Chapter 5

Results of the Simulation Model

5.1 Introduction

A comprehensive discussion of the main aspects of the southern bluefin tuna fishery, as represented by the model, are presented in this chapter. In addition to the payoffs returned, the actual levels of various age-classes will be considered, as well as the parental biomass - an accepted indicator of the parental stock and thus of the future levels of recruitment to the fishery.

While 81 combined policies have been simulated by the model, specific details of only four of these will be provided. These are the identified optimal strategy, the threat strategy used in the analysis and two harvesting strategies which have similarities to recent practices in the fishery (an optimistic and pessimistic scenario). Thus, through an assessment of a range of competitive interactions, the general type of policy which appears effective for the management of the fishery can be identified - that is, the form of harvesting which leads to both reasonable economic returns and also a sustainable population structure. Naturally, such a process should also allow the identification of policies which most radically depart from such an objective, thus, the most destructive policy aspects will also be identified and addressed.

Finally, the results of a sensitivity analysis will be presented. This analysis considers variations in the identified optimal strategy, under changes of settings of the model - this includes changes in the levels of quotas, prices and harvesting costs for both participants, as well as the selection of the threat strategy.

5.2 The Payoff Matrix

The data from the payoff matrix are presented in Figure 5.1, where, the points represent the payoffs to the participants associated with a particular harvesting policy (transformed profit levels), and the contours are increasing levels of the objective function, shown as percentage levels of those associated with the optimal strategy. The points above the 90 percent contour are classed as the feasible set. Table 5.1 summarises these data, indicating the relative position of strategies with respect to the objective function.

Several features of the policies identified in the feasible set (the above 90 percent level) should be noted. The most common Australian strategy is PA7 (a South Australian catch). The only strategy in this set which includes a Western Australian catch is PA2, and this is paired with a very low level Japanese policy (PJ4). The optimal Japanese solution is PJ7. This represents a low level of catch over a broad age range (seven-to 15-year-olds). PJ4, however, is the most frequent Japanese strategy included in this set, this again represents a low level of catch, but one over a narrower age band (six-to 11-year-olds). Only two Japanese policies not representing the lowest level of catch are included in this set, both of these (PJ3 and PJ8) define a midrange level of catch.

Of the four policies of interest, only the optimal one is in the feasible set. The threat strategy (PA1/PJ9) has a very low level of payoff (30 percent level), while the two other policies (PA1/PJ6 and PA2/PJ2) are placed in the 60 percent and 40 percent levels, respectively. This suggests that the former policy, at least with respect to returns, is preferred. Both are, however, markedly superior to the threat policy, with regard to the level of payoff.

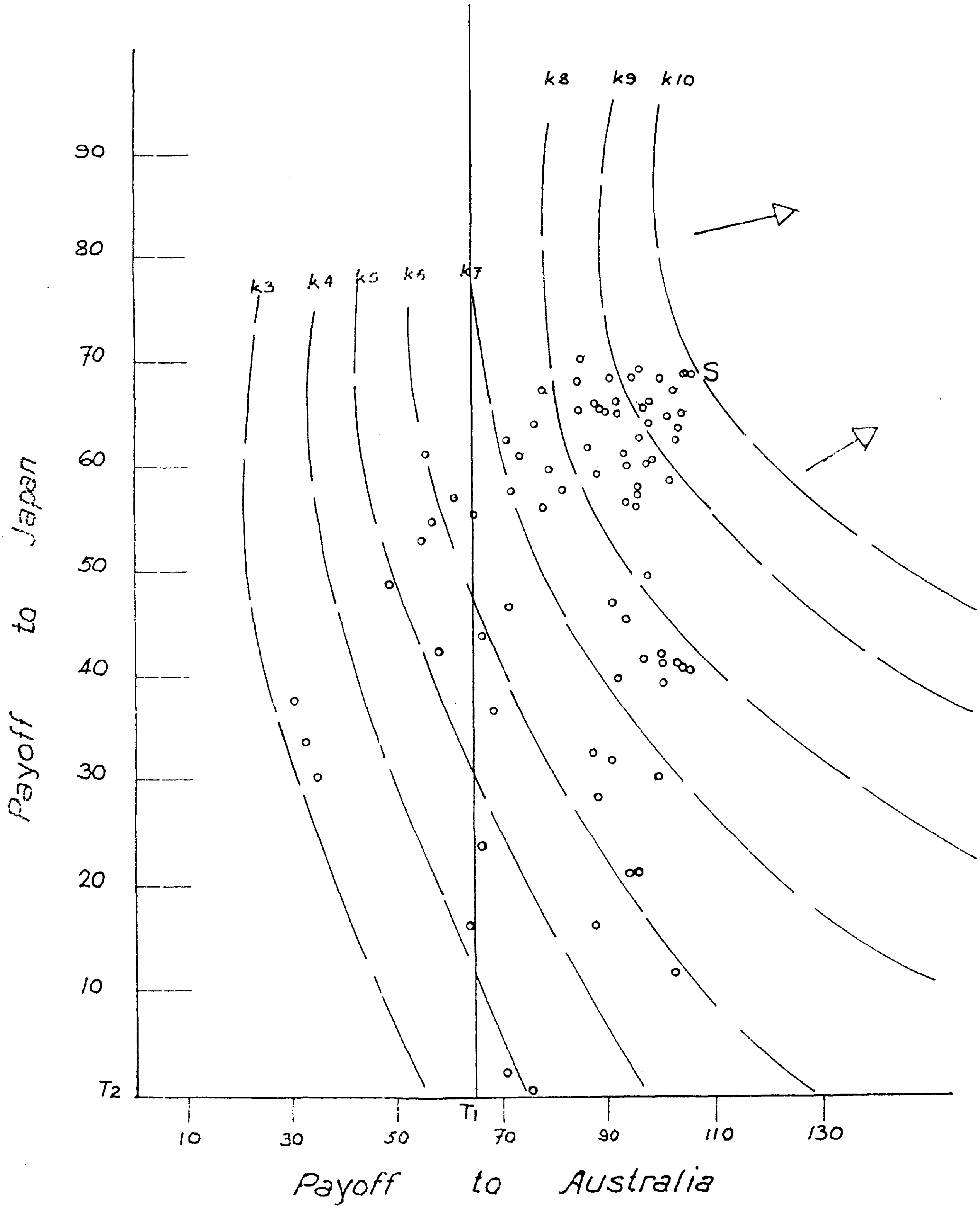

Figure 5.1: The values from the payoff matrix, with levels of k, the objective function, shown.

Table 5.1: Proportion of the objective function associated with simulated harvesting policies (decreasing levels within sections).

Proportion of k	Harvesting policies (combined strategies)				
$\geq 90\%$	PA7/PJ7*	PA7/PJ1	PA7/PJ4	PA3/PJ4	PA7/PJ8
	PA4/PJ4	PA3/PJ8	PA8/PJ4	PA4/PJ8	PA8/PJ8
	PA2/PJ4	PA5/PJ4	PA7/PJ3		
$80 - 90\%$	PA6/PJ4	PA7/PJ5	PA5/PJ8	PA4/PJ3	PA8/PJ3
	PA2/PJ8	PA5/PJ7	PA6/PJ8	PA3/PJ3	PA5/PJ3
	PA9/PJ7	PA8/PJ9	PA6/PJ7	PA6/PJ3	PA7/PJ9
	PA9/PJ4	PA5/PJ1	PA9/PJ8	PA4/PJ9	PA9/PJ1
	PA6/PJ9	PA5/PJ9	PA3/PJ5		
$70 - 80\%$	PA3/PJ7	PA9/PJ3	PA3/PJ1	PA4/PJ7	PA4/PJ1
	PA8/PJ7	PA2/PJ1	PA6/PJ1	PA1/PJ7	PA8/PJ1
	PA6/PJ5	PA9/PJ9	PA3/PJ9	PA5/PJ5	PA1/PJ6**
	PA8/PJ5	PA9/PJ5			
$60 - 70\%$	PA7/PJ6	PA2/PJ3	PA1/PJ5	PA2/PJ5	PA1/PJ4
	PA4/PJ6	PA4/PJ5	PA6/PJ2	PA3/PJ6	PA9/PJ2
	PA3/PJ2				
$50 - 60\%$	PA7/PJ2	PA2/PJ7	PA8/PJ2	PA2/PJ9	PA1/PJ1
	PA1/PJ2	PA4/PJ2			
$40 - 50\%$	PA5/PJ2	PA2/PJ6	PA1/PJ3	PA2/PJ2**	
$30 - 40\%$	PA1/PJ8	PA8/PJ6	PA9/PJ6	PA1/PJ9***	PA6/PJ6
$10 - 20\%$	PA5/PJ6				

* - optimum solution
** - current policies
*** - threat policy

5.3 Biological Results

5.3.1 Population Levels

It is vital to know just what the structure of the population is, and how this changes over time, under any particular management policy. Perhaps the most critical levels to consider are those of initial recruitment (the number of one-year-olds in the fishery), however, it is also of interest to know the levels available to the various parties exploiting the fishery.

To gain some idea of the changes in the population levels over the twelve years of the simulation, such numbers are shown by the year of the simulation, for the four policies discussed above. These are, the levels of one-year-olds (recruitment), three-year-olds (level of the juvenile population) and nine-year-olds (level in the adult population). Also, a comparison of the levels at the end of the major period of exploitation (12-year-olds) is provided below.

The optimal solution

The identified optimal harvesting policy is the combination of strategies PA7/PJ7. The catch levels, by age-class, associated with this policy are shown in Figure 5.2. The Australian strategy basically represents a South Australian catch (three- to five-year-olds) while the Japanese strategy is a low level one, over a broad age range (seven– to 15–year–olds). The levels of the critical age-classes in the fishery are presented in Figure 5.3.

In the optimal strategy recruitment into the fishery maintains a relatively stable pattern. Although fluctuating between four and seven million one-year-olds, there is no tendency for decline. These fluctuations reflecting a pattern of good and bad years for the fishery (induced by the random simulation process used in determining the level of annual recruitment), rather than any downward trend. The level of three-year-olds shows a similar slight upward trend, again reflecting a population not stressed by the harvesting strategy adopted. The levels of nine-year-olds, an indicator of the numbers available to the Japanese operation, do initially show a slight downward

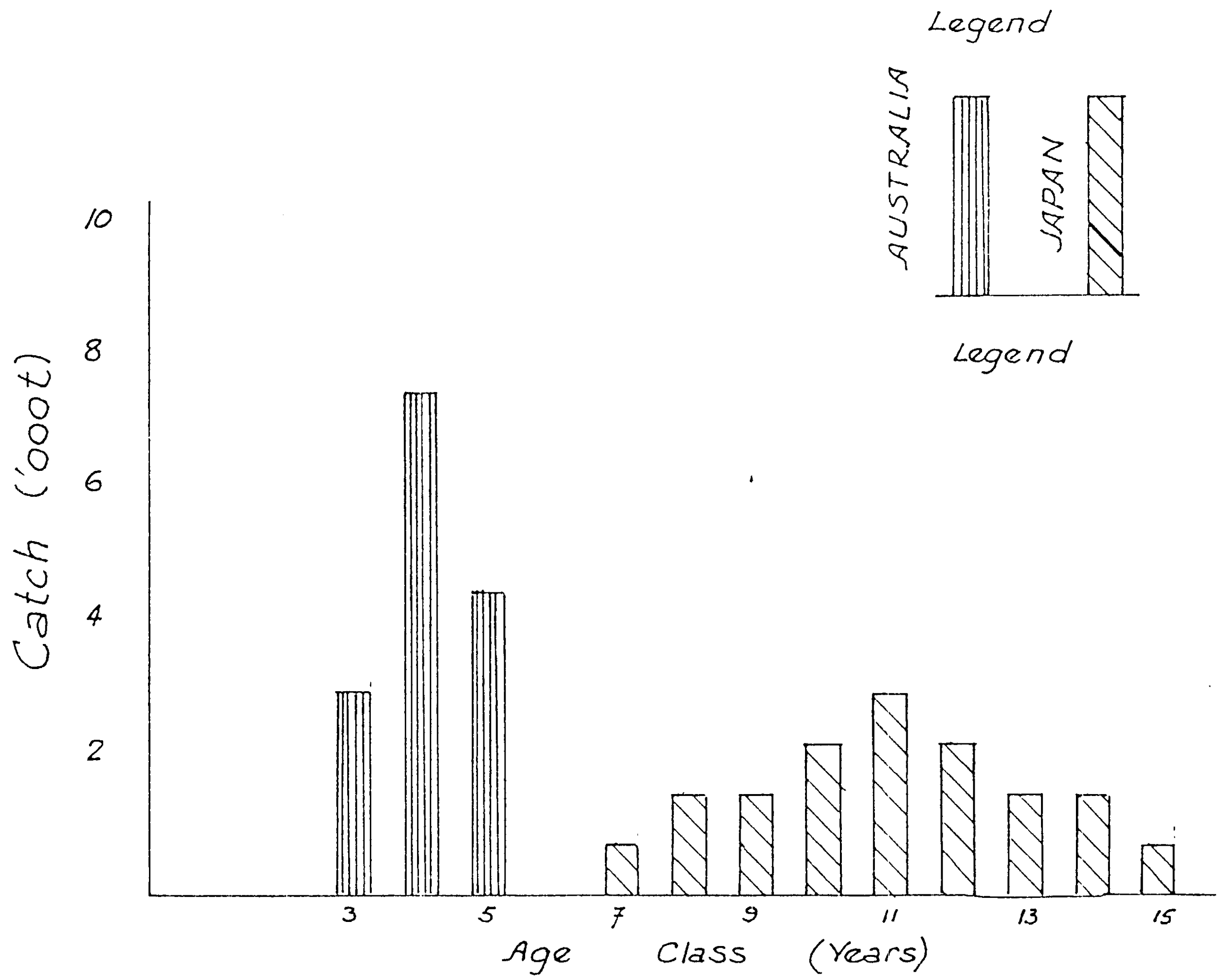

Figure 5.2: Harvesting policy under PA7/PJ7.

