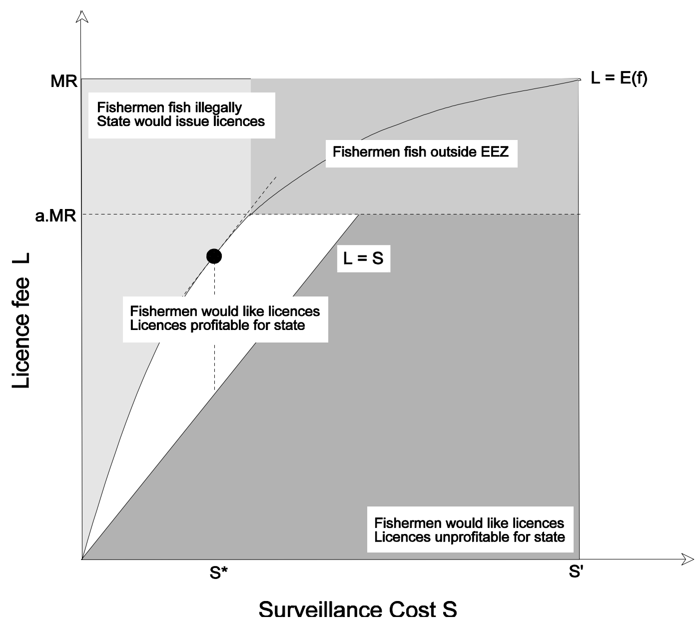
R. 5049 CONTROL OF FOREIGN FISHERIES

ADAPTIVE RESEARCH

FINAL REPORT



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FINAL REPORT

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FINAL REPORT

1. Objectives

The objective of this project is to apply the methodology and results of the analyses done in Project R 4775 (Control of Foreign Fisheries, MRAG 1993) to assess the extent that they can be used in practice by governments of developing countries in forming policies for controlling foreign fishing in their Exclusive Economic Zones (EEZs), and to make modifications as necessary.

2. Work carried out in the period

The work carried out during this adaptive project revolved around the case studies. Four potential case study areas were identified at the start of the project: the Seychelles, the South Pacific, Namibia and the British Virgin Islands. The British Virgin Islands had been the subject of a previous ODA-funded project related to foreign fishing that was undertaken by MRAG, so the fisheries and data availability were already known. For each of the other three case studies, field visits were undertaken for familiarisation and collation of data on the fisheries, surveillance capabilities and fisheries law. Analysis of these data provided estimates of benefits of fishing in the EEZs for foreign fishermen, estimates of detection probabilities resulting from surveillance, and information on likely penalties for illegal fishing.

Later in the project, it was decided to include two more short case studies: the British Indian Ocean Territory and South Georgia and the South Sandwich Islands. Fisheries in the zones of these two British dependent territories had special features that allowed different aspects of the control of foreign fisheries to be studied. Similar data were collected and analyses carried out as for the other case study areas.

Some amendments were made to the methodology developed during the Control of Foreign Fisheries research project in order to be able to account for complexities that arose in the case studies. In particular, the surveillance model was substantially improved.

3. Summary of results

In the original Control of Foreign Fisheries project, a basic analytic framework was developed to allow evaluation of the effectiveness of alternative policies for controlling foreign fishing activities in the EEZ of a developing country. Potential management policies essentially involve selecting appropriate levels for three control variables: the level of licence fees, the extent of surveillance activities and the level of penalties set for illegal fishing. The analytic framework was used to identify those combinations of control variables that maximized the net income to the country from the management of foreign fishing. A prototype management game was developed for potential use by fishery managers and administrators in developing countries to illustrate the options available for management and the tradeoffs between them. The results of this work were very encouraging, with a number of important general principles emerging. Of necessity, however, the model on which the analysis was based was a rather simplified version of what actually occurs in practice. The aim of the adaptive project was to examine how well these results transferred to the practical situations faced in developing countries. This was to be achieved by detailed analysis of a number of case studies.

