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- ☐ NEW PROPOSAL
- ☐ CONTINUING PROJECT
- ☒ FINAL REPORT
- ☐ PROGRESS REPORT

FISHING INDUSTRY RESEARCH TRUST ACCOUNT

TITLE OF PROPOSAL/PROJECT: THE DETERMINATION OF OPTIMAL MANAGEMENT REGIMES FOR THE SOUTHERN BLUEFIN TUNA FISHERY IN THE CONTEXT OF THE AUSTRALIAN FISHING ZONE.

ORGANISATION: LA TROBE UNIVERSITY.

PERSON(S) RESPONSIBLE: J. KENNEDY

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SOME RESULTS FROM MODELLING THE ECONOMIC RETURNS FROM SOUTHERN BLUEFIN TUNA

by

John Kennedy and Jim Watkins

Final report to the Fishing Industry Research Committee on the project:

Determination of Optimal Management Regimes for the
Southern Bluefin Tuna Fishery in the Context of the
Australian Fishing Zone

funded by FIRTA from July 1982 to December 1983.

School of Economics
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Bundoora, Vic. 3083.

March 1984

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SOME RESULTS FROM MODELLING THE ECONOMIC RETURNS FROM SOUTHERN BLUEFIN TUNA

John Kennedy and Jim Watkins

Introduction

It is now officially recognized that harvesting of southern bluefin tuna (SBT) must be restrained in the interests of conserving stocks. Scientists have emphasized the importance of ensuring that breeding stocks are not further depleted so that the risk of recruitment failure may be reduced. In response to these concerns, the harvesting countries, Australia, Japan and New Zealand, have agreed that there must be a global constraint on the catch of SBT.

In line with this agreement, in October 1983 Australia introduced quotas on the Australian catch for the 1983/84 season as an interim measure (see Franklin and Burns, 1983). To help with the formulation of longer-term measures, the Industries Assistance Commission was requested in November 1983 to conduct an inquiry into the most suitable management plan for SBT and whether adjustment assistance was necessary (see IAC, 1983).

From July 1982 to December 1983 the Fishing Industry Research Committee funded a project for investigating the economic impact of quotas on the SBT fishery. Two models have been developed - a behavioural model and an optimizing model. A summary of the results

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is presented in this paper. Before outlining the two models, some principles in the economic analysis of the fishery are introduced in the next section. For more information on the detail of the structures and parameters of the models readers are referred to Kennedy and Watkins (1984a) and Kennedy and Watkins (1984b).

Economic modelling

An economic model of a fishery usually requires specification of: submodels of the biology of the fishery and of the economic flows resulting from harvesting; policy variables such as quotas or quota prices; and performance indicators for evaluating the impact of alternative settings of the policy variables.

These were specified for both of the SBT economic models. A biological submodel simulates the processes of recruitment, growth, migration, natural mortality and fishing mortality for SBT. An economic submodel keeps track of the economic benefits resulting from harvesting, and the costs of harvesting. The principles of the evaluation of the benefits and costs of harvesting is discussed further with reference to Figure 1.

The straight line AFH is a demand schedule showing how the quantity of fish consumers will buy increases as the price of fish falls. The economic value of any particular quantity of fish sold $\overline{q}$ is the sum of the values of each unit of fish sold. It is the consumers' willingness to pay (denoted WTP($\overline{q}$) for that quantity of fish, and can be read off Figure 1 as the area under the demand schedule from $q = 0$ to $q = \overline{q}$.

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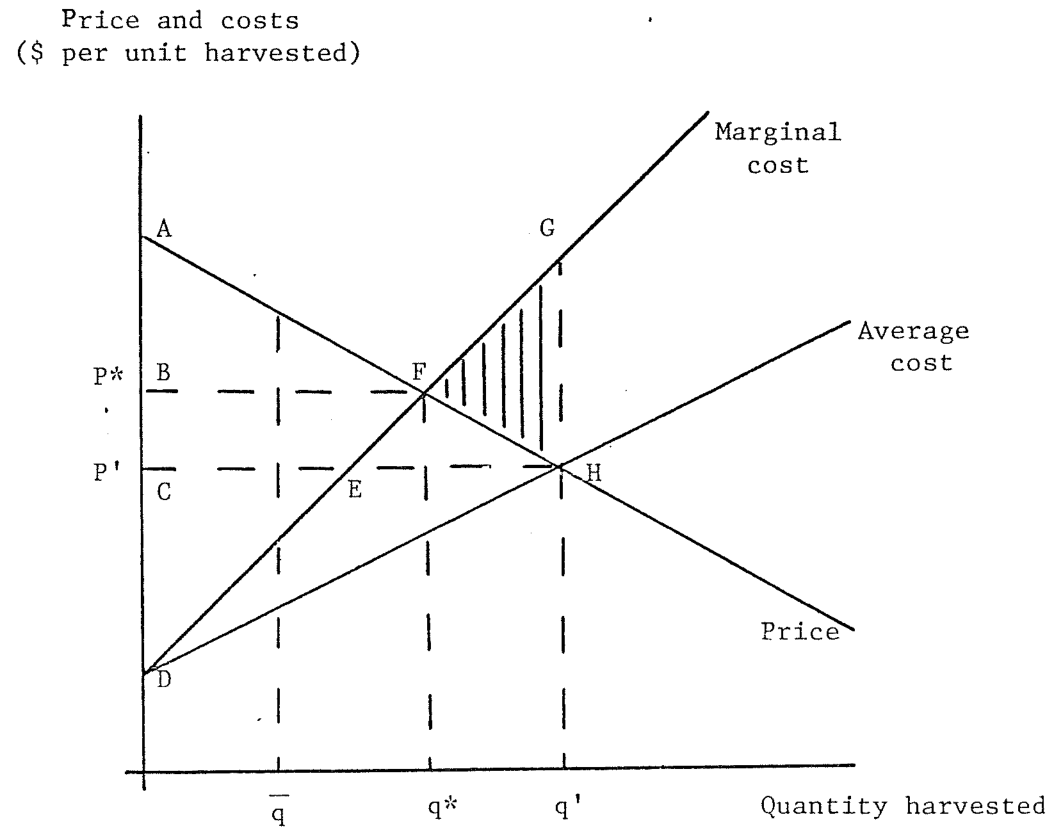

FIGURE 1 : Demand and Cost Schedules for Fish

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The straight line DH is an average cost schedule, showing how average harvesting cost is assumed to increase with the quantity of fish harvested. If q in Figure 1 is low enough for price to exceed average cost (AC), profits accrue to the fishery. This holds for all levels of q up to q', at which level price equals AC, and no profit or rent accrues to the fishery. If it is assumed that additional harvesting effort is attracted into the fishery as long as positive rents accrue, the equilibrium level of harvesting for an uncontrolled, open-access fishery will be q'. A comprehensive discussion of open access theory can be found in fisheries economics texts such as Anderson (1977) or Clark (1976).

Corresponding to the AC schedule is the marginal cost (MC) schedule DEFG which shows the increase in total cost for each additional unit of fish harvested. The total cost of harvesting the quantity of fish $\overline{q}$ (denoted $TC(\overline{q})$) can be read off Figure 1 as either $AC(\overline{q}) \times \overline{q}$ or equivalently as the area under the MC schedule from $q = 0$ to $q = \overline{q}$.

One measure economists use for judging the social worth of harvesting the quantity $\overline{q}$ is social surplus generated, or $WTP(\overline{q}) - TC(\overline{q})$. Under certain simplifying assumptions, maximizing social surplus maximizes economic efficiency over one period. Although social surplus is the measure often adopted, it is not the only economic criterion of interest. Other criteria are the distribution of any surplus between fishermen, proccessors, consumers and society in general, and the level of employment in the fishing industry. Another criterion may be the long-run level of stocks.

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It can be seen from Figure 1 that the social surplus generated by the open-access level of fishing q' is less than that generated by level q^*. The social surplus generated by level q^* is the area under the demand schedule less the area under the MC schedule, or the area DAF. If harvesting were increased to q', the social surplus would be reduced by the shaded area FGH. Consumers would gain by consuming more fish at a lower price, but the gain would be more than offset by the loss to producers. It is also evident that if the level of fishing were less than q^*, social surplus would again be reduced. In other words, the level of fishing effort for which price equals marginal cost is the level for which social surplus over one period is maximized.

The interest in fisheries management more usually is to measure the social worth of harvesting across a number of time periods, T. An obvious multiperiod criterion is the discounted sum of social surplus flows. If $SS(q_t)$ stands for the social surplus generated in season t equal to $WTP(q_t) - TC(q_t)$, the welfare criterion is

$$W = \sum_{t=1}^{T} SS(q_t)/(1+r)^{t-1}$$

where r is the rate of discount.

The management problem may be seen as determining the sequence of harvests q_1 to q_T such that W is maximized. In the multiperiod case it no longer follows that reducing the harvest in any period from the open access level q' to q^* is optimal. The effects of discounting and of the dynamics of the fishery have to be considered. If harvesting at the level q^* leads to total stock losses greater than additions to stock from recruitment, stocks in the following period are reduced. This is likely to lead to an upward shift of the AC and MC schedules, and a reduction in returns from harvesting. Taking account of the future cost increases

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resulting from current harvesting may mean that the harvesting level in any period which maximizes W is less than q*.

In the two models developed at La Trobe University, the welfare criterion W was used for evaluating harvesting over time. The models are outlined in the next two sections. The first model is a behavioural model, the second an optimizing model.

A behavioural model of the SBT fishery

The main components of both models are the price and AC schedules, and equations for updating stocks from period to period in line with modelled harvesting levels. In both models the price and average cost situation presented in Figure 1 is extended to allow for two demand schedules, and six average cost schedules.

Linear demand schedules are specified for both Australia and Japan. This is because the Australian harvest is sold on a market which is quite distinct from the Japanese market. The Australian harvest is largely either canned or exported to Europe. The Australian tuna price appears to be unresponsive to the size of the Australian harvest, which means that the Australian demand schedule can be taken to be horizontal. On the other hand, much of the Japanese catch is sold as sashimi fish, attracting a price about ten times the Australian price. Given that the Japanese price does appear to fall with increased catch, an appropriate downward-sloping demand schedule was estimated for Japan.

