort, increase for the remaining operators. These increased returns per unit effort are resource rents. These resource rents would be quickly dissipated by the entry of more boats if open access to the fishery were restored.

The problem is to distinguish between the different rent components when measuring profitability in the industry under ITQs. The method used here is that suggested in Anderson (1988). This method relies on the identification of the average cost of production of the marginal (least profitable) boat in the fleet. The amount of intramarginal rents earned per tonne of southern bluefin tuna caught by other operators is then estimated as the difference between their average costs of production and those of the marginal boat. Since, by definition, the marginal operator can earn no intramarginal rents any above-normal profits earned by this operator are resource rents.

In the figure below, the estimated average costs per tonne of southern bluefin tuna caught by individual producers in 1986-87 are shown in ascending order against their quota holdings. A single weighted average price for the fish is also shown.

The sum of the differences between the average returns and the average costs per tonne of fish caught is the total economic rent

Economic rents in the fishery



earned in the fishery. This is estimated at around $10.2m if the fleet catches 14.3 kt. The resource rent per tonne of fish caught is estimated at $453, this being the difference between the average cost per tonne incurred by the marginal boat ($1547/t) and the average price received ($2000/t). Multiplying by the total number of tonnes of southern bluefin tuna caught gives an estimate of the total resource rents earned in the fishery of $6.5m. The residual $3.7m is intramarginal rent.

7 Key results of simulations

Item	Unit	Aggregate quota	Aggregate quota with limited entry	ITQs
Boat numbers a				
South Australian pole boats	no.	22	22	14
South Australian purse seiners	no.	4	4	6
Western Australian boats	no.	106	77	17
Total boats	no.	132	103	37
Total capital employed	$m	43	41	31
Annual resource rents a				
South Australian pole boats	$m	0	0	4.0
South Australian purse seiners	$m	0	0	2.0
Western Australian pole boats	$m	0	1.6	0.5
Total resource rents	$m	0	1.6	6.5

a When the fleet stabilises.

5.3 Prospects for the fishery

Maintaining a healthy resource base is, of course, essential for the continued economic well-being of the industry. Declining fish abundance increases the amount of fishing effort required to take a given catch, raising the costs of fishing and reducing the profitability of the industry. Ultimately, the commercial existence of the industry will be at risk if a decline in the abundance of fish is not arrested.

Biologists indicated in 1988 that recruitment to the fishery is probably declining. Many of the projections of the parent stock presented at the 1988 meeting of southern bluefin tuna biologists in Wellington, New Zealand, suggested that at 1987-88 catch levels the parent stock would continue its long term decline. Two sets of projections of the parent stock, one given a continuation of 1987-88 catch levels, and the other with catches corresponding to 1987-88 quotas, are shown in figure F. The projections indicate that the 1987-88 catches of Japan and Australia are unsustainable and would, if continued, lead to the demise of the stock. Concern that the fishery might collapse led biologists to recommend major reductions in catch across the entire fishery.

As a result, catch limits have been administratively reduced by more than 40 per cent compared with the catches taken in 1987-88. The new catch limits are 6.25 kt for Australia, 8.8 kt for Japan and 0.45 kt for New Zealand.

It is important to note that the decline in the parent stock which made the current catch reductions necessary resulted mainly from the large catches taken by both Japanese and Australian fleets in the early 1980s and before. Since the introduction of ITQs in 1984 the number of fish caught by the Australian fleet has been more than halved as a result of lower total catches and the increase in the average size of fish caught.

Fishing pressure on the stock has, therefore, been substantially reduced. However, the benefits of this reduction in the catch of small fish have not yet flowed through strongly to the parent stock. Further reductions in catch in the short term were necessary to allow the parent stock to recover.

The quota cuts were administered by the Australian, Japanese and New Zealand governments. Although there were probably economic incentives for the Japanese to pay for further reductions in Australian catches, biologists indicated that Australian restraint alone would not be sufficient to avert the risk of recruitment failure and the possible collapse of the fishery. Japanese catches of mature fish also had to be reduced in the short term.

