Chapter 1

Introduction

1.1 Introduction

The southern bluefin tuna is a very important species, not only to Australia, but also on the broader world market. In Australian coastal waters it is subject to extensive exploitation from a diverse Australian operation. The fish are mainly processed and sold on the domestic (canning) market, though some are also exported to Italy (for canning) and to the Japanese sashimi market. Additionally, however, there is a long history of exploitation from the Japanese - servicing the highly priced sashimi market.

Within the fishery, there is a strong element of competition. The impact of any particular harvesting strategy and the returns from it will be dependent not just on the current state of the stock and the possible returns from the market, but also on which harvesting strategy is selected by one's competitor. This will also have an impact on the levels of fish available, and thus the effort required to harvest them.

Management of the fishery is subject to many of the general problems which have led to fisheries management being both complex and frequently unsuccessful. Techniques of stock assessment are often both indirect (for example, tag release/recapture programs) and generally suffer from lengthy time lags between the occurrence of a problem and its identification in an assessment program. This is a particular problem in such a long lived species as southern bluefin tuna (fish surviving to over twenty years of age). Thus, while the cohort analysis technique has been extensively and effectively used in this fishery, its value in management is limited by its need for time sequence data of age-classes (cohorts).

Understandably, a more recent trend in management has been the development of simulation models - from these it is possible to assess the long term effects on a fishery of a range of potential harvesting policies. Such evaluations not only need to consider biological criteria but also to assess the economic viability of management options - therefore, the question of whether a policy is sustainable from the point of view of the resource and also for the agents utilizing this resource, is addressed.

This form of analysis appears to offer a far more effective technique for the identification of a 'sustainable' strategy of resource exploitation than do other techniques aimed at identifying sustainable levels of harvest. For example, in the past, there has been a heavy dependence on the use of Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY). However, while the aims of these methods are excellent, these techniques are relatively simple in their representation of complex biological and economic systems. Waugh (1984, p.4), in a consideration of the economic management of marine resources, found that although the concept of maximum sustainable yield has been widely used in the past, it is '... thoroughly discredited from both ecological and economic viewpoints'. Unfortunately, he also suggests that such concepts and also the even more general idea of an optimal sustainable yield, are still widely applied.

An important aspect of resource management, emphasised by Randall (1987), is that, while resources such as the southern bluefin tuna may well be renewable, they are also destructible. This latter point is frequently forgotton by managers. Although it has been recognised that the southern bluefin tuna population is overexploited (for example, Murphy and Majkowski 1981 and Australian Fisheries 1988a), and so is threatened, at least as a commercial species, it is difficult for participants in such a fishery to seriously accept such a conclusion while it is still a commercially viable enterprise. Although the future parent stock (measured by the parental biomass level) may be recognised as being heavily overfished there will always be a timelag between such a recognition and its impact on the level of harvesting attained. High harvesting levels *may* be due to a stable resource, but equally can be the product (at least temporarily) of technological advances in technique or increased or changed effort levels in the fishery.

The recent findings on the state of this fishery (Australian Fisheries 1988a, 1988b) recognise that it is a severely depleted resource in danger of both economic and biological extinction. The most recent catch levels, markedly decreased over those of previous seasons, are consistent with this finding, with projected quotas now lower than any since the early sixties.

1.2 Objectives of the Current Research

The objectives of this study are:

1. To develop a model to simulate the southern bluefin tuna population and then link this to a game theory model.
2. To use the game theory model in the specification of a set of biologically and economically feasible policies for the fishery.
3. To comment on these policies from a fisheries management point of view.

1.2.1 Fishery Management

By setting competitive strategies for the two participants (Australia and Japan), and then simulating the negotiation and decision making in this fishery, suggestions for reasonable management options will be made. In a real situation, such decisions are made between competitors, here Japan and Australia are in a competitive relationship where the policy adopted by both participants can have direct (if lagged) effects on the other party. Knowledge of the current status of the fishery, in the short term, is unreliable so that simulation models are generally becoming a valuable tool in fisheries management.

While the current study does use a standard simulation technique to analyse the impact upon the fishery and the returns to those exploiting this resource, its approach also allows competitive strategies, which might be adopted by one participant in the fishery, to be evaluated under varying conditions *including* a range of alternative strategies which could be adopted by the other party.

1.2.2 Game Theory Analysis

This research will apply the technique of game theory. It is a methodology by which the competitive interaction between two parties in a fishery can be assessed at a relatively early point in exploitation and possible acceptable policies identified and a strategy negotiated. Also, by examining the population under the impact of a range of strategies the effect of specific policies on the dynamics of the tuna population in the long term may be gained. This will provide a better insight into management issues from the perspective of the biological stability of the resource and also the economic efficiency of its utilization.

This method does not rely on the level of profit outcomes but rather the relative positions of comparative strategies with respect to profit (or some other decision variable). Thus, the objective of the analysis is not to find specific return levels for the fishery, but to assess the relative benefits of a range of options (potential management strategies).

While the game theory technique can be used to identify an optimal strategy, it also can be used to identify strategies which consistently have an acceptable impact and from which the optimal solution will be selected. It is felt important to consider several groups of strategies. Firstly, the identified optimal strategy. Secondly, strategies which have a marginally less attractive outcome, these being defined within a 90 percent band of the optimal outcome. This total group will be labelled the feasible set. It is of value to define this broad group of possible solutions, for they provide possible input for the negotiation process and also allow managers to select policies which, although having a slightly lower return, have other appealing aspects not included in the decision criteria. Finally, strategies which have a strong impact on the fishery and which lead to non-viable policies should be considered. These may be non-viable either from an economic or biological viewpoint.

1.3 Hypotheses

1. That the current management policies within the fishery do not
lie within the defined feasible set (that is, a 90 percent band of the optimal policy).
2. Using a Nash nonzero-sum, two-person game (Nash 1953) on the southern bluefin tuna industry, the feasible set is not empty.

These hypotheses, while not being testable at a statistical level can clearly be assessed in the light of the identified optimal solution and the feasible set of sub-optimal solutions.

Policies with similarities to those recently used in the fishery can be identified and the occurrence of such policies in the feasible set ascertained. Similarly, it is conceivable that no policy will satisfy the biological constraint on the optimal solution (that is, that the policy has an acceptable level of parental biomass). In such a case the feasible set would be empty and the second hypotheses, reflecting the value of the technique, would be rejected.

1.4 Outline of the Study

In the following chapter a detailed background to the southern bluefin tuna fishery is provided. Aspects of the history of the harvesting of tuna as well as details of the participants in the fishery and the markets available to them are discussed.

The game theory technique, and in particular the Nash nonzero-sum, two-person game, is outlined in Chapter 3. Specific details of the simulation model used to derive the payoffs for the Nash game are provided in Chapter 4. This section also includes references to the relevant literature used in developing this model.

Finally, the results from this model and the implications of these are presented in Chapters 5 and 6. Here, both the specific results from the simulation model and their general implications are discussed.

Chapter 2

The Southern Bluefin Tuna Fishery

2.1 Introduction

Southern bluefin tuna is a highly migratory species fished primarily by Australian and Japanese fisheries - although there has developed a small catch taken by New Zealand longliners (see Figure 2.1 for areas of operation). The species, in its juvenile phase, moves through the Australian coastal waters and then enters the Japanese longline operation at about six-to eight-years of age (when mature). There is, however, a degree of outmigration (that is, fish not actually passing through any or all of the coastal waters) this being indicated by arrows in the flow patterns in Figure 2.1. The movement within the coastal region, while leading to some geographical separation between age-classes, is not totally distinct, with overlaps being found between Western Australia and South Australia and South Australia and New South Wales.

The history of the catch may be summarised in Figure 2.2. While Australia has some management responsibility for the fishery within its Exclusive Economic Zone (200 nautical mile zone, see Figure 2.1) the movement or harvesting of the species is not confined to this area. Australia has the right to negotiate access conditions for the Japanese to fish within the zone. Currently, the Japanese pay a fee which allows them to operate in specific areas within the Australian zone (for example,

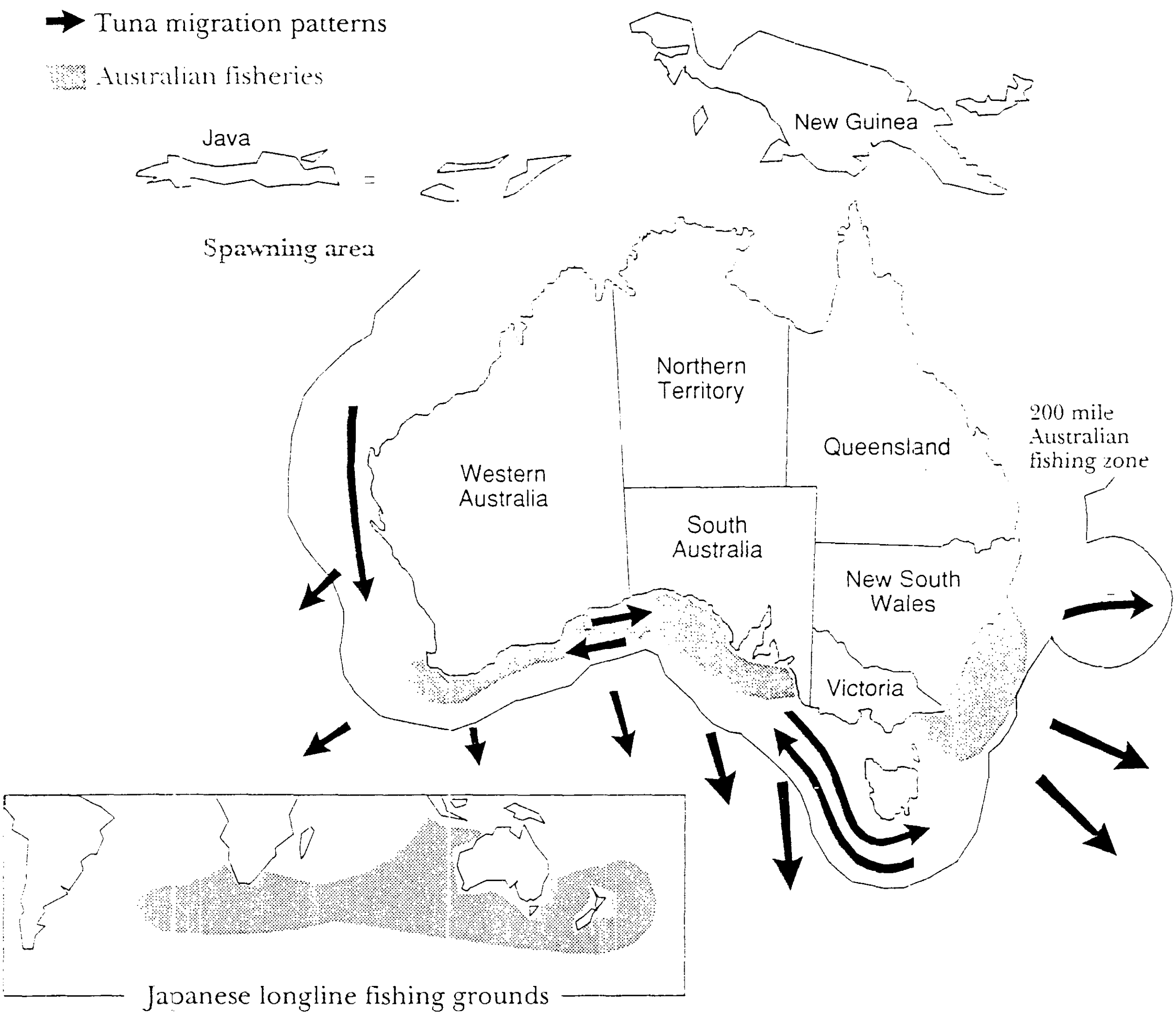


Figure 2.1: The southern bluefin tuna fishery (Geen and Nayer 1989)