Because SBT are a long-lived, migratory species, it was necessary to model the harvesting of fish by age category. Figure 2

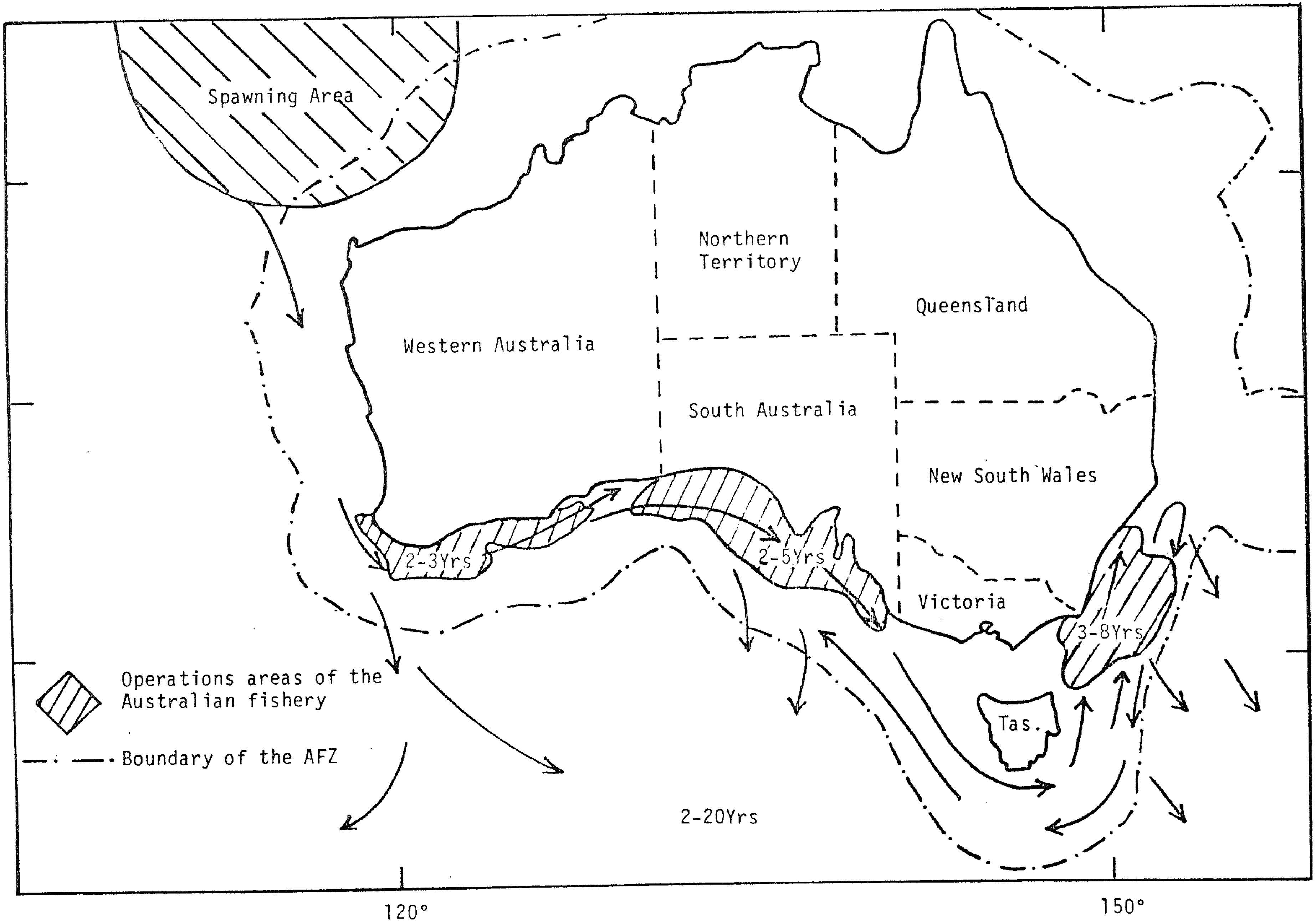

Figure 2: Migration flows of SBT juveniles

shows the migration pattern of SBT as determined by Australian and Japanese scientists (see Majkowski, Williams and Murphy, 1981; Murphy and Majkowski, 1981; and Shingu, 1981). Many of the fish remain in Australian coastal waters to the age of six. Three age groups, G1 to G3, cover the ages 1 to 2, 3 to 4 and 5 to 6. A fourth age group, G4, covers the remaining ages, 7 to 20. Whereas Australia harvests primarily from G2 and G3, Japan harvests primarily from G4. However, there is overlap, with Australia taking some fish from G4, and Japan some from G3. In the models, Australia can harvest from all age groups, but Japan only from G3 and G4.

As shown in Figure 2, some juvenile SBT outmigrate from Australian waters. In the models, all fish which outmigrate are assumed to escape the risk of capture by either Australian or Japanese fleets until they enter G4. The way in which harvesting is modelled by age category and location in the behavioural model is shown in Figure 3.

A total of six harvesting activities are modelled, four for Australia and two for Japan. A linear average cost schedule is specified for each harvesting activity. Instead of relating average cost linearly to the absolute level of harvest, as in Figure 1, average cost for each group is related linearly to the harvest expressed as a proportion of its stock at the beginning of the harvest period. Analysis showed this to be appropriate if certain simplifying assumptions were made.

A set of linear equations were specified for updating stocks, taking account of recruitment, growth, migration, natural mortality and fishing mortality. Published research findings by the CSIRO (e.g. Hampton

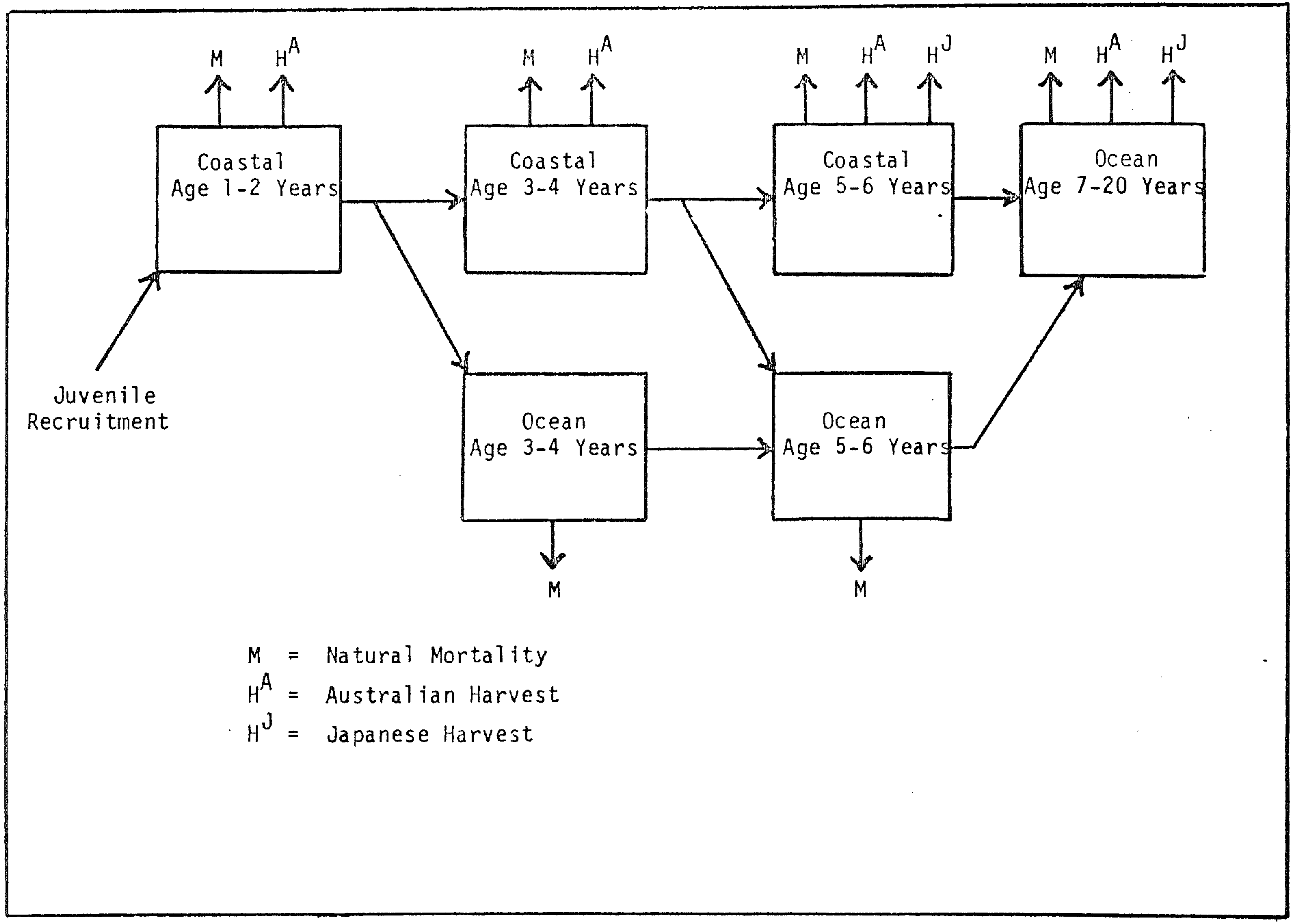

Figure 3: Flow chart of stocks by age and location

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and Majkowski, 1983) were used in formulating the equations. However the updating equations in the behavioural model were much more restricted in form than was necessary because they were tailored for use in the optimizing model. Certain approximations have therefore been built into the updating equations which could be eliminated in the behavioural model. The updating equations were kept common to both models in the interests of comparability.

The behavioural model is so called because it simulates harvesting period by period on the assumption that the fishery is an open-access fishery. The solution technique may be termed recursive quadratic programming because of its close resemblance to recursive linear programming suggested by Day (1963) for modelling agricultural sectors. The principles outlined in the previous section are used. Without any controls on harvesting, harvesting of each fishable age group by Australia and Japan is taken to the level for which price equals average cost.

Experiments were conducted with the model to test the effects on welfare of alternative quota controls. The results were dependent on many assumptions discussed more fully in Kennedy and Watkins (1984a), which should therefore be consulted for an appreciation of the significance of the results. The extent to which results changed when some alternative assumptions were made is also discussed.

