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A GAME THEORY ANALYSIS OF MANAGEMENT STRATEGIES FOR THE SOUTHERN BLUEFIN TUNA INDUSTRY

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Game theory offers an alternative approach to standard means of resource assessment which can be of value in the definition and assessment of policy options for competing parties. Using a Nash co-operative game it has been possible in this paper to show the significance of fishing strategies for southern bluefin tuna which take into account the age distribution of the catch. Assuming Japan and Australia act according to a cooperative game then the optimal fishing strategy was found to involve Australia avoiding the fishing of the very young cohorts and Japan taking a moderate catch in subsequent older age classes but not the oldest of the age classes. Sub-optimal strategies were also presented and evaluated along with an indication of the level of biomass associated with different strategies. It was concluded that harvesting policies need to be developed both according to weight of fish harvested and age class.

Introduction

In this paper game theory is applied to the problem of identifying policy options for competing parties in a resource allocation situation. Although current exploitation of the southern bluefin tuna fishery is of low levels (with the global quota since 1990 being set at 11750 tonnes), a consideration of the history of this fishery allows a demonstration of the effectiveness of the method.

The southern bluefin tuna is a long-lived species, with individuals being recorded up to twenty years of age. The species is a migratory one, spending periods of its lifecycle in the Australian coastal regions, the Australian Fishing Zone and also outside the Australian 200 mile zone. While there is an increasing overlap between the Australian and Japanese operations, traditionally, the Australian fishing operations have exploited the younger, coastal groups, supplying the local cannery market, while the Japanese have concentrated on the offshore adults. These larger fish are ideal for sashimi and bring very high

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prices on the Japanese sashimi market,[1] and so are selectively targeted by the Japanese. Since the late 1980s Australian fishing operators have also begun to gain access to this market, although this has involved major changes both in the fishing techniques used (including areas worked) and marketing strategies applied.

There is a competitive interaction between the major participants: the Australian operators' harvest directly affects the availability of tuna to the Japanese operation; while the Japanese harvest directly affects the level of the breeding stock — the parental biomass, and thus in the longer term, the state of the breeding stock and the availability of fish to Australian operators. However, there is also a strong element of potential cooperation between the participants. The Japanese have extensive operations within the Australian 200 mile zone and are involved in joint policy discussions about the stock with scientists and managers from Australia and New Zealand.

Simulation of the effects on population numbers of a fishery under alternative harvesting strategies is a technique widely used in the decision making process leading to the identification of reasonable harvesting levels. As well as affecting different age groups of the population, the nature of the competitive interaction between the participants in the southern bluefin fishery identifies this problem as one quite different to that of a single harvester. The interaction has a significant time lag, with the impact of the Australian effort on the Japanese harvest occurring up to six years after the actual harvesting occurs. As the Australian operators were harvesting younger fish, compared with the mature fish harvested by the Japanese, the impact from the Japanese fishery was less obviously related to the density of the breeding population. Hampton and Majkowski (1986) suggest that while at high population densities there may be no effect on the level of new recruitment in the population, at low densities of parental biomass recruitment may be a function of the parental biomass. The possibility of population collapse may occur if parental stock is seriously reduced, as is suspected to have occurred recently (Australian Fisheries 1988). Certainly, it appears very likely that with stocks of tuna at the level suggested in 1990, recruitment into the population will be a function of the size of the breeding stock, and thus, as the Japanese harvest mainly the mature fish, the effect of their effort on the Australian fishery will be through the level of recruitment into the fishery.

While various researchers have proposed levels of harvests which may lead to a sustainable population structure (for example, Kennedy 1987, Kennedy and Pasternak 1991), such research has not investigated the problem of the composition of the harvest. Similarly, while management strategies such as quotas are used in the fishery, a con-

[1] Williams and Longworth 1988, refer to an exceptional fish that fetched $A35,000 on this market.

sideration of the sensitivity of the age-class composition to such quotas has not been carried out. The extremely heavy harvests in the 1980s, when very large proportions of cohorts were harvested, have been implicated in the recent problems in the fishery. Although it may be hoped optimistically that with the continued application of individually transferable quotas (see Geen and Nayer 1989) there will be a continuation of the trend for the taking of medium — rather than small — sized juvenile fish, the importance of the structure as well as the size of the harvest should be recognised.