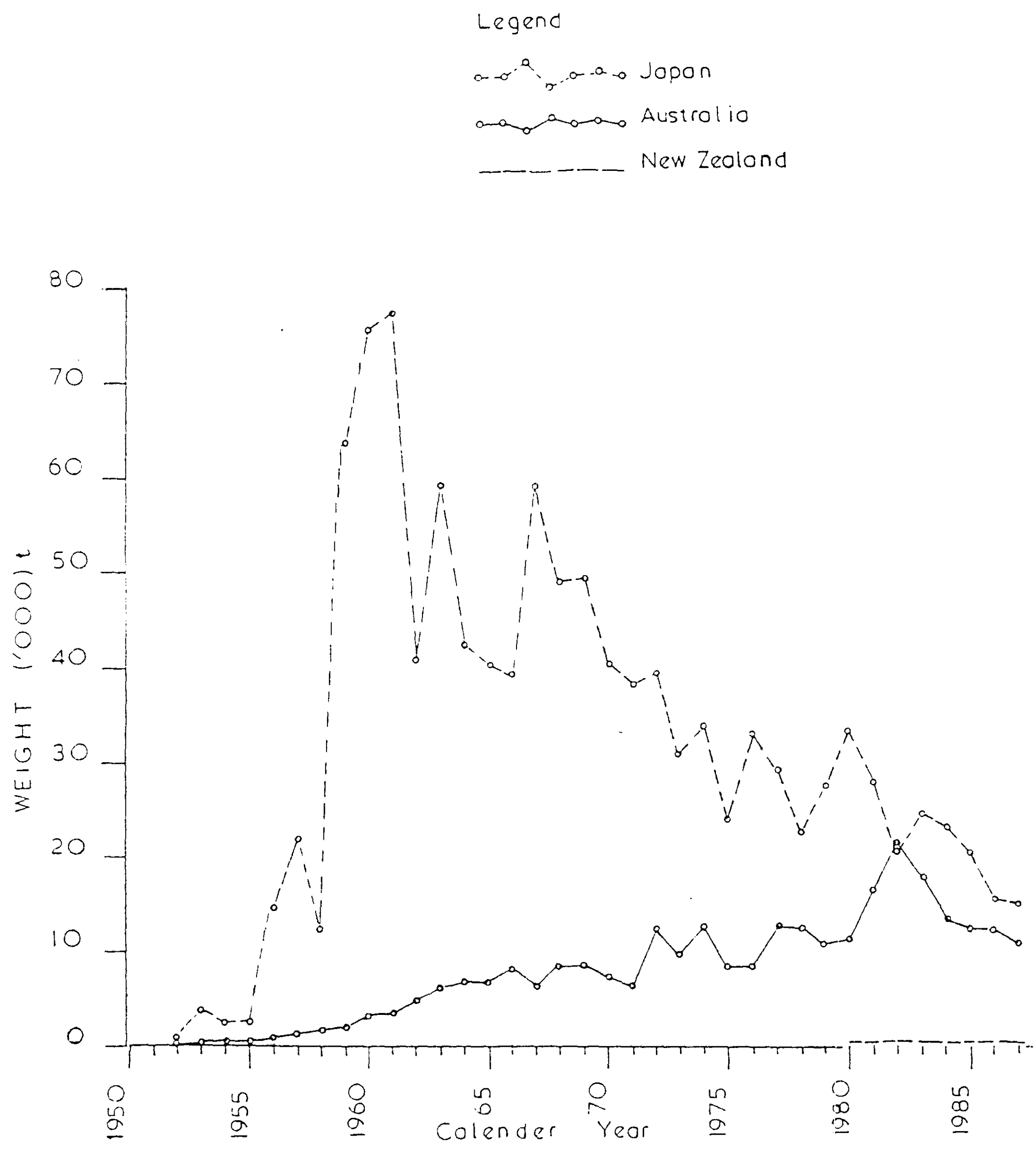


Figure 2.2: Catch of southern bluefin tuna by the major participants in the fishery (data : Kuronuma 1988).

Australian Fisheries, 1983f). However, only a small proportion (around 10 percent) of the total Japanese catch is actually taken within this zone.

This review aims to consider briefly some of the important aspects of the fishery, particularly those relevant to this research. It will provide a background to the operations of the two major participants and the associated markets, and also give some consideration to the currently recognised status of the stock. A more comprehensive review of the fishery, and in particular its history and economic aspects, is provided by Kuronuma 1988.

2.2 History

Figure 2.2 provides details of the catch history of the major participants in the fishery. The very large catches by the Japanese in the early years reflect exploitation of a previously untouched resource. While large tonnages were taken, it is also significant to note that the average size of fish in those years was far greater than in more recent times. Thus there existed an unexploited stock with large numbers available in the later age-classes.

2.2.1 The Australian Operation

Introduction

The Australians operate a primarily surface fishery, relying heavily on poling and purse-seining as techniques. Poling is used on surface schools, where, once the fish are in a feeding frenzy (after bait fish are thrown in) long poles with barbless hooks are used to lift the fish (using their own momentum) onto the boat. Purse-seining relies on a very large boat (often working with the smaller poling boats) sending a large deep net around a school. The net is then drawn in, the fish being caught in the tail. Using this method very large schools can be harvested quickly and efficiently.

Esperance (Western Australia), Port Lincoln (South Australia) and Eden (New South Wales) are used both as ports close to the availability of fish and also as locations where much of the processing of fish is carried out. There are, or have been, canneries located at Eden, Port Lincoln and Albany (near Esperance). Port Lincoln is currently also the centre for movement of tuna for export both to Italy and Japan.

Early fishing by the Australians was carried out using trolling (surface lines pulled behind slowly moving vessels). However, poling has been the major technique used in the surface fishery. More recently, purse-seiners working in cooperation with the poling boats have enabled a more efficient harvesting of large schools. The major effort in the Australian operation has been through ports in South Australia and New South Wales, with many boats moving between these ports to work an extended season. Usually boats are affiliated with one of the major purchasers (Heinz, SAFCOL or South Australian Tuna Processors). Spotter planes, which are able to direct boats to areas where surface schools are located, provide assistance.

The establishment of an operation at Esperance is relatively recent (see Figure 2.3) and even in its development this operation has been less devoted to southern bluefin tuna than were the comparable operations in South Australia and New South Wales. Out of the tuna season many boats rely on catches of other species, these boats being designed more for general fishing than specifically for southern bluefin tuna. Figure 2.3 highlights both the vary large numbers taken by South Australia and Western Australia in recent years and also the decline of the New South Wales operation.

In 1984, following debate about the state of the stock, there was an Industries Assistance Commission inquiry into the fishery (Industries Assistance Commission 1984). Following this, individually transferable quotas were introduced into the Australian sector in an attempt to control the level of catch. These provided a means of allocating to fishermen a share of the allowable Australian quota. The level of quota is set annually based on the biological situation of the fishery. The actual allocation of these quotas (Australian Fisheries 1984d, and Geen and Nayer 1989) is based on the previous catch level taken during the period 1980 to 1983 and also the capital investment in the fishery. This allows fishermen operating within the Australian region immediately prior to the introduction of individual transferable quotas to be able, with a proportionate share of the catch, to continue to work. However, the quotas are transferable and thus individuals may purchase a greater share than they were

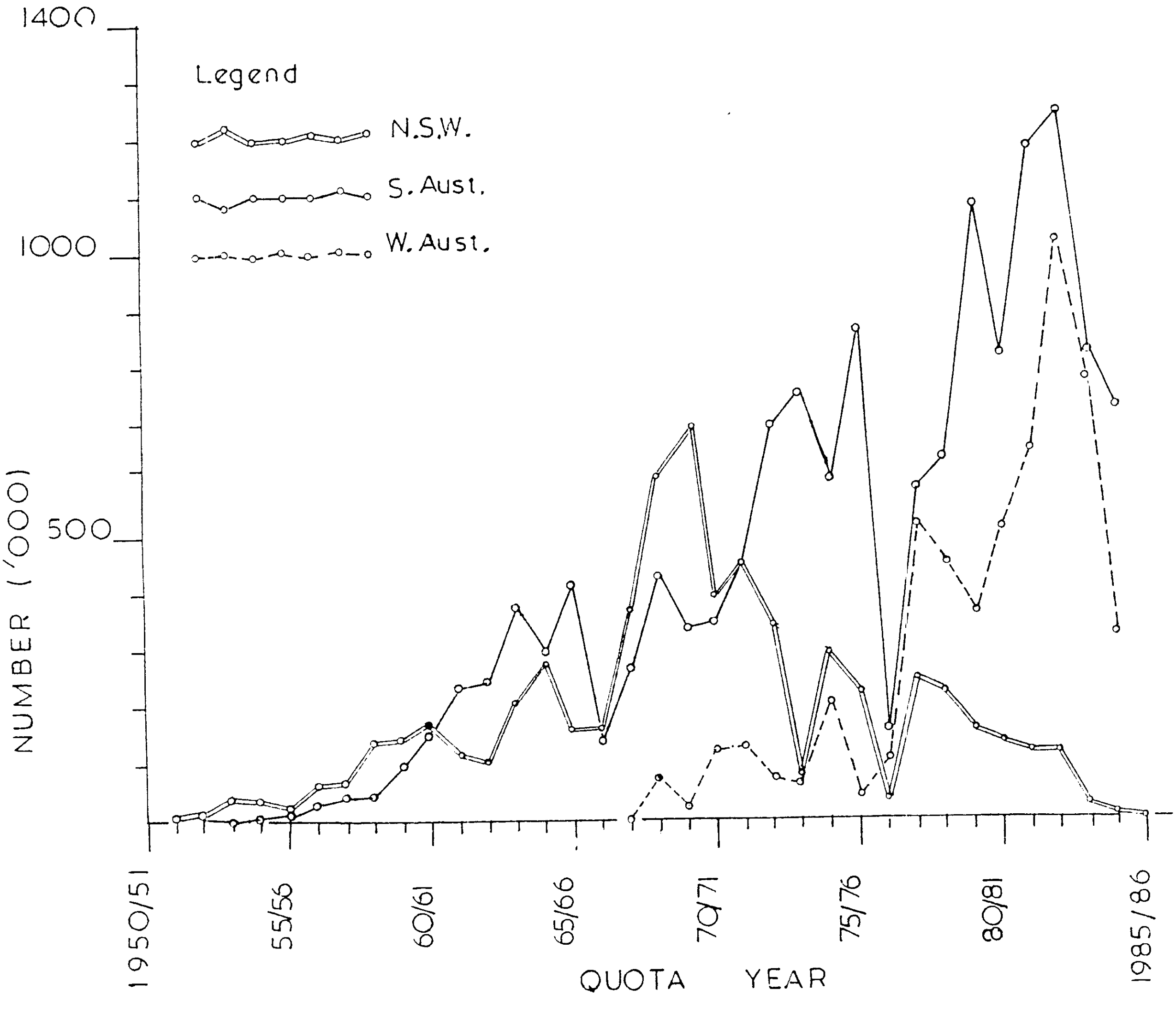


Figure 2.3: Catch of southern bluefin tuna by state and number of fish (data : Kuronuma 1988)

originally allocated. This, in fact, has occurred since their introduction, with a large part of the allocated Western Australian quota being bought by the South Australian fishermen. Quotas are, however, allocated by tonnes taken and do not relate to the actual age group of the fish. So, while there is some incentive to preferentially target older fish, if the Japanese market can be accessed, for many fishermen a major factor will remain ease of harvesting.