The way in which quotas were found to affect W^A, the present value of the stream of Australian social surpluses over five years, is depicted in Figure 4. A discount rate of 10 per cent is used. In the experiments for Figure 4, quotas were set at percentages of 1980-82 harvests, uniformly across age groups. Because a horizontal

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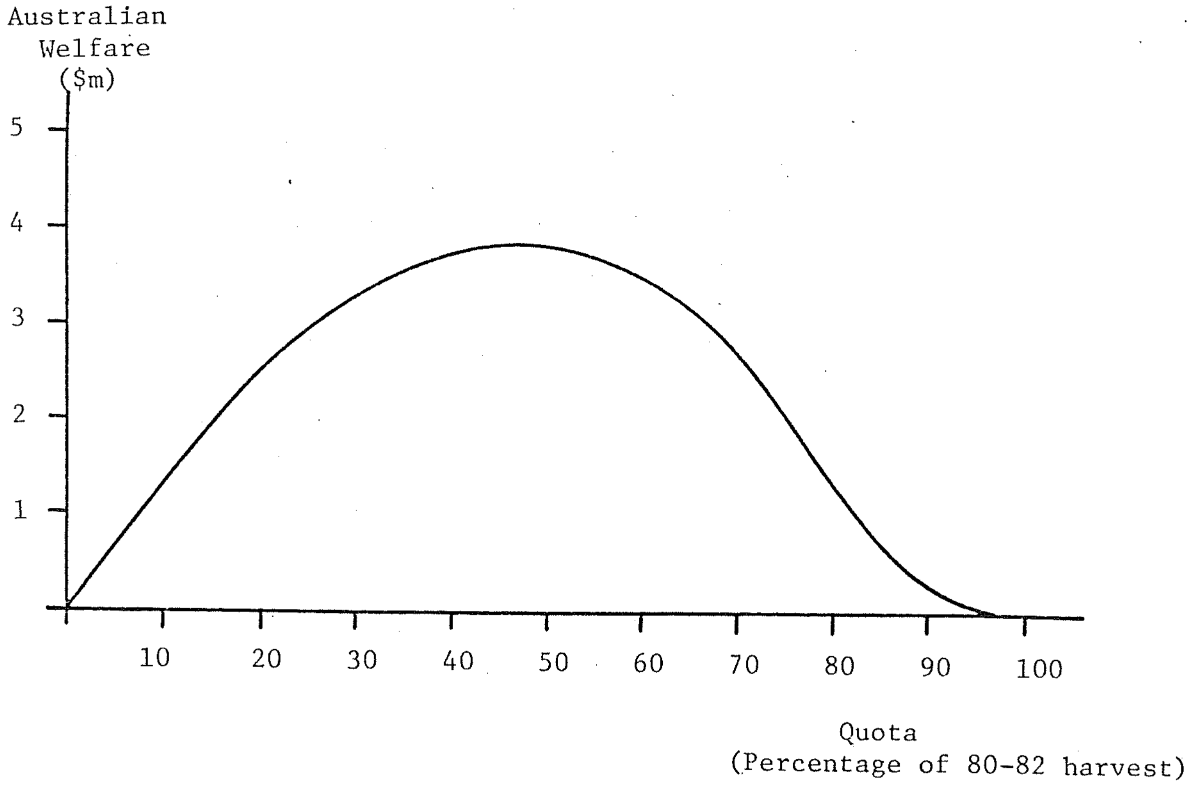

FIGURE 4 : The welfare impact of quotas on Australian harvesting

Australian demand schedule is assumed, and quota levels at 1980-82 harvest levels are not restrictive, W^A is zero for a quota percentage of 100. W^A rises to a maximum of \$3.88 million if the quota percentage is reduced to about 50. Other experiments showed that W^A could be further increased to \$4.35 million by eliminating harvesting from G1 and relaxing quotas slightly on the other age groups.

An optimizing model of the SBT fishery

The great merit of the behavioural model, which has yet to be fully exploited, is that there are few restrictions on the type of process which can be modelled within the period. Although the demand, average cost and updating equations have so far been assumed to be linear and deterministic, these assumptions could be relaxed. On the other hand, a drawback with the behavioural model is the large amount of computation required to identify optimal harvest levels. In the experiments for the results reported in Figure 4, quotas on each age group are assumed to be fixed for each of the five years. However, it is likely that optimal harvest levels will change from year to year. The amount of computation required to find optimal harvest levels, different for each year, would be very large with the behavioural model.

To overcome this problem an optimizing model was developed based on dynamic programming. In the context of Figure 1, the dynamic programming model can be thought of as permitting the estimation of a revised MC schedule which would lie above the MC schedule shown in Figure 1. The revised MC schedule takes account of the impact of current harvesting not only on current harvesting costs but also on future

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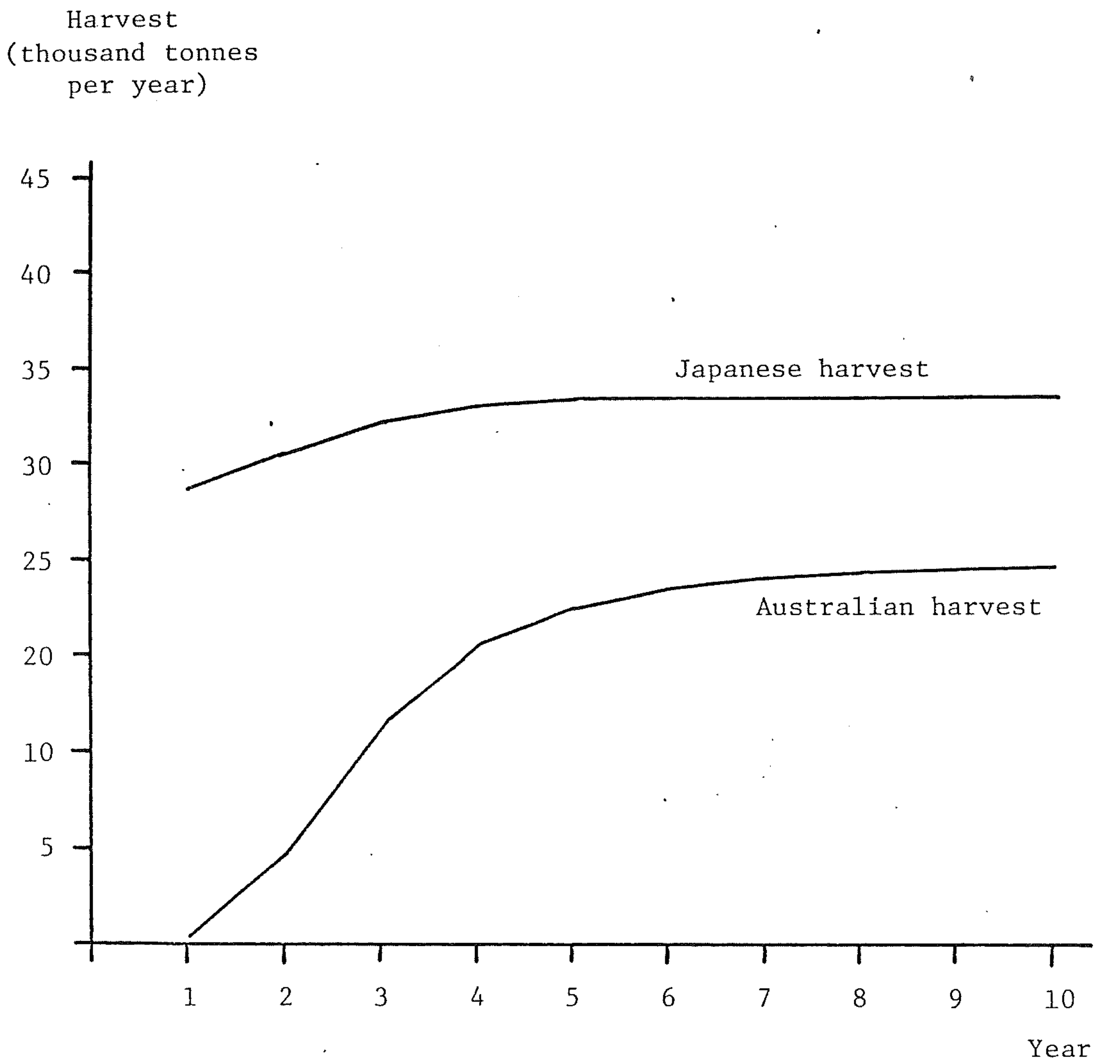

FIGURE 5 : Optimal harvest levels for Australia, assuming Japan harvests fixed proportions of available stocks.

harvesting costs through stock depletion. The position of the revised MC schedules is a function of stock levels. Optimal harvesting levels are represented by the q for which the demand schedule intersects the revised MC schedule.

Optimal harvest levels which were obtained by making assumptions similar to those made in experiments with the behavioural model are shown in Figure 5. The outmigration system is slightly altered from that shown in Figure 3 to permit a proportion of 1 to 2 year-old fish to avoid the risk of capture. However, the rate of outmigration assumed is comparable to that assumed for the results shown in Figure 4. The annual Australian harvest levels shown in Figure 5 are optimal assuming that Australian welfare W^A is maximized over an infinite planning horizon, and assuming that the proportions of stocks fished by Japan each year remains constant at the average proportions for 1980-82. The results indicate that for all years it is optimal for Australia to harvest only fish aged five years and older. The optimal plan starts by virtually banning Australian harvesting for one year, and then progressively relaxes harvesting restrictions. This allows numbers of larger fish to build up in the older age categories, making it eventually worthwhile to harvest at levels which are relatively high by historical standards.

The results shown in Figure 5 were obtained assuming constant recruitment each year, unrelated to parental stocks. Because the precise relationship between recruitment and parental stocks is not known, it is of interest to know what results are obtained by making the simplest assumption of fixed recruitment. When experiments were conducted with recruitment positively related to the parental stock, the same shape of harvest profile through time was optimal. However, for optimality, Australian harvesting does not start until year 3 when only 870 tonnes are taken, thereafter rising rapidly but at a decreasing rate to reach a plateau of about 15,000 tonnes by year 10. Again, only fish older than 5 years are harvested. The levels of Japanese harvesting through time do not differ significantly from the levels shown in Figure 5.

Experiments were conducted with alternative policy objectives. As well as finding the harvest profile through time for which Australian welfare is maximized, the harvest profile which maximizes the combined welfare of Australia and Japan was determined. Results showed that it is optimal for Australia to leave all fishing of SBT to Japan. Assuming fixed recruitment, optimal Japanese harvests increase from about 18,000 tonnes in year 1 to just over 31,000 tonnes in year 10. With recruitment positively related to parental stock, optimal Japanese harvests increase from about 16,000 tonnes in year 1 to just under 31,000 tonnes in year 10. Because Australia takes no catch, there is no way of increasing Japan's welfare further at the expense of Australia's. These harvest profiles therefore also maximize Japan's welfare alone.

Other results suggest that Japan could gain by more than compensating Australia for agreeing not to follow her optimal harvesting strategy. This is indicated in the following table which shows welfare payoffs to Australia and Japan from Australia following her optimal harvesting policy, and Japan following hers. The figures are for recruitment fixed, and are relative to the open-access welfare levels.

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TABLE 1

Australian and Japanese welfare from alternative harvest plans
(Present value over 10 years, $ million)

Harvest plan	Welfare	
	Australia	Japan
Optimal for Australia	+13	+208
Optimal for Japan	0	+411

Japan could pay Australia $13 million, and still be better off by $190 million if the plan optimal for Japan were adopted. However, even if the sums shown in Table 1 approximate the magnitudes involved, such a deal is likely to be politically unacceptable to Australia. There is scope for such a deal largely because of the much higher price obtained by the Japanese for SBT. A more likely outcome is for Australia to adopt alternative processing technologies and to seek more valuable markets. There is some evidence that this is starting to happen (see e.g. Freeman, 1984).

Conclusions

Results from both the behavioural and optimizing models suggest that it is in the interests of both Australia and Japan to reduce or eliminate the harvesting of under-five-year-old fish. An important reason is the rapid rate of growth of the juvenile fish. If harvesting of young fish were reduced, enough social surplus should be generated to implement adjustment assistance to the Western Australian and South Australian fleets currently harvesting young fish.