The aim of this research is to identify some of the critical elements in the definition of quotas for the harvesting of tuna and the results may offer information useful in development and evaluation of policy options in similar situations. The type of technique which is required is one that will incorporate both the effect of dual harvesting on the fishery and also allow for the identification of the optimal policies. It should be recognised that there is not necessarily a best approach by either Australia or Japan, the effect of any policy depending on the policy adopted by the competitor. The technique of game theory seems particularly appropriate because it is possible to include the interaction between the participants as an integral part of the problem. A game theory approach has previously been considered, for example, Kennedy (1987) adopted a non-cooperative game. In this research the situation considered is one in which there is prior negotiation by the parties involved in the fishery over levels of catches to be taken. A cooperative game is thus considered to be more appropriate.[2]

The specific problem, that of the resource allocation of the southern bluefin tuna between Australia and Japan, is assessed. The returns to Australia and Japan from a set of joint harvesting strategies are found, and these are ranked with respect to their economic payoffs and impact on the fishery as measured by the parental biomass of the fishery. From this set of strategies an optimal and feasible set of strategies is then identified. Such a set provides an initial basis for negotiations, where the two parties would have a more concrete basis for compromise and negotiation.

The Simulation Model

Game theory is a technique which has some valuable applications in fisheries biology (for example, see Kaitala 1985, Kennedy 1987, Kennedy and Pasternack 1991). The Nash, two-person cooperative game (Nash 1953) was selected as the approach by which to analyse the problem of resource allocation posed in this paper.

Using game theory, it is possible to identify the optimal solution by formally identifying strategies and their associated returns. In addi-

[2] It is recognised that all preferences may not be included in the analysis. The additional information, in the form of a set of sub-optimal strategies, is available to assist in this case.

tion, further information on the sub-optimal solutions can be evaluated. This aspect of the technique is perhaps considered more valuable than the actual identification of a single optimum, for there is then available a set of closely valued alternatives which may have similar characteristics in terms of the model but are different in ways which make them preferable to either party and thus of value in negotiations. Further, by defining strategies in terms of age-distributions of possible harvest levels, it is then possible to assess, for a set harvest weight, the effect of alternative harvest compositions. The biological structure and economic returns from the fishery under different harvesting policies were evaluated first. Then, from these payoffs the solution to the Nash two-person game was identified. In addition, a set of feasible harvesting policies was then identified, i.e. those policies with returns within ninety percent of the return of the optimal strategy.

The fishery was simulated under the effects of dual harvesting over a period of twenty years[3] with the initial population set at levels comparable to those in the early 1970s. The numbers of fish in each of 15 age classes were calculated annually during this period, so providing a record of the changing age structure. Firstly, the model included biological relationships used to simulate the population dynamics of the species. The payoffs accruing to each participant were evaluated as discounted net present values ($r = 0.08$). From the matrix of payoffs a Nash cooperative solution was identified and a broader feasible set of policies defined. Such payoffs were subject to an acceptable biological threshold (the level of parental biomass) before being considered for inclusion in either the feasible set, or as the optimal point.

For the simulation model, the following basic parameter settings were adopted. The harvest levels for Australia and Japan were set to 15,000 t and 15,000 t to 30,000 t respectively, the latter range allowing for strategies of varying harvest weight in the Japanese operation. While there has been considerable variation in the levels of harvest, since the mid 1970s Australia has taken levels between 10,000 t and 20,000 t (except for the early 1980s when catches over 20,000 t were taken) and, for the same period, Japan has generally taken between 20,000 t and 30,000 t. The levels set for this model should provide comparable harvesting effects to those which occurred during the period 1970 to 1990, with the main variation between strategies being the actual age distribution of those harvests.

Market prices used in the model were selected from distributions with means of $A1,200 per tonne and $A20,000 per tonne and standard deviations of $A200 per tonne and $A5,000 per tonne for the Australian and Japanese operations, respectively. These levels reflect both the

[3] For details of the simulation model see Klieve 1989.

very different returns received and also the different levels of variation found on these alternative markets for the period considered.[4]

To allow effective comparison between simulations run under different harvesting policies, the same random effects were used for comparable years of the simulation, thus effectively establishing the same good or bad years in the modelled fishery. Naturally, recruitment will not be the same, this depending on the parental stock as well as the random effects in the model.