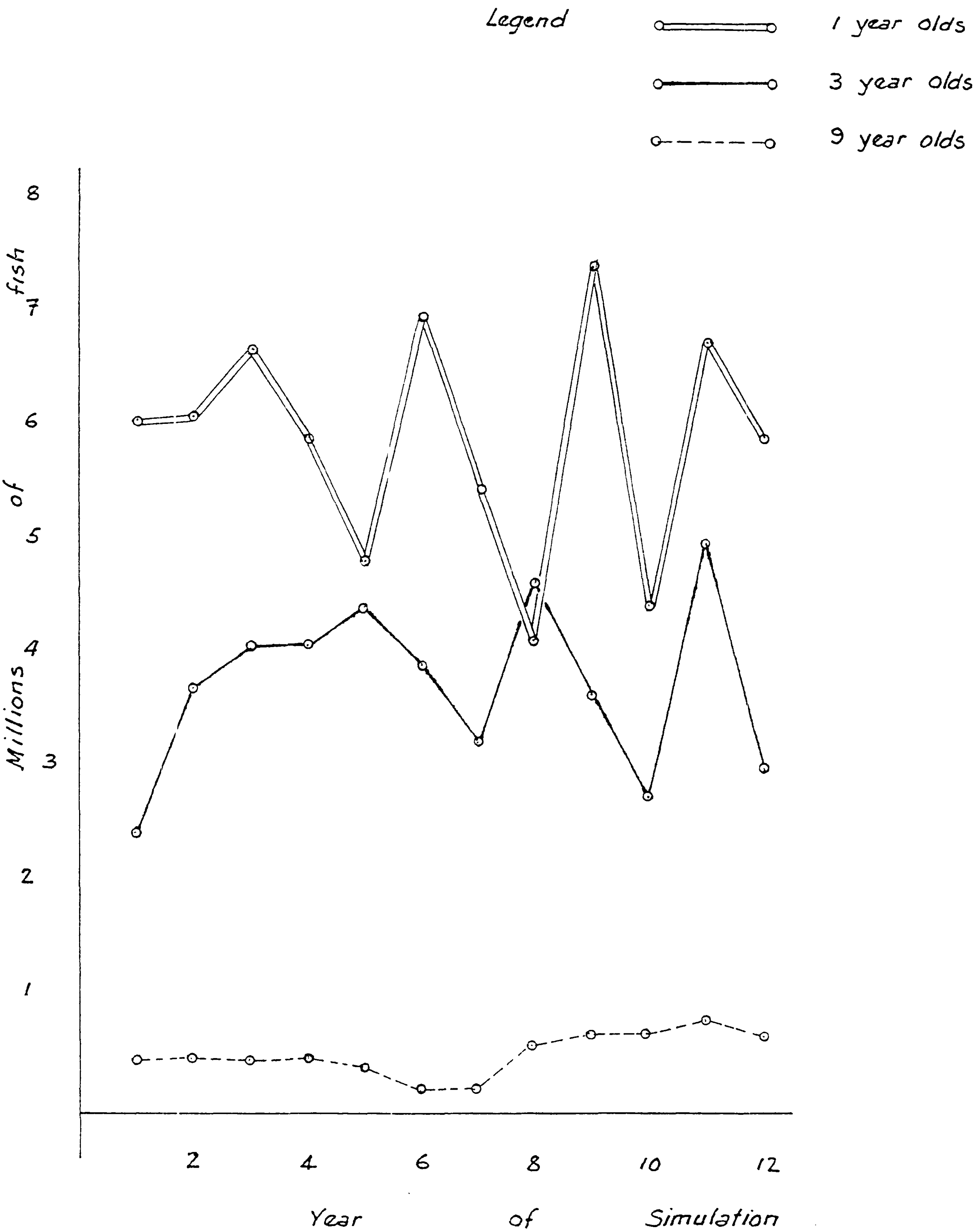

Figure 5.3: Number of 1, 3, and 9-year-olds under PA7/PJ7.

move. However, after the seventh year of the cycle this is reversed, and the final level of this group is higher than the initial level. This initial downward trend is associated with the establishment of the population under the given harvesting policy, as it takes several years before any impact on the levels of fish available to the Japanese after the Australian exploitation, will be felt.

Under the optimal harvesting policy one would expect the Australian operation to be mainly localised to South Australia, whilst the Japanese would apply a relatively low level of effort targeted at a broad rather than narrow age range. The initial catch for the Japanese is of seven-year-olds, and this suggests that the fleet would not be targetting any inshore fish, as has been the tendency in more recent years.

The threat strategy.

The threat adopted here is that of the Australians selecting strategy PA1 and the Japanese PJ9. Thus, where one party defaults on the agreed optimum, both would adopt easy, high profit level policies, potentially damaging to the future of the fishery. These policies are shown in Figure 5.4.

The Australian policy, suggesting an operation centred mainly in Western Australia, is likely to be, in the long term, quite destructive to the fishery. However, it would also be the most threatening policy that the Australians could adopt, providing the greatest impact on the Japanese catches. The Japanese strategy PJ9 is not the most destructive available (PJ6 would probably take this place) but it would reflect the highest level of effort available, very broadly directed and offering reasonable rates of return. The effects on the numbers in the fishery resulting from this harvesting policy, are presented in Figure 5.5. Here, a strong decline in the levels of all three groups is apparent. The level of recruitment, at the end of the simulation process, is around three million fish, with a low point (year 10) of around two million fish. This pattern suggests that the overall impact of this harvesting policy has led to a significant decline in the levels of the breeding stock, and thus the parental biomass.

The declining levels of recruitment into the fishery observed under this policy would naturally have an impact on the numbers in the later age-classes. This is clearly seen in the reduced levels of three-year-olds. The final year of the simulation

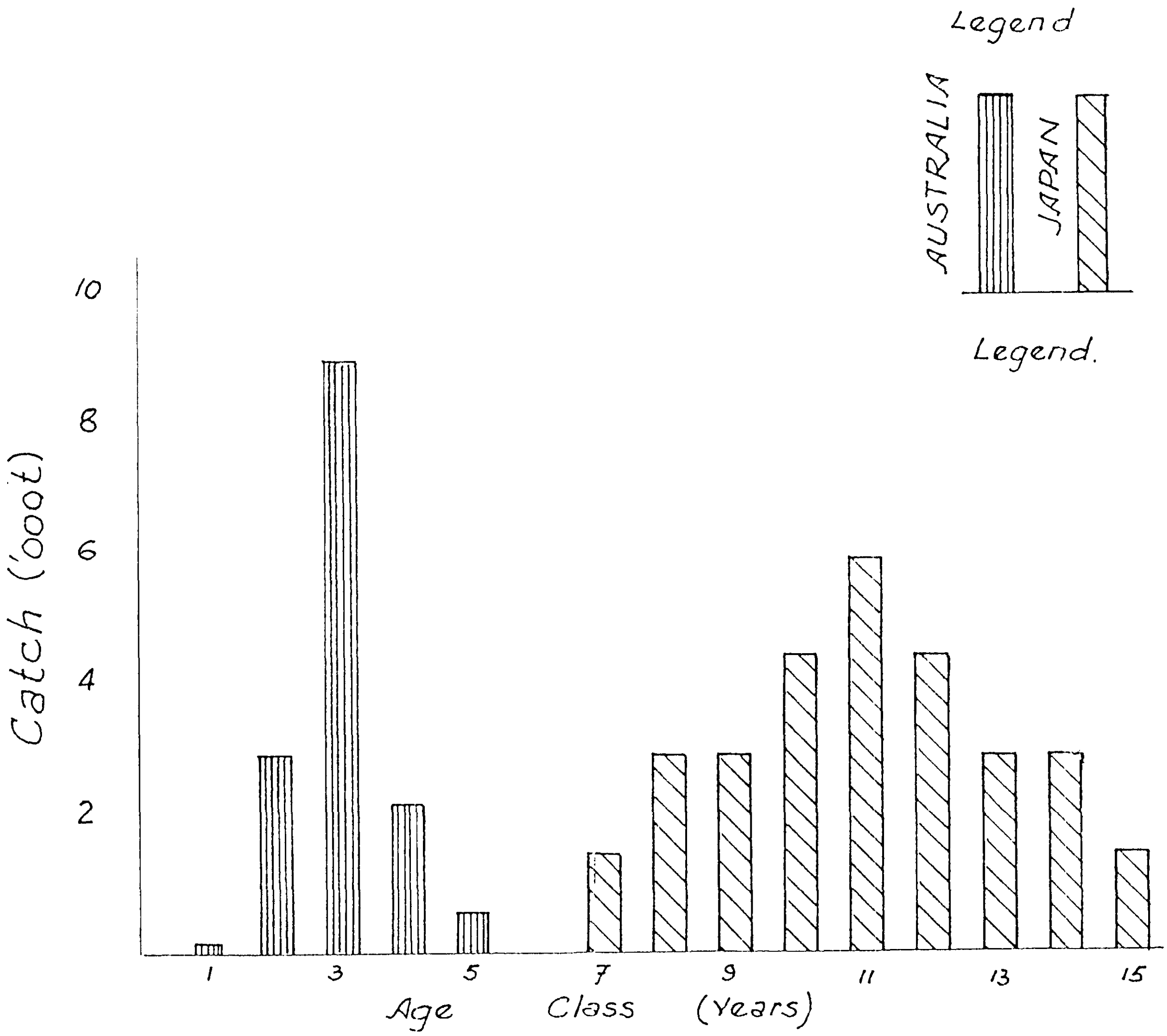

Figure 5.4: Harvesting policy under PA1/PJ9.

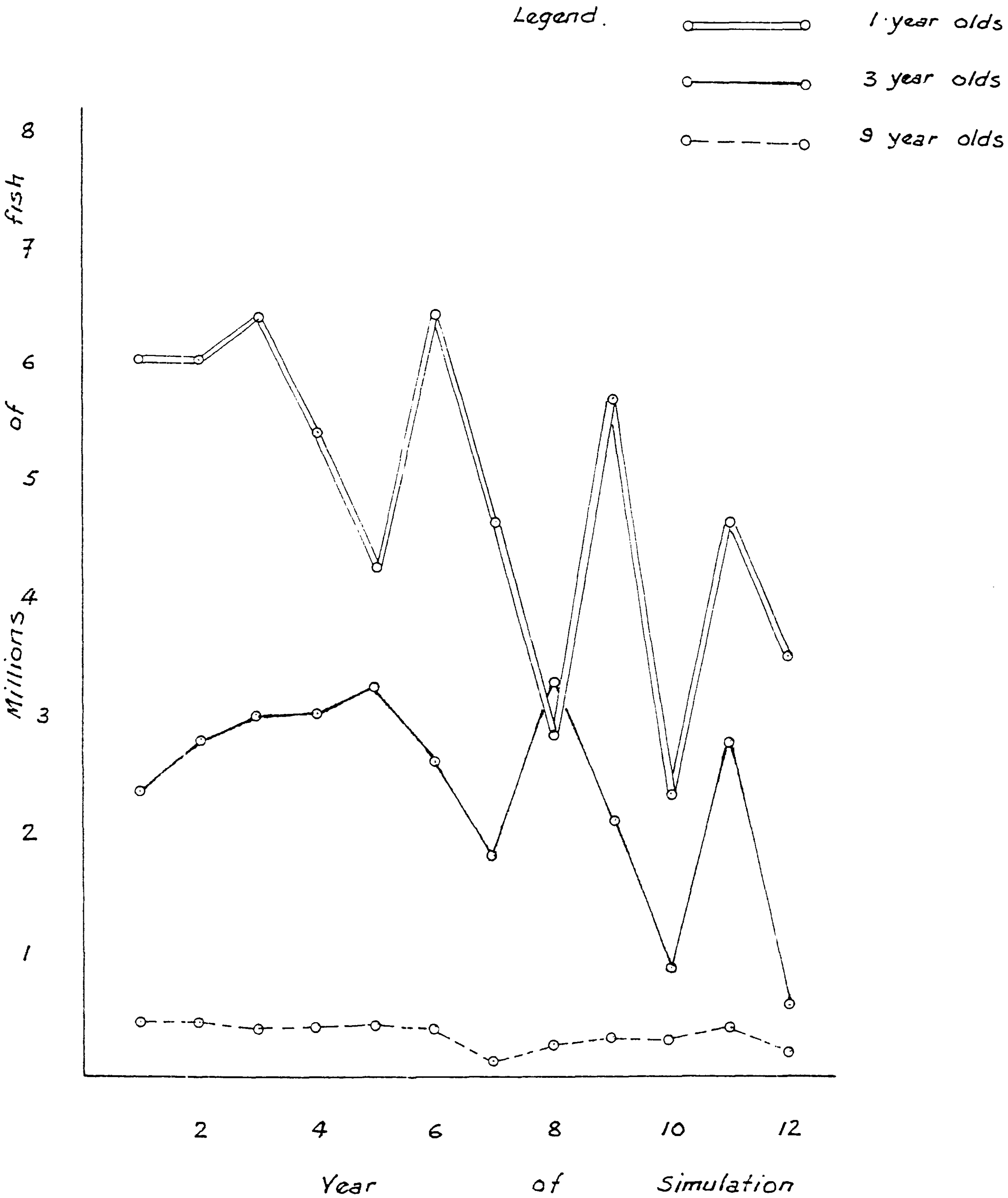

Figure 5.5: Numbers of 1, 3, and 9-year-olds under PA1/PJ9.

has a level of well under one million fish, suggesting little future for any fishery based on this stock.

Recent harvesting patterns in the fishery.

Since 1980, particularly, there has been a strong growth in the catch of the youngest age-classes (by the Western Australian boats) and a subsequent decline in the catches from the New South Wales operation. Also, the Japanese catch levels have been relatively high, with most catches during the 1970s and early 1980s being of the order of 30 000t. These catches have included a greater proportion of smaller fish rather than the older fish predominant in the very early years of the fishery. Thus, to consider a policy which reflects recent management practices it is important that it includes catches of the early age-classes and also high levels of age-classes normally associated with a Japanese catch. Two policies have been selected, PA2/PJ2 and PA1/PJ6. The former reflecting a slightly less heavy impact on the population than would be expected from latter. PA2/PJ2 has a peak of harvesting set at three-year-olds then a lower, constant level on five-to-14-year-olds. PA1/PJ6, on the other hand, has a very strong catch of three-year-olds with another heavy peak centred on the eight-to nine-year-olds. These options are shown in Figure 5.6, and the levels by age-class resulting from the adoption of these two policies are shown in Figure 5.7 and Figure 5.8.

The results of policy PA2/PJ2 suggest a decline in the level of all age-classes. However, there does appear to be some tendency towards stabilization, although at a level below the initial one, with the level of recruitment around four million and the number of three-year-olds between one and two million at the end of the simulation. The levels of nine-year-olds shows a slightly more optimistic trend with the final levels returning around that of the initial population. The effects of the policy PA1/PJ6 are far more dramatic, with all indicators declining throughout the period of the simulation. The level of recruitment oscillates around the one million level, while the number of three-year-olds is around the half million. The level of nine-year-olds in the population is thus dangerously low. Little future for a fishery could be projected from the final levels of the younger age-classes.