Potential case studies selected at the start of the project were the tuna fisheries in Seychelles waters, the tuna fisheries in the South Pacific, the hake fisheries off Namibia and the sports fishery in British Virgin Islands waters. Subsequently, two more case studies with special features were added: the tuna fishery in the recently declared Fishery Conservation Management Zone around the British Indian Ocean Territory (BIOT), and the toothfish fishery in the Maritime Zone around South Georgia and the South Sandwich Islands (SGSSI).

It turned out not to be possible to pursue two of these potential case studies. Namibia had only just become an independent nation with a 200 mile EEZ at the start of this project and it was in the process of developing its fishery management policies. This happened very rapidly, and a policy was adopted that focused strongly on the development of a local fishing industry, partly through the setting up of joint ventures, and minimizing the involvement of licensed foreign fishing. Because of this, the methodology of the Control of Foreign Fisheries project is no longer directly applicable. For the British Virgin Islands sport fishery, suitable arrangements for conducting the case study could not be made.

The other four case studies, however, were pursued with considerable success. In the South Pacific, by far the most complex of the case studies, collaborative research involving two visits to the Solomon Islands was carried out with staff of the Forum Fisheries Agency. On the first visit, lengthy discussions allowed the elaboration of the special features and needs of the Pacific island states in relation to management of their tuna fisheries. This led to suggestions for amendment to some aspects of the methodology that were carried out and used in the each of the other case studies. The second visit allowed a comprehensive research plan to be developed that detailed the work that would be necessary to apply the methodology to management of foreign fisheries in the region. Much of this involved analysis of existing extensive data, as well as the collection of new data, in order to obtain reliable estimates of the various parameters needed as input to the model. This research plan envisaged substantial inputs from both MRAG and Forum Fisheries staff, for which funding was not available in the current project. Separate funding will be necessary for further progress, but it is clear that the methodology would indeed be practicably applicable once this research had been completed, thus meeting the objectives of the adaptive project.

Analyses of catch and effort data for the tuna fisheries in Seychelles waters contained in a comprehensive database supplied by the Seychelles Fisheries Authority have been completed. These were used to estimate the benefits to the different foreign fleets of fishing within the Seychelles EEZ. It was found that these varied markedly amongst both months and years. Models of the surveillance undertaken by the Seychelles authorities were developed and these were used, along with the catch and effort analyses, to investigate optimal licence fees, fine levels and surveillance activity for both longline and purse seine fleets. Given the marked variability across months and years in the estimated benefits to the fishermen of fishing within the EEZ, precise estimation of optimal licence fees and net revenue to the state is not possible. However, the relative merits of alternative licensing policies were elaborated and the relationships between current licence fees and net benefits were investigated.

The remaining two case studies involved foreign fisheries in the waters of two British Dependent Territories. The BIOT Fishery Management Conservation Zone was declared in 1991 and the management regime adopted already incorporated some of the guidelines developed in the Control of Foreign Fisheries research project. The methodology was very successfully applied, using estimates of benefits of fishing inside the Zone derived from logbook data and models of the two types of surveillance undertaken within the zone. The results clearly demonstrated the effectiveness of high fines for illegal fishing and allowed advice to be developed on appropriate levels of surveillance activity. This case study was particularly instructive in illustrating the effect of changes in perceived risks of detection for unlicensed fishing on the part of the fishermen. It also further highlighted the effects of inter-annual variability in benefits of fishing inside the Zone seen in the Seychelles case study.

The toothfish fishery in the Maritime Zone around South Georgia and the South Sandwich Islands differs from all the other case study fisheries in that only a very restricted number of licences can be issued because of conservation constraints. Many more foreign fishing vessels than can be licensed have applied for licences, and there is a strong incentive for unsuccessful applicants to fish illegally. Application of the control of Foreign Fisheries methodology in this case concentrated on surveillance and fine levels. Policies were successfully derived that would allow effective deterrence of illegal fishing while keeping the cost of surveillance to within the amount available from licence fees.