Biological Relationships

Harvesting Strategies

For purposes of the model, a harvesting level, by weight, was set for Australia and Japan. The possible harvesting strategies were defined by the proportion of the total weight per age-class (see Table 1). Thus, if Australia harvests 15,000 t and adopts a strategy defining an equal harvest, by weight, for ages from two- to- six-year-olds, then a harvest of 3000 t per age class would be implied. Naturally, 3000 t of two-year-olds represents a far greater number of fish than of six-year-olds and so such a strategy would suggest a high catch of relatively young fish — and so probably a fishery based mainly in South and Western Australia.

While these hypothetical quotas reflect neither the actual state nor a future structure of the fishery, they are aimed at facilitating some comparison of the effects which differently composed harvesting levels may have. For the Australian case these reflect catches from different regional zones of the fishery. A policy of mainly taking two- to- four- year-olds (PA1, PA2 or PA3) would reflect a combined Western Australian and South Australian operation, while a policy of mainly harvesting fish between four and eight years of age (for example PA5, PA6 or PA8) would suggest a combined South Australian and New South Wales operation. For the Japanese, it is naturally far more difficult to define catches in clearly separated age-classes. Therefore, the Japanese strategies have been defined for either broad or narrow age distributions (six- to eleven-year-olds or seven- to fifteen-year-olds) and, for each of these, light to heavy catches. To incorporate a light or heavy catch, Japanese strategies were defined as either at the minimum harvest level (a sum to 1.0), the

[4] The Australian price used in this model is relatively high by market levels. It was assumed that some of the Australian catch would be marketed in Japan, thus a slightly higher price than that received from the cannery would be expected. The current structure of the fishery is very different, with virtually no product supplied for canning. Although it is desirable for values to reflect the real operation at the time considered, the aim of the research was not to predict actual returns but rather to provide a comparison of the relative levels of returns under different policies. Thus the level of return must provide a reasonable reflection of the outcomes under different strategies, rather than accurately predicting the revenue flow.

TABLE 1
Catch Strategies for the Australian (PA1 to PA9) and Japanese (PJ1 to PJ9) Operations

Strategy	Proportion of Catch by Age Class														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Australian strategies															
PA1	0.01	0.2	0.6	0.15	0.04										
PA2	0.01	0.1	0.25	0.3	0.25	0.09									
PA3		0.1	0.15	0.4	0.25	0.1									
PA4		0.05	0.15	0.3	0.3	0.1	0.1								
PA5		0.05	0.1	0.2	0.2	0.2	0.2	0.05							
PA6			0.1	0.2	0.2	0.2	0.2	0.1							
PA7			0.2	0.5	0.3										
PA8			0.1	0.4	0.3	0.05	0.05	0.05	0.05						
PA9					0.1	0.3	0.3	0.1	0.1	0.1					
Japanese strategies															
PJ1					0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
PJ2					0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
PJ3					0.1	0.1	0.1	0.2	0.25	0.25	0.2	0.1	0.1	0.1	
PJ4						0.1	0.15	0.25	0.25	0.15	0.1				
PJ5						0.1	0.25	0.45	0.45	0.25	0.1				
PJ6						0.2	0.3	0.5	0.5	0.3	0.2				
PJ7							0.05	0.1	0.1	0.15	0.2	0.15	0.1	0.1	0.05
PJ8							0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.1	0.1
PJ9							0.1	0.2	0.2	0.3	0.4	0.3	0.2	0.2	0.1

maximum level (a sum to 2.0) or between these points. All strategies set for the Australian catch were at the set harvest level, thus providing a range of possibilities by which a given harvest might be taken. The use of an overall harvest level is consistent with recent policy in the fishery, where an overall quota is set by fisheries managers. This is then allocated to fishermen by ownership of an individually transferable quota — a portion of the total set quota.

Using age-length and then length-weight relationships (defined by Hampton, Majkowski and Murphy 1984) the strategies were converted to a number of fish harvested by age (calculated for the average size of fish by age).