Age Distribution of Catches

As can be seen from Figure 2.1, there is some level of separation by age class for the three sectors of the Australian operation - younger fish first being taken off Esperance, then a somewhat older group off Port Lincoln, and finally the oldest group within the Australian area, caught off Eden. This separation has been used in the model of the fishery in this research to define strategies that relate to one or more regions of fishing. Thus, a catch distribution ranging from two-to five-year-olds would suggest fishing in South Australia and Western Australia while one incorporating catches of three-to seven-year-olds would suggest a South Australian and New South Wales operation.

However, while this age separation has been marked in the past, with a more mobile Australian fleet (utilizing larger boats and aerial spotters) any shortage in the normal fishing grounds has been compensated for by increased effort in further offshore areas. Thus there is some overlap with the normal Japanese target population. While it has been recognised for a number of years that the stock appears to be severely stressed, only very recently are catch figures indicating this. A report in the industry publication, Australian Fisheries (1983d), commenting on the very good 1983 season, also recognised definite changes in the type of effort. It suggested that as fish had not appeared in the traditional areas, boats were fishing up to 600 miles from Port Lincoln. Further, it recognised that the number of small fish coming through the coastal area has declined, so that almost half the catch was made up of adult fish.

Markets

The Australian operation has primarily sold its fish to the canning market. This is a part of a world market for tuna which is currently showing signs of declining demand - a trend that is not expected to change in the near future (Australian Fisheries 1983a). Kennedy and Watkins (1985) have assumed independent demand schedules for the Australian and Japanese markets. In the past, very little of the Australian catch was sold on the Japanese sashimi market due, both to the very high quality required and also the associated marketing costs. While, to some extent, this remains the case, in the last few years there has been a concerted effort from the Australians to enter this market, and thus benefit from the far higher returns (which Kennedy and Watkins 1985 suggests are of the order of 10 to 20 times those received on the Australian market).

There have been several initiatives centred in Port Lincoln. In 1983 a new firm, Australian Southern Bluefin Exporters Pty Ltd was established (see Australian Fisheries 1983b). Sharing premises with this group are local sashimi exporters, Lukin and Sons. These new premises facilitate export of tuna to Italy (an already established market) and also to the Japanese sashimi market. Such a venture means that it is possible for high quality tuna landed in Australia to be sold on the higher priced markets rather than being sold on the cannery market.

Associated with facilities available for processing tuna ready for the sashimi market is the construction of new boats designed to efficiently handle the longlining technique (Australian Fisheries 1983c). Further, fishermen are also developing skills in this technique, with the NSW Fishing Industry Training Council (Alexander and Harada 1988) running formal courses to develop these skills and also skills to aid in the preparation of fish for the export market. Although it is difficult to accurately predict an actual price on the cannery market, this being dictated by factors such as time of year and level of supply, it is of the order of A$1 000/tonne, with Kennedy and Watkins (1985) suggesting a level of A$880 for the 1980-1982 prices.

2.2.2 The Japanese Operation

Introduction

The Japanese have a considerable interest in fisheries, fish products traditionally forming an important component of the Japanese diet. Southern bluefin tuna represent an important product to the Japanese, with sashimi in particular, being highly valued. Although other species of tuna are used for sashimi, southern bluefin tuna is one of the preferred and thus also most highly priced of the species of tuna available. As can be seen from Figure 2.2 the Japanese involvement in the fishery has been over a long period of time and also at a high level of effort.

The harvesting technique used by the Japanese is longlining. This is a more passive technique than poling, directed at the more solitary adults. However, using this technique, it is not possible to actually target specific species. Thus, as well as southern bluefin tuna, several other tuna species are taken, as well as occasional catches of species such as black marlin.

While it is preferred by the Japanese to have access to the Australian fishing zone. a high proportion of their total catch is actually taken outside this zone. Their access to the zone is negotiated, with Australia receiving considerable payment by the Japanese for this right. The fee for such access is of the order of \$2 million annually (\$1.388 for 1982, Australian Fisheries 1981). This access is negotiated by area, with specific areas often being excluded (for example, South Australian coastal).

In such negotiations Australia has the right to exclude Japan from the zone and this can happen, particularly if Japan does not abide by its agreement or a mutually suitable access arrangement is not found (thus, in 1984 Japan was excluded, Australian Fisheries 1984e). The Australian Fishing Industry Council, for example, has always been happy for the Japanese to have access '... so long as this does not conflict with our own industry' (Australian Fisheries 1980, p.43).

Age Distribution of Catches

Unlike the Australian coastal operation, the Japanese are far less able to exert control over the size (thus age-classes) of the fish caught. While sizes are noted to vary, by time of year caught and also area fished, such variation is not in relation to a specific age group, but rather a tendency to a somewhat broader or narrower age band. For example, in records of catches taken by Japanese longliners off Tasmania (Australian Fisheries 1984b) it was noted that smaller fish formed a more significant part of the July/August catch (30 percent of the recorded catch less than 40 kg) while more than 90 percent of the November sample was of larger fish (more than 40 kg).

By considering catches by the Japanese in different areas it is possible to identify the fishing grounds where large proportions of southern bluefin tuna might be caught (Australian Fisheries 1984a). This information also indicated that high proportions of the overall Japanese catch are not of southern bluefin tuna. For example, varying proportions of southern bluefin tuna of 1.1 percent, 32.7 percent and 0.5 percent in monthly catches were noted. While the cost of the harvesting operation specifically refers to the catch of southern bluefin tuna, and may indicate reasonable levels of cost for this operation, there frequently will be additional returns of other species associated with that catch (that is, the catches of other species associated with effort directed toward southern bluefin tuna). Thus, there will be additional returns to the fisherman from this catch in addition to those related to the southern bluefin tuna effort. Kuronuma (1988) also notes the effect of these additional catches on the efficiency of cost and revenue estimates. It is important, therefore, to be aware that any final profit level associated with a catch of southern bluefin tuna might significantly underestimate the actual returns received by the fisherman.

Markets

The Japanese sell their tuna for the sashimi market, fish being offered chilled (the preferred more highly priced form) or frozen. Normally fish are sold whole (the Americans do remove the head to reduce the transportation costs), however, it is possible to sell ready processed tuna as sashimi - this option being adopted by the recently formed South Australian group. Although the prices received for this latter product may be considerably lower than for whole fish, it does offer an attractive marketing alternative to Australian fishermen who previously sold their entire catch to canneries, irrespective of size or quality.

A very comprehensive account of some of the factors that influence the price received for tuna on the Japanese market is provided by Williams and Longworth (1988, also Williams 1986). Details are also provided by Alexander and Harada (1988) in their manual for longlining, developed for the N.S.W. Fishing Industry Training Council. The actual Japanese export market chain is shown in Figure 2.4. Alexander and Harada (1988) suggest that the costs of exporting tuna to the Japanese market will cost around 14 to 50 percent of the final auction price received. This estimate provides some indication of the reasons for the lack of participation by Australian fishermen in this market in the past.

While many of the factors are not able to be controlled by the actual fishermen, for example, the day of the week the fish are sold, actual time of auction or the number of bidders, the information about the importance of various product related features is something they do need to become aware of. The effect of minor abrasions, colour, freshness and general dressing style are all aspects over which the actual fishermen can exercise some degree of control or selection.

The price paid on the Japanese market varies greatly, however, even taking this into account, it provides a very desirable option to the cannery market for a high quality product. While a cannery price is relatively stable over different sizes and conditions, and is of the order of A$1 000/t, the Japanese market will usually pay 10 to 20 times this level. Williams and Longworth (1988, p.3) note that :

> A carefully selected good quality Australian fish weighing around 80 kg could be expected to sell for up to $80 per kg or $6,400 per carcass. The same fish would be worth about $1 per kg on the Australian market. As the break-even price landed in Japan has been estimated at $8 to $10 per kg, the exporting of chilled tuna should be a most attractive venture. (One extra special tuna carcass was sold at auction in Tokyo in 1987 for $35,000.)

With the added market knowledge provided by such research, Australian fishermen are starting to feel some confidence in dealing with this market. This, however, is a recent trend, with fishermen in the past often perceiving the market to be colluding

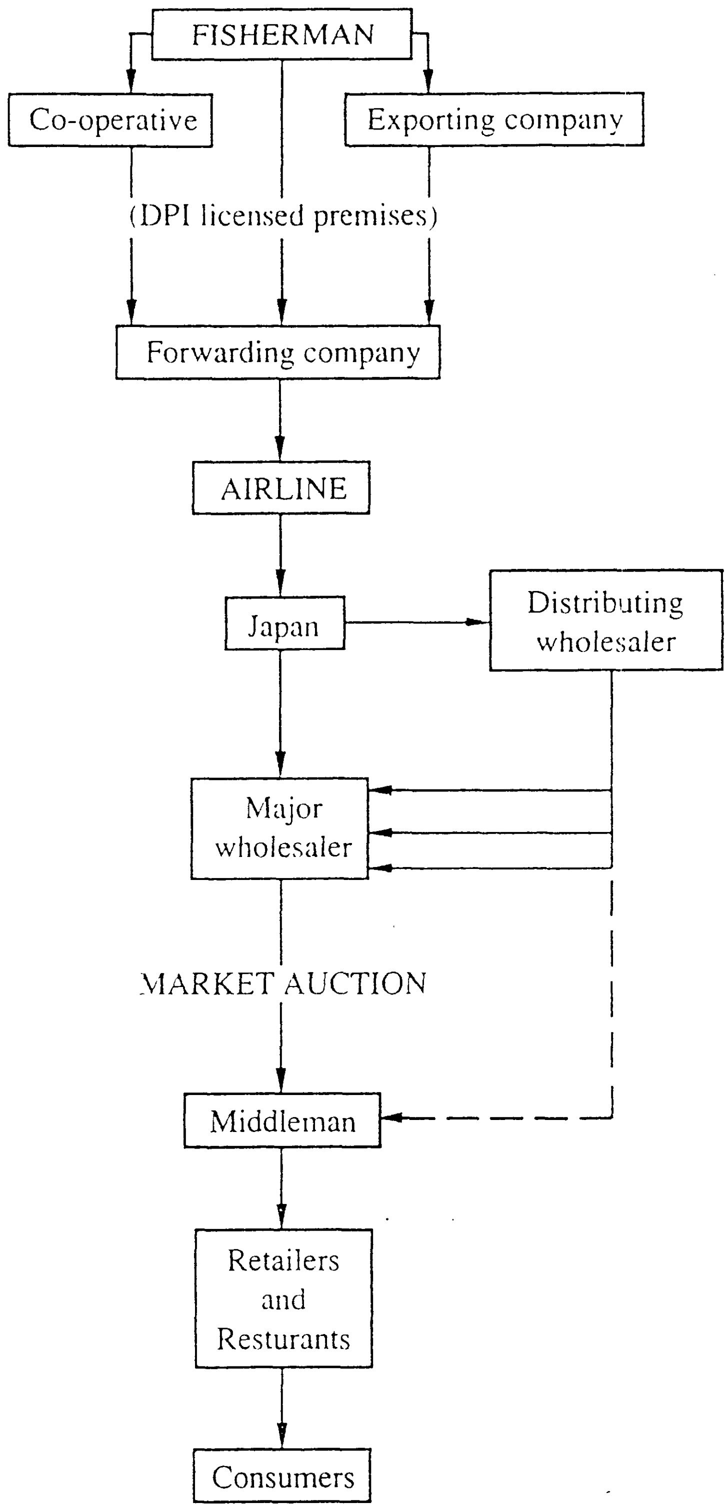


Figure 2.4: The Japanese export market chain (Alexander and Harada 1988)

to keep them out, and also reacting very strongly to the high costs associated with dealing on this market (Williams and Longworth 1988).