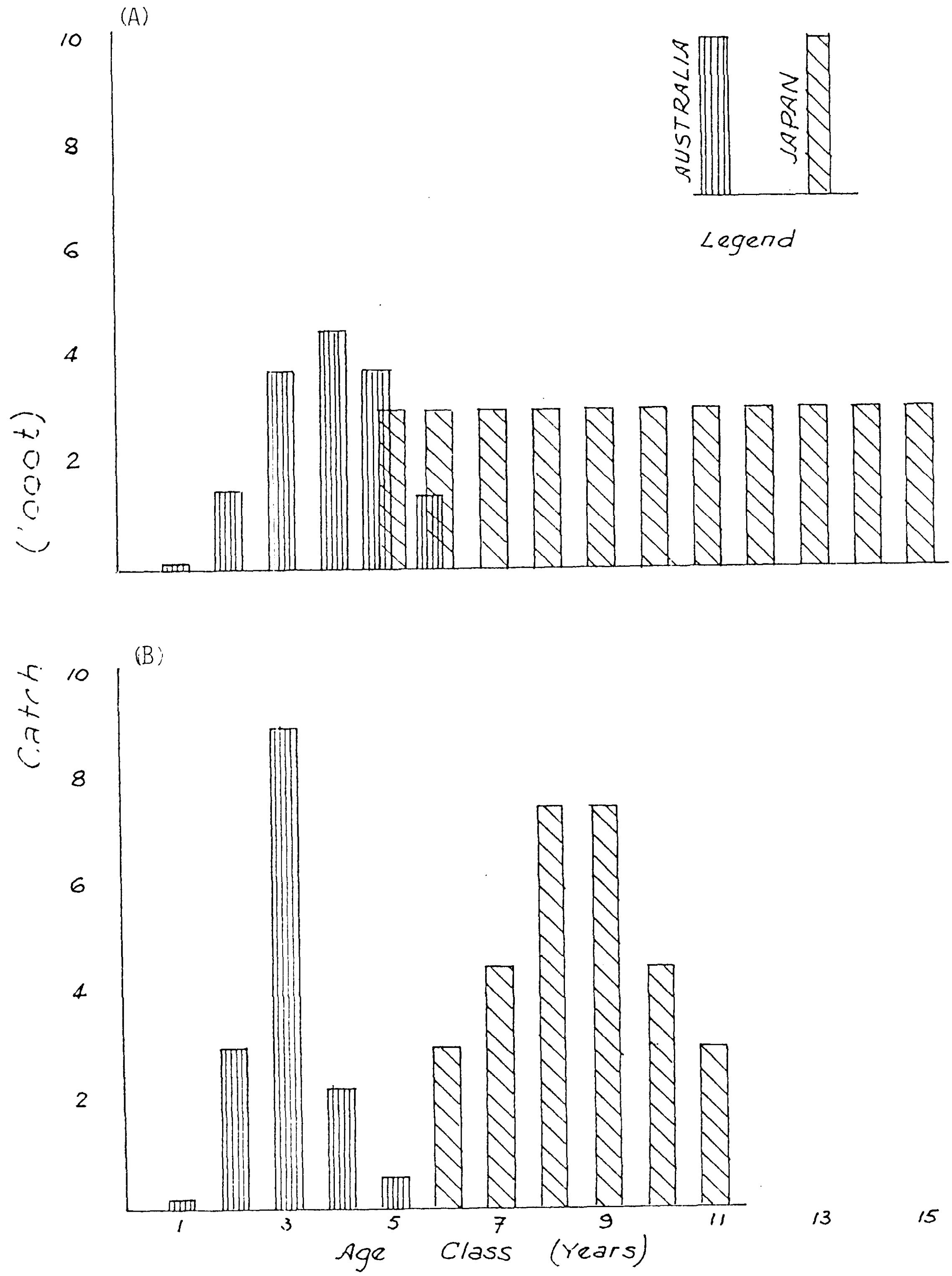

Figure 5.6: Harvesting policy under PA2/PJ2 (A) and PA1/PJ6 (B).

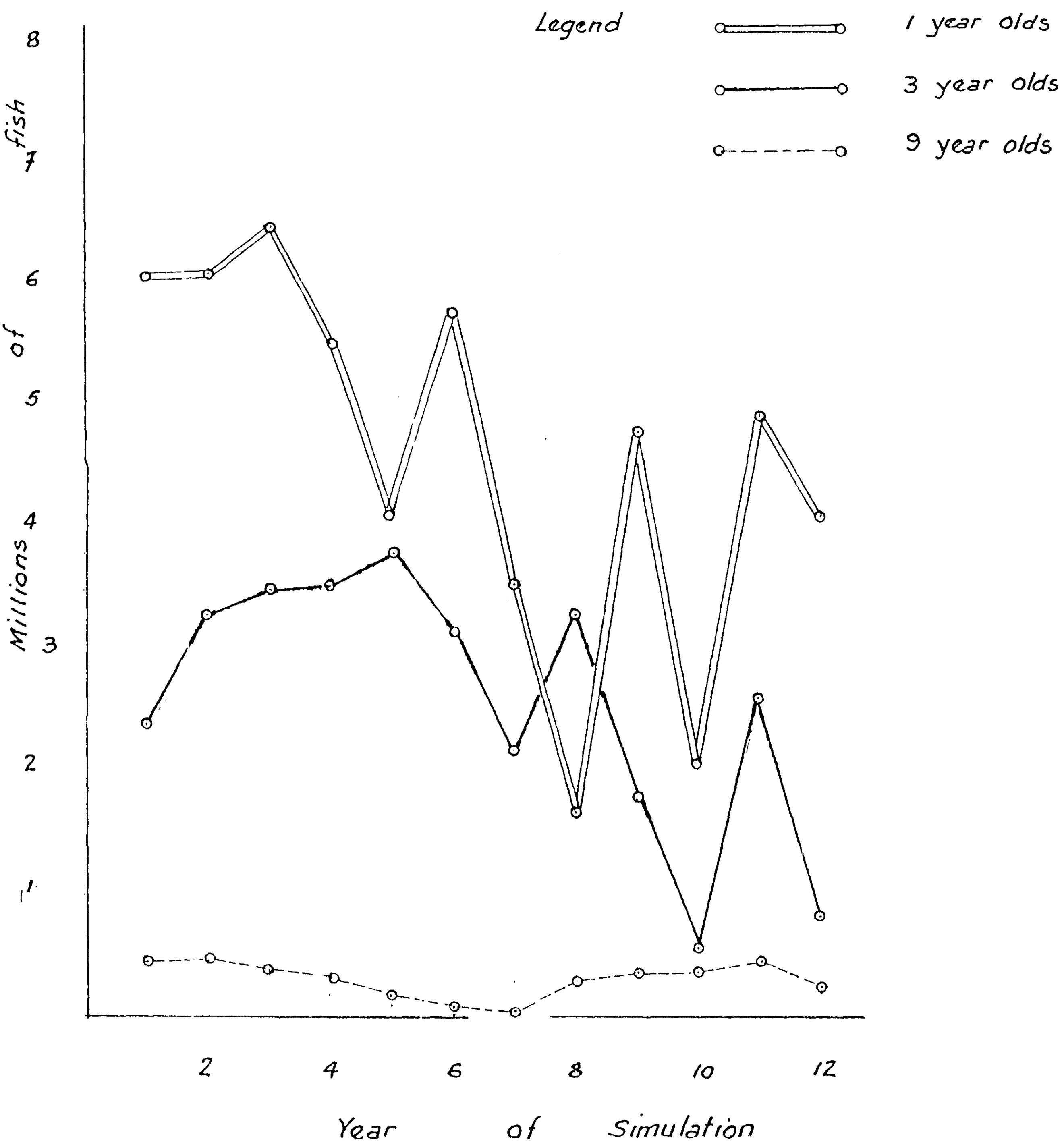

Figure 5.7: Number of 1, 3, and 9-year-olds under PA2/PJ2.

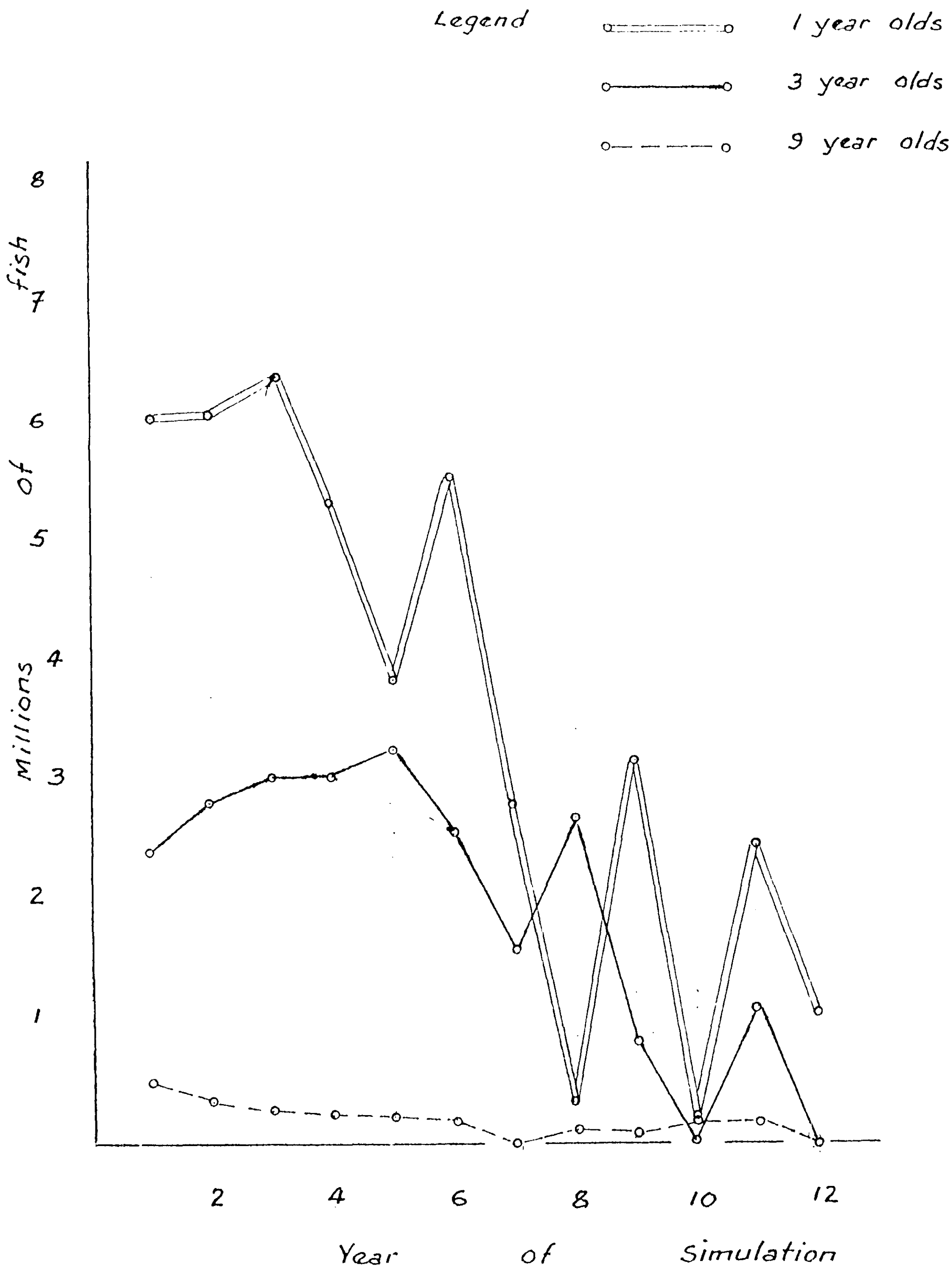

Figure 5.8: Number of 1, 3, and 9-year-olds under PA1/PJ6.

Comparison of policies

This section provides specific comparisons with regard to the actual numbers of different age-classes available in the fishery. In an attempt to simplify discussion, future reference to the policies of interest will be to the optimal (PA7/PJ7), threat (PA1/PJ9), normal 1 (PA2/PJ2) and normal 2 (PA1/PJ6) policies.

A consideration of three-year-olds provides an index of the levels available at, or soon after entry to the Australian operation. In Figure 5.9 the optimal policy appears to provide an improvement over the initial level, with numbers remaining at relatively high levels. Two options show an initial decline, then stabilize at a lower level (normal 1 and the threat policy) and the normal 2 policy leads to a rapid decline in numbers.

For the numbers of nine-year-olds presented in Figure 5.10, only the optimal policy appears to offer any chance of a sustainable fishery. Again, there is a very strong decline in the levels under the normal 2 policy, with some gaps (entirely fished out age-classes) being noted. The two middle level policies (normal 1 and the threat), although having very similar levels for the last half of the cycle, differ during the early phase, with normal 1 having a far more rapid early decline - probably due to the more constant, though diverse harvesting pattern. Interestingly, once this policy has become established, and a feedback effect had time to occur, it may offer a more sustainable option than does the threat policy.