General conclusions arising from the research are given in section 4 below.

4. Implications of the results

The principal conclusion from these case studies is that it is indeed possible to apply the methodology and results developed in the Control of Foreign Fisheries research project to develop practical advice on management of foreign fishing. In order to apply the methodology, it is necessary first to undertake two types of analyses. In the first of these, catch and effort data pertaining to fishing both inside and outside the coastal state's EEZ must be analysed in order to determine the estimated benefits to foreign fishermen of fishing within the EEZ. In the second, estimates need to be made of the probabilities of detection and successful arrest of unlicensed fishing vessels arising from different levels of surveillance activities.

For both types of analysis, it is necessary to tailor the analysis to match the particular fisheries and surveillance characteristics of the region or country. For the BIOT and SGSSI case studies, this was relatively simple because only a single fishery, fishing fleet and state was involved. For the Seychelles, the situation was rather more complicated, with a number of fleets taking different species at different times of the year, and thus the analyses and interpretation of the catch and effort data were rather more complex. For the South Pacific, the situation was so complex, with multiple fisheries, fleets and states, that it was only possible within the time and funds available to detail the research and analyses that needed to be done before applying the methodology. The South Pacific is clearly a special case, but it remains true that the data analyses necessary to apply the methodology can be quite time consuming and complex.

Each of the case studies emphasised the importance of imposing large fines for illegal fishing activities. This was also a primary conclusion of the original Control of Foreign Fisheries research project. In each case study, the funds available to the coastal state to pay for surveillance activities were very limited. If there is a significant benefit associated with fishing inside the EEZ, then it is reasonable for the coastal state to want to set quite high licence fees. This is only possible, however, provided the expected fine faced by the fishermen for unlicensed fishing considerably exceeds the licence fee. If the amount of surveillance that can be afforded is limited, this can only be ensured by imposing very high fines, as is the case with the BIOT regime. The importance of affordable surveillance is very clear in the SGSSI case study, where deterrence of illegal fishing is the primary management issue. Again, the key to achieving this is large fines.

The BIOT case study particularly emphasised the vital difference between the perceived and actual risks of detection when fishing illegally. For the first three seasons after the Zone was declared, exactly the same levels of surveillance activities were maintained. For the first two of these seasons, there were few licence applications from foreign fishing vessels. However, following the near record fine imposed on one vessel for illegal fishing activities, there was a sudden rush to obtain licences. Clearly this arose because the perceived risk of being detected and fined had risen to a sufficient level that the expected fine now exceeded the cost of obtaining a licence, though the actual risk had not changed at all. While this single arrest had a major effect on fishermen in BIOT waters, it is important that any heightened perception of risk is maintained. For this to occur, it is necessary that fishermen remain aware of continuing surveillance activities.

In the earlier Control of Foreign Fisheries research project, it was found that licence fees should be calculated as a proportion of the marginal benefit arising from fishing inside the EEZ, rather than as a proportion of the catch taken within the zone. Particularly in the Seychelles and BIOT, when these benefits were estimated from the available data, there was strong inter-annual variability in the estimated benefits. In calculating appropriate levels of licence fees, average estimated benefits were used, but this still meant that in some years the cost of a licence fee considerably exceeded the actual benefit gained. Should this occur several years in a row, foreign fishermen are likely to become increasingly reluctant to continue to seek licences. A case therefore can be made that licence fees perhaps should include some element that takes account of the effort expended in the zone.

5. Priority tasks for follow up

The main follow-up task is to ensure appropriate dissemination of the results. Confidential versions of the sections describing completed case studies will be sent to the Governments concerned. These will contain the results of all the calculations performed and their policy implications, many of which had to be omitted from this report because of the requirements of confidentiality. A more general summary of the findings of this and the previous project will be prepared for publication in the scientific literature and for wide dissemination amongst developing countries.

Consideration should be given to seeking funding for the research project developed for the South Pacific jointly with the Forum Fisheries Agency.