2.3 Status of the Stock

Currently the management of this species, recognised as being under severe threat, is jointly carried out by members of a group made up of scientists, fisheries managers and fishermen from the countries involved. While this high level of cooperation is a relatively recent trend, it does very clearly demonstrate that, currently, decision making with respect to overall management policies is a cooperative process.

It now appears that the stock of southern bluefin tuna is severly threatened, not just as a commercial resource but even possibly as a species (Australian Fisheries 1988a,c) . There has been an awareness of this situation for some time, with CSIRO declaring, in 1981, that the population was fully exploited (Murphy and Majkowski 1981).

The levels of catch and harvesting effort have not, in the past, been seriously controlled, with perhaps the first real initiative in management to reduce catch levels coming after the Industries Assistance Commission (1984) findings. The introduction of individually transferable quotas followed (Australian Fisheries 1984c). It was suggested as early as 1976 that there was a decline in the stocks of southern bluefin tuna, and a limit was placed on the number of purse seiners (a highly efficient form of harvesting) entering the Australian area in 1975 (Australian Fisheries 1975).

However, there have been some optimistic views on the prospects for management, with the Bureau of Agricultural Economics suggesting (Australian Fisheries 1983e, p.12) that while the species could be fished to commercial extinction ' ... evidence suggested that potential for output controls to effectively stabilise the tuna catch were high'.

In the first year of individually transferable quotas, the overall Australian quota was set to 14 500 t (Australian Fisheries 1984c), still a relatively high level and higher than any catch before 1980. It was also recognised at this time that the composition of the catch would dictate the effectiveness of any catch restrictions, thus the impact of significant catches of small fish could be very large with respect to the overall population (Majkowski and Caton 1984). Although they recognised that the initial decline in the population was caused mainly by the longline operation, the recent expansion in the Australian catch of small fish was seen as having an even greater impact.

Interestingly, while individually transferable quotas were introduced into the fishery in 1984, and thus provided a means of allocating a maximum level of Australian catch (in tonnes) amongst those already involved in the industry, they did not aim or direct the catch toward any particular age classes within the Australian coastal operation. Any tendency toward this has occured by the enterprise of a group who have purchased quotas from other fisherman and have investigated the possibilities of entering the Japanese market - thus targeting the more desirable larger fish.

Several recent findings have further contributed to the knowledge of the current state of the population. Kennedy and Watkins (1985) considered the impact of the setting of quotas in the fishery on the Australian and Japanese harvest levels. One conclusion was that the level of Australian welfare would increase by the elimination of fishing of the youngest age group available. Their 1986 paper (Kennedy and Watkins 1986) goes further to conclude that it would be in the interests of both Australia and Japan if harvesting of all fish under four years of age was eliminated - this effectively closing the Western Australian operation and reducing that based in South Australia.

While there has been considerable research done on the southern bluefin tuna, there have been no definitive answers to the problem, except that currently there appears strong agreement that this stock is severely overfished. The main measure of the state of the tuna population used is the level of the spawning stock - the parental biomass. It has been recommended that this needs to be maintained at or above 210 000t (Majkowski and Caton 1984).

2.4 Summary

The southern bluefin tuna fishery is, economically, an important one both to Australia and Japan. It has a relatively long and stable history with well established markets in all areas of operation. These markets are quite distinct, offering very different levels of return but also having very different requirements. The Japanese market, one that has quite high associated costs and requires a very high quality of fish also provides, potentially, very high levels of return. The Australian market, on the other hand, pays a relatively standard, low price for a wide variety of quality and sized fish. To the fisherman, however, this offers an easy marketing option which has, until recently, been the almost exclusive choice of those within the Australian operation. As well as very diverse markets, these two operations (the Australian and Japanese) also use very different fishing techniques aimed at relatively distinct age-classes of the population. This effort is applied in geographically distinct areas.

While considerable research has been carried out on the southern bluefin tuna fishery, with much of the recent research incorporating both biological and economic aspects, there is a need in this area for a tool which can provide predictive assessment of the state of a fishery before it reaches a level of overexploitation. Much of the biological assessment suggests that the stock is severely depleted and, while many conclusions have been reached, there is an overall agreement on the state of the fishery. The value of the research in this dissertation is the provision of an alternative method which is less dependent on specific values for the fishery. For example, cohort analysis, extensively used by CSIRO requires information on the complete age-classes before meaningful results can be obtained. Thus, for this species there is about a 15 year lag before meaningful results can be obtained. This study should permit a different perspective on the problem to be given and at the same time provide support for other research findings. In addition, it should provide a model with which to consider and assess the possible negotiations that might take place between participants in finding mutually acceptable harvesting policies. This can be done by considering the effects, both economic and biological, of a range of alternative harvesting strategies.

Chapter 3

Game Theory

3.1 Introduction

The application of the game theory technique to decision problems calls on a decision maker to move his perspective from one of maximizing an objective, to one of viewing the world in a competitive framework. Rather than using a technique to maximize the returns to a particular operator and assuming that other conditions will remain constant, the object here is to accept that two participants are, essentially, in a state of competition for a resource. The behaviour adopted by one competitor can only be assessed after first considering the options which may be adopted by his competitor. And in the case where the participants are both informed of the general outcomes from combined policies and also on the possible policies their competitor may adopt, then a cooperative situation may be present and negotiation used to consider mutually acceptable options. Such an agreement will not necessarily result in a policy which is either the most preferred or the profit maximizing one. However, participants will be aware that their adoption of a maximizing policy might well lead to some threat (a highly unattractive strategy by their competitor) being carried out. Overall, both parties will benefit in the long-term from the results of the negotiation. In essence, then, game theory represents an attempt to simulate this type of decision situation.

3.2 Game Theory and its Applications

Aumann (1985), in considering and assessing the overall concept of game theory and its aims, provides some interesting comments on the area. While game theory has something to offer as a descriptive technique, its normative function really cannot be separated from its descriptive applications. It only provides a model of what the real man *Homo sapiens* might do based on what the rational man *Homo rationalis* would do.

The early development of game theory is detailed in Von Nemuann and Morgenstern (1947), with Luce and Raiffa (1957) providing a more general overview, including some of the early developments. There has been considerable use of game theoretic techniques not only in economics, but also in such diverse fields as evolutionary biology. In this field, Maynard Smith (1982) developed the concept of the evolutionary stable strategy, which Aumann views as a type of Nash equilibrium point. It provides an effective technique by which to view or model competitive interactions and perhaps predict likely outcomes (thus, the descriptive and normative components).

Harsanyi (1967) provided a detailed method for considering games with incomplete information - a valuable extension to the theory. Another area which has received considerable attention, and which is of interest here, is that of bargaining. Nash (1950) developed a way of looking at this issue, and while there has been extensive work in this area, his basic techniques (Nash 1950, 1951, 1953) are still applied. Such extensions are covered by, for example Malouf and Roth (1981) who looked at incorporating disagreement into the bargaining framework, while Hessel (1981) viewed the issue of the effect of the actual costs associated with the actual bargaining process. He found that the presence of actual costs (even a time constraint) appears related to the need for a bargaining procedure.

In an experimental evaluation of two commonly used bargaining solutions (the Nash (1950) and Kalai and Smorodinsky (1975) solutions) Felsenthal and Diskin (1982) found that, in extreme cases (eg. a linear frontier intersecting with at most one axis) there can be some variation in the identification point between technique. This problem of slight variation in solution evaluation under extreme conditions appears the main area of criticism of the Nash solution and other alternative methods. While this problem needs to be taken into account, the technique still has a lot to offer, particularly in areas which are suited to the general conditions of the model. In this current research, while the actual optimal point will be identified, it is also felt worthwhile to recognise suboptimal points close to the optimal one which might be of interest to negotiators taking more general considerations into account than those included in the model.

3.2.1 Game Theory in Fisheries Research

There is considerable scope for applications of game theory in the fisheries management area, particularly since the Law of the Sea agreement (implemented in 1983) which aimed at some rationalization of the use of fishery resources. Kaitala (1985), in an extensive survey of the applications of game theory models in fisheries management, provides a thorough coverage of the various models available. While there is a very small, recent literature, on stochastic fisheries games, these are not included in his review (however, see Sobel 1982 for a coverage of stochastic games).

Tisdell (1983) in a consideration of the economic problems of managing Australia's marine resources, suggests the applicability of the Nash bargaining solution with a threat condition incorporated into the model (the Nash 1953 cooperative solution). Recognising the levels of conflict and competition inherent in the rivalry between Australia and Japan in relation to the southern bluefin tuna fishery, Tisdell suggests the application of a game theory technique using a payoff function associated with levels of return (as in the Industries Assistance Commission approach detailed in Hagan and Henry 1987). One interesting extension to the concept of the cooperative game approach is that provided by Fischer (1981), who adopts a hierarchical game approach. While it would not be applicable to consider this approach for the Australia/Japan interaction, it does offer interesting possibilities for evaluating strategies if one were considering the interaction *within* the Australian area - this in itself is another major problem area.

Kennedy (1987), in an extension of his earlier work on tuna, considered the application of game theory, using the case of the southern bluefin tuna fishery to develop a model with non-cooperative harvesting strategies for sequential fisheries (that is, each player makes his decision of a strategy based on the previous decision adopted by his competitor). In this model, by using a dynamic programming approach, he develops a non-cooperative game and then compares the results to the cooperative case (a joint maximization model). His research provides an interesting extension to that already carried out on southern bluefin tuna and should also be useful when considering the results of the research in this dissertation.

3.3 Terminology

Intrilligator (1971) provides a useful background to the terminology of game theory. Decision makers are usually referred to as *players* and the *game* that they play is simulated by considering the outcomes from a range of alternative policies. The outcome is assessed from the *payoff matrix* (values of the objective function under varying paired policies). Thus, all players have options or *strategies* which they may adopt. The return or *payoff* associated with these strategies depends both on the actual strategy adopted and also that adopted by the other player(s). These payoffs are summarised in a payoff matrix: where there are two players and each has two possible strategies, this will be a 2×2 matrix. If it is a *nonzero-sum game*, the payoffs to the two players for each strategy pair do not sum to zero. In this case two matrices of payoffs are required, those indicating the payoffs to the first and second players respectively.

There are several ways of classifying games, for example, classification by the number of players, type of payoff function or the presence of any pre-play negotiotion. Here, interest is on a two-person cooperative, nonzero-sum game. That is, there are two participants (Australia and Japan) who negotiate before play to decide on mutually acceptable strategies (thus cooperative). The payoff function is not a constant value, summing to zero, but rather the elements of both conflict and cooperation inherent in the process lead to a nonzero-sum situation (Intrilligator 1971). What one wins the other does not necessarily lose, in fact, both may have positive returns in any situation.