Finally, a consideration of the levels of twelve-year-olds (not included in the assessment of individual policies above) provides some picture of the stock after the major harvesting effort has taken place. Figure 5.11 shows the final flow on from the level of nine-year-olds, after additional harvesting effort. The optimal policy at first has a relatively stable level, followed by a sharp decline in numbers at year seven. However, the last two years of the cycle indicate a relatively strong recovery, with the final numbers above the initial levels. On the other hand, the normal 2 policy declines rapidly, but its heavy impact on the adult population obviously would not make it possible to recover from such low levels, and the elimination of the population of older fish in the long term is suggested. Normal 1 offers a better long term option than does the threat policy. Although there is a serious decline in the former, it appears

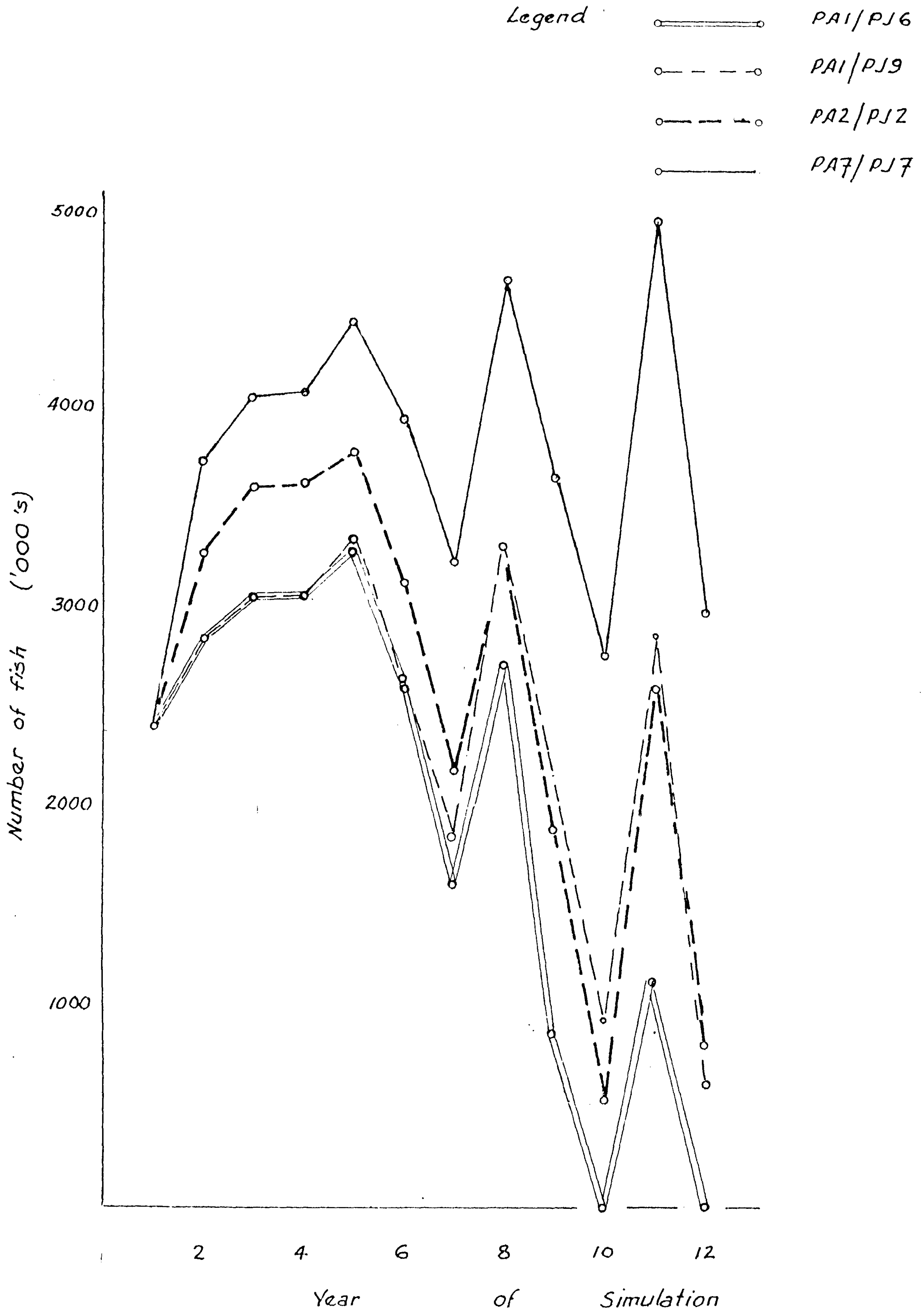

Figure 5.9: Numbers of three-year-olds.

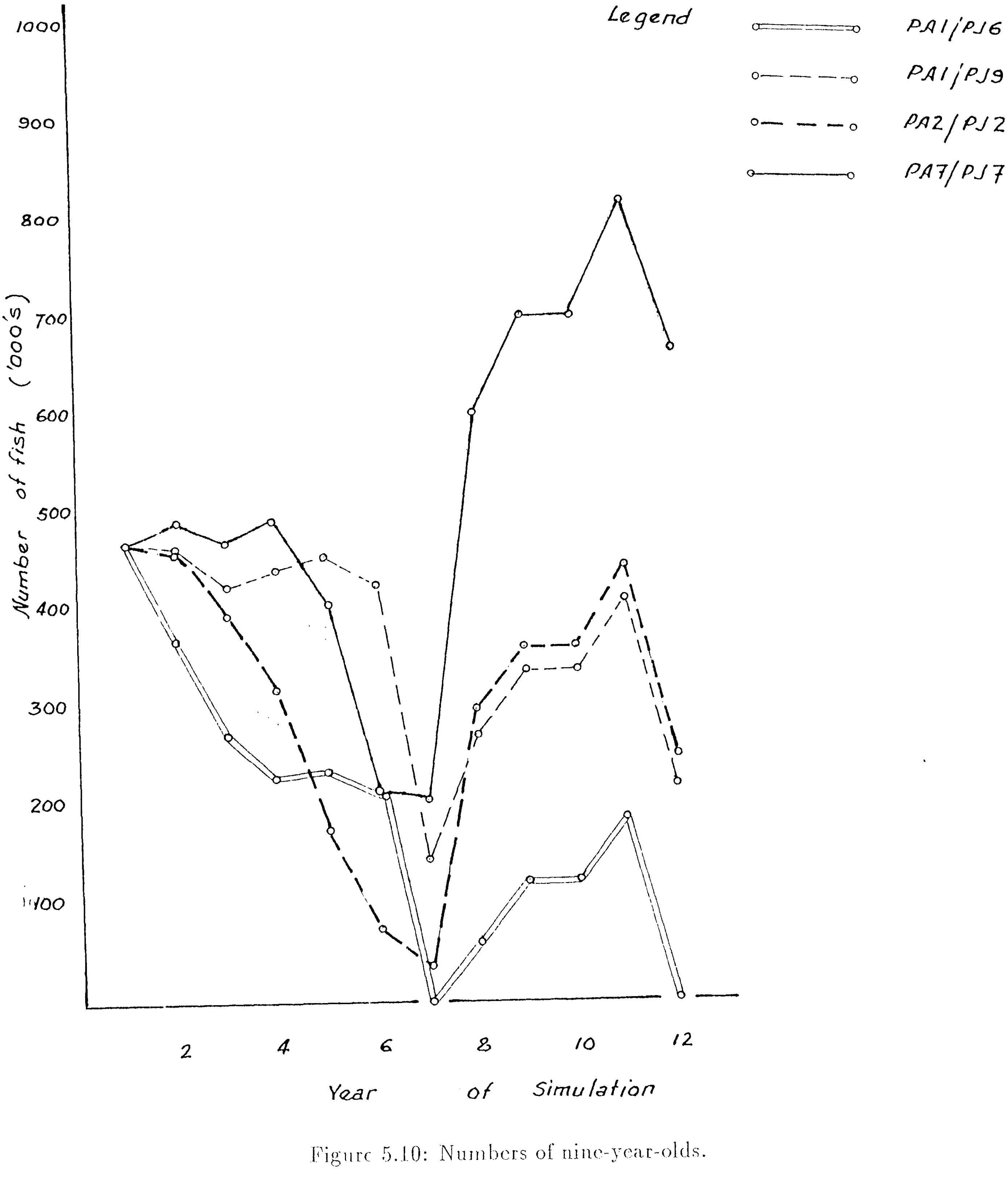

Figure 5.10: Numbers of nine-year-olds.

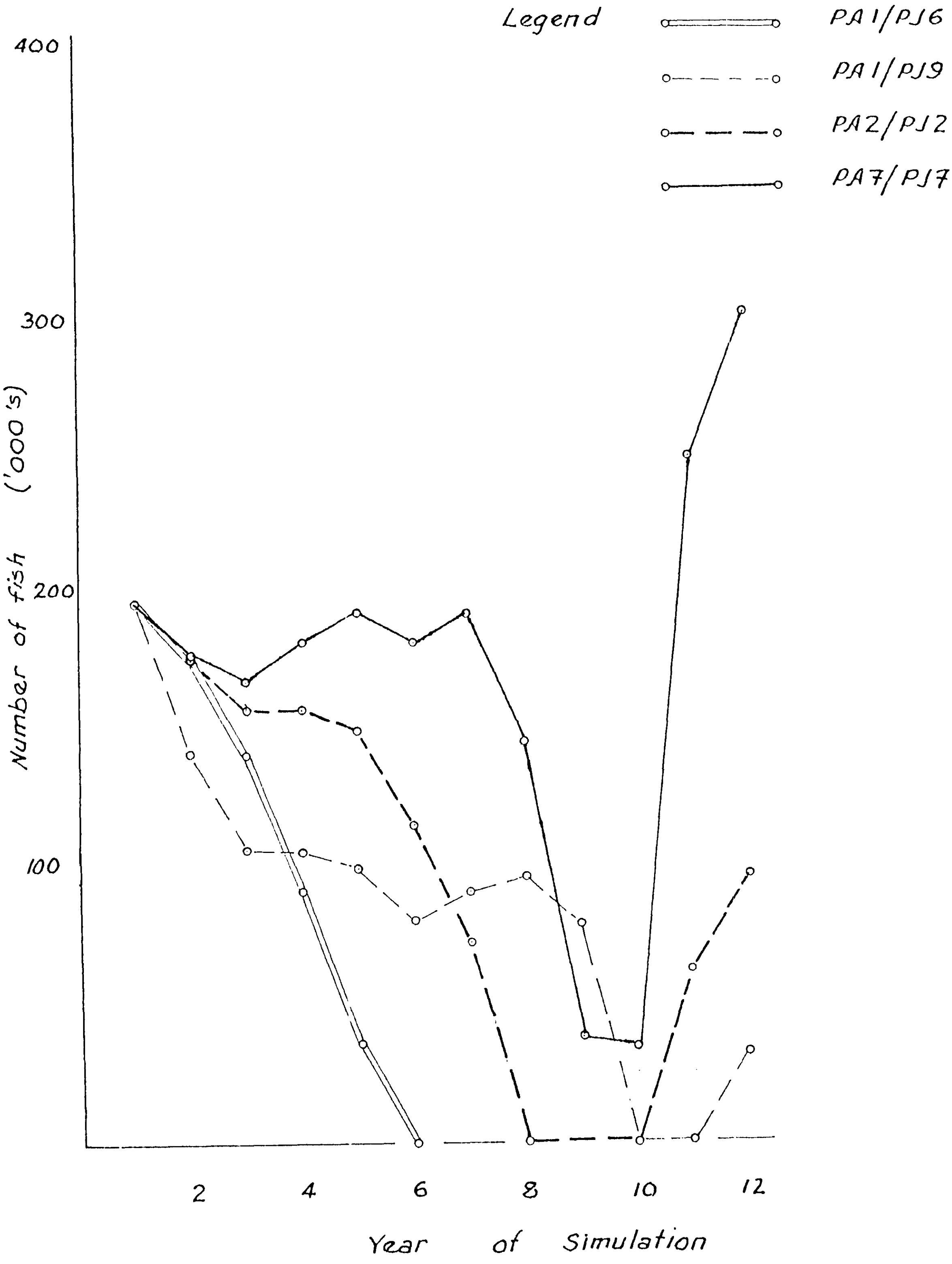

Figure 5.11: Numbers of 12-year-olds.

more of a sudden drop, reflecting strong over fishing of one age-class, probably associated with a poor year for recruitment. The numbers for the last two years, however, do show signs of recovery, so this option, while extreme, is probably less destructive in the long term than the threat policy.

5.3.2 Parental Biomass

The level of the parental biomass (weight of the breeding stock) is accepted as an important indicator of the state of the breeding stock, and has been frequently used in stock assessment models as an indicator of the effect on the future population. The change in the level of parental biomass is evaluated over the simulation period. It should, however, be recognised that there is a time lag of about six years before the full impact of any particular policy will be felt on this indicator. Therefore, the final level for any strategy will be the most important (and also is the level used to assess if a strategy reaches the required biological criterion).

Table 5.2 summarises the relative positions of the strategies with regard to the level of parental biomass in the final year of the simulation cycle. A rather different pattern to that noted in Table 5.1 occurs here, both in the general order of strategies and, in particular, of the four policies of interest. The optimal policy is still in the above 90 percent group, although not at the top of this group. However, the positions of the others are all well below the critical level of 220 000t, with the normal 2 policy in fact having the lowest return of all strategies. The threat policy is slightly below the normal 1 policy, though neither suggest a fishery able to sustain reasonable, long term, exploitation.

The information from this, and also Table 5.1, is summarised in Table 5.3. This shows the relative positions of both indicators, for all the strategies - thus allowing easy assessment of strategies with repect to both their biological and economic potential. From this table it is apparent that a high level of payoff is not an automatic indicator of a correspondingly high level of parental biomass. All policies included in the feasible set have acceptable levels of parental biomass, however, not all of these are above the 80 percent level (a reasonable high level of parental biomass) - this particularly applying to policies including the strategies PA2, PA3 and PA4.

Table 5.2: Proportion of the final maximum level of parental biomass associated with simulated harvesting policies (decreasing levels within sections).

Parental Biomass	Harvesting policies (combined strategies)			
$\geq$ 90%	PA9/PJ7	PA9/PJ1	PA6/PJ7	PA9/PJ8
(365 561t)	PA8/PJ7	PA9/PJ4	PA5/PJ7	PA6/PJ1
	PA7/PJ7*	PA4/PJ7	PA6/PJ8	PJ8/PJ1
	PA9/PJ9	PA8/PJ8†	PA9/PJ3	PA5/PJ1
	PA6/PJ4	PA5/PJ8		
80 – 90%	PA3/PJ7	PA8/PJ4†	PA7/PJ1†	PA4/PJ1
(324 943t)	PA7/PJ8†	PA4/PJ8†	PA5/PJ4†	PA6/PJ9
	PA6/PJ3	PA8/PJ9	PA2/PJ7	PA7/PJ4†
70 – 80%	PA8/PJ3	PA4/PJ4†	PA3/PJ1	PA5/PJ9
(284 325t)	PA3/PJ8†	PA9/PJ2	PA9/PJ5	PA5/PJ3
	PA7/PJ9	PA4/PJ9	PA7/PJ3†	
60 – 70%	PA3/PJ4†	PA4/PJ3	PA2/PJ1	PA2/PJ8
(243 207t)	PA6/PJ2	PA3/PJ9	PA6/PJ5	PA8/PJ2
	PA8/PJ5	PA2/PJ4†		
50 – 60%	PA3/PJ3	PA5/PJ2	PA5/PJ5	PA2/PJ9
(203 089t)	PA9/PJ6	PA7/PJ2	PA7/PJ5	PA1/PJ7
	PA4/PJ2	PA2/PJ3	PA4/PJ5	
40 – 50%	PA6/PJ6	PA3/PJ2	PA3/PJ5	PA8/PJ6
(162 471t)	PA1/PJ1			
30 – 40%	PA1/PJ8	PA5/PJ6	PA7/PJ6	PA2/PJ2**
(121 854t)	PA1/PJ4	PA2/PJ5	PA4/PJ6	
20 – 30%	PA1/PJ9***	PA3/PJ6	PA1/PJ3	
(81 236t)				
10 – 20%	PA2/PJ6			
(40 618t)				
< 10%	PA1/PJ2	PA1/PJ5	PA1/PJ6**	

* - optimum solution

** - current policies

*** - threat policy

† - member of the feasible set

Table 5.3: Levels of Payoff (p) and Parental Biomass (b) associated with harvesting strategies.