Stock Updating

With the number of fish harvested defined by number and with the fishing mortality set to 0.2 (a value generally used in the fishery, for example, Murphy and Majkowski, 1981) a stock updating process was carried out using equation (1):

$$(1) \qquad XNOS_{i+l,L+1} = XNOS_{i,L}\, exp(-M - F_{i,1} - F_{i,2})$$

where $XNOS_{i+1,L+1}$ refers to the number of fish in age class $i+1$ and year $L+1$ of the simulation. M and F are respectively, the rates of natural and fishing mortality, where $F_{i,1}$ refers to the i-th age class in the Australian operation, and $F_{i,2}$ refers to the i-th class in the Japanese operation. While Hampton and Majkowski (1986) suggest that the level of recruitment of new fish into the fishery may be density independent at high levels of population numbers, they also stress that at some point, recruitment will become a function of the breeding stock. The parental biomass has been used as an indicator of this stock with a critical level of 220,000 t being adopted (Majkowski and Caton 1984, suggest a level of 210,000 t). In this case, $XNOS_{1,L}$ was assumed to be a normally distributed random variable, having a mean of $\overline{XNOS}_{1,L}$ and a standard deviation of 897,459. The mean was determined by a functional relationship to $PBIOM_{L-1}$, the level of parental biomass in the previous year:

$$(2) \qquad \overline{XNOS}_{1,L} = \alpha\, PBIOM_{L-1}/[1 + (PBIOM_{L-1}/K)^{\beta}],$$

where the parameters a, b and K are given values (from Hampton and Majkowski 1986) of 34.88 recruits per tonne, 1.5 and 345 935 tonnes, respectively. The level of $PBIOM_{L-1}$ was determined from equation (3):

$$(3) \qquad PBIOM_{L-1} = \sum_{i-8}^{20} (XNOS_{i,l-1}\, WTT_i)\,,$$

where it is assumed that all fish, eight years and over, are sexually mature, and WTT_i is the average weight of a fish as it graduates to age-class i. To evaluate the level of fishing mortality $F_{i,k}$ in equation (4), a grid search procedure was used. $H_{i,k}$ is the known level of harvesting and $XNOS_{i,L}$ the age-structure of the population, where k refers to the Australian (1) and Japanese (2) fleets:

$$(4) \qquad H_{i,k} = XNOS_{i,L}\,[\,F_{i,k} / (F_{i,k} + M\,)]\,[1 - \exp(-F_{i,k} - M\,)].$$

Economic Relationships

The revenue, R_k, returned to the fishermen was evaluated for the Australian and Japanese markets, with prices received being randomly selected from a distribution of prices. Thus:

$$(5) \qquad R_k = \sum_{i=1}^{20} (P_{i,k}\, H_{i,k}),$$

where $H_{i,k}$ is the number of fish harvested from each age-class and $P_{i,k}$ the price per fish on each market, k (where market prices are evaluated in \$A per tonne while $P_{i,k}$ is in \$A per fish). The harvesting costs for each fishery, used in calculating the profit returned to each operation, were those derived by Kennedy and Watkins (1985). These costs, set for each age class and fishery (see Table 2), are in \$A per unit of fishing mortality, and thus reflect the fact that harvesting is a function of the effort expended on the operation as well as the actual level of harvest taken. Owing to the nature of the fishery, different strategies are employed to harvest different aged fish. In addition, there is a strong interaction between the population level and the amount of effort (thus cost) needed to harvest a given catch. Thus, given $HK_{i,k}$ as the harvesting cost per unit of fishing mortality, and $F_{i,k}$ the fishing mortality, the total harvesting cost, c, is given by:

$$(6) \qquad c = HK_{i,k}\, F_{i,k.}$$

TABLE 2

Total Costs for the Australian and Japanese Fisheries (\$Aus / t)

Age class	1-2	3-4	4-7	8-15
Australia	8.60	20.50	17.51	130.18
Japan	0.00	0.00	203.10	1395.14

Source: Kennedy and Watkins (1985).

The Nash Cooperative Solution

The use of the Nash two-person cooperative game implies that the 'game' between Australia and Japan has an element of cooperation. Basically, this implies that there is prior negotiation between the participants and that mutually acceptable strategies are decided before harvesting. Under such a structure, it is apparent that either party could benefit by defaulting on the agreement, having already established what their competitor's strategy will be. A normal response to such cheating would be for the other party to respond with an equally damaging policy.