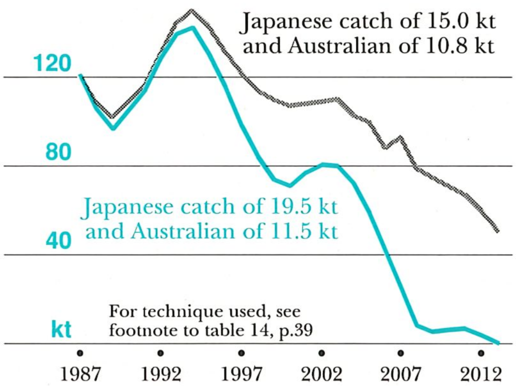
Changes in the size of the Australian quota are facilitated by the ITQ program.

The allocation of ITQs as a percentage of a total allowable catch explicitly recognises the potential need to adjust catches to reflect changes in stock size. Because the market value of quota rights is linked to the fish stock, fishermen holding ITQs have an incentive to heed biological advice on catch restraint to protect the long term value of their rights in the fishery.

Trade in ITQs among Australian fishermen serves to mitigate potential economic hardship from a reduction in the total allowable catch. With further proportional reductions in the size of individual quota holdings, the lowest cost, most efficient producers have the incentive to purchase additional quota to enable their boats to continue to operate at efficient catch levels. Less efficient operators who choose to retire from the fishery receive some compensation for doing so, in the form of the purchase price received for their quota. Quota trading allows total fishing costs to be reduced and the industry to continue to operate efficiently at a lower quota level.

F Projections of the parent stock with declining recruitment

ABARE chart



This outcome contrasts with that which would be likely to occur under an aggregate quota. In similar circumstances of a reduction in total catch, individual fishermen would have strong incentives to increase their fishing effort in an attempt to maintain their historical catch levels. An escalating rush to catch and an associated shortening of the fishing season could be expected to result. This would raise industry costs and exacerbate the economic hardship faced by operators.

Because of the currently depleted state of the fish stock, quotas have been reduced to try to avert a stock collapse. Australian and Japanese quotas have been lowered by an equal proportion. If in the longer term the stock recovers and catch limits can be increased, incentives will probably still exist for Japanese to pay Australians to catch less fish, unless Australians can substantially improve their returns per tonne of fish caught, perhaps by adopting longlining as their main fishing method. In fact, the proximity of Australia to the main longline fishing grounds, and the cost advantages which this implies, may place Australian fishermen in a strong competitive position to supply increasing quantities of larger southern bluefin tuna to the Japanese market.

Direct industry to industry agreements on Australian catch restraint evolved as a result of the assignment of ITQs in the Australian fishery. This is because with more secure property rights in the fishery, Australian fishermen now focus less on the physical division of the harvest and more on the division of net economic benefits to be derived from the resource. The Japanese industry, recognising the costs which Australian catches of juvenile fish impose on their activities, has demonstrated already its willingness to compensate Australian operators for reducing their catch.

The possible recovery of the stock in the longer term might result in southern bluefin tuna once more becoming available off the New South Wales coast. If the average size of fish caught off New South Wales were larger than elsewhere in Australian waters, as was the case in the early 1980s, there would be strong incentives for the focus of the Australian industry to shift to New South Wales to target these higher value fish. The ITQ system facilitates industry adjustment of this sort by allowing fishermen greater freedom to choose where and when they want to fish.

6. Discussion

The introduction of ITQs to the southern bluefin tuna fishery and the associated reduction in the total catch resulted in a rapid adjustment to the structure of the fleet. Between 1984 and 1988 the number of boats in the fishery fell by more than 70 per cent. The catch rates of the remaining boats increased, lowering the costs of fishing per tonne of tuna caught.

Increased targeting by fishermen of larger fish for the lucrative Japanese sashimi market increased the gross revenues from the catch. As a result profitability in the industry grew strongly. The resource rent earned by the fleet in 1986-87 is estimated to have been in excess of $6.5m.

Simulations of the fishery under alternative management regimes indicate that the amount of resource rent earned by the fleet would be less than 25 per cent of that earned under ITQs, for the same total catch. Also, the capital employed in boats under management based on aggregate quota would likely have been $10m to $12m greater than with ITQs. It can be concluded that the economic performance of the fishery has been substantially improved by the changeover to ITQs.