Another use of the two economic models is to experiment with the effects of alternative quota prices on harvesting and welfare. Estimates of optimal quota prices through time are reported in Kennedy and Watkins (1984b).

An important limitation of the models is that they are deterministic. All the model parameters are assumed to be known with certainty. The restrictiveness of this assumption depends on the purposes for which the models are used. They cannot be used in their current form for commenting on the risk of recruitment failure, or the variability of projected welfare due to uncertainty.

Another limitation is that decisions on investment in harvesting and processing capacity are not incorporated. The absence of the capital dimension means that results from the behavioural model are likely to show harvest levels changing too rapidly from year to year.

On the positive side, the research has highlighted some of the implications of the price, cost and biological data relevant to the SBT fishery, and the strengths and weaknesses of different economic models.

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QUI CHERCHE TROUVE

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30th March, 1984.

The Secretary,
Fishing Industry Research Committee,
Fisheries Division,
Department of Primary Industry,
CANBERRA. A.C.T. 2600

Dear Sir,

FIRTA Project 82/76

The Determination of Optimal Management Regimes for the Southern Bluefin Tuna Fishery in the Context of the AFZ.

In compliance with the conditions of the grant for the above project, I enclose ten copies of a final report on the project entitled "Some Results from Modelling the Economic Returns from Southern Bluefin Tuna" by Jim Watkins and myself. It summarizes the results of two models of the fishery, a behavioural model and an optimizing model. It is written with the possibility of publication in "Australian Fisheries" in mind.

The behavioural model is the subject of a paper by Jim Watkins and myself "The Impact of Australian Quotas on the Southern Bluefin Tuna Fishery". It was submitted to the Australian Journal of Agricultural Economics in January for consideration for publication.

The optimizing model is the subject of another paper by Jim Watkins and myself "Optimal Quotas for the Southern Bluefin Tuna Fishery" which we have submitted to the Journal of Marine Resource Economics, a new journal published in the USA. We enclose copies of both papers.

I would like to thank the Committee for funding what for us has been an absorbing project, and hope the results are of some use to the Committee.

Yours sincerely,

John O.S. Kennedy

John O.S. Kennedy.

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THE IMPACT OF QUOTAS ON THE AUSTRALIAN SOUTHERN BLUEFIN TUNA FISHERY*

Jim Watkins and John Kennedy
La Trobe University, Bundoora, Vic. 3083

A model of the Australian southern bluefin tuna fishery is discussed, in the light of Federal power to control both domestic fisheries and foreign access to the 200-mile Australian Fishing Zone. The fishery is modelled as a common property resource by maximizing recursively a single-period quadratic objective function. It is used to examine the viability of the fishery under present harvesting conditions and the welfare impact of regional fishing quotas.

INTRODUCTION AND BACKGROUND

The southern bluefin tuna fishery

In December 1982 the United Nations Convention on the Law of the Sea was signed by the overwhelming majority of the World Community. The action gave Australia the force of international law (subject to ratification by at least 60 nations) in controlling the fish resources within 200 miles of its coastline, legitimizing a power Australia had exercised since the introduction of the Australian Fishing Zone (AFZ) in November 1979.

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* This paper reports some of the work carried out on a research project financed by the Fishing Industry Research Trust Account. The assumptions made and views expressed are not necessarily shared by the Fishing Industry Research Committee.

The need for a global framework to protect the seas' resources arose in part from technological developments in fisheries that threaten many of the world's fish stocks. Under the Convention coastal states not only have the power to determine other nations' access to their fishing zones but have an obligation to protect and conserve their coastal fisheries.

The southern bluefin tuna (SBT) fishery is a high-revenue-earning operation. It is conducted by both Australia and Japan in Australian coastal waters and by Japan in the Southern, Indian and Western Pacific Oceans, predominately south of 30°S. Fisheries biologists have voiced strong fears for the continued viability of the SBT fishery given the 83 per cent increase in Australian poleboat and purse-seine harvesting between 1978 and 1982. Whilst the Japanese have been progressively excluded from parts of the AFZ, they have intensified their fishing effort in other areas of the AFZ[1]. Table 1 shows the Australian and Japanese harvests for the financial years 1976/77 to 1981/82.

(Table 1 near here)

Because the juvenile stocks of SBT are concentrated within the AFZ, control over fishing in the AFZ has important consequences for both the Australian and Japanese fisheries. Juvenile fish enter the AFZ from spawning grounds to the north-west of W.A. and follow the Australian coastline south. Older fish concentrate further to the east along the southern and south-eastern Australian coastlines.

Between the ages of 3 and 5 the tuna make seasonal migrations between the S.A. and N.S.W. fisheries. Six-year olds spend about half the year in the West Wind Belt (40°S-50°S) and the remainder of the year in the more northerly feeding grounds off New Zealand, the East coast of Australia and South Africa. Above age 6 most remain within the West Wind Belt, moving to northerly grounds only in the breeding season. The migration pattern of juvenile SBT is shown in Figure 1.

(Figure 1 near here)

Because SBT have a relatively long lifespan of up to about 12 years, the state of the fishery can best be described by numbers in age cohorts. Age cohorts of the SBT are concentrated in particular parts of the Australian coastal zone (Shingu, 1981, p.60). For modelling purposes it is assumed that fishing grounds can be defined on the basis of age cohorts. The four age cohorts used in the model are shown in Table 2, and the corresponding fishing grounds (G1 to G4) in Figure 1.

(Table 2 near here)

As Table 1 shows, Australian harvests off W.A. and S.A. have increased in recent years. The increased harvests off W.A. have already resulted in a reduction in the age at first capture (Murphy and Majkowski, 1981). Important questions have been raised as to whether the increased harvesting may threaten the future economic viability of the fishery, and even the maintenance of stocks of SBT (BAE, 1983b).

Another major issue is the level of Japanese access to SBT in the AFZ. The extent of any threat to domestic harvests posed by Japanese longliners in the AFZ is unclear (Majkowski, Williams and Murphy, 1981). There has been some suggestion that Australia's ultimate goal may be to replace all foreign fishing by domestic fishing within the AFZ (Parliament of the Commonwealth of Australia, 1982). How would this affect Japanese interests? The recursive quadratic programming model described below was developed to help answer some of these questions.

Modelling the common access fishery

A behavioural modelling approach is adopted, describing the way fishing fleets are likely to respond to the economic conditions existing in the fishery, and to any measures introduced by government. Open access conditions are assumed to hold for the fishery[2], with fleets expanding their operations to the point at which average revenue (AR) equals average cost (AC) on each ground. That is, factor inputs are applied to the fishery until all resource rents are eliminated. The finding that returns to equity in the fishery have in recent years been low or negative (BAE, 1983b) suggests that expansion of the fishery has gone beyond the bionomic equilibrium suggested by the theory of open access. The fishery is now failing to cover total costs of operation, still less receive a rental return on fish stocks. This may reflect earlier over-commitment of capital to the fishery when its harvesting potential was uncertain.

The modelling method used is similar to recursive linear programming (Day, 1963). Recursive linear programming (RLP) is commonly applied in modelling agriculture, where the decision-making environment is uncertain and foresight is often limited. RLP involves 'myopic-suboptimization' period by period rather than 'complex intertemporal optimization' (Day, 1977, p. 83). Uncertainty applies, perhaps with even greater force, to the fishery. However, the open access nature of the fishery makes myopic decision-making by individual fishermen rational, if socially suboptimal. Because fishermen do not have property rights in the fishery, there is no incentive for them to moderate current harvesting levels in the interests of higher future harvesting levels. The RLP approach is therefore particularly appropriate for modelling an open access fishery. It is surprising it has not been applied previously to fisheries problems.

The present model differs from RLP in that the objective function for each period is quadratic rather than linear[3]. It is a stationary model in that demand and cost parameters do not change through time. Effort levels are determined such that AR equals AC in each period. Stock is updated period by period in line with the modelled levels of effort, migration, natural mortality and recruitment. No flexibility constraints have been incorporated in the model.

THE RECURSIVE QUADRATIC PROGRAMMING MODEL

Table 1 indicates the variability in harvesting levels over recent years. For modelling purposes, a harvest profile across fleets and grounds was required which could be taken to be both typical of recent years under open access conditions, and sustainable. Table 3 shows the harvest profile assumed. The Australian harvests are averages for the four years 1978/79 to 1981/82. The Japanese harvests are the 1978/79 harvests, being the most recent harvests before the introduction of the AFZ. It is difficult to judge whether these harvests could be sustained indefinitely. Some support for this assumption can be drawn from the reference by the DPI (1980, p.11) to biological evidence indicating that SBT were fully (as opposed to over) exploited by the time of writing.

Demand and cost parameters for the linear AR and AC schedules were estimated for the same periods. The AR and AC schedules are described below, before specifying the model in more detail.

(Table 3 near here)

Demand functions

For both the Australian and Japanese markets the demand schedules were assumed to have the linear form

(1) $$AR = r + sz$$

where z is the annual weight of harvest sold and r and s are parameters.

Unlike the Japanese market for SBT, the Australian market is open. Over the period 1978/79 to 1981/82, 37 per cent of the Australian harvest was exported, primarily to Italy, and 32 per cent of domestic consumption was imported. The Australian price does not appear to be sensitive to the level of Australian harvests. It is heavily dependent upon world demand and supply for tuna fish in general. The Australian demand schedule was therefore assumed to be horizontal. Lewis (1975) found a horizontal demand schedule to be suitable for a similar fishery in the United States.[4]

No elasticity estimates of Japanese demand for SBT could be found from other studies. A rough estimate of the Japanese demand elasticity was made by assuming that the demand curve, but not the supply curve, was stable over the period of estimation. Arc elasticities were estimated using data on monthly landed catch and ex-vessel prices at the major tuna market of Yaizu from July 1978 to September 1980. In the absence of an adequate price index for all Japanese SBT landings, it was assumed that the elasticity value determined for the Yaizu fish market (which handled 39 per cent of the Japanese 1978-1980 SBT catch) holds for Japanese demand as a whole. Japanese prices were converted to Australian prices using the mid-1979 exchange rate of $1A equal to 250 Yen.

Table 4 shows the estimated elasticities and the co-ordinates through which the linear demand curves (Equation 1) were assumed to pass. The Australian and Japanese markets for SBT are quite distinct. Most of the Australian harvest is canned. Much of the Japanese harvest is specially processed and sold as highly priced sashimi fish. Table 4 shows the Japanese price to be nearly 20 times the Australian price. So far Australia has sold very little on the Japanese sashimi market, partly because of the difficulty in meeting the stringent quality conditions required by the Japanese. For these reasons the Australian and Japanese demand schedules used in the model are independent.