The inclusion of a threat policy is an important part of this game. If either party defaults on its agreed policy, the threat policy, declared during negotiations, will be invoked. This threat strategy is a policy which reflects the response of each participant when its competitor defaults. While the response will not necessarily be a long-term destructive policy, normally it would be expected to show high short-term returns. The strategies used as the threat policy were PA1/PJ9 (see Table 1) that is, the Australian operators adopt a very heavy harvest of the younger, easier to catch fish while the Japanese adopt a heavy harvest spread over a broad older age range — thus taking a high proportion of older fish. These reflect high return policies in the short term, but policies that would be expected to be extremely detrimental in the long term.

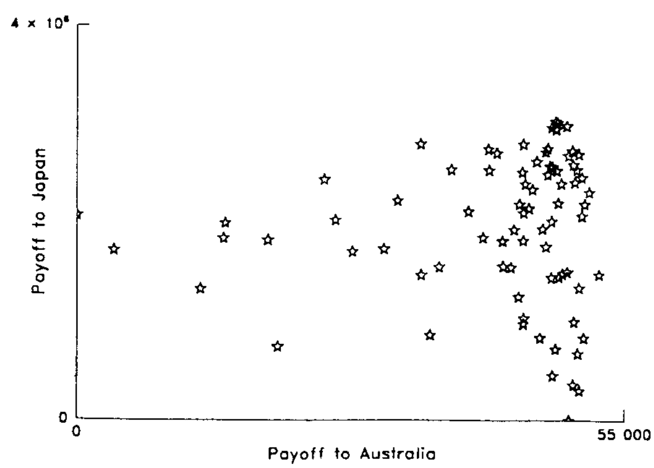
The Nash solution, as defined by Intrilligator (1971), is the maximization of z, where:

$$z = (p_1 - T_1)(p_2 - T_2)\,, \tag{7}$$

and p_1 and p_2 refer to the payoffs associated with each strategy, and T_1, T_2 refer to the payoffs associated with the threat strategies of Australia and Japan as previously defined. The maximum point is shown in Figure 1. Before this function was applied to the matrix, a linear scaling was applied to the payoffs (these linear transformations do not change the solution, (Nash 1953). The final payoffs used are in relative rather than absolute values and so the two points on the axis refer to the minimum Australian and Japanese payoffs.

FIGURE 1

Nash Solution and Returns from Alternative Strategies



In this analysis an additional constraint has been placed on the possible solution points. As well as having a high level of z they must also reflect a biologically sound policy, this being judged by the population having a reasonable level of parental biomass (the indicator of the state of the breeding stock) at the end of the simulation cycle. A threshold level of parental biomass was set at 220,000 t. If any harvesting option results in a level below this, it was not considered as a solution point, or as a candidate for inclusion in the feasible set, no matter how high its level of returns.

Naturally, with an increasing time horizon, the relationship between optimal economic returns and biological equilibrium would be expected to become closer. This is because returns are tied to the level of the stock and where overfishing occurs, the cost of harvesting will become increasingly high. Thus in the longer term, a stable population level and secure economic returns are mutually dependent objectives.

Results

Ten replications of the model were carried out. From these, three different policies were identified as optimal, PA8/PJ4 in six, PA7/PJ4 in three and PA4/PJ4 in one replication. In all cases the same Japanese strategy, PA4, was identified (a low level harvest taking 6-11 year-old fish). The three identified Australian strategies are very similar, all taking a catch predominantly of three to five year-olds (PA4 75%, PA7 100%, PA8 80%).

Detailed results for six policies are provided in this paper. These reflect important groups among the possible policies: the optimal solution (PA4/PJ4, PA7/PJ4 and PA8/PJ4), the threat policy used (PA1/PJ9) and two policies which reflect aspects of recent exploitation within the fishery (PA2/PJ2 and PA1/PJ6). In the case of Australian strategies PA1 and PA2, heavy catches of very young fish are taken-these suggest relatively large catches by a Western Australian fishery (as occurred particularly during the early 1980s). PJ2 and PJ6 are Japanese strategies with heavy harvests, particularly of young fish (five and six-year-olds) which have been increasingly targeted (Hampton, Majkowski and Murphy 1984). The results presented are from one simulation. However, by providing these for all the identified optimal strategies it is apparent that there is a distinct difference between the optimal or sub-optimal strategies and the others detailed below.