Nash (1953), in an extension of his treatment of the bargaining problem (Nash 1950), considers the situation of two-person cooperative games. This form specifies a game, without side payments. As Intrilligator (1971, p.123) explains: 'The players reach an agreement on coordinating their strategies where failure to reach such an agreement would give each player a certain fixed payoff known as the threat payoff'.

Nash (1953) analyses this game situation using two independent derivations, firstly by reducing it to a non-cooperative game, the actual negotiation process provides the moves in the non-cooperative model. Also, he adopts an axiomatic method, where, by outlining the expected properties of the solution, one is able to use the axioms to uniquely determine such a solution. This approach leads to the same solution found by the alternative negotiation approach.

3.3.1 Selection of the Nash Cooperative Solution

The decision to adopt a game theory approach and then specifically the Nash solution for this research project is based on various factors.

While game theory has critics as a decision making process (for example, Anderson, Dillon and Hardaker 1977) it has, in an appropriate situation, much to offer. In the case of the southern bluefin tuna fishery, the competition between the two participants provides an interactive situation where the policy adopted by one party will have a direct impact upon the availability of the resource to the other. The work of both Tisdell (1983) and Kennedy (1987) recognises this form of interaction, as also does Kuronuma (in his review of the fishery in 1988).

As to the form of the game adopted for this research, there are several aspects to consider before deciding on a technique. While there are in fact three nations utilizing the resource (Australia, Japan and New Zealand), New Zealand's participation is both recent (since 1980) and small (its catch is considerably less than one percent of the total, with regard either to weight or fish numbers). Further, New Zealand uses the same fishing technique as do the Japanese, and also harvests similar age classes, thus it appears reasonable to group their catch with that of the Japanese.

The decision to use a nonzero-sum game again has a justification in the nature of the fishery. Both participants may receive positive benefits from any particular combined strategy - and it is unlikely that negotiations would successfully find a solution without this property. Thus, in the form of the game which is being modelled, one must include the possibility of mutual gain or loss (Intrilligator 1971).

Following from the nonzero-sum form comes the decision to adopt a cooperative strategy. In the cooperative game a degree of prior negotiation between participants and also the knowledge of the effects of the adoption of possible strategies is assumed. This is unlike the non-cooperative theory where it is assumed that '... it is impossible for the players to communicate or collaborate in any way' (Nash 1953, p.129). Considering the specific application of this technique (and management situations in general) where joint harvesting policies are discussed and negotiated at international meetings, it appears appropriate that the cooperative form be adopted.

It may be of advantage to both players to reveal their preferred strategy and negotiate with their competitor in an attempt to obtain higher mutual returns. Certainly, the realities of management within the fishery suggest that such a policy will have long term gains to both participants. There is in fact consultation on the state of the stock between all participants, and also discussion of the possible effects of harvesting policies which might be adopted.

While there is the possibility that either party could default on the agreed policies, this would have an associated chance of retaliatory action from the other participant. The final element of the model adopted here is the inclusion of the threat position (if either party fails to follow their agreed strategy) in which both will resort to a previously defined threat strategy. This is in fact something that could occur in the fishery. Firstly, Australia has the right to exclude Japan from its Exclusive Economic Zone if Japan fails to follow the negotiated agreement (for which it pays around A$1 million). Japan has, temporarily, been excluded in the past. Further, if either ignored agreed fishing levels and appeared to be threatening the stock, the other party could well adopt an equally damaging short term policy, ensuring it too gained benefits before the resource was exhausted. In the actual situation being considered, such a threat strategy might occur where the Australians decide on a very heavy harvest of the youngest age classes, in response to a Japanese adoption of a non-directed, but very heavy level of harvest. The outcome of these joint policies would be, in the short term, high level returns. However, on a slightly longer time frame, the stability of the population may be at stake.

Thus the Nash two-person cooperative game (Nash 1953) has been adopted in this research.

3.3.2 Formal Representation of the Game

Each of the players (one and two) has a space S_i of mixed strategies s_i - these representing the courses of action that one player can take, independent of the other. A similar space B exists in the (u_1, u_2) (where u_1 and u_2 refer to utilities) plane, this is formed from pairs of strategies which can be realised by the players where they cooperate. For each pair of strategies, (s_1, s_2), from S_1 and S_2, there will be utilities (or payoffs) of $p_1(s_1, s_2)$, $p_2(s_1, s_2)$ to the two players respectively, from the situation where these strategies are applied. Thus $p_1(s_1, s_2)$ is the payoff to the first player when he adopts strategy s_1 and player 2 adopts strategy s_2. These points form the set B in the (u_1, u_2) plane. Each p_i is a linear function of s_1 and s_2, or alternatively, p_i can be viewed as a bilinear function of s_1, s_2. As every pair of independent strategies (s_1, s_2) represents a joint policy by the participants, every point in the (u_1, u_2) plane that is, $(p_1(s_1, s_2), p_2(s_1, s_2))$, must be a point in B, the set of utilities resulting from the negotiated strategies and their associated payoffs.

In working with such a game, one is moving from a space of strategies (S_i, in the above notation), to a similar space of utilities (or payoffs) associated with these strategies, thus B in the u_1, u_2 plane. And it is in this latter space where the optimum solution is defined.

Nash (1953) proposes the solution of this game as the maximum value of k , where k is given by

$$k = [p_1(s_1, s_2) - p_1(t_1, t_2)][p_2(s_1, s_2) - p_2(t_1, t_2)]. \tag{3.1}$$

Here p_1 and p_2 refer to the utilities to the two players (Australia and Japan, respectively), associated with the strategy pair (s_1, s_2) and the threat strategy (t_1, t_2), for the game. Thus, $[p_1(s_1, s_2) - p_1(t_1, t_2)]$ is the difference in utility, to Australia, between a particular strategy, (s_1, s_2), being realised and the adoption of the threat position (t_1, t_2). Similarly, $[p_2(s_1, s_2) - p_2(t_1, t_2)]$ is the difference in utility to Japan of the adoption of a particular strategy (s_1, s_2), and the threat position (t_1, t_2)

A value of k is evaluated for each of the possible policies (that is, pairs of strategies), where the threat policy (t_1, t_2) is set for the entire game. The solution proposed by Nash, the maximization of the products of the increased utility of a particular policy over the given threat point for each participant, is represented in Figure 3.1. It is apparent that only points on the outer boundary of this set would be selected by either player, for any point not on this boundary represents a suboptimal position where one player can increase his utility without any loss of utility to his competitor.

The increasing levels of the objective function are represented by the set of hyperbolas, k_i. The optimal policy occurs at point S, where the highest level curve is tangential to the set B. Naturally, as the levels of k relate to the selection of the threat strategies, the actual policy chosen as the threat could have some influence on the identification of the optimal point. The solution point defined by Nash is one that, for a set threat position, offers the greatest joint increase in utility over the adoption of the threat policy. While obviously either player may find a policy which leads, personally, to a greater increase, this policy would not be as attractive to his competitor.

To actually calculate the optimal point, the payoffs associated with all the paired strategies are evaluated for each player, and then the axes are scaled to provide positive values of all returns (this linear transformation will have no effect on the actual selection of the optimum policy, Nash 1953, Axiom III).

A value of k associated with each paired strategy is then evaluated (using the payoffs calculated above) and the maximum level of k then found, and the actual strategies associated with this point specified.

As it is recognised that policies with marginally lower values of k may in fact represent valuable bargaining positions, or options that could take into account aspects not included in the model, a feasible set is defined. This includes all policies with a level of the objective function within a band defined by 90 percent of that associated with the optimal solution.

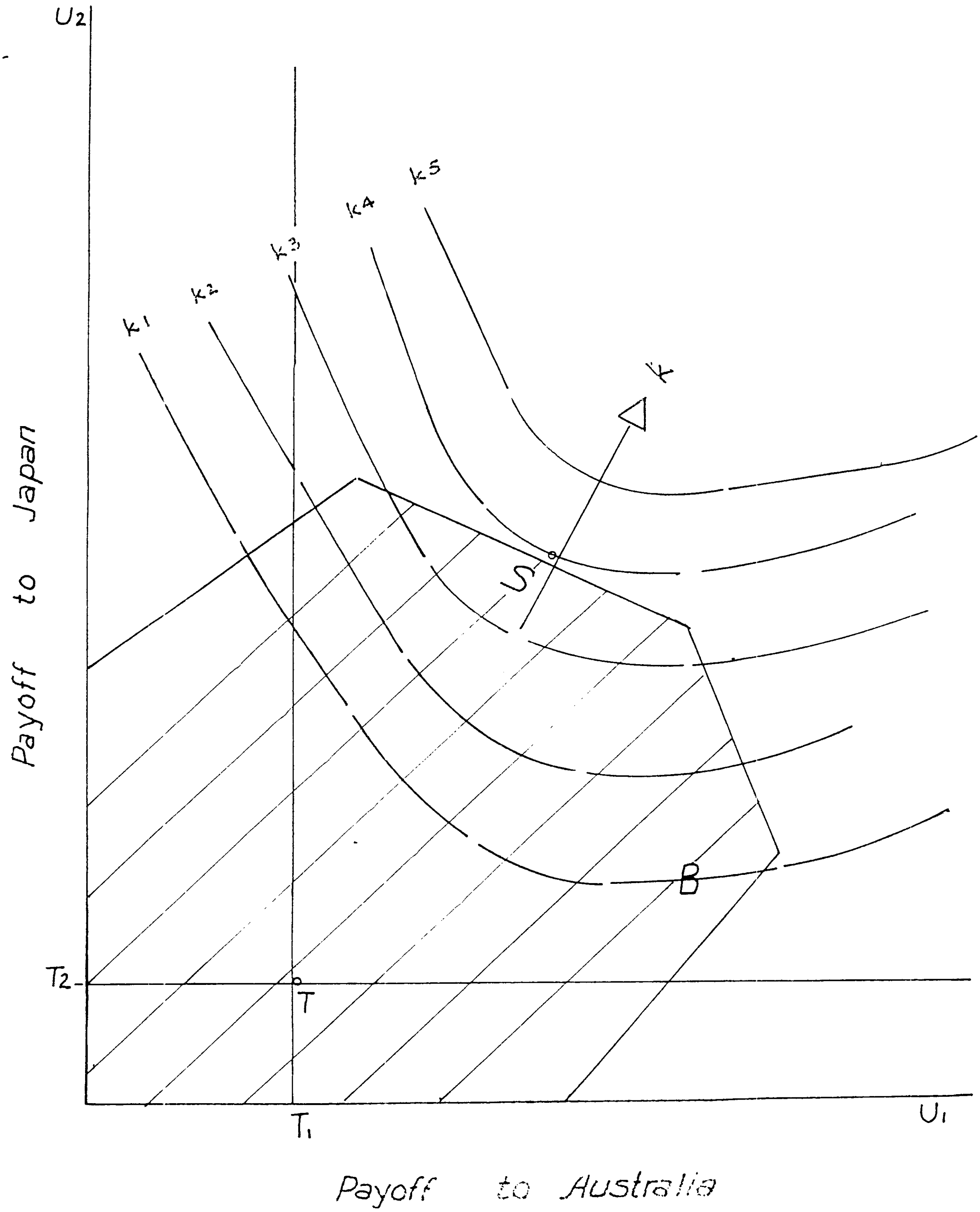


Figure 3.1: The Nash cooperative solution showing increasing levels of k and the optimal point S

3.4 Summary

The selection of the Nash cooperative solution as a form of game theory to simulate the interactive process between the two players in the exploitation of the southern bluefin tuna appears a reasonable one. Although the main limitation in the Nash solution (or in any game theory solution) is one of slight variations in the specific optimal point and also that there will be aspects of the fishery not accounted for in the negotiation process, it is felt that the broadening of the solution, to include a feasible set, accounts for such problems.