(Table 4 near here)

Cost functions

It is usual to assume in fisheries economics that harvesting cost is a function of stock density, or stock numbers, as well as harvest level. The cost functions used in the model relate the cost of one year of harvesting to the harvest for the year, h, as a proportion, q, of the opening stock, x. The functions are based on a continuous model of the fishing process. Four assumptions are made. First, fish are subject to a constant instantaneous rate of natural mortality, m. Secondly, fishing effort (boat days or hooks sunk) results in a proportional instantaneous rate of fishing mortality[5], f. Thirdly, fishing effort is applied at a constant level throughout the year. Fourthly, harvesting cost is directly proportional to fishing effort.

It follows that fish numbers at any instant t during the year are:

(2) $$x_t = x \exp((-f-m)t) \quad .$$

Harvest for the year is cumulative fishing mortality

(3) $$h = x \int_0^1 f \exp((-f-m)t)dt$$

$$= x \; (f/f+m))(1-\exp(-f-m)) \quad .$$

From Equation (3) it follows that the proportion of the initial stock harvested is a function of f and m :

(4) $$q = h/x = (f/(f+m))(1-\exp(-f-m)) \quad .$$

It is possible to use Equation (4) to find f a function of q and m. For a range of q larger than that likely to be encountered in practice, $0 \leq q \leq \cdot 6$, f was found to be a quadratic function of q to a reasonable degree of accuracy. That is

$$f = u\{m\}q+v\{m\}q^2 \tag{5}$$

where u and v are parameters, functions of m.

If k is the cost of fishing effort per unit of fishing mortality, the total cost of harvesting over one year is

$$fk = kq(u+vq) \tag{6}$$

and the average cost of harvesting h over one year is

$$AC = fk/h = (k/x)(u+vq) \quad . \tag{7}$$

Six cost coefficients, k, are required for the model : four for the Australian fishing fleet on G1 to G4; and two for the Japanese fishing fleet on G3 and G4. Attempts to estimate the cost coefficients directly did not prove satisfactory because of limitations in available data.[5] Instead, they were calculated as those values required in the model to sustain modelled harvests equal to the typical harvests in Table 3.

Harvesting levels

The model simulates the proportions of opening stocks harvested by Australia on G1 to G4 and by Japan on G3 and G4, year by year. The proportions are determined such that all fishing rents are competed away

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to zero. Essentially each fleet's proportions must be found for which the horizontally aggregated AC schedule intersects the AR schedule. The proportions were obtained by solving an artificial constrained maximization problem. This method was chosen for the ease of dealing with non-negativity and quota constraints on the proportions. The problem set is to maximize y, equal to the sum of the relevant areas below the two demand schedules and above the six AC schedules. For linear AR and AC schedules, the problem is the following quadratic programming (QP) problem. The modelling approach is similar to the use of QP to solve spatial equilibrium problems (e.g. Takayama and Judge, 1971).

(8) $$\underset{q_i^A,\, q_j^J}{\text{Maximize}} \quad y = r^A z^A + s^A (z^A)^2/2 + r^J z^J + s^J (z^J)^2/2$$

$$- \sum_{i=1}^{4} k_i^A (u_i^A q_i^A + v_i^A (q_i^A)^2/2)$$

$$- \sum_{j=3}^{4} k_j^J (u_j^J q_j^J + v_j^J (q_j^J)^2/2)$$

subject to

$$0 \le q_i^A \le Q_i^A \qquad i = 1,\dots,4$$

$$0 \le q_j^J \le Q_j^J \qquad j = 3,4$$

$$q_3^A + q_3^J \le 1$$

$$q_4^A + q_4^J \le 1$$

$$z^A = \sum_{i=1}^{4} h_i^A w_i = \sum_{i=1}^{4} x_i q_i^A w_i$$

$$z^J = \sum_{j=3}^{4} h_j^J w_j = \sum_{j=3}^{4} x_j q_j^J w_j$$

where superscripts A and J refer to the Australian and Japanese fleets respectively; $Q_i = 1$ if there is no quota on fishing effort on ground i, and $Q_i < 1$ otherwise; and w_i is the average weight of fish on ground i.

Estimating joint fishing costs

The Australians and Japanese jointly fish on G3 and G4. The fishing costs of the two fleets on G3 and G4 are interdependent, the level of fishing effort expended by one fleet affecting the fishing costs of the other. In terms of the model variables, the cost coefficients u_i^A, v_i^A depend on q_i^J, and u_i^J, v_i^J depend on q_i^A (i=3,4). To ensure that u_i^A, v_i^A and u_i^J, v_i^J are consistent with solution values q_i^J, q_i^A an iterative procedure is followed. Denote Australia's rate of fishing mortality at the k-th iteration by f_k^A, and Japan's by f_k^J. Then Australia can be assumed to perceive its uncontrollable rate of mortality of the fish as $m + f_k^J$, and likewise Japan as $m + f_k^A$. The u and v parameters are revised iteratively using Equations 9 to 12 which refer to the functions on the right hand side of Equation 5.

(9) $u_{k+1}^A = u\{m+f_k^J\}$

(10) $v_{k+1}^A = v\{m+f_k^J\}$

(11) $uk+1^J = u\{m+f_k^A\}$

(12) $u_{k+1}^J = v\{m+f_k^A\}$

Iterations start with k=0 and $f_0^J, f_0^A = 0$. Values for q^A and q^J on all grounds are obtained by running the QP model with appropriate u and v parameters. The values for q^A and q^J on G3 and G4 imply values for f_1^A and f_1^J which are used in Equations 9 and 12 to revise the u and v parameters on G3 and G4. The QP model is then run again. Iteration proceeds in this way until the difference between q^A and q^J across all grounds on two successive iterations is negligible.

Migration and stock updating

Stock on grounds G1 to G4, represented by x_1 to x_4 are updated at yearly intervals, dependent on the annual harvesting levels obtained from the QP model, and assumptions about migration, natural mortality and recruitment. To be fully consistent with the assumptions made in deriving the functions for fishing costs, updating should be continuous rather than periodic. The stock updating equations used in the model only approximate the analagous, perhaps more appropriate, continuous equations.

The equations are based on the following assumptions. First, a proportion M = .2 of the stock remaining after harvesting is assumed to succumb to natural mortality[7]. Secondly, for G1 to G3, half of the stock remaining on ground i after harvesting and natural mortality migrate to ground i + 1. Thirdly, for the 7-12 year-old fish on G4, after allowing for natural mortality and harvesting throughout the year at rate M, an additional one-sixth of the stock die from natural causes at the end of the year.

Equations (13) to (17) were used for updating.[8]

$$(13)\qquad x_{1,t+1} = [(x_{1,t} - h_{1,t})(1-M)/2] + R_{t+1}$$

$$(14)\qquad x_{i,t+1} = [(x_{i,t} - h_{i,t})(1-M)/2] + [(x_{i-1,t} - h_{i-1,t})(1-M)/2] \qquad \ldots\ i = 2,3$$

$$(15)\qquad x_{4,t+1} = [(x_{4,t} - h_{4,t})(1-M)(5/6)] + [(x_{3,t} - h_{3,t})(1-M)/2]$$

$$(16)\qquad h_{i,t} = q_{i,t}^{A}\, x_{i,t} \qquad \ldots\ i = 1,2$$

$$(17)\qquad h_{i,t} = (q_{i,t}^{A} + q_{i,t}^{J})\, x_{i,t} \qquad \ldots\ i = 3,4$$

where h_i is the number of fish caught on ground i and R is recruitment to G1.

Recruitment and stock updating

It is assumed that adults on G4 produce recruits at the beginning of the year which add to fish numbers on G1 at the beginning of the following year. The relationship between stock numbers in millions on G4 (x_4) and recruits in millions (R) is not known with any precision, but is likely to be critical in investigating the possibility of a stock collapse. Two recruitment functions were tested for their suitability in the model. The first function (RF1) is

$$(18)\qquad R = \begin{cases} 29.2x_4 & x_4 \leq .218 \\ 6.41 - .21x_4 & x_4 > .218 \end{cases}$$

and the second function (RF2) is

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$$
(19)\quad R = \begin{cases} 29.4x_4 & x_4 \leq .309 \\ 11.02 - 6.45x_4 & x_4 > .309. \end{cases}
$$

The functions are displayed in Figure 2.

(Figure 2 near here)

One of the requirements for both RF1 and RF2 was that it pass through point E on Figure 2. Point E represents the combination of x_4 and R which is consistent with sustaining indefinitely the typical harvest levels shown in Table 3, given an estimate of x, and the updating Equations (13) to (17). The corresponding steady state stock numbers on each ground are shown in Table 3.

An important question is how recruitment numbers are affected if parental numbers are less than that given by point E. Murphy and Majkowski (1981, pp. 26-27) point out that "fish stocks are remarkably resilient in respect to the size of the spawning stock required to maintain a satisfactory flow of recruits". They add that it is even possible for recruitment numbers to increase with harvesting levels because a large adult biomass may reduce the survival of eggs.

The recruitment function RF2 is a simple approximation in two linear segments to the form of recruitment function developed by Ricker (Clark, 1976, Ch.7). The approximation is based on preliminary estimates of a Ricker curve for the SBT made by biologists. Recruitment function RF1 is similar to RF2, but with the difference that recruitment numbers are kept essentially fixed for all values of adult stock numbers above .22 million.

A check was carried out to see if modelled stock levels on G1 with harvests maintained at zero level would approximate the virgin stock numbers estimated by Shingu (1981, p. 74). As shown in Figure 3, the correspondence is reasonably close for RF1. The use of RF2 resulted in extreme oscillations in stock levels. Although oscillations cannot be ruled out under zero fishing, the oscillations obtained with RF2 were sufficiently by large to question its plausibility.

THE IMPLICATIONS FOR STOCKS OF RECENT HARVESTING LEVELS

The population model was used to test for the imminence of a stock collapse if the high Australian harvests of the last few years were maintained. The population model was run with 1981/82 harvests,[9] starting with the stock numbers shown in Table 3.

Figure 3 illustrates the outcome for RF1. It shows that G1 stocks collapse to zero by 1991/92. For RF2 the stock collapse was initially less severe but was complete by 1992/93.

(Figure 3 near here)

It was also found, however, that by alternatively fixing the proportion of stock harvested, and hence the level of fishing effort, at 1981/82 levels, declining stocks depressed harvesting levels through time and forestalled any collapse. For RF2, G1 stocks actually increased from reduced cannibalism.

To determine the likely economic response of the fishery to collapsing stocks an experiment was also conducted with the economic model. This tested the continued viability of the fishery for cost coefficients that would initially induce 1981/82 harvest levels. In this case there was a substantial fall in Australian harvesting (62 per cent on G2) in the second year, only partially offset by increased Japanese harvesting on G4. Harvests stabilized within 6 years at about 60 per cent of the 1981/82 level for G2, with less significant falls elsewhere. Stocks ultimately fell no more than 8 per cent on any ground.

THE ECONOMIC IMPLICATIONS OF FISHING QUOTAS

Restrictions imposed to date on access to SBT in particular areas within the AFZ have involved limiting vessel numbers rather than harvests. Quota restrictions on fishing effort were considered for both the Australian fleet on G1 and the Japanese fleet on G3.