	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9
PJ1	p=5 b=4	p=7 b=6	p=7 b=7	p=7 b=8	p=8 b=9	p=7 b=9	† p=9 b=8	p=7 b=9	p=8 b=9
PJ2	p=5 b=0	** p=4 b=3	p=6 b=4	p=5 b=5	p=4 b=5	p=6 b=6	p=5 b=5	p=5 b=6	p=6 b=7
PJ3	p=4 b=2	p=6 b=5	p=8 b=5	p=8 b=6	p=8 b=7	p=8 b=8	† p=9 b=7	p=8 b=7	p=7 b=9
PJ4	p=6 b=3	† p=9 b=6	† p=9 b=6	† p=9 b=7	† p=9 b=8	p=8 b=9	† p=9 b=8	† p=9 b=8	p=8 b=9
PJ5	p=6 b=0	p=6 b=3	p=8 b=4	p=6 b=5	p=7 b=5	p=7 b=6	p=8 b=5	p=7 b=6	p=7 b=7
PJ6	** p=7 b=0	p=4 b=1	p=6 b=2	p=6 b=3	p=1 b=3	p=3 b=4	p=6 b=3	p=3 b=4	p=3 b=5
PJ7	p=7 b=5	p=5 b=8	p=7 b=8	p=7 b=9	p=8 b=9	p=8 b=9	* p=9 b=9	p=7 b=9	p=8 b=9
PJ8	p=3 b=3	p=8 b=6	† p=9 b=7	† p=9 b=8	p=8 b=9	p=8 b=9	† p=9 b=8	† p=9 b=9	p=8 b=9
PJ9	*** p=3 b=2	p=5 b=5	p=7 b=6	p=8 b=7	p=8 b=7	p=8 b=8	p=8 b=7	p=8 b=8	p=7 b=9

† - member of the feasible set
* - optimum solution
** - current policies
*** - threat policy

Some of the poorer combinations should also be noted. The first Australian strategy, PA1, basically a West Australian catch, while having reasonable levels of payoff (many around the 50 to 60 percent level), appears to have very low levels of parental biomass. A similar, though less extreme, pattern can be observed in the policies including the Japanese strategy PJ6 - a high level catch compressed over a small age distribution.

The changes in levels of parental biomass during the 12 years of the simulation cycle for the four policies of interest, are shown in Figure 5.12. From these results three general outcomes can be observed, these basically similar to the patterns noted in comparisons of age-class numbers. Firstly, a very optimistic one for the optimal policy. Here, after an initial decrease, associated with the establishment of the effect of this policy on the adult population, there is a definite increase, with the level of parental biomass appearing to stabilize around 400 000t.

The threat and normal 1 policies show relatively similar patterns, although the initial impact of normal 1 is more extreme. The normal 2 policy, on the other hand, appears to produce a very quick, detrimental impact on the breeding stock. The difference between this and the threat policy (both having the same Australian strategy), is that the Japanese strategy, also at a high level, is both more compressed and earlier starting (thus from six- to 11-year-olds, compared to seven- to 15-year-olds). The impact on the fishery of this difference appears to be very significant.

5.4 Validation of Results

As this model is used to investigate the effect of potential harvesting strategies on the fishery, it is not possible to formally validate the results against actual values found for any particular year. However, as each simulation starts with the same population structure taken from a period prior to heavy exploitation of the fishery (1970 numbers, from Hampton, Majkowski and Murphy 1984), it is possible to consider the reasonableness of the outcomes in the light of the actual levels observed in the fishery.

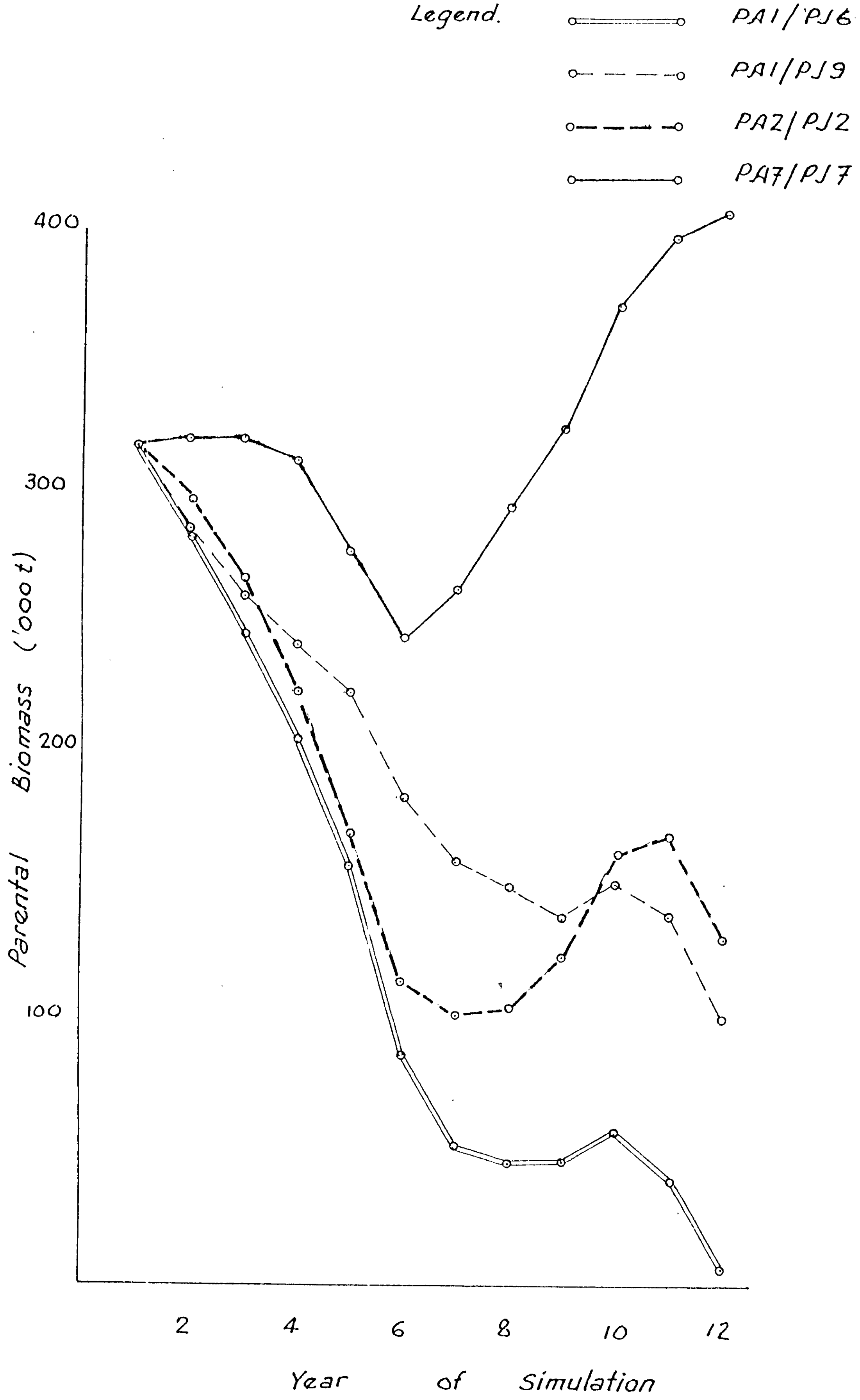

Figure 5.12: Changes in parental biomass during the simulation cycle.

In simulating the population structure, not only is the first age structure set for each simulation, but also the same random elements determining the level of recruitment are maintained for all simulations - thus avoiding the introduction of additional variation between the strategies to be compared.

As can be seen from the results above, the levels of the indicators of the population structure are maintained at feasible levels when the harvesting pressure is not too intensive. These levels, which relate to the exploitation pressure placed on the fishery rather than random variation, appear very similar to those observed in the actual population . The best indicator of this is the level of parental biomass.

Murphy and Majkowski (1981) suggest that the level of parental biomass of the population in the early seventies (derived from the same input data used in this model) would be around 340 000t - the same level identified in the model. Further, the most recent estimates of the current parental biomass in the fishery are around 100 000t, an extreme drop from the pre-exploitation levels of 500 000t (Geen and Nayer 1989). This research identifies similarly low levels for a population under a harvesting policy such as normal 1, while it suggests even lower levels under the normal 2 policy.

Although this simulation is carried out for a period of 12 years, it is felt that, in the real population, it might represent a slightly longer period. This is because, over the period of the simulation there is a set level of exploitation applied each year. In reality, there have been some years below the levels used in the model and a few above it. Further, such exploitation would often not take as close to the set harvesting strategies as is suggested by the model, particularly where age-classes are depleted. In the real fishery, fishermen, when faced with such shortages, would either change their strategy slightly to exclude low numbered age-classes or cease fishing before they reached their target. Thus, while these very heavy years have had an extreme impact on the fishery, and in particular on one or two age-classes, the overall impact of the simulated policies are probably slightly more intense, and thus their impact time somewhat longer than 12 years. It would thus appear likely that for a simulation starting from a 1970 population, the results could be relatively representative of the mid to late 1980 population structure. As the current population is stated to be in danger of recruitment failure with a suggested parental biomass of around 100 000t, this appears a reasonable picture.

5.5 Sensitivity Analysis

The results so far presented in this chapter are based on the adoption of a given range of model settings outlined in Chapter 4. Variations in the settings and the identification of the optimal solution with the varying levels of these settings are reported in this section.

While it is of interest to observe if the particular solution varies, the main interest is as to whether or not such variation extends to policies outside of the identified feasible set. Some variation in a specific solution might be expected, the value of the model will be strengthed if the identified feasible set consistently contains the preferred solution. As each run of the model is repeated for 10 random price selections, results indicate whether all or some of these identified a particular solution.

5.5.1 Quota Levels

The first aspect to be considered is the setting of quotas for the participants in the fishery. These have been placed at 15 000t for both Australia and Japan - this setting all strategies for Australia at this level while those for Japan range from 15 000t - 30 000t.

For the analysis of quota levels, the Japanese level was held constant while varying the Australian quota from 9 000t to 21 000t (in 2 000t increments), similar variations were then carried out on the Japanese quota setting.

The lowest setting (Australia 9 000t and Japan 15 000t) led to identification (9 of the 10 replictions) of PA7/PJ4 as the optimal solution in 90 percent of all the cases, with one replication identifying PA3/PJ4 as the optimal solution (PA3 harvests mainly three-to five-year-olds, though has low level catches of two and six-year-olds, while PJ4, in common with PJ7, is a low level catch though catching six-to 11-year olds instead of seven-to 15-year-olds). These results are summarised in Table 5.4.

Although there was some variation noted in the identification of the optimal policy, all solutions identified were in the feasible set. Further, in all but one replication, the Australian strategy PA7 was included in the optimal policy, and all identified Japanese strategies represented the lowest level of harvesting (thus PJ1, PJ4 and PJ7).

Table 5.4: Selection of the optimal solution under variations in the setting of quota levels.

Australia	Japan	Identified optimal solution				
Quota in t		PA3/PJ4	PA7/PJ1	PA7/PJ4	PA7/PJ7	PA7/PJ8
9 000	15 000†	1		9		
11 000	15 000†			*		
13 000	15 000†			*		
15 000†	15 000†				*	
17 000	15 000†				*	
19 000	15 000†				*	
21 000	15 000†				*	
15 000†	9 000			*		
15 000†	11 000			*		
15 000†	13 000		*			
15 000†	15 000†				*	
15 000†	17 000		2		8	
15 000†	19 000		1		9	
15 000†	21 000				*	

† - standard setting in the model
* - all ten replications

5.5.2 Market Prices

The model was again used to consider the effects of variations in the levels of Australian and Japanese market prices. These results are presented in Table 5.5. The Australian prices range from A\$800/t to A\$1 600/t, while the Japanese are over the

Table 5.5: Selection of the optimal solution under variations in the level of market prices.

Mean level		Identified optimal solution				
Australia (A$'s)	Japan (A$'s)	PA3/PJ4	PA7/PJ1	PA7/PJ4	PA7/PJ7	PA7/PJ8
800	20 000†				*	
1 000	20 000†				*	
1 200†	20 000†				*	
1 400	20 000†				*	
1 600	20 000†				*	
1 200†	16 000				*	
1 200†	18 000				*	
1 200†	20 000†				*	
1 200†	22 000				*	
1 200†	24 000				*	

† - standard setting in the model.
* - all ten replications

range A$16 000/t to A$24 000/t.

For all price variations and replications the identified optimal policy was PA7/PJ7. The consistency of these results is not entirely unexpected. The model was designed to take into account the relative positions of policies rather than the actual returns recieved. Thus, as the prices are not linked to the actual age distribution of the catch, this factor should not affect the identification of the solution.

5.5.3 Harvesting Costs

Variation in the costs of harvesting fish, by age-class and operation, were then considered. While the results for this section might again (as for prices) be expected to be relatively similar, the fact that costs vary by both age-class and fishery could introduce some variation.

These costs have been varied by decreasing or increasing the standard level by some factor. Thus, in Table 5.6, where we are considering a .7 Japanese cost, with the Australian costs held to the standard level, the Japanese setting has been reduced by a factor of 0.3. In this case, two replications identified PA7/PJ1 as the optimal point (a low level Japanese strategy taking a slightly younger age range than PJ7), the remainder all identified PA7/PJ7. While only two of the ten replications identified this option, this variation might be due to the lower costs associated with harvesting the younger age-classes in the Japanese fishery. However, as this policy is only identified in two instances, it does not suggest any strong movement to a different optimal point. Further, PA7/PJ1 is a policy only marginally less attractive then PA7/PJ7, with respect to the objective function. Thus only a slight variation in returns would have been required to alter to this point.

No other movements from the identified point was observed with regard to this variable.

5.5.4 The Threat Strategies

This perhaps, is the most critical element considered in the sensitivity analysis. Logically, a variation in the selection of these strategies could lead to significant changes in the identified optimal solution, if there was a wide dispersion of points across the frontier of Figure 5.1. Also, to aid in the validity of the model, the selected threat strategies need to be fairly realistic ones, suggesting real policies which might well be adopted under a real event of negotiation breakdown. The results for this section are presented in Table 5.7.

Here, a range of alternative threat policies are considered. All Australian policies which include a West Australian catch have been paired with all possibilities of a

Table 5.6: Selection of the optimal solution under variations in the level of harvesting costs.