It should be noted that the resource rent is not captured by present holders of quota alone but by all who were originally allocated quotas. The operators who left the fishery share in the rents through the proceeds from the sale or lease of their quotas to the remaining fishermen.

When assessing the net gains from ITQs from a public perspective the costs of managing the fishery must be allowed for, as must any related costs or benefits which arise outside the fishery. The cost of managing the fishery in 1986-87 was close to $600 000 for the year, 44 per cent of which was paid by fishermen. The remainder was a cost to Australian taxpayers, which must be deducted from the gains generated within the fishery.

The advent of the 'user pays' policy, in relation to the recovery from fishermen of a percentage of fisheries management costs, has led fishermen to examine closely whether or not the management services provided represent value for money. As noted above, the resource rents earned by quota holders in 1986-87 were probably in excess of $6.5m, while the costs incurred by them in purchasing management services were less than $0.3m. Because all of the resource rents in the fishery are generated by ITQ management, it can be said that for every $1 invested by quota holders in management services, they received, on average, a return of around $21 in resource rents. Naturally, the amounts of resource rents earned in the future will vary according to the size of the quota, the average price of southern bluefin tuna and the costs of fishing.

The redeployment of the labour and capital which left the fishery after the introduction of ITQs should result, theoretically, in additional wealth being generated elsewhere in the economy, a gain which could also be attributed to the ITQ system. However, if these surplus resources entered alternative fisheries they may have had the opposite effect, reducing overall profitability if the fisheries were already fully exploited in an economic sense. Other Bureau research has found that many of the operators who left the fishery did enter or increase their effort in other fisheries such as the south-east trawl fishery.

Although most of the New South Wales operators who left the fishery increased their effort in an already heavily fished part of the south-east trawl fishery, all of these operators would probably have left the fishery in any case because of the decline in the availability of southern bluefin tuna in New South Wales waters.

Their activities cannot, therefore, be said to result from the effects of the ITQ scheme except insofar as the ITQ scheme increased the rate they left the southern bluefin tuna fishery and led to a more rapid change to full time trawling than might otherwise have been the case. Also, the payments received from the sale of southern bluefin tuna quotas may have been reinvested by some operators in their boats to increase their trawling capabilities. If this occurred, extra costs would have been imposed on the trawl fishery.

Simulations indicate that in South Australia 18 of the 24 boats which left the fishery following the introduction of ITQs would have left the fishery even if the fishery had been managed by aggregate quota, with or without limited entry. However, their exit would probably have been more gradual. Many of the South Australian boats which left the fishery started fishing in the south-west sector of the south-east trawl fishery which was, at that time, considered to be underdeveloped. Their activities may have proved beneficial to the economic performance of that fishery.

The simulations also suggest that most Western Australian operators would probably have continued to fish for southern bluefin tuna under aggregate quota. The reduction in the number of boats in Western Australia is, therefore, attributable to the effect of ITQs. Some of the boats which left the fishery entered or increased their effort in other fisheries, some of which were believed to be already overexploited.

However, if costs resulting from increased fishing effort were imposed on these alternative fisheries, they would at least be partly offset by the gains generated from the capital and labour which a proportion of former southern bluefin tuna operators invested in shore based industries, and the possible gains generated by South Australian boats which turned to trawling. If then, net costs were incurred outside the southern bluefin tuna fishery as a result of the ITQ scheme, the costs are likely to have been small relative to the substantial gains within that fishery.

While it is clear that ITQ management has many desirable features, ITQs can produce incentives for fishermen to discard lower valued fish in an attempt to increase the returns from catching their quota by landing only fish of relatively high value. Although this has not been reported in the southern bluefin tuna fishery under ITQ management (Wesney 1988), it is probably because operators have generally been unable to fill their quotas profitably due to low fish abundance.

If the stock were to recover so that individual quota limits became constraining, the dumping problem might arise because of the price differential between canning and sashimi grade tuna. If dumping of fish did occur, there would be a long term cost on the industry which is not accounted for in this analysis.