The major value in the selection of the game theory model is the perspective that it offers to the decision maker. One is asked to consider the fishery not just from the viewpoint of the Australian operation, given a stable known operation carried out by Japan, but rather as part of an interactive process. One particular strategy adopted by Australia will only offer a reasonable outcome if the other player, Japan, adopts an acceptable strategy.

In the analysis of the results from the model, one might then expect that while there might be a relatively dominant strategy, it will not be viable under all circumstances. Similarly, while particular strategies might be seen as nonviable management options, it is unlikely that such a classification will extend over the entire range of the competitors possible strategies. The effectiveness, then, of any policy option is dependent upon the combined strategies and not just strategies that are selected independent of such considerations.

Chapter 4

A Simulation Model of the Fishery

4.1 Introduction

The primary aim of the model is to simulate the southern bluefin tuna population, and evaluate associated payoff levels, under conditions of various harvesting strategies - and so providing input data for a payoff matrix.

By carrying out such a simulation, it is possible to evaluate and compare aspects of the fishery resulting from various harvesting strategies. In particular, it is valuable to consider directly the effect of harvesting strategies on the population density and the parental biomass, and thus assess the long term biological sustainability of the fishery.

Following checking procedures (identification and sensitivity analysis), the model will be used to investigate the effects of various potential management strategies.

4.2 Migration Movements

This simulation model relies on relationships developed in earlier work on the fishery. Kennedy and Watkins (1985) provide a model of the flows of southern bluefin tuna. Figure 4.1 shows this pattern and also indicates areas of loss from the fishery (natural and fishing mortality). These losses can be viewed as proportional losses in the population level per unit of time, due to natural deaths (natural mortality) or that associated with the fishing effort exerted by Australia and Japan (fishing mortality).

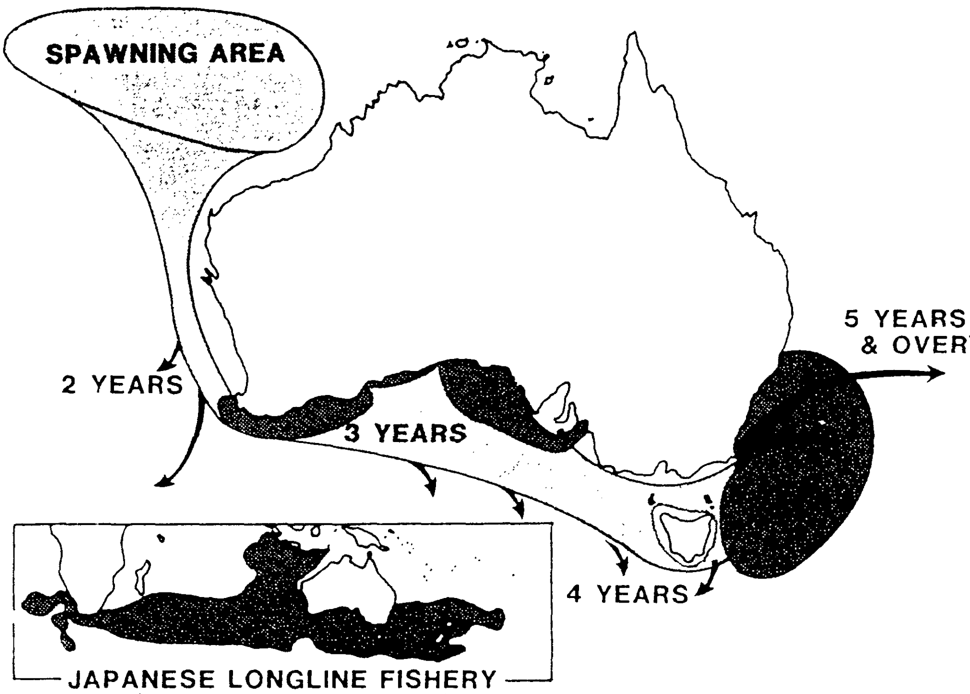


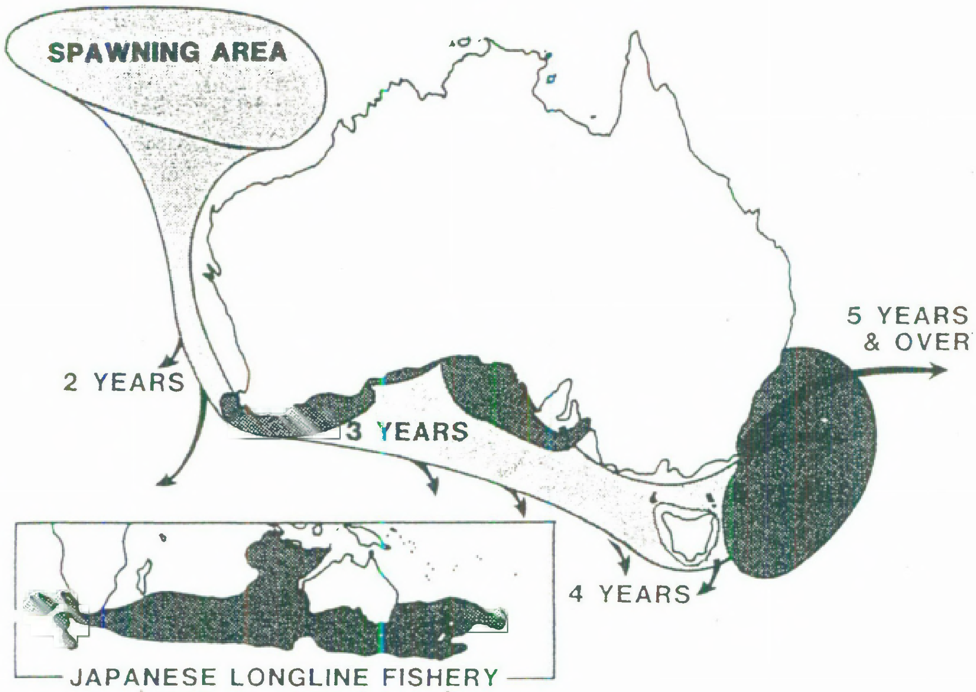
Figure 4.1: The movement of Southern Bluefin Tuna, showing the harvesting areas of Australia and Japan and general age-classes available (Murphy and Majkowski 1981)

The fishery will be considered by age-classes (1 to 15 years) and under the effects of activities by two participants (Australia and Japan). While this obviously is a simplification, it does provide a reasonable picture of the flow of tuna through the system.

4.3 General Relationships

4.3.1 Introduction

The overall aim of the model is, firstly, to carry out a simulation of the population numbers of southern bluefin tuna. Then, from this structure, the returns (or payoffs) associated with the fishing effort exerted by Australia and Japan (fishing mortality).



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4.3 General Relationships

4.3.1 Introduction

The overall aim of the model is, firstly, to carry out a simulation of the population numbers of southern bluefin tuna. Then, from this structure, the returns (or payoffs) to each operation exploiting this resource, will be evaluated. Finally, after repeating this process for a range of combined strategies, the returns, as well as an indicator of the biological state of the fishery under each harvesting policy, will be assessed and an optimum strategy identified.

Basic population dynamics relationships are used to simulate the population structure and then economic relationships (of costs and price functions) are applied to evaluate the level of profit to each participant (Australia and Japan) resulting from a given harvesting policy.

Figure 4.2 indicates a general flowchart of the model (subroutines are indicated on the right hand side of the figure, named in capitals). This section aims to provide an initial, conceptual, understanding of the relationships applied in the model. However, specific details of these relationships are provided in full in the next section.

4.3.2 Biological Relationships

The population is defined by age-class i (where i takes values from 1 to 15 years), and operation k (k taking values 1 or 2, representing the Australian and Japanese operations, respectively), where the numbers in each age-class are recorded during a twelve year simulation cycle (the year of the cycle being denoted by the subscript L). This simulation is repeated under the effects of a range of harvesting policies (combined Australian and Japanese strategies). These strategies are defined by proportions of the total catch (WTTA and WTTJ, the quota, by weight, set for Australia and Japan) allocated to different age-classes. This allocation is by weight, however, age/length and then length/weight relationships are used to convert these levels to average harvest numbers to be taken by each strategy. The process used calculates, for a defined age-class, the average length associated with such a fish. The average weight for a fish of this length is then found (a direct age to weight relationship not being available). Finally, using the total weight of catch allocated to a particular age-class, the number of fish to be harvested is found by dividing this total weight by the average weight of an individual fish.

For each defined policy ($PA_{i,m}$ the m-th Australian strategy and $PJ_{i,n}$ the n-th strategy adopted by the Japanese), the actual numbers of fish to be harvested, by

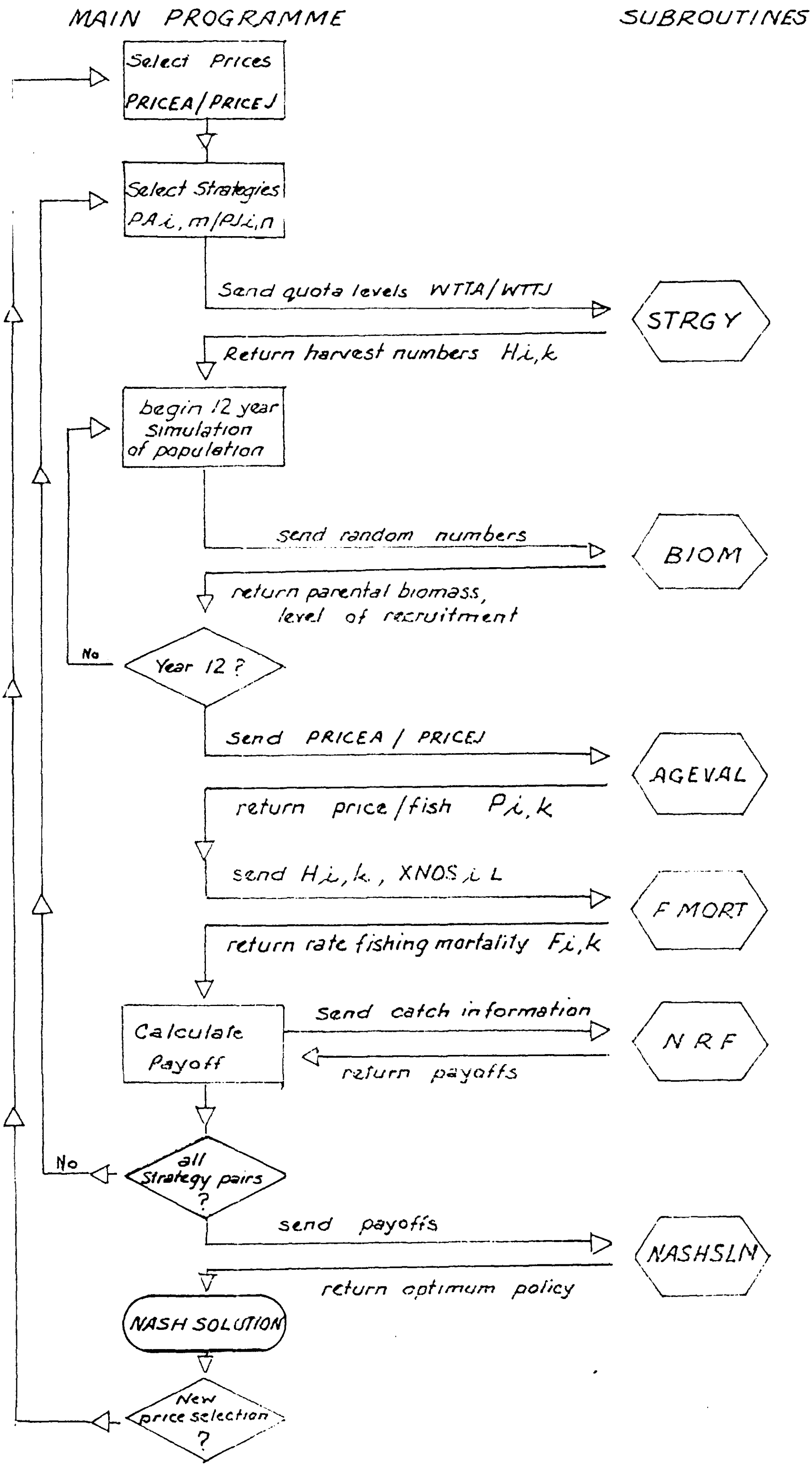

Figure 4.2: Flowchart of the Simulation Model.