Evaluation of policies

The effects of quotas are evaluated both in terms of total welfare indicators for Australia and Japan, and in terms of their effect on the value of Australian fishing activity. Annual Japanese welfare is the sum of consumers' and producers' surplus

$$(20) \qquad W^J = r^J z^J + s^J (z^J)^2/2 - \sum_{j=3}^{4} k_j^J u_j^J q_j^J + v_j^J (q_j^J)^2)$$

and total Japanese welfare is

$$(21) \qquad PVW^J = \sum_{t=1}^{5} W_t^J/(1+r)^t$$

where annual welfare flows are discounted over 5 years (a realistic predictive horizon for the model) and r is a real rate of discount of 10 per cent. A similar total welfare indicator, PVW^A, holds for Australia.

For a horizontal Australian demand curve, the requirement that AR = AC results in $PVW^A = 0$, there being neither consumers' surplus nor resource rent to producers. Although a change in Japanese harvesting levels affects Australian harvesting levels, PVW^A remains unchanged at zero. Nevertheless, the effect on Australian harvest levels is of interest, particularly in times of high unemployment. For this reason a 5-year average of annual total revenue (TR^A) is also used to indicate the effect of quotas on the value of fishing activity in Australia. That is

$$(22) \qquad TR^A = \sum_{t=1}^{5} (r^A z_t^A)/5 .$$

The effect of restricting Australian effort off W.A.

Figure 4 shows that PVW^A is maximized for an effort level off W.A. restricted to about half the 1978/9 - 1981/2 average level. This gain of about \$A.65 million (March 1983 prices) accrues, however, only to W.A. fishermen. With no quota, effort is overextended on G1, as on all other grounds. A quota results in AC < AR on G1 and $PVW^A > 0$.

(Figure 4 near here)

Whilst Australia benefits from a reduction in fishing effort off W.A., Japanese welfare is not increased. It might be expected that Japan would benefit as a result of more fish eventually flowing into G3 and G4. However, the increased flow into G2 stimulates an increase in fishing off S.A. If G1 is totally closed to fishing, fish stocks on G3 actually fall by 22 per cent. As Figure 4 shows, Japanese welfare falls marginally.

Figure 5 shows that reducing fishing effort on G1 leads to an overall increase in Australia's fishing of SBT. The eventual fall in stocks on G3 depresses fishing off N.S.W. but the increased fishing effort off S.A. more than makes up for reductions on G1 and G3.

(Figure 5 near here)

These results are dependent on the assumption that the Australian price for SBT remains constant for all harvest levels. This assumption ought perhaps to be relaxed for harvest levels significantly larger than those observed to date. However, if stock conservation is the aim of quota policy, the results suggest that restrictions on G1 need to be accompanied by restrictions on other grounds to be effective.

The effect of restricting Japanese effort off N.S.W. and Tasmania

Restrictions on Japanese access to G3 in the AFZ does not increase Australian consumers' and producers' surplus but does lead to an increase in Australian harvests off NSW. Most of the reduction in the Japanese catch is matched by the increase in the Australian catch. For example, if Japan is completely excluded, G3 stocks increase by less than 2 per cent over 5 years. TR^A increases by 59 per cent. However AFZ access fees paid by the Japanese would be lost. Japan is currently paying \$A1.44 million per year.

Figure 6 shows that restricting Japanese fishing effort on G3 to 40 per cent of the 1978/79 level results in very little reduction in Japanese consumer and producer surplus. Further restrictions lead to noticeable but not substantial losses in Japanese welfare.

(Figure 6 near here)

CONCLUSION

Experiments with the model suggest that SBT stocks would be threatened with collapse if Australian harvests were maintained at the 1981/82 level. However, the associated increase in harvesting costs make it very unlikely that the harvest level would be maintained.

Restrictions on Australians fishing off W.A. lead to an increase in Australian welfare, but so would restrictions on the other grounds in the AFZ. They do not lead to an increase in stock levels in the absence of controls on other grounds.

If Australia imposes no controls on access by the Australian fleet to grounds in the AFZ then the common access model shows no welfare gain to result from restrictions on Japanese access to the AFZ. However, restrictions on Japanese access do lead to increased harvests for Australia.

The results are conditional on many assumptions which can be questioned. An important biological assumption was that the Australian harvest level which is the average of the 1978/79 to 1981/82 harvests is sustainable. Assumptions about the parameters of the recruitment functions were also important. Whilst results from experiments on the possibility of stock collapse were dependent on which recruitment function was assumed, results from the experiments on the effects of quotas were not.

Recent evidence suggests that juvenile SBT may leave the AFZ at all ages (Murphy and Majkowski, 1981). Allowance for flows to G4 which bypass G1, G2 and G3 would reduce any likelihood of a stock collapse from overfishing by Australians. The flows could be readily incorporated in the model.

There are two other important caveats in interpreting the results of the model. First, the model is deterministic. The biology and economics of the SBT industry are subject to many uncertainties which should ideally be modelled in attempting to determine the likelihood of a stock collapse. Secondly, any political repercussions of controls on Australian or Japanese welfare have been ignored. For example, the present Australian/Japanese longlining agreement recognizes that if the Japanese were totally excluded from the AFZ, Australia might lose access to the potentially lucrative Japanese sashimi market (DPI, 1980-1983).

A recursive QP approach was found to be useful for modelling the common-access behaviour of fleets fishing stock of several age categories. The model could be used for investigating many other policy questions, such as the level of Australian regulation on all grounds in the AFZ which would maximize Australian welfare, and the optimal licence fees which Australia should charge Japan for access to the AFZ.

The present model permits sudden changes in fishing effort from year to year. Sudden changes are unrealistic given the long-term effects of investment in vessels, fishing gear and fishing skills. The QP model could be extended by including flexibility constraints to capture the effects of over capitalization in the industry by restricting year to year reductions in fishing effort.

FOOTNOTES

1. For example, the Japanese in 1981 set three times the hooks set in 1980 off Tasmania 40°-50°S; 140°-150°E (DPI, 1980-1983).

2. Although access restrictions of various types have applied to both fleets in the period 1978 to 1982, for the Australians these proved largely ineffective (DPI, 1981a). The Japanese have consistently used less fishing vessels in the AFZ than have been licenced under the Australia/Japan Longlining Agreements.

3. Watkins and Kennedy (1982) describe a RLP model of the SBT fishery which incorporates stepped AR and AC schedules.

4. King (1979) reports a price of .31 for tuna as a whole in the U.S. However, for the Eastern Pacific yellowfin tuna fishery, Lewis (1975) shows that the level of landings has historically had no significant effect on price.

5. Clark (1976, Ch.1) gives a rationale for this assumption.

6. Some empirical cost coefficients were determined from budgetary studies of the Australian industry undertaken by the DPI (1979 and 1981b). The cost coefficients used in the model for Australia on G2 and G3 were 14 per cent above the estimated costs, whilst for the Japanese the cost coefficient for G4 was 24 per cent below the empirical estimate. Because there were gaps in the empirical data and different assumptions underlying the different cost coefficients no closer correspondence was expected.

7. This proportion is based on an assumed instantaneous rate of natural mortality m = .2 used by Majkowski et al., 1981.

8. If fishing mortality f and natural mortality m occurred continuously, the general updating equation would be $x_{t+1} = x_t \exp(-f-m)$. Regressing exp(-f-m) on q over the range $0 \leq q \leq .6$ gave $\exp(-f-m) = .817 - .889q$. Equations (13) to (15) were modified by incorporating the regression coefficients, but model results were not significantly changed.

9. In the absence of complete harvesting figures for the Japanese, the Japanese harvests were maintained at the 1978/79 level.

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TABLE 1

Southern Bluefin Tuna Landings (tonnes)

Year	Australia[a]				Japan[c]			Total[a] World Catch
	W.A.	S.A.	N.S.W.	Total	AFZ[b]	Non-AFZ	Total[a]	
1976/77	178	8776	307	9261	2257	31457	33714	42975
1977/78	2394	4921	4757	12073	3455	26140	29595	41668
1978/79	1855	4338	4278	10472	5189	17811	23000	33472
1979/80	1417	6862	3578	11857	n.a.	n.a.	24425	36282
1980/81	2602	9276	3159	15037	3562	21559	25121	40338
1981/82	3391	12525	3276	19192	3160	n.a.	n.a.	n.a.

[a] Source : BAE (1983b). World total for 1980/81 includes 180 tonnes harvested by New Zealand.

[b] Source : DPI (1981a and 1980-83).

[c] Figures for Japanese landings are for the calendar year preceding the financial year.

TABLE 2

The Distribution of Age Cohorts and National Fleets by Ground

Ground[a]	Age (years)	Average weight (Kg)	Fished by[b]
G1	1.25	1-2	Australia (i=1)
G2	8.15	3-4	Australia (i=2)
G3	20.35	5-6	Australia (i=3), Japan (j=3)
G4	46.00	7-12	Australia (i=4), Japan (j=4)

a See Figure 1.

b Subscripts used in the text are shown in brackets.

TABLE 3

Typical Harvesting and Stock Levels

	Ground			
	1	2	3	4
Harvest : (tonnes per year) Australia	2,600	8,500	2,500	1,200
Japan	0	0	5,000	15,000
Stock numbers (millions)	9.00	3.87	1.61	0.74

TABLE 4

Demand Parameters for Australia and Japan

Market	Elasticity	Price co-ordinate ($A/tonne in March 1983 prices)	Quantity co-ordinate (tonnes per year)
Australia	$-\infty$	897	14,800
Japan	- 1.43	17,702	20,000