Management by aggregate quota would also be likely to lead to fish dumping. This is because minimum size restrictions would probably be necessary to partly counter the incentives for fishermen to rush to catch as many fish as possible, with little regard to their size. Discarding of fish smaller than the size limit would probably result, as occurred in the 1983-84 season, even if the quota were unconstraining as it was between 1984-85 and 1987-88. Insofar as the costs associated with the probable discarding under an aggregate quota scheme have, to date, been averted through management by ITQs, there are also gains due to the ITQ scheme which have not been included in the analysis.

The southern bluefin tuna fishery has several features which make it particularly amenable to management by ITQs. Foremost is the fact that it is based on a single species of fish. With only one species under quota control the problems of balancing multispecies catches and quotas, as experienced in New Zealand inshore fisheries (Geen 1987), do not arise.

Second, because the market outlets for southern bluefin tuna are relatively few and well defined, the scope for black market sales is very limited. This does not imply, however, that monitoring the quantities of fish flowing through the known marketing channels is simple, particularly with the advent of offshore fish transshipment by the Australian fleet to Japanese carrier boats; rather, that the difficulties of enforcement are somewhat less than they might otherwise be.

Notwithstanding the beneficial effects on management costs of these features of the fishery, it is important to note that the extent of the gains from the ITQ system is such that management costs would have to be very large indeed before the effectiveness of the ITQ approach was prejudiced.

Under management based on input controls or aggregate quotas, the costs of managing the fishery could be expected to increase over time as more and more supplementary regulations were added in attempts to prevent fishing effort from increasing. In contrast, the level of management services provided under ITQs can be expected to fall as the number of operators in the fishery declines, and as the incentives for self-policing among remaining fishermen grow. Such incentives are likely to result from the realisation by fishermen that the value of their quota rights will be eroded if catches are allowed to exceed the specified total quota.

So while input controls or aggregate quotas may initially seem more attractive than an ITQ scheme when considering the costs of management, this advantage is likely to disappear in the longer term.

The advent of the 'user pays' policy in relation to management costs can be expected to help gradually dismantle another major hurdle to the more widespread application of ITQs in Australia. In the past, Australian taxpayers were the effective purchasers of fisheries management services. Because society was generally unaware of the gains, if any, being generated by these services, there was little incentive for it to permit fishery managers to implement more costly but more effective management programs. However, since fishermen are now becoming the purchasers as well as the main beneficiaries of management services, they can be expected to increasingly demand services which will offer them greatest value for money.

While ITQs will not be the most effective management tool in all cases, their success in the southern bluefin tuna fishery should prompt those concerned with the management of other fisheries to consider ITQs more closely as an alternative management strategy.

Appendix Model specification and data used in the model

The purpose of the model was to simulate the flow of economic returns and costs, the amount of capital employed and changes in the stock of southern bluefin tuna over time under various management regimes.

The model consists of a series of mathematical relationships (see below). These relationships are simplified representations of the actual biological and economic processes in the fishery.

A given number of boats of each type and a tuna population age structure are initially entered into the model. For each year the number of boats in the fishery and the size and age structure of the stock are calculated.

The size and age structure of the stock are determined by the size of the total quota or catch from the stock, the age structure of the catch, the stock–recruitment relationship, and the rate of natural mortality. The number of boats in the fishery in a given year depends on the size of the total quota and past and present profitability.

In the model, catches and economic returns are calculated per boat. As all boats of a given type are assumed to generate the same catches and face the same costs and prices the calculations performed on a per boat basis are simply summed to give fleet totals.

Equations

The symbols used in the model are defined in table 8 on page 36.

Biological component

Parent stock. The fish stock is divided into nineteen age classes or cohorts (1 to 19). The parent stock is the sum of the number of fish in cohorts 8 to 19 multiplied by their mean weight.

(A1) $PBM_t = \Sigma_i N_{ti}[w_i/1000]; \quad i = 8 \text{ to } 19.$

Recruitment. Recruitment is modelled as a knife-edged process occurring once a year. Recruitment can be modelled as being either constant, and therefore independent of the size of the parent stock, or it can be affected by the size of the parent stock. In the latter case recruitment is constant when the parent stock is above a certain level. Below that level it declines linearly with declining parent stock.