Proportion of harvesting costs Australia	Japan	PA3/PJ7	PA7/PJ1	PA7/PJ4	PA7/PJ7	PA7/PJ8
1.0†	.7		2		8	
1.0†	.8				*	
1.0†	.9				*	
1.0†	1.0†				*	
1.0†	1.1				*	
1.0†	1.2				*	
1.0†	1.3				*	
.7	1.0†				*	
.8	1.0†				*	
.9	1.0†				*	
1.0†	1.0†				*	
1.1	1.0†				*	
1.2	1.0†				*	
1.3	1.0†				*	

† - standard setting in the model
* - all ten replications

Table 5.7: Results of variations in the selection of the threat policy.

Threat Strategy Australia	Japan	Identified Optimal Solution PA3/PJ4	PA7/PJ1	PA7/PJ4	PA7/PJ7	PA7/PJ8
PA1†	PJ2		2		8	
PA1†	PJ6		2		8	
PA1†	PJ9†				*	
PA2	PJ2				*	
PA2	PJ6				*	
PA2	PJ9†				*	
PA7	PJ2				*	
PA7	PJ6				*	
PA7	PJ9†				*	

† - standard setting in the model
* - all 10 replications

high level Japanese catch (thus, PA1 and PA2 with PJ2, PJ6 and PJ9). In addition, a less destructive Australian option has been included, PA7, this again being paired with the heavy Japanese strategies.

There is a very strong level of agreement in the selection of the optimal policy PA7/PJ7, the only deviations from this that are noted are two replications identifying PA7/PJ1 for threats of PA1/PJ6 and PA1/PJ2. These both representing the highest level Western Australian catch which could be taken by Australia.

Overall there appears a very strong consistency to the identified optimal solution for all possibilities of threat policy. The reason for this consistency might be expected from a consideration of Figure 5.1. Here the optimal policy is very similar to several other policies, in particular PA7/PJ1 and PA7/PJ4, thus the adoption of a feasible set, which includes all the optimal solutions from the sensitivity analysis appears a reasonable procedure, allowing both for variation in settings of the model and other factors, such as administrative convenience to be considered.

5.6 Summary

The results presented above provide details of four specific policy options, and general indicators of the biological and economic effects of the strategies considered in this analysis.

It is apparent that the identified optimal policy, PA7/PJ7, offers desirable levels of payoff to both participants. In addition, the indicator of breeding stock, the parental biomass, has a level well above the critical point suggested for the fishery. In fact, for all the policies identified in the feasible set, there are high levels of return and acceptable levels of parental biomass. This is particularly true of policies including the Australian strategies, PA7 and PA8 (strategies mainly centred on three-to five-year-olds).

The threat strategy used in the model, PA1/PJ9, while not the most destructive policy available, presents a reasonable option that might conceivably be adopted. While the results for this policy imply immediate reductions in levels of fish available and a rapid decline in the parental biomass – a decline that does not appear to stabilize in the short term – the policy does provide, initially, quite high returns to both parties, and in the face of long term over-utilization by a competitor, could well be a typical threat policy adopted by the other participants.

The two policies described as being similar to recent harvesting regimes (that is, PA2/PJ2 and PA1/PJ6) show the extremes of over-fishing that could occur. Neither offer any sustainable policy, from either a biological or economic aspect. In fact the implementation of either policy appears likely to lead to reduced quotas and potential closure of the fishery, particularly if maintained for the time period simulated by this model.

The sensitivity analysis carried out implies that, although slight variations from the optimal solution might occur, these are unlikely to extend outside the range of the feasible set - in fact, such variation is almost entirely restricted to the identified Australian strategy PA7, and to a low level Japanese catch (thus PJ1, PJ4 or PJ7). Thus this suggests that the defined feasible set offers a range of potential harvesting policies which provide the options of a sustainable fishery with reasonable levels of returns to all participants

Chapter 6

Conclusions and Discussion

6.1 Introduction

The results presented in Chapter 5 lead to the conclusion that while there may be viable management options available from the strategies presented, policies similar to those recently practiced in the fishery would be likely to leave the population in a state of potential recruitment failure. This conclusion is consistent with current findings in the fishery which suggest that it is in a state of potential biological and economic extinction (Australian Fisheries 1988a).

It is of interest to consider aspects of the policies defined in the feasible set which appear to be associated with sustainable harvesting patterns. Policies which have the most detrimental impact on the fishery also need to be assessed and relevant features identified. Both these aspects are discussed below.

This chapter will begin with an evaluation of the hypotheses set for this research, then a discussion of various aspects of policies simulated for the fishery is provided, by considering the important aspects of the strategies identified above. Finally, consideration will be given to policy options which could be implied from this research and also further stages of research using this model.

6.2 Results of the Hypothesis Tests

The first hypothesis stated that the current (or recent) management policies within the fishery do not lie within the defined feasible set.

The two policies suggested as having similarities to current practices both led to unacceptable indicators with respect to returns, and particularly, biological impact on the population. Further, no policy was included in the feasible set which suggested any harvesting of the youngest age groups. As harvesting in the Western Australian area has been an established part of the fishery for some time, this hypothesis cannot be rejected.

The second hypothesis stated that, using a Nash nonzero-sum two-person game on the southern bluefin tuna industry, the feasible set would not be empty.

As the feasible set includes a range of policies which have acceptable levels of both the biological and economic indicators, it is apparent that the second hypothesis also cannot be rejected.

While the results of the hypotheses provide some indication of the success of the aims of this research, there are specific conclusions which can be drawn from the results.

6.3 Implications of the Results

6.3.1 Successful Harvesting Strategies

Looking firstly at the feasible set of strategies, it is apparent that the most preferred Australian strategy is PA7 - a South Australian catch. This strategy occurs in the feasible set with all Japanese options except those representing the heaviest level of harvest, thus PJ2, PJ6 and PJ9, and also a midrange early catch, PJ5. The Australian strategies PA3, PA4 and PA8 (all describing either broad South Australian, or South Australian and New South Wales combinations) paired with PJ4 and PJ8 (a low level, relatively narrow Japanese option and a medium one spread over a wide age band) all have the characteristics of catches spread over relatively wide age ranges. However, it is interesting that the three policies associated with the higher level, but more diverse Japanese catch (that is, PJ8) have a more positive effect on the level of the parental biomass than do the lighter catches associated with the narrower catch distribution, PJ4.

It can be concluded from these policies 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). Although the logical extension of this may be that it would be best for the Australians to postpone fishing to take only the oldest group of fish available to the surface fishery (or previously available, those off New South Wales), such a strategy would then impose higher harvest levels on the older age-classes which are also exploited by the Japanese - and this does not appear the best option (for example, PA9, a catch of five-to 10-year-olds, is not included in the feasible set in any combination).

Considering the actual level and distribution of the Japanese catch, it is interesting that higher levels of catch (over 22 000t) can be taken under PJ8 while still maintaining attractive levels of both parental biomass and payoff. There are four policies in the feasible set associated with this Japanese strategy, all describing a later, broad catch of juveniles (either a South Australian, broad South Australian or South Australian and New South Wales harvest). It is felt, then, that where the Japanese catch is very broadly spread (from seven-to 15-year-olds) the actual tonnage taken can be somewhat higher than for a catch over a more limited age distribution. This will be particularly true when the policy is paired with a later starting and broader Australian catch (for example, PA3, PA4, PA7 and PA8). However, where significant levels of one and two-year-olds are taken (as in the Australian strategy PA1, there appears to be no policy that would allow reasonable levels of harvest.

6.3.2 Detrimental Aspects of Harvesting

Turning to policies which have the most destructive effects on the fishery, one can first consider the first two Australian strategies (PA1 and PA2). Both these strategies include elements of a Western Australian catch taking the youngest age-classes, and therefore also involve a greater number of fish harvested per tonne. Over the entire range of the Japanese strategies, these show the most extreme effects on the levels of the parental biomass, with policies also involving a heavy catch (PA1/PJ2, PA1/PJ5 and PA1/PJ6) all having parental biomass levels below 40 000t. This suggests that where a higher level catch of older fish, no matter what their age distribution, is associated with a harvest directed at the earliest group in the fishery, long term recruitment failure seems a likely outcome. Interestingly, PA2, a strategy which includes some one and two-year-olds, but is more centred around the three-to five-year-olds, is actually included in the feasible set when it is associated with a Japanese strategy harvesting a low level of six-to 11-year-olds (PJ4). In this case there is a reasonable gap in harvesting before the second wave of exploitation begins. Although it leads to a level of parental biomass only just above the critical level of 220 000t, it is interesting that this combination is far less destructive than the others discussed.

It appears then, 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 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 of this situation.

While the effect on the fishery of catches of the youngest age-classes is most marked, similar patterns can be noted from the harvesting of adults. The strongest effect on the parental biomass occurs when the harvesting is over a narrow age range - this results in a greater impact on any particular age-class than would occur through a broader harvesting policy. This pattern would appear to be directly related to the rate of fishing mortality on the age-classes in the population. The earlier an age at which a high level of harvest occurs, the lower will be the numbers in later age-classes of that cohort (year class), thus the greater impact of such catches. In this case the effort required to harvest a given number of fish will be higher, due to their scarcity.

Overall then, a catch over a spread of age groups is preferred for the harvesting of adults, while the most destructive effect for juveniles occurs when harvesting is commenced at a very early age.

6.3.3 The Impact of Policies on the Level of Payoffs

The main impact felt on the level of payoffs associated with a particular policy is through the effects of fishing mortality. Where there is a high rate of fishing mortality (either extremely high harvests or harvests from a depleted population) the effort needed to achieve such catches will be high, and the associated costs of such policies will also be high (where cost is measured by units of fishing mortality in the population). Naturally, in a fishery where there are high levels in all age-classes, the impact on the profits associated with such harvesting policies will be quite different. While the price levels received are also important, this aspect will not so effectively differentiate between strategies as does fishing mortality.

There is, then, a relatively strong relationship between having a reasonable population level (assessed by the parental biomass) and a reasonable rate of return. While this is far from a high correlation, a population with a parental biomass level well above the critical level (above the 60 percent level) will generally also have a reasonable associated payoff. Exceptions to this occur where, though the population has a low but reasonable level of parental biomass, and there is a very heavy catch of adults, high harvesting costs associated with these catches may lead to lower returns (for example the policy PA8/PJ2). Also, where there is a low catch of adults, spread over all age classes, associated with a relatively early catch of juveniles (for example PA2/PJ7) the parental biomass may be attractively high, but due to the higher proportion of smaller fish taken, the returns will probably be relatively low, thus not presenting an attractive harvesting option.

6.4 Policy Implications

One important implication of the results of this study is that the general adoption by Australia of a strategy such as PA7, where the youngest groups are not caught, will have a reasonable effecton the fishery. For a stock of the order of six million fish, living to around 15 years of age, exploitation of the youngest age-classes to an extent of over one million fish, leaves little chance for a fishery based on the older age-classes. This is what occurred in the early 1980s, where there were catches of over one million fish from two and three year-olds.

From the Japanese point of view, it appears that a low level of catch of around 15 000t, could easily be sustained with this Australian catch (PA7). With the catch being taken in any age distribution, a somewhat higher catch (such as PJ8, a mid-level catch) could also be a viable option.

The idea of limiting the age structure of the catch, while recognised as potentially desirable for the fishery (for example, Kennedy and Watkins 1985, 1986), is a major policy step which would not be attractive to many of those operating in the fishery. The introduction of individually transferable quotas has to some extent reduced the level of the Western Australian operation, however, if the southern bluefin tuna fishery is to have some chance of recovery, stronger restrictions may have to be introduced. Certainly, with the possibility of a total moratorium on fishing for southern bluefin tuna being one of the current management possibilities (Prime Minister's statement on the environment, Australian Fisheries 1989), it must be seen as more acceptable to implement severe restrictions than has been the case in the past.

The value of this form of analysis for policy negotiations is that it provides some measure of the relative attractiveness of a range of harvesting policies available to both participants (policies which can be set for the model). The assessment of these policies is not just limited to the payoffs received, but also extends to the biological state of the fishery. So, although an optimal policy will be identified from any set of strategies, more important will be the feasible set which provides a set of acceptable sub-optimal policies available for the negotiation process. For at this stage, there may be preferences which make sub-optimal policies far more attractive than the optimal solution. Further, where such sub-optimal policies are available for selection the negotiation process might be strengthened.

While this research has taken into account management strategies that could be considered for adoption at an early stage in the exploitation of the southern bluefin tuna (thus, around the 1970s), the next step in the use of this model would be with the starting population reset to around currently recognised levels. It would then be possible to analyse ongoing management, and a reasonable set of options identified.

6.5 Concluding Comment

One issue which is considered in this research is the importance of assessing management policies not just from the level of financial returns but also from the point of view of the maintainence of a sustainable resource. Although, in the long term, these two objectives must converge, it is becoming increasingly important in any research relating to management of exploited resources that the state of the resource is formally addressed. If this is not done, the long term implications might well not appear until after permanent, and irreversible damage, has been sustained. Such damage may occur when there is an insufficient time period for a feedback effect of the biological state onto the financial returns, particularly if technological changes alter the efficiency of the exploitation process, but also, damage may result from the occasional view that extermination of a species is impossible. Clark (1973, p.951), while considering that such extinction may not occur for most animal resources, does suggest that it 'may be valid for many fisheries'. This unfortunately widespread belief in the reversibility of the effects of such management policies (see Waugh 1984) has led to some lack of caution in management decision making, including the use of the assumption that a constant level of recruitment can be relied upon, irrespective of the state of the stock. Following from such a general belief come policies which, while aiming at the maximization of some type of yield (whether sustainable or economic) never really consider that the worst outcome could be anything more than the industry operating at the wrong point on the production curve.

It is only relatively recently that biological research into the southern bluefin tuna fishery (for example Hampton and Majkowski 1986) has formally recognised that, while the level of recruitment into the fishery is generally independent of the size of the parent stock, there is some critical level of parent stock below which such recruitment will not occur. Thus, Hampton and Majkowski (1986) suggest that it is unlikely that a long term level of mean recruitment could continue when the parental biomass has been reduced to around 17 percent of its unexploited level. Earlier work has implicitely assumed that recruitment will be stable. In this regard, Kennedy and Watkins (1986, p. 311) recognise that a limitation in their model is the lack of any provision '...to reflect risk of recruitment failure if parental stocks fall too low'.