The number of three-year-olds in the fishery over the period of the simulation cycle under different strategies is presented in Figure 2. In Figure 3 the corresponding pattern of nine-year-olds is provided. These reflect the levels of fish coming into the main age-groups of the Australian and Japanese operations. There is an initial period in the simulation where the effect of the adopted policy is being established in the population. All strategies follow the same general trends (that is, they reflect the same random annual effects), with numbers under the optimal strategies being markedly higher at both ages presented. Numbers under PA1/PJ6 drop dangerously low, while those under PA2/PJ2 and PA1/PJ9 following similar patterns, are better than under PA1/PJ6 but well below those of the optimum strategy and these do not represent sustainable policies.

FIGURE 2
Number of Three-Year Olds Under Selected Strategies

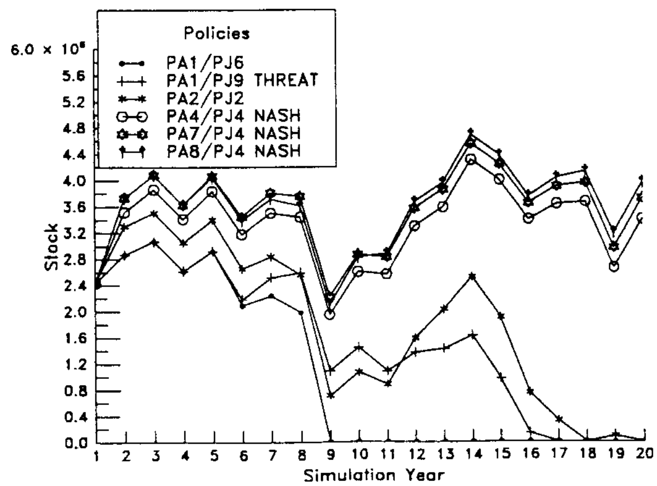
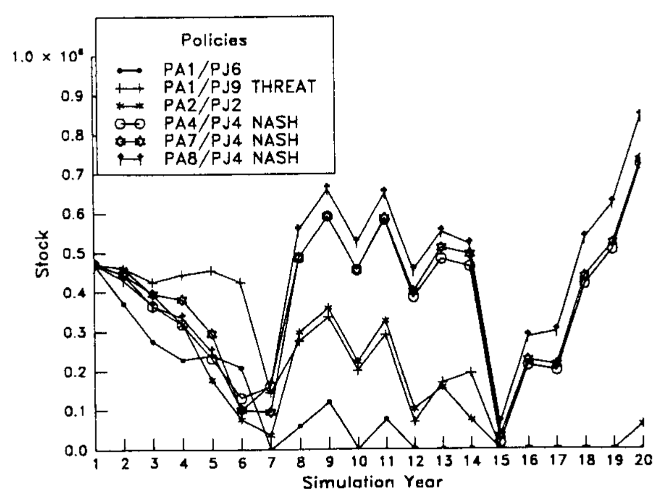
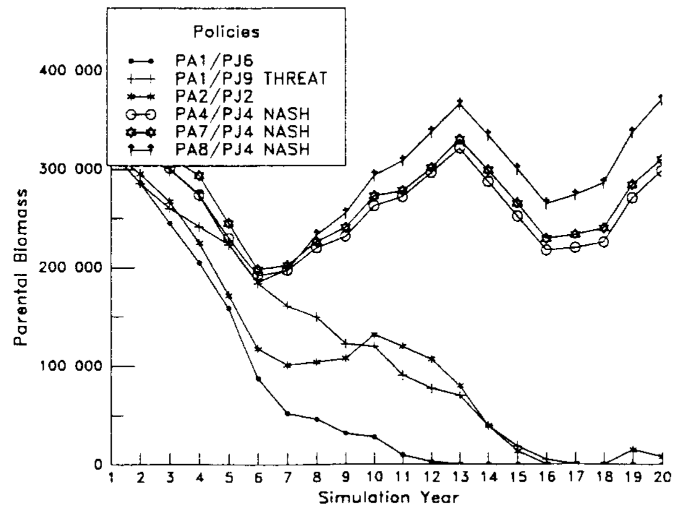


FIGURE 3
Number of Nine-Year Olds Under Selected Strategies



The change in parental biomass is presented for the six policies discussed (Figure 4). An initial decline is noted under all policies. However, the only policies leading to a strong future biomass are the optimal policies. The biomass under both PA2/PJ2 and PA1/PJ9 strongly declines, suggesting that long-term recruitment problems would be likely. Early levels of unsustainable population numbers are predicted under the policy PA1/PA6.