The form taken by the recruitment–parent stock relationship depends on estimates of historical parent stock and recruitment produced by virtual population analysis. These estimates in turn depend on the parameter combinations and assumptions used in the virtual population analysis (see, for example, CSIRO 1988).

(A2) $N_t = \begin{cases} 5495243 & \text{if } PBM_{t\text{-}1} \geqslant 215420 \\ 25.728PBM_{t\text{-}1} & \text{otherwise.} \end{cases}$

Size of next year's fish population (numbers of fish by cohort).

(A3) $N_{(t+1)(i+1)} = N_{ti}\exp(\text{-}m) - CN_{ti}\exp(\text{-}m/2).$

Physical component

Catch coefficients. Equations (A4) and (A5) give the fleet and boat catchability coefficients for the base year of the simulation. The fleet coefficient measures the fraction of the total number of fish in a cohort *i* caught by all boats in boat type *b* in the base year. The boat coefficient is the fleet coefficient averaged over the total number of boats of that type.

Over time the boat catch coefficients change in response to variations in the number of boats in the fleet. In equations (A6) and (A7) the catchability coefficients are adjusted as a result of the quota being redistributed to all boats remaining in the fleet.

Although the absolute values of the boat coefficients change with the number of boats, the relativities between coefficients remain the same, thus preserving the base year catch–age structure.

(A4) $Q_{0ib} = TN_{0ib}/N_{0ib}\exp[-m/2]$.

(A5) $q_{0ib} = Q_{0ib}/NV_{0b}$.

(A6) $q_{tib} = a_{tb}q_{0ib}$.

(A7) $a_{tb} = QUOTA_b/\Sigma_i N_{0ib}q_{0ib}[w_i/1000] \exp[-m/2]NV_{tb}; \quad i = 1 \text{ to } 19$.

Fishing effort. Effort is measured as an index relative to the base year in which effort is assumed to be unity — equation (A8). Effort in a given year is proportional

8 Symbols used in the model

Subscripts

t	Year
i	Cohort
b	Boat type
0	Base year
j	Number of lagged years

Variables

CN_{tib}	Catch, in number of fish, in year t from cohort i by a type b boat
C_{tib}	Catch, in tonnes, in year t from cohort i by a type b boat
E_{tb}	Level of effort exerted in year t by a type b boat (index)
q_{tib}	The proportion of the total number of fish in cohort i harvested in the year t by a type b boat
NV_{tb}	Number of type b boats in the fishery in year t
N_{ti}	Number of fish in cohort i in year t
R_{tb}	Revenue earned in year t by a type b boat
TC_{tb}	Total cost incurred in year t by a type b boat
VC_{tb}	Variable cost (per unit of base year effort) incurred in year t by a type b boat
FC_{tb}	Fixed cost incurred in year t by a type b boat
LC_{tb}	Labour cost incurred in year t by a type b boat
PR_{tb}	Profit earned in year t by a type b boat
PR^*_{tb}	Expected profit in year t by a type b boat
PBM_t	Parent stock in year t
a_{tb}	Scaling factor to adjust the catch coefficients of a type b boat from the base year to year t.

Parameters

OC_{tb}	Opportunity cost of capital in year t by a type b boat
NV_{0b}	Number of type b boats in the fishery in the base year
N_{0i}	Number of fish in cohort i in the base year
w_i	Average weight of fish in cohort i
TN_{0ib}	Total number of fish in cohort i harvested in the base year by all boats of type b
$QUOTA_b$	Total allowable catch in tonnes, for all boats of type b
q_{0ib}	The proportion of the total number of fish in cohort i harvested by one boat of type b in the base year
Q_{0ib}	The proportion of the total number of fish in cohort i harvested by all boats of type b in the base year
P_t	Average price per tonne in year t
W_j	Weights assigned to lagged boat profits in expected profit calculation
β_b	Boat exit and entry parameter for boat type b
m	Instantaneous rate of natural mortality

to the abundance of fish in that year relative to the base year — equation (A9).