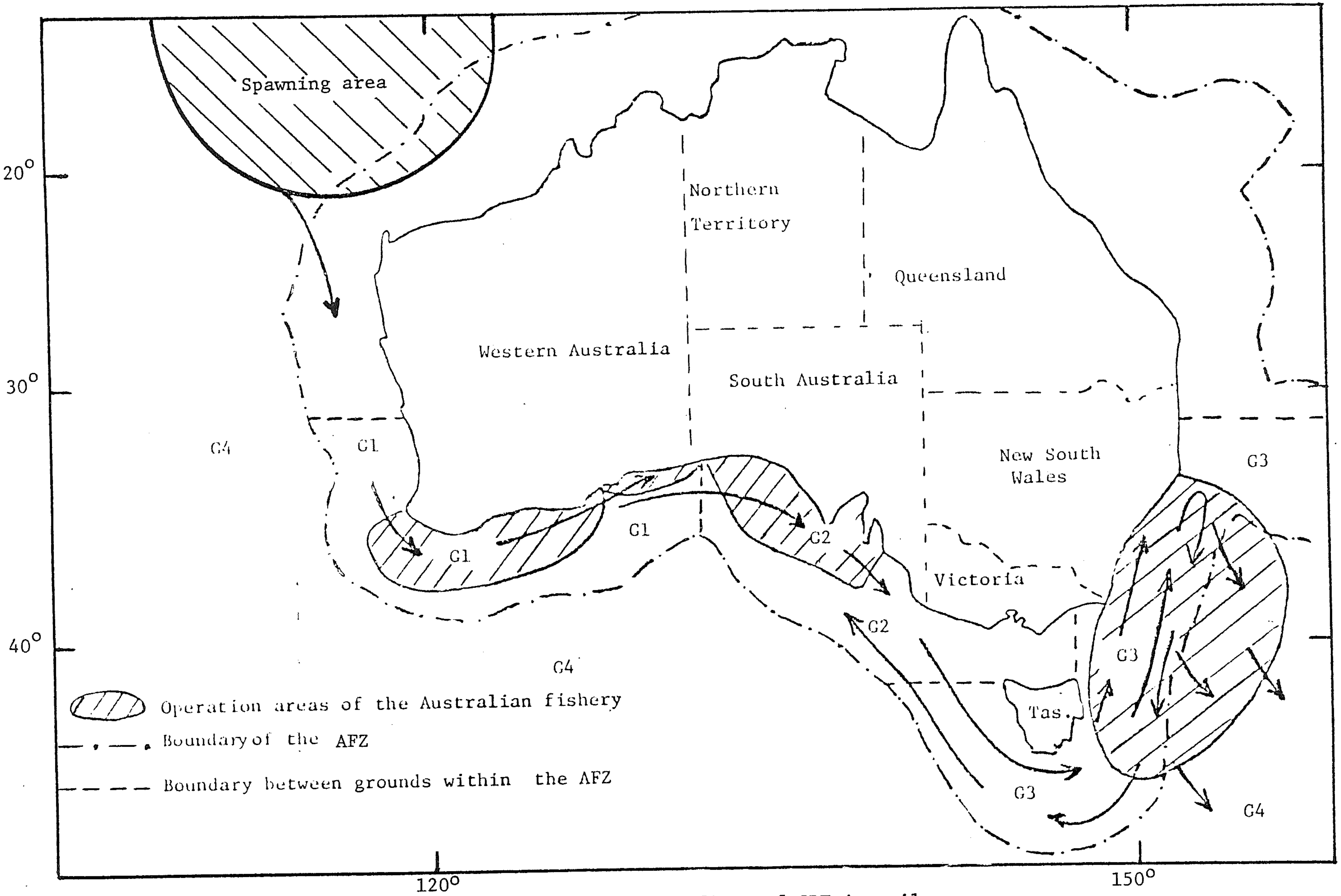

FIGURE 1 - Migration flows of SBT juveniles

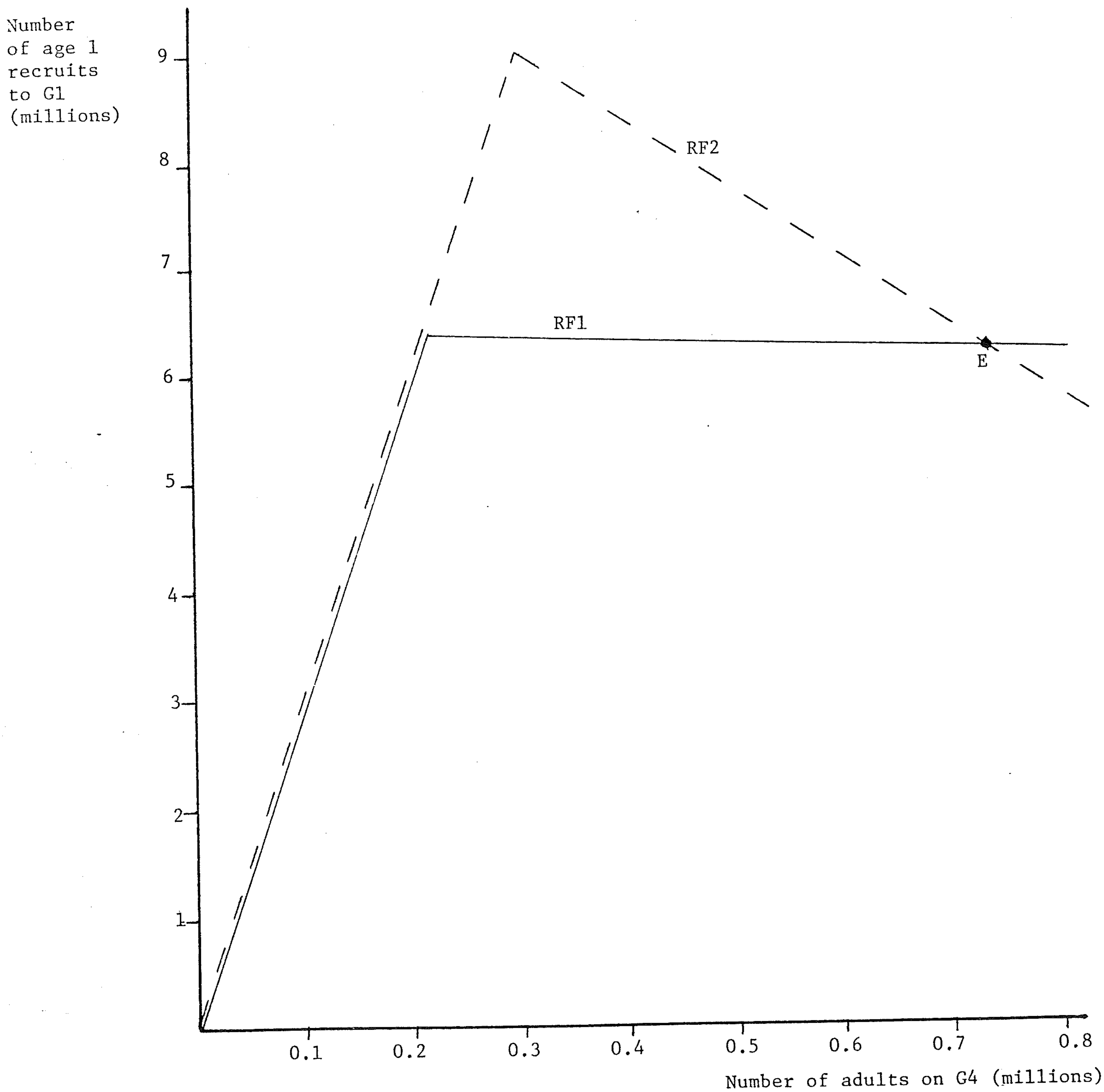

FIGURE 2 - Recruitment functions (RF1 and RF2)