FIGURE 4
Level of Potential Biomass Under Selected Strategies



A summary of the relative position of each possible policy with respect to biomass and payoff is presented in Table 3. All sub-optimal policies were ranked on a 1 to 8 scale; this reflecting the level among the 80 policies. The identified optimal policy with regard to payoff was labelled 9. This ranking allows the overall effect of different policies to be assessed with respect to both their biological (b) and economic impact (z). The policies having a payoff within 10% of the maximum are defined as in the feasible set.

The preferred Japanese policy overall is PJ4 (this provides a high level of return for all Australian strategies although when paired with PA1 or PA2 it leads to dangerously low levels of parental biomass). PJ1 is preferred to the other low strategy, PJ7. This latter policy harvests fish over a wide age range with 60% being over 10 years of age. When such a policy is joined with a large catch of young fish, PA1, an early depletion of the stock will occur. A similar, though lesser effect will occur when a large harvest is taken of older fish, this mainly affecting the parental biomass (as can be seen in Table 3). It is apparent that while some strategies appear good (for example PJ4, PJ1, PA8,

TABLE 3

Levels of Payoff (z) and Parental Biomass (b) Associated with the Various Harvesting Strategies

Japanese strategies	Australian strategies								
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9
PJ1	b=2	b=4	b=5	b=6	b=7	b=8	b=7	b=7	b=8
PJ2	b=1	b=1	b=2	b=2	b=3	b=4	b=3	b=4	b=6
PJ3	b=1	b=2	b=3	b=4	b=5	b=5	b=4	b=5	b=7
PJ4	b=1	b=3	b=4	b=5	b=6	b=7	b=5	b=7	b=8
PJ5	b=1	b=1	b=2	b=3	b=3	b=4	b=3	b=4	b=6
PJ6	b=1	b=1	b=1	b=2	b=2	b=3	b=2	b=2	b=4
PJ7	b=3	b=6	b=7	b=8	b=8	b=8	b=8	b=8	b=9
PJ8	b=2	b=4	b=5	b=6	b=7	b=7	b=6	b=7	b=8
PJ9	b=1	b=3	b=4	b=5	b=6	b=6	b=5	b=6	b=7
PJ1	z=5	z=4	z=6	z=7[a]	z=6	z=7[a]	z=7[a]	z=7[a]	z=2
PJ2	z=8	z=5[b]	z=4	z=1	z=1	z=3	z=5	z=2	z=6
PJ3	z=8	z=2	z=2	z=6	z=6	z=7	z=6	z=7	z=3
PJ4	z=8	z=6	z=7[a]	z=8[a]	z=7[a]	z=8[a]	z=9[a]	z=8[a]	z=7[a]
PJ5	z=8	z=4	z=3	z=4	z=2	z=5	z=6	z=3	z=6
PJ6	z=8[b]	z=8	z=8[a]	z=3	z=1	z=1	z=4	z=1	z=5
PJ7	z=3	z=5	z=6	z=2	z=2	z=4	z=2	z=3	z=5
PJ8	z=3	z=2	z=1	z=1	z=1	z=4	z=1	z=3	z=5
PJ9	z=7[c]	z=1	z=3	z=4	z=5	z=2	z=4	z=5	z=4

[a] Optimum solution/Feasible set. [b] Current policies. [c] Threat policy.

PA7, PA4) and others very poor (for example PA1, PA2 and PJ6) the final assessment must be a function of the jointly defined policy.

It appears that even in the relatively short term, the impact of heavy catches in the early age classes can be seen to reduce the availability in the later age-classes. More importantly, a flow-on effect of reduced parental stock from such policies then leads to a detrimental impact on the level of recruitment and the long-term associated problems with this situation. This situation is directly related to the effect the rate of fishing mortality has on the age-classes in the population.