age-class i, and operation k, are evaluated in the subroutine STRGY. This subroutine provides the actual levels of fish caught - $H_{i,1}$, the Australian catch and $H_{i,2}$, the Japanese catch.

$$PA_{i,m}, PJ_{i,n} \Longrightarrow H_{i,k}$$

The simulation is carried out for a period of twelve years, which allows the impact of the harvesting of the adult fish to flow through to the entire population. To move from year L of the simulation to year L+1 (thus 1 to 2, 2 to 3 and so on) new age distributions must be updated for the effects of loss both from natural and harvesting effects. These are referred to as the rates of natural and fishing mortality, M and F, respectively. As the actual catch numbers are specified in the model ($H_{i,1}$ and $H_{i,2}$, the Australian and Japanese catches) these are used, rather than indirectly using them to calculate the rate of fishing mortality, F. Then, year L+1's population structure, $XNOS_{i+1,L+1}$, is evaluated from the numbers in the previous year, $XNOS_{i,L}$, by removing the effects of natural deaths and catches (where the reduction associated with M is a proportional one, dependent on the population level, as shown in the next section).

$$XNOS_{i,L} - M - H_{i,1} - H_{i,2} \Longrightarrow XNOS_{i+1,L+1}$$

This updating process obviously cannot be used to provide numbers of one-year-olds actually entering the fishery (that is, the level of recruitment). To evaluate the level of recruitment, $XNOS_{1,L+1}$, it is assumed that recruitment is dependent upon the level of the adult stock - thus where the adults have been severely overfished there would be a very low level of recruitment into the fishery the next year. This is the assumption made by Hampton and Majkowski (1986), and will be discussed in detail in the next section. The actual level of the adult stock is assessed through the measure, parental biomass (evaluated in the subroutine PBIOM), and the level of recruitment is selected from a distribution with parental biomass as a parameter in the relationship.

$$(ParentalBiomass)_L \Longrightarrow XNOS_{1,L+1}$$

4.3.3 Economic Relationships

Once the biological simulation of the fishery has been completed, the economic returns that would occur from this fishery are then evaluated. The AGEVAL subroutine randomly selects prices from distributions of Australian and Japanese market levels. These values ($P_{i,k}$, the price by age-class and operation) are used in the NRF subroutine to evaluate a revenue level associated with a particular catch, thus the revenue is evaluated from the price per fish times the number of fish actually harvested.

$$P_{i,k} \times H_{i,k} \Longrightarrow Revenue_{i,k}$$

The cost associated with a particular harvesting policy is then evaluated by:

$$HK_{i,k} \times F_{i,k} \Longrightarrow Cost_{i,k},$$

where $HK_{i,k}$ is the harvesting cost per unit fishing mortality and $F_{i,k}$ is the rate of fishing mortality for a given age-class i and fishery k. The rate of fishing mortality applied is directly proportional to the effort level expended in the fishery (Kennedy and Watkins 1986), and in this equation, reflects the higher costs of catching a given number of fish where population numbers are at a low level than in periods of abundance.

The overall profit is then evaluated for each individual operation (Australian and Japanese) by a relationship of the form:

$$\sum_{i=1}^{12}(Revenue_{i,k} - Cost_{i,k}) \Longrightarrow Profit_k,$$

where the profit for a particular fishery k is found by summing over all returns for age-class i.

4.3.4 Identification of the Solution

After evaluating the profit associated with each operation, the simulation process is then repeated using the next combination of strategies, until all pairs have been considered and the associated payoffs and population parameters found.

Once all pairs of strategies have been evaluated (for nine Australian and nine Japanese strategies, thus 81 evaluations) the optimal solution is found - this process is carried out in the NASHSLN subroutine. The optimal value is that which maximises the product of the differences in payoff between the actual strategy and the threat strategy for each nation. The threat strategy, discussed in Chapter 3, refers to the strategy which each nation threatens to adopt, if either participant fails to follow his agreed policy. In the event of negotiation failure, both participants may adopt strategies which have high returns in the short term but are relatively destructive to the fishery in the long term.

Finally, the entire process, including the identification of a solution, is repeated for ten random selections of market prices for the two operations. This repetition is carried out to ensure that the optimal policy identified is not dependent on the particular prices selected for a particular run of the model.

4.4 Equations used in the Model

4.4.1 Age Relationships

These age relationships allow one to relate general physical characteristics (length and weight) to an age grouping. They are applied throughout the model where there is a need to convert a given weight of fish, as in the harvesting quota, to an actual number of fish caught. Similarly, in the AGEVAL subroutine they are used to evaluate the average price paid for an i-year-old fish, given an overall market price per tonne.

The relationships used are those from Hampton, Majkowski and Murphy (1984). Note that here, age 1 refers to fish in the range 0 to 1 years. Also the variable names from the model are used, not those from the literature (unless stated). This provides consistency between the theory and the model.

The following length/age relationship allows for the conversion of length (in cm) for a given age, i:

$$XL_i = XL_\infty(1 - e^{-K(i-i_0)}), \tag{4.1}$$

where XL_i is fork length in cm (for the midpoint of the ageclass), i is the age in years

and XL_∞ is the maximum attainable length.
The values of the parameters are:

$$i_o = -.394yr$$

$$XL_\infty = 207.6cm$$

$$K = 0.127yr^{-1}$$

(from Kirkwood, 1983).

Further, the weight, WTT_i(kg), for a given length, XL, can be found as follows:

$$WTT_i = aXL_i^b, \tag{4.2}$$

where $a = 3.13087 \times 10^{-5}$ when XL< 130 cm (Robins 1962)
$a = 2.50470 \times 10^{-6}$ when $XL \geq 130$ cm (Warashina and Hisada 1970)
and b=2.9058 when XL< 130 cm (Robins 1962)
b=3.4229 when $XL \geq 130$ cm (Warashina and Hisada 1970).

These relationships are used in the STRGY subroutine to convert catch levels by age (in tonnes) to harvest numbers by age and operation.

4.4.2 Stock Updating

To complete the biological simulation of the population, the actual numbers of fish, by age-class, in each subsequent year, must be estimated. The reasons for loss from a particular age-class are grouped as either natural or due to the fishing process, thus natural and fishing mortality. Hampton et al (1984) provide the following equation to update the population numbers for the effects of natural and fishing mortality:

$$XNOS_{i+1,L+1} = XNOS_{i,L}exp(-M - F_{i,1} - F_{i,2}), \tag{4.3}$$

where $XNOS_{i,L}$ is the initial abunbance of age-class i in year L of the simulation, and M and $F_{i,k}$ are the associated levels of natural and fishing mortality. M is set at

0.2 for all age-classes, this being a standard setting accepted by researchers in this area (for example, Murphy and Majkowski 1981).

However, as actual numbers of fish harvested by age class i and operation k can be derived from the defined strategies, it was felt to be more accurate to use the number harvested than calculate the associated fishing mortality, $F_{i,k}$. Thus, the relationship used was:

$$XNOS_{i+1,L+1} = (XNOS_{i,L}exp(-M)) - H_{i,1} - H_{i,2}, \tag{4.4}$$

where $H_{i,k}$, k=1,2 are the harvesting levels for the Australian and Japanese operations (respectively) by age-class i.

4.4.3 Recruitment

Recruitment refers to the process of new stock entering a particular age-class or fishery (age-class one). Here, it is used to refer to the number of one-year-olds entering the fishery each year, following spawning. This is the initial age-class of a cohort of fish.

The following relationships are used in the BIOM subroutine. This subroutine calculates the parental biomass from year L and uses this to estimate the initial population level (recruitment) for year L+1. As it is generally assumed that only fish eight years and over are mature (that is, part of the breeding population), these calculations are restricted to this subset of the population (see Geen and Nayer 1989).

To consider levels of recruitment, one needs to assess the state of the adult population. Hampton and Majkowski (1986) suggest that the level of recruitment may either be density independent (Case 1) or dependent (Case 2).

In the first case, the level of recruitment $XNOS_{1,L}$, is a normally distributed random variable with constant mean. Recruitment is independent of the level of $PBIOM_{L-1}$, the parental biomass in the previous year.

In Case 2, $XNOS_{1,L}$, while again assumed to be a normally distributed random variable, has a mean of $\overline{XNOS}_{1,L}$. This value is determined by a functional relationship to $PBIOM_{L-1}$:

$$\overline{XNOS}_{1,L} = aPBIOM_{L-1}/[1 + (PBIOM_{L-1}/K)^{\beta}], \tag{4.5}$$

Where the parameters a, β, and K are given values (in Hampton and Majkowski 1986) of 34.88 recruits per tonne, 1.5 and 345 935 tonnes respectively. The level of parental biomass, $PBIOM_{L-1}$, is determined from Equation (4.6),

$$PBIOM_{L-1} = \sum_{i=8}^{15} XNOS_{i,L-1} WTT_i, \tag{4.6}$$

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. Spawning is assumed to be an annual discrete event that takes place on January 1. In reality, only the peak occurs at this time. However, as it is a relatively short period in the lifespan of the species it is felt that it can be treated as an instantaneous event. This assumption is generally used in research into this species (for example, Hampton and Majkowski 1986).

If parental biomass continues to decline (as has been reported), Case 1 will cease to be relevant at some time. The second case has been adopted here to determine a possible level of recruitment for the simulation. The model randomly selects a value of the initial population level (INTLEV) which is then returned to the main program providing the initial population numbers for the next generation.

Note that $PBIOM_L$, the weight of the spawning population, is converted to tonnes from kg before use.