Much of the research done into the state of the stock, both from a biological and economic perspective, suggests that there are various management options that may be of value in developing a sustainable resource. However, while it has appeared clear to many researchers for some time that the stock of southern bluefin tuna is in a serious state of over-exploitation, there are a number of problems in applying such conclusions. Firstly, the fishermen directly involved in the fishery, often find it hard to appreciate the serious state of the stock and also the implications of overfishing, particularly where such participants have been able to maintain a reasonable level of catch - even if this has been achieved by the utilization of more effort or more efficient techniques. Further, as Australian fishermen are not the only group utilizing the resource, many of the problems associated with common property resource utilization can occur (as discussed by Gordon 1954 and also Munro 1982). Certainly, extreme restraint practiced by the Australian operation would be hard to maintain if the Japanese continued fishing at a relatively high level. This would be so even if the Japanese concentrated on the relatively larger fish, and thus were having a significantly lower impact on the parental biomass, than would occur from a similar Australian harvest of small fish.

From the Australian point of view, the introduction of various management policies, involving unattractive restrictions on sections of the industry, would not be something which the government would undertake lightly. While Geen and Nayer (1989) recognised that one objective of the individually transferable quotas was the significant reduction in the West Australian catch, it was obviously felt preferable to achieve this by allowing natural market forces to operate as long as possible (thus, the quotas belonging to many of the West Australian operators were bought out by the more established South Australian operators) rather than legislating for such changes. The disadvantage in this is that it may involve necessary changes being made far later than is desirable for the resource.

6.6 Summary

This study has provided an assessment of the possibility of identifying harvesting strategies, for the southern bluefin tuna industry, which would allow economic returns and the long-term survival of the fishery. It has been shown that strategies which minimize the fishing effort on very young fish and have a reasonable level of effort distributed over the older age categories can provide reasonably long-term returns along with a reasonable level of parental biomass.

Using game theory it was shown that an optimal strategy for both Australia and Japan could be found and a feasible set of policies defined. The identified optimal policy from this analysis involved an Australian catch of 15 000t taken from three-to five-year-olds and a Japanese catch, also of 15 000t, which targetted fish from seven-to 15-year-olds.

While the model used has included what would have been reasonable strategies to implement in the fishery during the mid to late seventies, validation against the current state of the fishery suggests that it could also effectively be used to examine future management strategies, given some knowledge of the current state of the stock.