(A8) $E_{0b} = 1$.

(A9) $E_{tb} = \Sigma_i N_{0ib} q_{0ib} [w_i/1000] / \Sigma_i N_{tib} q_{0ib} [w_i/1000]; \quad i = 1 \text{ to } 19.$

Catch. Catch (equation A10) is determined by the abundance of fish, their vulnerability to fishing gear (catch coefficients), and the amount of fishing effort. The entire catch is assumed to be taken instantaneously at the mid-point of the year. The term exp[$-m/2$] allows for the loss of fish from natural causes during the first half of the year.

By assigning a mean weight to fish in each cohort the catch in tonnes by each boat type is calculated using equation (A11).

(A10) $CN_{tib} = E_t q_{ti} N_{ti} \exp[-m/2]$.

(A11) $C_{tib} = CN_{ti}[w_i/1000]$.

Economic component

Revenue. Revenues (equation A12) are the product of the average price per tonne of southern bluefin tuna and the sum of catches from each cohort.

(A12) $R_{tb} = P_t \Sigma_i C_{tib}; \quad i = 1 \text{ to } 19.$

Cost. Boat costs (equation A13) are either fixed costs (insurance, depreciation and so on) or variable costs (fuel, gear repairs and so on). Crew are paid a share of the total revenue — equation (A14).

(A13) $TC_{tb} = FC_{tb} + E_{tb} VC_{tb} + LC_{tb}$.

(A14) $LC_{tb} = 0.15 R_{tb}$.

Profit. Net profit is calculated in equation (A15) as the difference between revenues and total costs.

(A15) $PR_{tb} = R_{tb} - TC_{tb}$.

Expected profit. Expected profit next year is a weighted sum of current year profit and two previous years' profits, with the greatest weight being assigned to the current year and the least weight to the earliest year.

(A16) $PR^*_{t+1,b} = \Sigma_j PR_{t-j,b} W_j; \quad j = 0 \text{ to } 2.$

Boat exit or entry. The rate of boat exit and entry varies according to the difference between the expected profit and normal profit levels. The value of β constrains the rates of exit and entry.

(A17) $NV_{t+1b} = \beta_b (PR^*_{tb} - OC_t) NV_{tb}$.

Data used in the model

The data used in the model are given in tables 9–15.

9 Simulated distributions of catches across boat types and states

Sector	Catches: Aggregate quota	Catches: ITQs
	t	t
Western Australia		
Pole boats	4 408	1 249
South Australia		
Pole boats	5 227	7 981
Purse seiners	4 700	5 102
Japan	19 500	19 500

10 Average prices

Year	Aggregate quota	ITQs
	$/t	$/t
1984-85	809	810
1985-86	1 178	1 222
1986-87	1 875	2 000

11 Fishing costs

Sector	Aggregate quota: Fixed	Aggregate quota: Variable	ITQs: Fixed	ITQs: Variable
	$/boat	$/t	$/boat	$/t
Western Australian				
Pole boats	32 324	534	35 115	326
South Australian				
Pole boats	249 000	734	259 719	440
Purse seiners	460 656	301	469 418	421

12 Catchability coefficients (per boat), ITQ simulations [a]

Age class	Western Australian pole boats [b]	South Australian pole boats [b]	South Australian purse seiners [b]	Japanese longliners [c]
1+	0.000 040 1	0.000 002 17	0.000 003 24	0
2+	0.001 95	0.000 996	0.001 49	0.000 007
3+	0.000 810	0.005 63	0.008 4	0.000 053
4+	0.000 194	0.004 04	0.006 03	0.000 162
5+	0.000 014 7	0.004 86	0.007 25	0.000 214
6+	0.000 001 78	0.001 41	0.002 11	0.000 463
7+	0	0.000 415	0.000 619	0.000 656
8+	0	0.000 281	0.000 419	0.007 751
9+	0	0.000 030 1	0.000 045	0.008 275
10+	0	0.000 006 5	0.000 009 69	0.006 500
11+	0	0.000 001 2	0.000 001 79	0.004 220
12+	0	0	0	0.002 948
13+	0	0	0	0.002 150
14+	0	0	0	0.001 364
15+	0	0	0	0.000 669
16+	0	0	0	0.000 434
17+	0	0	0	0.000 254
18+	0	0	0	0.000 133
19+	0	0	0	0.000 067

a Estimates of the proportions of each age class harvested by the average boat of each type in the base year. **b** Based on 1987 estimated fish numbers and catches. **c** Japanese catch coefficients per 1000 days fished, based on 1986 estimated fish numbers and catch.