4.4.4 Market Prices

In the past there has been a clear delineation between the Australian and Japanese fisheries, both in geographical area and market. However, more recently, the Australian fishery has not only broadened its target range of fish, but also the markets within which they are offered. Many of the larger fish, now caught using longlining techniques similar to those employed by the Japanese, are sold on the Japanese market. Some fish are also exported to Europe, where they are canned in Italy. The Australian market price used in this model is set somewhat above the level offered by the cannery, to account the higher returns to fishermen accessing alternative markets for some of their catch. This is, however, still of the order of A\$1 000/t compared to levels for the Japanese market of around A\$20 000/t.

For the Australian market, prices with a mean of A\$1 200/t, and a standard deviation σ, of A\$200/t are used, while for the Japanese market, the mean price is set at A\$20 000/t, with a standard deviation of A\$5 000/t.

The value per tonne for fish on the two markets (PRICEA and PRICEJ, selected randomly from given μ and σ for Australian and Japanese markets) is selected by the model. The simulation is repeated for a range of ten price selections, to evaluate the effect of this variable on the identification of an optimal solution.

From the selected values of price/t the AGEVAL subroutine determines a matrix of prices (in A\$) by age-class and market, (thus, $P_{i,k}$).

The form of revenue to the fisherman is summarised as:

$$\sum_{i=1}^{12} P_{i,k} \times H_{i,k}, \tag{4.7}$$

where $P_{i,k}$ is the price per fish and $H_{i,k}$ the number of fish caught. This is calculated separately for the Australian and Japanese operations (k=1,2).

4.4.5 Harvesting Costs and Fishing Mortality

The harvesting costs, that is, the total cost involved in the process of harvesting a given number of fish, are varied over different operations. Although the use of costs averaged over diverse fishing fleets is normal, it is of value to recognise that there will be different costs associated with different aspects of the fishery. Kennedy and Watkins (1985) have evaluated harvesting costs by age groups and operations, differentiating not only between the costs of the Australian and Japanese effort but also within these areas. These cost relationships are used in this model.

Realistically, however, such costs, are related to the level of effort applied rather than to the number of fish harvested. So, it will be more expensive to catch 1 000t where the population levels are low than if there were large numbers of fish available. The issue of just how much effort is applied needs to be addressed.

Kennedy and Watkins (1986) use the basic relationships of cost and fish stock changes to derive a relationship for average cost. This assumes that the fishing effort in the fishery is directly proportional to the rate of fishing mortality. It is also assumed that this effort is applied at a constant rate. Although this is not actually the case (the fishery being a seasonal one), it is again an assumption used in most research and one which is reasonable when whole year effects or longer are being considered. Further, the total cost of harvesting, c, is assumed to be directly proportional to the rate of fishing effort. Thus, using $HK_{i,k}$ as the harvesting cost per unit fishing mortality, $F_{i,k}$, total cost is given by:

$$c = HK_{i,k} \times F_{i,k}. \tag{4.8}$$

In this case, cost is related to both the actual activity (age-class harvested by a particular operation) and the rate of fishing mortality applied to achieve such a catch. Naturally, the costs associated with harvesting a given number of fish from a depleted population will be far higher than from an unexploited population where fish are more numerous.

The relationship defined by Kennedy and Watkins (1986, p.295) between the initial population level, x_0, the final population level, x_t, and the levels of fishing and natural mortality (f and m) occurring over time t, is shown below:

$$x_t = x_0 exp[(-f - m)t]. \tag{4.9}$$

From this, by integrating over time, it was found that the harvesting rate, h, over one time period, is:

$$h = x_0[f/(f + m)][1 - exp(-f - m)]. \tag{4.10}$$

In our notation, this becomes:

$$H_{i,k} = XNOS_{i,L}[F_{i,k}/(F_{i,k} + M)][1 - exp(-F_{i,k} - M)]. \tag{4.11}$$

As $F_{i,k}$ is the only unknown in this relationship, a grid search procedure was used to solve for $F_{i,k}$, this value then being used in equation (4.8).

Kennedy and Watkins (1985) have evaluated, from their model, levels of $HK_{i,k}$, the harvesting cost per unit fishing mortality, for age-class i, and operation k - and derived a set of values shown in Table 4.1.

Table 4.1: Costs by age-class for Australian and Japanese fisheries (A$million) per unit $F_{i,k}$ (from Kennedy and Watkins 1985)

Age-classes	1-2	3-4	4-7	8-15
Australia	8.60	20.05	17.51	130.18
Japan	0.0	0.00	203.01	1395.14

As this research deals with hypothetical fishing fleets with undefined levels of effort (in real world fisheries these are no easy matter to estimate either) it was felt better to use equation (4.8) and estimate $F_{i,k}$ from the harvesting relationship (4.11) rather than formally assessing effort itself. It is, however, recognised that the eventual estimate of the cost of fishing might be somewhat distorted, due to two major limitations in the derivation of cost functions for the fishery. Firstly, Kennedy and Watkins (1985) calculated their six cost coefficients from the model rather than evaluating them from the actual fishery. Secondly, particularly in the Japanese fishery, the southern bluefin tuna catch, while the most desirable, is far from the total tuna catch. The by-catches probably represent a return that makes the enterprise profitable. This certainly is becoming the case in the Australian fishery where the larger fish are being targeted, and fishermen are moving into the longline areas where the catches are made up of several species of fish, not just southern bluefin tuna.

4.4.6 The Payoff Function and its Optimal Solution

As the aim of this research is to compare and evaluate harvesting strategies, rather than specific returns, the actual level of the profits is not as important as the relative returns across the policy options available.

The payoff associated with a particular policy is assessed by using the following equation:

$$XNRF_k = \sum_{i=1}^{15}(P_{i,k} \times HNOSEP_{i,12,k} - HK_{i,k} \times F_{i,k}), \tag{4.12}$$

where $XNRF_k$ refers to the payoffs returned to the Australians and Japanese, repectively, $P_{i,k}$, the price for fish by age-class and fishery (converted to millions of dollars), $HNOSEP_{i,12,k}$ the harvest taken by each operation in the final year of the simulation, $HK_{i\,k}$ the harvesting cost and $F_{i,k}$, the associated fishing mortality. This function evaluates the returns to each operation associated with the harvesting process.

Before finding the optimal policy, two further steps are taken. Firstly, these payoffs are scaled to provide positive values, this aiding in the identification of the optimal policy. As this is a linear transformation, the relative positions are unaltered.

Then, all policies are screened for a satisfactory level of the biological criteria - the parental biomass. It is suggested (Majkowski and Caton 1984) that a level of above 210 000t is required for a sustainable fishery. Only policies with levels of parental biomass above a level of 220 000t (in the final year of the simulation) are considered in the selection of the optimal strategy.

Intrilligator (1971) details the Nash solution to a payoff matrix as a maximization of k , given by

$$k = (\pi_1 - T_1)(\pi_2 - T_2) \tag{4.13}$$

where π_1 and π_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 defined for this analysis.

4.4.7 Strategies

The strategies defined in this model provide possible harvesting policies which might be adopted by the participants. These include policies similar to those that are, have been or might be used in the fishery. These strategies are defined by the levels of catch of a total quota, in tonnes (thus WTTA and WTTJ, the values set in the model), and the distribution of this weight over the age-classes in the population. A summary of these strategies is provided in Table 4.2.

The Australian strategies (PA1 to PA9) define policies of harvesting in one or more areas of the Australian operation. This depends on the partial age separation by area that occurs in the coastal regions of the fishery. PA1 (the first Australian strategy) harvests from one to five-year-olds, with the maximum catch of two and three-year-olds. This strategy represents fishing centred in Western Australia. PA2, harvesting a similar age range (one to five-year-olds) but a higher proportion of older fish, suggests a strategy centred in Western Australia and South Australia. PA6, on the other hand, reflects a South Australian and New South Wales catch, (ranging from three to eight-year-olds), while PA7, defining catches of only three to five-year-olds, is a strategy suggesting an almost exclusively South Australian catch.

For the Japanese operation it is not possible to closely target age-classes, although over time and in different areas there is some pattern for larger or smaller fish (in the mature range). The strategies (PJ1 to PJ9) defined for this operation reflect two policies aspects - a broad or narrow age range and a light or heavy catch.

To allow for some variation in the level of catch adopted by the Japanese operation (through the strategies defined), the sum of the levels associated with age-classes vary from 1 to 2. A value of 2 reflects a total catch of twice WTTJ, the quota set in the model. Low catches are set for PJ1, PJ4 and PJ7, these levels all summing to 1. PJ2, PJ6 and PJ9 all define high catch strategies (levels summing to 2). The remaining three strategies represent intermediate levels of catch.

Turning to the defined age range, strategies PJ1 to PJ3 are set to a very broad spread of ages, ranging from five to 14-year-olds. Such a strategy would suggest some fishing relatively close to the coastal areas where the younger age-classes may be taken (as has occurred in more recent times in the fishery). Strategies PJ4 to

Table 4.2: 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
PA1	.01	.2	.6	.15	.04										
PA2	.01	.1	.25	.3	.25	.09									
PA3		.1	.15	.4	.25	.1									
PA4		.05	.15	.3	.3	.1	.1								
PA5		.05	.1	.2	.2	.2	.2	.05							
PA6			.1	.2	.2	.2	.2	.1							
PA7			.2	.5	.3										
PA8			.1	.4	.3	.05	.05	.05	.05						
PA9					.1	.3	.3	.1	.1	.1					
PJ1					.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	
PJ2					.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	
PJ3					.1	.1	.1	.2	.25	.25	.2	.1	.1	.1	
PJ4						.1	.15	.25	.25	.15	.1				
PJ5						.1	.25	.45	.45	.25	.1				
PJ6						.2	.3	.5	.5	.3	.2				
PJ7							.05	.1	.1	.15	.2	.15	.1	.1	.05
PJ8							.1	.1	.2	.2	.3	.2	.2	.1	.1
PJ9							.1	.2	.2	.3	.4	.3	.2	.2	.1

PJ6 reflect a far tighter age distribution centred on the mid-range of the fish in the longline fishery (six to 11-year-olds). The final three strategies (PJ7 to PJ9) present a medium position between these, with catches taken from seven to 15-year-olds - a later starting broad range policy.

The aim of the strategies defined for the two participants in the fishery is to provide a set of possible harvesting policies which could be adopted. For the Australian operation these can be identified as policies reflecting a total catch in a particular region, for example a fishery restricted to South Australia, or a broad age distribution, suggesting an operation based at more than one geographical location, for example South Australia and New South Wales. For the Japanese operation they suggest policies of different levels of catch, directed at broader or narrower age distributions of fish.

4.5 Settings used in the Model

The parameter values chosen for the model have been designed to reflect the real situation which exists in the fishery.

The quotas for Australia and Japan (WTTA and WTTJ) are both set at 15 000t - indicating a total catch of 15 000t for all strategies in the Australian operation, and between 15 000t and 30 000t for strategies in the Japanese operation. The market prices used in the model are selected from distributions with means of A$1 200/t and A$20 000/t and standard deviations of A$200/t and A$5 000/t, for the Australian and Japanese operations respectively. These reflect the very different returns received on these markets and also the different levels of associated variation. The costs of the two operations are those from Kennedy and Watkins (1985). These values are shown in Table 4.1.

A total of 81 different policies have been defined, these made up of combinations of the available strategies. Included in these are policies which are similar to those recently practiced in the fishery. The defined threat strategies used here are PA1 and PJ9 - thus the Australians select to take a harvest of fish aged between one and five years (basically a heavy Western Australian catch with a South Australian component), while the Japanese select a very heavy (30 000t) harvest taken over a broad age range.