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Appendix A

The Simulation Program

This program simulates the population structure of the southern bluefin tuna under the impact of a range of Australian and Japanese harvesting strategies.
The payoffs to both participants and the parental biomass of the population under each pair of strategies is evaluated. An optimal policy (that is, pair of strategies), the solution to the Nash cooperative game, is identified.

```
      PROGRAM PAYOF
C     THE AIM OF THIS PROGRAM IS TO PRODUCE A PAYOFF MATRIX
C
C     FOR THE COMPETITIVE INTERACTION BETWEEN THE AUSTRALIAN
C
C     AND JAPANESE S.B.T. FISHERIES
C
C     VARIABLES - DESCRIPTION
C                  - PA/J(I) PRORORTION OF TOTAL QUOTA CATCH, BY YEAR CLASS
C             PAi:iTH AUSTRALIAN STRATEGY/PJi:iTH JAPANESE STRATEGY
C
C                  IX70(I) INITIAL STOCK LEVELS (NUMBERS)PER AGE CLASS
```

```
C              L : REFERS TO THE YEAR (i=1,12)
C
C               H(I,K) HARVEST LEVEL (NUMBER) / YEAR CLASS
C
C   ANNUAL  MATRICES RESET EACH YR, CUMULATED IN STORAGE MATRIX
C
      DIMENSION PMASS(12),IX61(15)
      COMMON /AREA1/PA(15,9),PJ(15,9)
      COMMON /AREA2/XNOS(15,12)
      COMMON/AREA3/RNO(12)
      COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
      COMMON/AREA5/PERWT(15),P(15,2)
      COMMON/AREA6/WTBIOM(15,2)
      COMMON/AREA7/Q(15,2),XNRF(2),HK(15,2),HNOSEP(15,12,2)
      COMMON/AREA8/XNASHPT(9,9),PAYOFF(9,9,2),PBIOM(9,9,12)
      COMMON/AREA9/F(15,2)
      COMMON/AREA10/L
      REAL V(15)
C             NOTATION SUBSCRIPTS: I=YR CLASS 1,15
C                   K=COUNTRY 1,2
C                    ISTRGY=AUST STRATEGY
C                    JSTRGY=JAPANESE STRATEGY
C     DATA 1977-HAMPTON,MAJ+MURPHY REPORT 165 CSIRO
      open(unit=20,file='ixodta',status='old')
      open(unit=22,file='biom',status='old')
       open(unit=21,file='fmort',status='old')
      open(unit=27,file='nashsln',status='old')
      open(unit=33,file='mainpgm',status='old')
C     VARIABLE IN STRGY CALL ARE KG - AUST AND JAPANESE CATCH
      DO 10 I=1,15
      READ(20,29)IX61(I)
```

```
C       WRITE(33,22) IX61(I)
8        FORMAT(1X,'PRICEA=',F10.2,3X,'PRICEJ=',F10.2)
9        FORMAT(1X,'IRUN=',I3)
10        CONTINUE
C             Prices on the Aust/Japanese markets will be simulated around
C             given mean and sd using the built in random number generator.
C             Values will be set as follows:
C              mean sd
C              Australia 1200 200
C              Japan 20000 5000
C
C
        S=3
        CALL RANDOMSEED(SIZE=S)
        DO 700 IRUN=1,10
        YY=0.
C       WRITE(22,9)IRUN
        WRITE(27,9)IRUN
        DO 15 I=1,12
        CALL RANDOM(V)
        YY=YY+V(I)
15        CONTINUE
        PRICEA=(YY-6)*200 + 1200
        PRICEJ=(YY-6)*5000 + 20000
C       WRITE(22,8)PRICEA,PRICEJ
        WRITE(27,8)PRICEA,PRICEJ
        CALL RANDOMSEED(SIZE=S)
        DO 20 J=1,12
         XX=0.
        DO 19 I=1,12
        CALL RANDOM(V)
```

```
      XX=XX+V(I)
19      CONTINUE
      RNO(J)=XX
20      CONTINUE
C             fills matrix of initial population random numbers
      DO 696 ISTRGY=1,9
      DO 695 JSTRGY=1,9
      DO 17 I=1,15
      XNOS(I,1)=IX61(I)
      H(I,1)=0.
      H(I,2)=0.
17      CONTINUE
21      DO 499 L=1,12
22      FORMAT(2X,'IX61=',I9)
29      FORMAT(I7)
      ISGY=ISTRGY
      JSGY=JSTRGY
C             STRATEGIES SET IN KG - IF PROPORTIONS SUM TO > 1 TOTAL WT
C             GREATER THAN GIVEN
      CALL STRGY(15000000.,15000000.,ISGY,JSGY)
72      FORMAT(1X,'H(I,K)=',F12.0,2(3X,I3))
C     UPGRADING POPULATION MATRICES BEFORE
C        USING STOCK UNDATING FUNCTION FROM HAMPTON ET AL 1984 P.5
C        N. AM. J CF FISHERIES MANAGEMENT VOL.6 P.77-87
      DO 400 I=1,14
C             new generation =*M - harvested nos
C         XNOS(I+1,L+1) is no 2 - 15 yolds in yrs 2 to 12
      IF(H(I,1).GT.XNOS(I,L))H(I,1)=XNOS(I,L)
      IF(H(I,2).GT.XNOS(I,L))H(I,2)=XNOS(I,L)
C             set harvest  max to pop level
      IF(L.EQ.12) GO TO 400
```

```
      XNOS(I+1,L+1)=XNOS(I,L)*EXP(-.2) - H(I,1) - H(I,2)
      IF(XNOS(I+1,L+1).LE.0.0) XNOS(I+1,L+1)=0.0
400     CONTINUE
      CALL BIOM(INT,PB)
      PMASS(L)=PB
      PBIOM(ISTRGY,JSTRGY,L)=PB
      IF(L.EQ.12) GO TO 475
       XNOS(1,L+1)=INT
475     DO 480 I=1,15
C            store yearly harvest in strategy output
      HNOSEP(I,L,1)=H(I,1)
      HNOSEP(I,L,2)=H(I,2)
480     CONTINUE
499     CONTINUE
      IF(IRUN.GT.1)GO TO 631
      WRITE(33,610) L
      WRITE(33,615)ISTRGY, JSTRGY
      DO 621 I=1,15
610     FORMAT(1H1,3X,14HFINAL MATRICES,I3)
615     FORMAT(1H ,2X,13HTOTAL POP NOS,I3,3X,I3)
      WRITE(33,620) (XNOS(I,L),L=1,12)
620     FORMAT(1X,12(F10.0,1X))
621     CONTINUE
C           prices in Australian $
C           randomly selected each run
631     CALL AGEVAL(PRICEA,PRICEJ)
C           Q(I)=PROPORTION OF OPENING STOCK NUMBERS HARVESTED
C           WITH HNOS(I,L),XNOS(I,L) VALUES SELECTED FROM
C           INITIAL YEAR(TO GET PGM RUNNING)
      CALL FMORT
      IF(IRUN.GT.1) GO TO 636
```

```
      DO 635 I=1,15
      WRITE(21,632)I, F(I,1),F(I,2)
632      FORMAT(1X,I3,3X,'AUST-F=',F7.4,3X,'JAP-F=',F7.4)
635      CONTINUE
636      CONTINUE
       CALL NRF(PT1,PT2)
      PAYOFF(ISTRGY,JSTRGY,1)=PT1
      PAYOFF(ISTRGY,JSTRGY,2)=PT2
695      CONTINUE
696    CONTINUE
      IF(IRUN.GT.1)GO TO 699
      DO 698 ISTRGY=1,9
      DO 697 JSTRGY=1,9
      WRITE(22,701)ISTRGY,JSTRGY
      WRITE(22,702)(PBIOM(ISTRGY,JSTRGY,L),L=1,12)
697      CONTINUE
698      CONTINUE
699      CALL NASHSLN
701      FORMAT(1X,'AUST-STRGY=',I3,3X,'JAPAN-STRGY=',I3)
702      FORMAT(1X,12(F9.0,1X))
700      CONTINUE
       STOP
       END
       SUBROUTINE STRGY (WTTA,WTTJ,ISGY,JSGY)
      COMMON /AREA1/PA(15,9),PJ(15,9)
      COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
C     GIVEN AN INITIAL STRATEGY CATCH LEVEL (WTT - IN KG)
C
C     AND THE DISTRIBUTION OF THIS CATCH STRATEGY ACROSS AGE
C
C     CLASSES, P(I),
```

```
C
C      THIS SUBROUTINE RETURNS  HARVEST NUMBERS BY AGE CLASS
C
C      STEPS REQUIRED:
C              1) WT(I) - PROPORTION CATCH / AGE CLASS
C
C              2) LENGTH ASSOCIATED WITH GIVEN AGE CLASS:XL(I)
C
C              3) HARVEST LEVEL OF ITH AGE CLASS - CALCULATED
C                 USING H(I)=WT(I)/INDIVIDUALS WEIGHT(I)
C                 IE:TOTAL AGE CLASS WT/WEIGHT OF 1 FISH=NO FISH
C
C               CONVERSION FORMULAES FOR WEIGHT (KG) TO LENGTH (CM)
C             TO AGE (YRS) ARE FROM HAMPTON,MAJKOWSKI & MURPHY (1984)
C             REPORT 165, CSIRO
C
C      VARIABLE DESCRIPTION:
C             WTTA/WTTJ : TOTAL CATCH (TONNES) BY STRATEGY(A-AUST OR J-JAP)
C             WT(I,K),  : WEIGHT (TONNES) FOR AGE CLASS
C             P.(I,K) : PROPORTION OF CATCH WEIGHT GOING TO AGE CLASS
C             XL(I) : LENGTH OF FISH (CM) IN AGE CLASS I
C             H(I,K) : HARVEST (NUMBERS) OF FISH IN AGE CLASS
C              K=1 AUST, K=2 JAPAN
C
C      LNOS 6000'S = AUSTRALIA  7000'S JAPAN
       DO 6020 I=1,15
       IF(PA(I,ISGY).EQ.0.0)WT(I,1)=0.0
       WT(I,1)=WTTA*PA(I,ISGY)
       IF(WT(I,1).EQ.0.0)GO TO 6011
       XL(I)=(1-EXP(.127*(-.394-I)))*207.6
C             DIFFERENT WEIGHT RELATIONSHIP IF XL(I) GT 130/LT 130
```

```
      IF(XL(I).GE.130)GO TO 6010
      H(I,1)=WT(I,1)/(3.13087E-5*XL(I)**2.9058)
      GO TO 6020
6010      H(I,1)=WT(I,1)/(2.50470E-6*XL(I)**3.4229)
      GO TO 6020
C            HARVEST=TOTAL WT / WT OF FISH
6011      H(I,1)=0.0
6020      CONTINUE
      DO 7010 I=1,15
      IF(PJ(I,JSGY).EQ.0.0)WT(I,2)=0.0
      WT(I,2)=WTTJ*PJ(I,JSGY)
      IF(WT(I,2).EQ.0.0) GO TO 7007
      XL(I)=(1-EXP(.127*(-.394-I)))*207.6
      IF(XL(I).GE.130) GO TO 7005
      H(I,2)=WT(I,2)/(3.13087E-5*XL(I)**2.9058)
      GO TO 7010
7005      H(I,2)=WT(I,2)/(2.50470E-6*XL(I)**3.4229)
      GO TO 7010
7007      H(I,2)=0.0
7010      CONTINUE
      RETURN
      END

      SUBROUTINE BIOM(INTLEV,PBIOM)
       COMMON /AREA2/XNOS(15,12)
      COMMON/AREA3/RNO(12)
      COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
      COMMON/AREA6/WTBIOM(15,2)
      COMMON/AREA10/L
C            from Majkowski & Hampton 1983 (Fishery Bulletin Vol 81)
C            p.728 Current biomass 167,371,601 kg.
C     CRITX=100000.
```

```
C            FUNCTION TO EVALUATE THE LEVEL OF PARENTAL BIOMASS
C            FOR THE YEAR 'L'. THIS IS CALCULATED USING AN ADAPTION
C            OF THE FORMULAE USED BY HAMPTON AND MAJKOWSKI (1986)
C            IN THIS CASE IT IS ASSUMED THAT ONLY FISH AGES 8+
C            ARE CAPABLE OF BREEDING AND THAT ALL THESE ARE
C            SEXUALLY MATURE. FURTHER IT IS ASSUMED THAT NO FISH
C            LESS THAN THIS AGE CLASS ARE SEXUALLY MATURE. THUS
C            BIOMASS IS OBTAINED BY SUMMING, I=8,12
C            NUMBER x WEIGHT OVER 2 FISHERIES
C
C             WEIGHT IN  KG'S
      XPBIOM=0.
      DO 5310 K=1,2
       DO 5300 I=8,15
        XL(I)=(1-EXP(.127*(-.394-I)))*207.6
        IF(XL(I).GE.130) GO TO 5200
        WTBIOM(I,K)=(3.13087E-5*XL(I)**2.9058)*XNOS(I,L)
        GO TO 5250
5200      WTBIOM(I,K)=(2.50470E-6*XL(I)**3.4229)*XNOS(I,L)
5250      XPBIOM=XPBIOM+WTBIOM(I,K)
5300      CONTINUE
5310      CONTINUE
      PBIOM=XPBIOM/1000.
C             converted to tonnes for use in recruitment relationship
C            H AND M 1986 TO EVALUATE IXO USED EITHER i)density indep:
C             OR, AS IS USED HERE                    ii) density dept
C            XNOS(1,L)=a*PBIOM/[1+(PBIOM/K)**b]
C            WHERE a=34.88 b=1.5 K=345935
C             sigma=897459
C            TO EVALUATE IXO WILL USE  SIM.
C             ASSUME APPROX. GAUSSIAN IS sum of 12 uniformly dist
```

```
C             GIVES GAUSSIAN DIST MEAN=6. SD=1.
C       THE CALL TO BIOM TRANSMITS THE MATRIX OF XX, THE NORMALLY
C         ADJUSTED R.V.
C             X GAUSSIAN RV MEAN 6 SD=1
C       WISH TO SELECT VALUE OF IXO FROM NORMAL WITH MEAN, EQN ABOVE,
C        SD=897459
5350        XMEAN=34.88*PBIOM/(1+(PBIOM/345935)**1.5)
        X=RNO(L)
        XNOS(1,L+1)=(X-6)*897459 + XMEAN
        IF (XNOS(1,L+1).LT.0.0) XNOS(1,L+1)=1000000.0
5400        CONTINUE
          INTLEV=XNOS(1,L+1)
          RETURN
          END
        SUBROUTINE AGEVAL (PAUST,PJAP)
C             SUBROUTINE TO TRANSFORM PRICE PER TONNE ON TWO MARKETS
C             TO PRICE PER FISH PER AGE CLASS ON THE SAME MARKETS.
C
C             SUBROUTINE OUTPUTS MATRIX P(I,K) WHERE P IS THE PRICE
C             RECEIVED PER FISH ON THE APPROPRIATE MARKET.
        COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
        COMMON/AREA5/PERWT(15),P(15,2)
        DO 8050 I=1,15
        XL(I)=(1-EXP(.127*(-.394-I)))*207.6
C             THIS GIVES FISH LENGTH PER AGE
C              DIFFERENT WEIGHT RELATIONSHIP FOR SMALL/LARGE FISH
C              WT IN KG'S
        IF (XL(I).GE.130) GO TO 8020
        WTT(I)=3.13087E-5*XL(I)**2.9058
        GO TO 8030
8020        WTT(I)=2.50470E-6*XL(I)**3.4229
```

```
8030      CONTINUE
C      WEIGHT IN KG. PRICE PER 1000 KG
       PERWT(I)=WTT(I)/1000.
C                PERWT(I) IS THE PERCENT OF TONNE BY AGE CLASS
C             P(I,K) IS PRICE PER FISH PER AGE
       P(I,1)=PAUST*PERWT(I)
       P(I,2)=PJAP*PERWT(I)
8050      CONTINUE
       RETURN
       END
       SUBROUTINE NRF (VALAUS,VALJAP)
C             SUBROUTINE TO EVALUATE THE PAYOFF TO EACH NATION
C             FOR EACH STRATEGY PAIR. THESE VALUES ARE RETURNED AND
C             STORED IN THE MATRIX PAYOFF(9,9,2).
C             INITIALLY CALCULATION IS OVER 1 YEAR BUT THIS SHOULD
C      CALCULATION OF NET REVENUE VALUE FOR EACH STRATEGY
C              FROM K+W 1986
C      WHERE P(K) : PRICE OF FISH ON THE MARKET
C            HNOSEP(I,L,K) : HARVEST LEVEL/FISHERY
C            HK(I,K) : HARVESTING COST/UNIT FISHING MORTALITY
C              EG. COST / HR SEARCHING IN MILL OF DOLLARS
C             THE PARAMETERS IN AGEVAL ARE PRICE/TON ON THE TWO MARKET
       DIMENSION DXNRF(2)
       COMMON/AREA2/XNOS(15,12)
       COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
       COMMON/AREA5/PERWT(15),P(15,2)
       COMMON/AREA7/Q(15,2),XNRF(2),HK(15,2),HNOSEP(15,12,2)
       COMMON/AREA9/F(15,2)
C             HK VALUES TAKEN FROM KENNEDY AND WATKINS 1985
C              in millions of Australian dollars
       HK(1,1)=8.6
```

```
      HK(2,1)=HK(1,1)
      HK(3,1)=20.05
      HK(4,1)=HK(3,1)
      HK(5,1)=17.51
      HK(6,1)=HK(5,1)
      DO 650 I=7,15
      HK(I,1)=130.18
65C      CONTINUE
      DO 651 I=1,4
      HK(I,2)=0
651      CONTINUE
      HK(5,2)=142.11
      HK(6,2)=HK(5,2)
      DO 652 I=7,15
      HK(I,2)=976.59
652      CONTINUE
       XNRF(1)=0.
       XNRF(2)=0.
      DO 655 K=1,2
      DO 653 I=1,15
      L=12
      Q(I,K)=HNOSEP(I,L,K)/XNOS(I,L)
C            IF Q(I,K) > 1 THEN IMPOSSIBLE
      IF (Q(I,K).GE.1.0)Q(I,K)=1.0
      IF (XNOS(I,L).LT.100.0) GO TO 653
      IF(HNOSEP(I,L,K).EQ.0.0) GO TO 653
C            XNRF CALCULATED FROM THE LAST YR OF THE TIME SERIES
C
C             EQUATION CHECK BY PARTS
      PART1=P(I,K)*HNOSEP(I,L,K)*.000001
C            to convert price to millions of dollars
```

```
       PART2=HK(I,K)
      PART3=F(I,K)
      XNRF(K)=XNRF(K)+PART1- PART2*PART3
653      CONTINUE
654      CONTINUE
655      CONTINUE
      VALAUS=XNRF(1)
      VALJAP=XNRF(2)
      RETURN
      END

      BLOCK DATA
      COMMON/AREA1/PA(15,9),PJ(15,9)
      DATA (PA(I,1),I=1,15)/.01,.2,.6,.15,.04,.0,.0,.0,.0,.0,
     1        .0,.0,.0,.0,.0/
      DATA (PA(I,2),I=1,15)/.01,.1,.25,.3,.25,.09,.0,.0,.0,.0,
     1        .0,.0,.0,.0,.0/
      DATA (PA(I,3),I=1,15)/.0,.1,.15,.4,.25,.1,.0,.0,.0,.0,
     1        .0,.0,.0,.0,.0/
      DATA (PA(I,4),I=1,15)/.0,.05,.15,.3,.3,.1,.1,.0,.0,.0,
     1        .0,.0,.0,.0,.0/
      DATA (PA(I,5),I=1,15)/.0,.05,.1,.2,.2,.2,.2,.05,.0,.0,
     1        .0,.0,.0,.0,.0/
      DATA (PA(I,6),I=1,15)/.0,.0,.1,.2,.2,.2,.2,.1,.0,.0,.0,
     1        .0,.0,.0,.0/
      DATA (PA(I,7),I=1,15)/.0,.0,.2,.5,.3,.0,.0,.0,.0,.0,.0,
     1  .0,.0,.0,.0/
      DATA (PA(I,8),I=1,15)/.0,.0,.1,.4,.3,.05,.05,.05,
     1        .05,.0,.0,.0,.0,.0,.0/
      DATA (PA(I,9),I=1,15)/.0,.0,.0,.0,.1,.3,.3,.1,.1,.1,
     1  .00,.00,.00,.00,.0/
      DATA (PJ(I,1),I=1,15)/.0,.0,.0,.0,.1,.1,.1,.1,.1,.1,.1,
```

```
     1  .1,.1,.1,.0/
        DATA (PJ(I,2),I=1,15)/.0,.0,.0,.0,.2,.2,.2,.2,.2,.2,
     1  .2,.2,.2,.2,.0/
        DATA (PJ(I,3),I=1,15)/.0,.0,.0,.0,.1,.1,.1,.2,.25,.25,.2,
     1       .1,.1,.1,.0/
        DATA (PJ(I,4),I=1,15)/.0,.0,.0,.0,.0,.1,.15,.25,.25,.15,.1,.0,
     1  .0,.0,.0/
        DATA (PJ(I,5),I=1,15)/.0,.0,.0,.0,.0,.1,.25,.45,.45,.25,.1,
     1       .0,.0,.0,.0/
        DATA (PJ(I,6),I=1,15)/.0,.0,.0,.0,.0,.2,.3,.5,.5,.3,.2,.0,.0,
     1       .0,.0/
        DATA (PJ(I,7),I=1,15)/.0,.0,.0,.0,.0,.0,.05,.1,.1,.15,.2,.15,.1,
     1       .1,.05/
        DATA (PJ(I,8),I=1,15)/.0,.0,.0,.0,.0,.0,.1,.1,.2,.2,.3,.2,.2,
     1       .1,.1/
        DATA (PJ(I,9),I=1,15)/.0,.0,.0,.0,.0,.0,.1,.2,.2,.3,.4,.3,
     1       .2,.2,.1/
        END
        SUBROUTINE NASHSLN
c        subroutine to evaluate the level (pi-T) for each nationality
c        then evaluate the max (pi1-t1)(pi2-t2), and thus find optimal value
        DIMENSION PYA(9,9),PYJ(9,9)
        COMMON/AREA8/XNASHPT(9,9),PAYOFF(9,9,2),PBIOM(9,9,12)
        DO 400 ISTRGY=1,9
        DO 300 JSTRGY=1,9
        PYA(ISTRGY,JSTRGY)=PAYOFF(ISTRGY,JSTRGY,1)
        PYJ(ISTRGY,JSTRGY)=PAYOFF(ISTRGY,JSTRGY,2)
299       FORMAT(1X,9(F7.0,2X))
300       CONTINUE
400       CONTINUE
        XAUST=MINVAL(PYA)
```

```
      XJAP=MINVAL(PYJ)
C     WRITE(27,401)XAUST,XJAP
401     FORMAT(1X,'MIN-AUST=',F12.1,3X,'MIN-JAP=',F12.1)
      T1=PAYOFF(1,9,1)
      T2=PAYOFF(1,9,2)
C           provides threat levels of Australian strgy 9, Japan strgy 1
      CRITX=220000.
      DO 600 ISTRGY=1,9
      DO 500 JSTRGY=1,9
      IF(PAYOFF(ISTRGY,JSTRGY,1).LE.T1)GO TO 450
      IF(PAYOFF(ISTRGY,JSTRGY,2).LE.T2)GO TO 450
      IF(PBIOM(ISTRGY,JSTRGY,12).LT.CRITX)GO TO 450
       PAYOFF(ISTRGY,JSTRGY,1)=PAYOFF(ISTRGY,JSTRGY,1)+ABS(XAUST)
       PAYOFF(ISTRGY,JSTRGY,2)=PAYOFF(ISTRGY,JSTRGY,2)+ABS(XJAP)
       WRITE(27,610)ISTRGY,JSTRGY,PAYOFF(ISTRGY,JSTRGY,1),
     1 PAYOFF(ISTRGY,JSTRGY,2),PBIOM(ISTRGY,JSTRGY,12)
450    XNASHPT(ISTRGY,JSTRGY)=(PAYOFF(ISTRGY,JSTRGY,1)-T1)*(PAYOFF
     1 (ISTRGY,JSTRGY,2)-T2)
C     THIS CREATES A MATRIX OF POSSIBLE POINTS TO BE MAXIMIZED C
C     NOW TO CHECK IF POINTS SATISFY A BIOLOGICAL CRITERIA, TEST:
      IF (PBIOM(ISTRGY,JSTRGY,12).LT.CRITX)XNASHPT(ISTRGY,JSTRGY)=-99.0
500     CONTINUE
600     CONTINUE
601     CONTINUE
      HI=0.0
610     FORMAT(3X,I3,3X,I3,3X,2(E10.4,3X),'PBIOM=',F12.0)
      DO 750 ISTRGY=1,9
      DO 700 JSTRGY=1,9
      IF(PAYOFF(ISTRGY,JSTRGY,1).LE.0.0 )GO TO 700
       IF (PAYOFF(ISTRGY,JSTRGY,2).LE.0.0)GO TO 700
      IF (XNASHPT(ISTRGY,JSTRGY).GT.HI) GO TO 630
```

```
620        GO TO 700
630        HI=XNASHPT(ISTRGY,JSTRGY)
        IST=ISTRGY
        I2ND=JSTRGY
700        CONTINUE
750        CONTINUE
        WRITE(27,799) PAYOFF(IST,I2ND,1),PAYOFF(IST,I2ND,2),HI,IST,I2ND
799     FORMAT(1H1,'PAYOFF OF',E10.4,2X,'AND',2X,E10.4,3X,'K VALUE =',E10.4,3X
     1  'AUST.STRGY=',I3,3X,'JAP. STRGY=',I3)
        WRITE(6,*) IST,I2ND
        RETURN
        END
        SUBROUTINE FMORT
        COMMON/AREA2/XNOS(15,12)
        COMMON/AREA4/WT(15,2),XL(15),H(15,2),WTT(15)
        COMMON/AREA9/F(15,2)
C       SUBROUTINE TO CALCULATE LEVEL OF FISHING MORTALITY ASSOCIATED
C         WITH GIVEN
C       HARVEST LEVEL, POPULATION NUMBERS AND NATURAL MORTALITY
C       SUBROUTINE USES A GRID SEARCH WITH ACCURACY LEVEL .01 TO EVALUATE
        DO 310 K=1,2
        DO 300 I=1,15
        F(I,K)=0.0
        IF(H(I,K).EQ.0.0) GO TO 300
        HTEST=0.0
        DO 130 J=1,200
        F(I,K)=J/100.
C              SELECTS .01 LEVEL OF ACCURACY FOR MORTALITY RANGE 0 TO 2
        HTEST=XNOS(I,12)*(F(I,K)/(F(I,K)+0.2))*(1-EXP(-F(I,K)-0.2))
        IF(HTEST.GE.H(I,K)) GO TO 150
130        CONTINUE
```

```
150       CONTINUE
300       CONTINUE
310       CONTINUE
      RETURN
      END
```