13 Catchability coefficients (per boat), aggregate quota simulations [a]

Age class	Western Australian pole boats [b]	South Australian pole boats [b]	South Australian purse seiners [b]
1+	0.000 171 0	0.000 035 8	0.000 246 8
2+	0.002 328 9	0.000 884 5	0.006 100 5
3+	0.000 266 9	0.002 269 7	0.015 638 2
4+	0.000 007 7	0.001 082 6	0.007 459 2
5+	0.000 001 0	0.000 386 4	0.002 662 9
6+	0.000 000 1	0.000 288 5	0.001 987 7
7+	0	0.000 190 9	0.001 315 6
8+	0	0.000 181 1	0.001 248 1
9+	0	0.000 089 6	0.000 617 5
10+	0	0.000 029 6	0.000 204 4
11+	0	0.000 003 9	0.000 027 5
12+	0	0.000 002 5	0.000 001 74
13+	0	0	0
14+	0	0	0
15+	0	0	0
16+	0	0	0
17+	0	0	0
18+	0	0	0
19+	0	0	0

a Estimates of the proportions of each age class harvested by the average boat of each type in the base year. **b** Based on estimated fish numbers and catches in 1983.

14 Numbers of fish in each age class a

Age class	1983	1984	1985	1985	1987
1+	5 083 581	5 053 299	5 072 852	4 832 475	4 342 124
2+	4 056 420	4 075 987	4 112 411	4 141 636	3 952 643
3+	2 348 513	2 283 372	2 654 024	3 027 179	3 181 323
4+	667 814	1 438 154	1 463 978	1 931 200	2 045 118
5+	563 967	375 557	1 050 722	1 049 132	1 394 968
6+	662 637	379 029	225 656	756 398	738 427
7+	745 565	469 326	259 572	119 490	582 841
8+	702 989	545 638	344 486	172 733	79 515
9+	568 946	499 618	397 485	237 987	119 332
10+	428 323	409 442	354 006	272 292	163 030
11+	346 848	306 503	289 847	246 805	189 836
12+	210 478	256 951	220 444	208 093	177 191
13+	142 249	155 926	190 354	163 309	154 159
14+	117 614	107 746	117 515	146 327	123 422
15+	94 964	92 150	83 546	91 257	114 575
16+	54 959	76 322	73 523	66 427	72 332
17+	29 532	44 515	61 852	59 575	53 411
18+	28 388	23 973	36 190	50 480	48 354
19+	59 877	52 234	38 421	45 503	65 239

a Estimated by Fisheries Division, CSIRO, using cohort analysis assuming an instantaneous rate of natural mortality of 0.2 $year^{-1}$, and a terminal rate of fishing mortality of 0.1 $year^{-1}$ with the terminal age class taken to be 12+. Numbers presented are beginning of year fish numbers.

15 Average fish weight in each age class

Age class	Average fish weight (beginning of year)	Average fish weight (middle of year)
	kg	kg
1+	0.7	1.7
2+	3.1	5.0
3+	7.4	10.1
4+	13.5	17.0
5+	21.0	25.0
6+	29.6	33.9
7+	38.8	43.4
8+	48.4	53.0
9+	58.0	62.5
10+	67.5	71.8
11+	76.5	80.7
12+	85.2	89.2
13+	93.4	97.1
14+	101.0	104.4
15+	108.0	111.2
16+	114.4	117.3
17+	120.3	122.9
18+	125.6	128.0
19+	132.0	134.1

Source: Fisheries Division, CSIRO.

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INDIVIDUAL TRANSFERABLE QUOTAS AND THE SOUTHERN BLUEFIN TUNA FISHERY

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