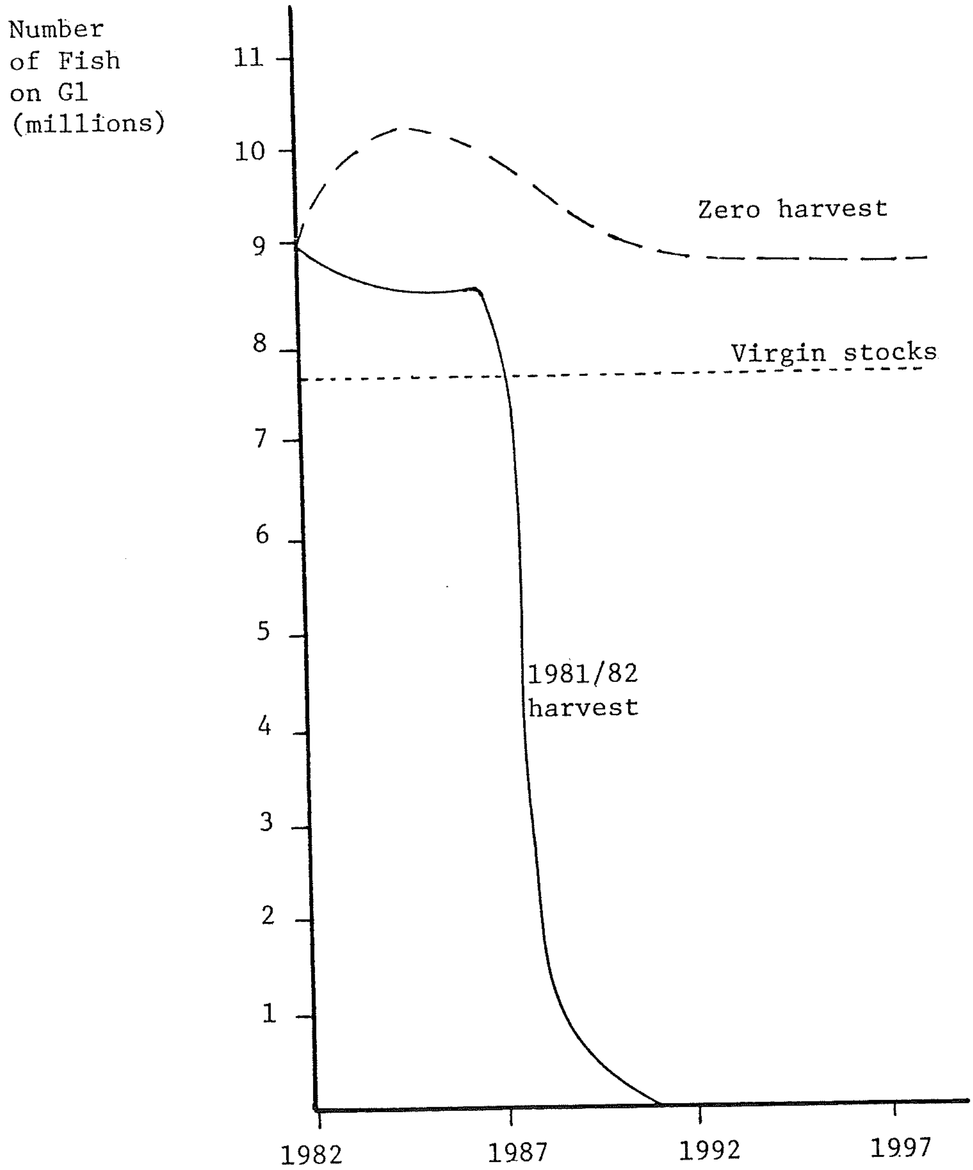

FIGURE 3 - G1 stocks for alternative harvest levels using RF1

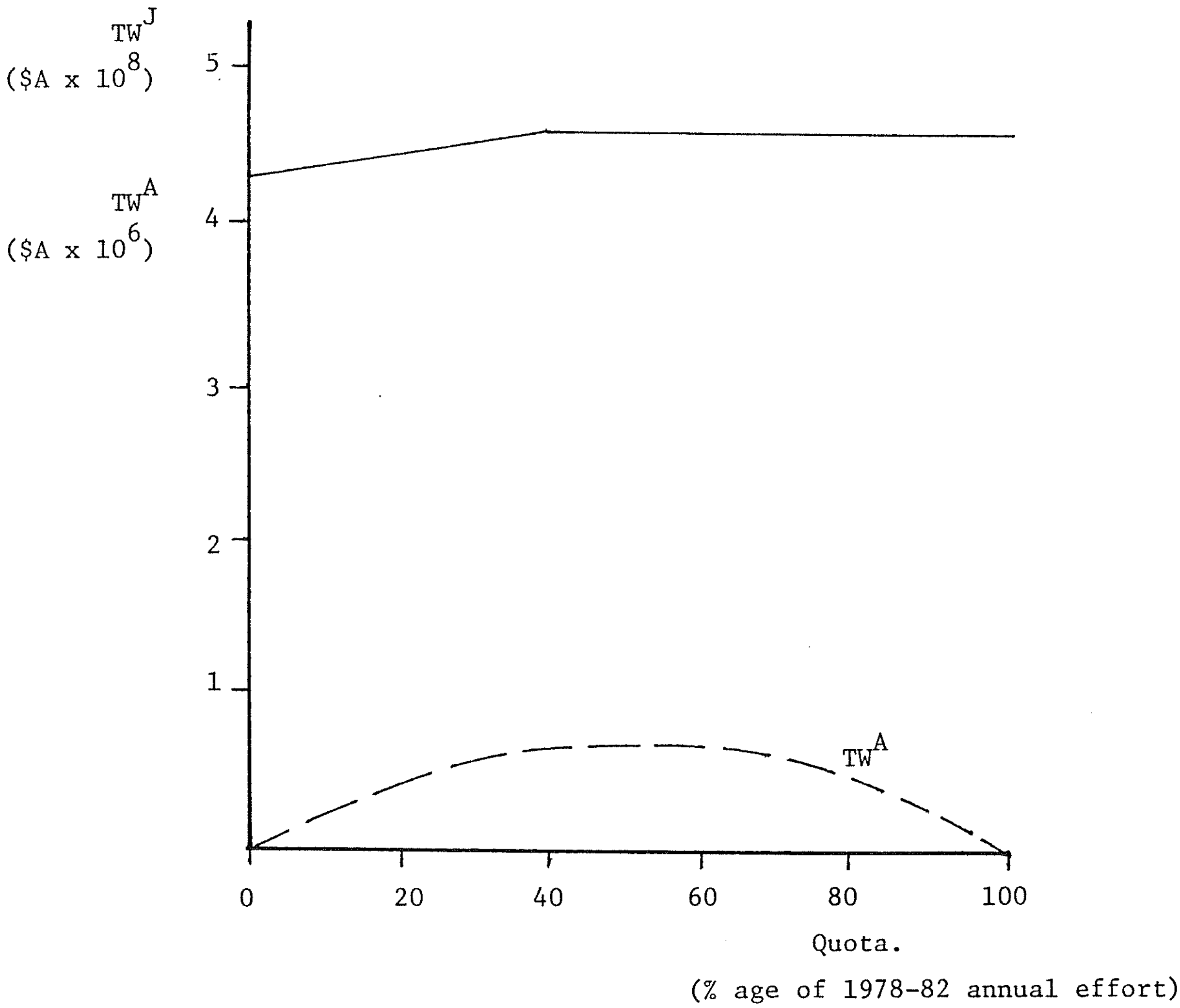

FIGURE 4 - Welfare effects of quotas on Australian Fishing effort on G1

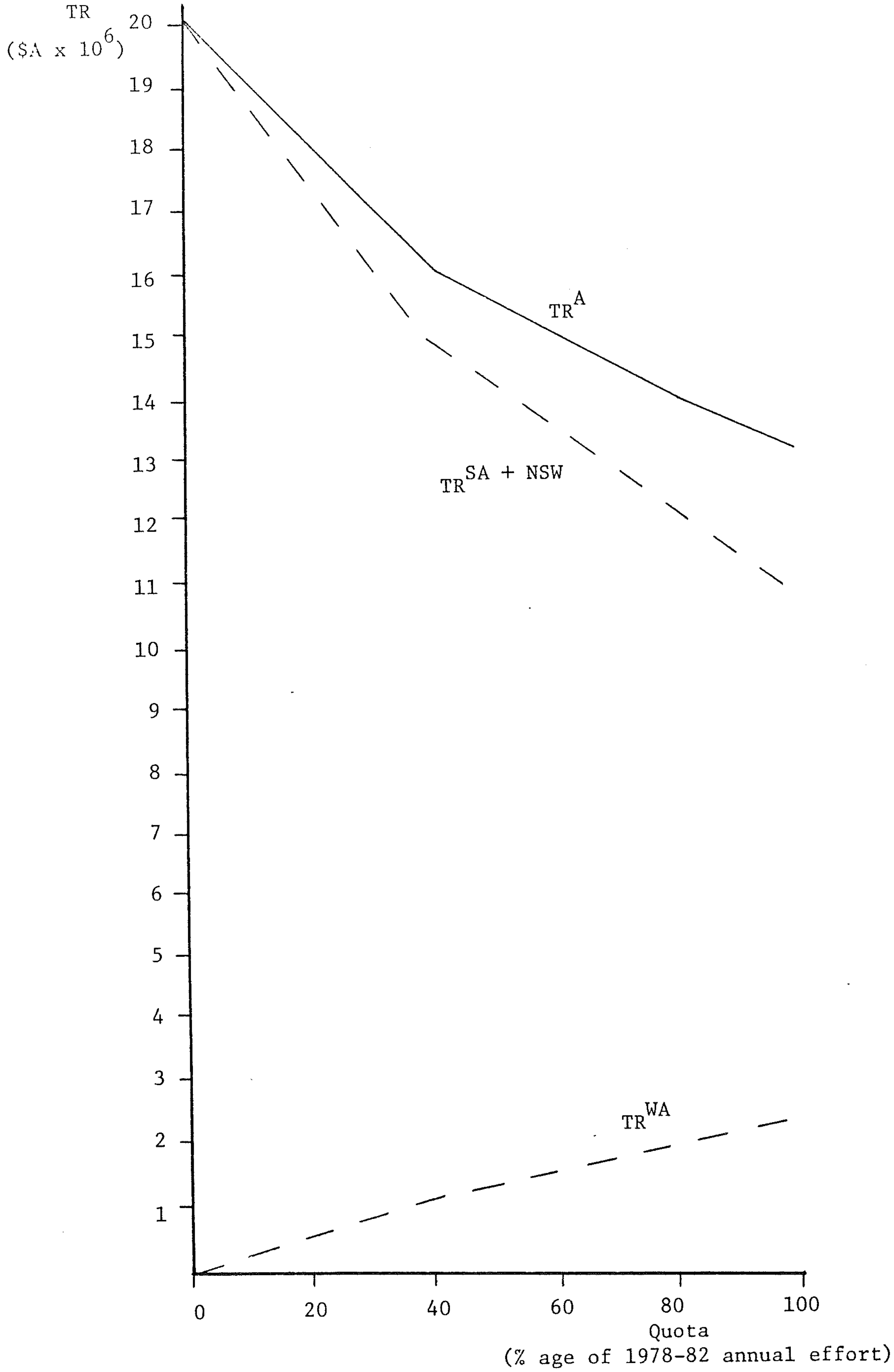

FIGURE 5 - Revenue effects of quotas on Australian fishing effort on G1

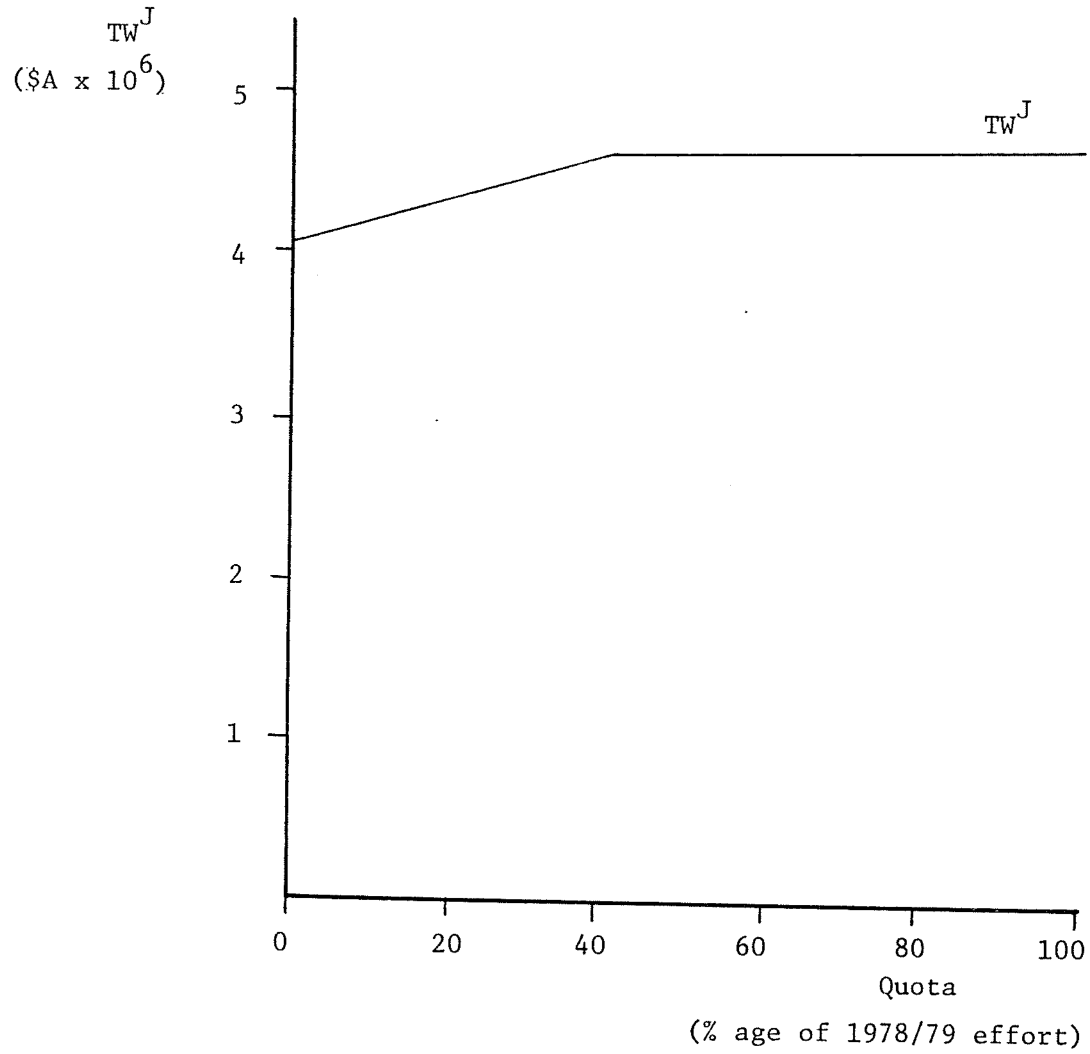

FIGURE 6 - Effects on Japanese welfare of quotas on Japanese fishing effort on G3