Discussion

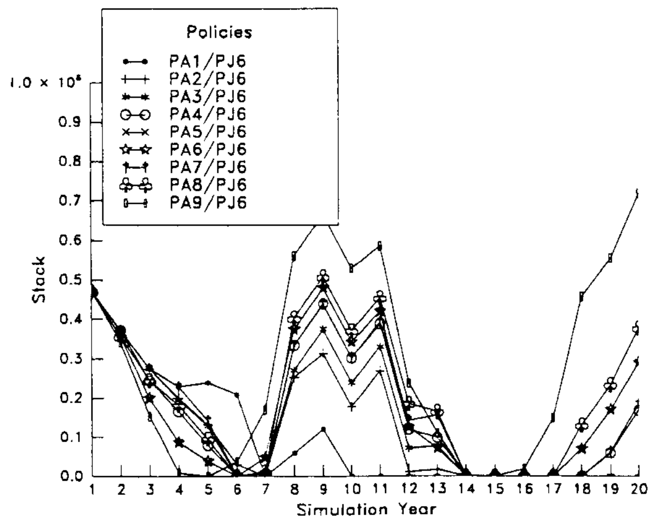
In recent work by Kennedy (1987) a game theory approach was used (with the southern bluefin tuna as an example) to consider the joint harvesting of fisheries. A joint rent maximizing solution was presented as well as the Nash non-cooperative solution. The solutions from these represent perfect cooperation and perfect non-cooperation. In a later paper, using the same approach but with a larger model, Kennedy and Pasternak (1991) compare social rents and harvest levels through time under both joint maximization and duopoly. They found a substantial reduction in the Australian harvests for the early years compared to those found for the duopoly solution. From this they concluded that it would be in the Japanese interest to buy Australian individual transferable quotas, without using them, in those years. Such a policy provides an opportunity for a recovery in the breeding stock while retaining a harvestable adult stock.

While it is important to identify the best policy, particularly if all the assumptions of the model are reasonable, there can be considerable additional information in other possible solutions. That is, the assessment of a range of possible management policies using the set of sub-optimal policies. Such sub-optimal policies may prove preferable when different subjective factors, difficult to quantify in a model, are taken into account. Further, the knowledge of such a set offers some scope in negotiations to find agreed harvesting policies.

It can be concluded that it is most beneficial for the Australian fishery not to harvest significant numbers of fish under three years of age (thus effectively excluding a Western Australian operation). The logical extension of this is that it would be best for Australian operators to postpone fishing and harvest only the oldest group of fish available to the surface fishery by using only the New South Wales fishery. However, such a strategy would mean higher harvest levels on the older age-classes which are also exploited by the Japanese. This does not appear to be a preferable option owing to the high total fishing mortality and higher harvesting costs for older fish. The direct effects of the current Australian policies are relatively clear: fishing by Australia results in a reduction of numbers in the later age-classes primarily exploited by the Japanese operators.

The effects on the Australian operation of Japanese policies are less clear. Such effects will arise primarily from dependence of the level of recruitment into the fishery on the breeding stock (currently measured by the parental biomass). As the Japanese predominantly exploit mature fish and as it appears that the population is now in a state of over-exploitation, such that recruitment will be influenced by fish density, then significant effects on the numbers available to Australian operators owing to reductions in the breeding stock would be expected. Such reductions are quite clear in Figure 5, which reflects the level of recruitment into the Australian operation.

FIGURE 5
Number of Nine-Year Olds Under Japanese Strategy PJ6 and Various Australian Strategies



Policy Implications

The simulation results reported in this study permit an examination of alternative fishing options which could have been taken in the past and their impact on both the economic returns and the biological status of the fishery. Currently the fishery is in a state where new long-term decisions must be made that will affect its existence as a continuing fishery. While this analysis does not attempt to comment on the current dynamics of the fishery, several implications for current policy are apparent. Firstly, even while the population is in a relatively stable state, it is important that excessive harvesting pressure is not placed on any age class within the fishery. To achieve this, records of catch levels considered in both tonnes and numbers may be useful, thus allowing the relative pressure on a particular cohort to be assessed. Certainly, when numbers actually harvested in the 1982 and 1983 seasons are considered and with some millions of two and three-year-old fish removed from these cohorts, it is hardly surprising that major reductions in the adult stock occurred in the late 1980s. With hindsight, it is obvious that such heavy harvesting could not be sustained.

Finally, in coming to management decisions it is important that a range of possible harvesting options is evaluated, so providing wider scope for final decisions. This application of game theory has demonstrated the value of this method in the assessment of a range of management options and the identification of the preferred policy.

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