RESULTS

1. Introduction

In a recent review of the status of world fisheries (FAO, 1994), it was reported that the global annual fish catch had increased with declining rate during the 1980's, before reaching a peak at the turn of the decade. Since then it had declined. Whether this declining trend will continue is unclear, in part because of the major contribution to these catches of small pelagic and other species that exhibit large inter-annual fluctuations in abundance. However, it is clear that the scope for sustained increases in catches is extremely limited. FAO (1994) estimated that over 70% of the world's fish stocks are either fully or over-exploited, and there are extreme levels of over-capacity in the world's fishing fleets. As the fish stocks available to the domestic fleets of major fishing countries have declined due to over-fishing, these countries have greatly increased their distant water fishing fleets, to the extent that the global fisheries sector is dominated by fleets from only a few maritime nations, such as Japan, USSR, Korea, Taiwan, USA, Spain and France.

The historical increase in distant water fishing fleets has been matched by a general movement towards unilateral extensions of marine zone sovereignty, as a direct response to the threat by distant water fishing nations to stocks of fish adjacent to countries which had their own domestic requirements or developing fishing industries. This began in the late 1970s and was finally embodied in the 1982 United Nations Convention on the Law of the Sea (UNCLOS). This convention was only finally ratified in November 1994, but well before then it had been accepted that extended fisheries jurisdiction, and the resultant 200 nm Exclusive Economic Zones constituted customary international law.

Of the principles that underlie the provisions set out in the Convention, the most important for the purposes of this research project is the principle of extended jurisdiction over all living and non-living resources by the coastal state within its EEZ. Essentially, this gives the coastal state the right to manage fishing activities within its EEZ, including the right to grant or deny access to foreign fishing vessels to take fish in the EEZ, subject to certain guidelines. Prior to UNCLOS, all waters outside a 12nm zone were considered to be high seas and thus open to fishing fleets from all countries.

For developed countries with large domestic fleets that were already exploiting fish stocks in what became their EEZs, the experience with extended fisheries jurisdiction has generally been good. This is particularly true in cases where the domestic fleet was capable of fully exploiting stocks that generally remained within a single country's EEZ; extended fisheries jurisdiction granted the right to deny access to foreign fishermen, thus easing the pressure on heavily fished stocks. Where fish stocks range across several EEZs, the same rights apply for each country concerned regarding granting of access to foreign fishermen, but proper management of the stocks requires cooperation amongst the countries.

Highly migratory fish are a special case, in that their range frequently includes parts of the EEZs of many coastal states, as well as large areas of what remains international waters. Management of these stocks, of which tunas are an archetypical example, generally is carried out by international fishery management bodies governed by international convention, such as the International Commission for the Conservation of Atlantic Tunas (ICCAT). Typically, these bodies agree annual Total Allowable Catches (TACs), which are then divided by agreement amongst member governments. For these species, responsibility for overall management of the stocks has been ceded to the inter-governmental organisation, but the coastal states still have the right to charge for access to their EEZs for foreign fishermen to take those species.

In contrast to developed coastal states, the experience with extended fisheries jurisdiction for developing countries has been more mixed. At least in principle, permitted access to foreign fishing, usually involving transfer of income from the distant water fishing nation to the coastal state, can be or considerable value to a developing country, especially if it is unable to exploit the resource fully itself. Other benefits than just licence fees may also be realised by coastal states, such as increased local landings and local fishery development through joint ventures with distant water fishing nations. An example of such a joint venture is in Mauritania, where French fishermen exploiting langoustine stocks faced either substantial increases in access fees, or agreement to joint ventures for investment in development using the coastal state fishing fleet. This situation, common to many developing countries, arises when the allocation of access rights through licence fees contributes little in the way of economic growth and development. The so-called Second Generation Agreements currently being negotiated between the EU and developing countries are based on a move away from simple, licensing agreements towards more long term development-orientated relationships. These can extend to the granting of benefits in kind for fishing access in trade or other areas not related to fisheries at all.

In practice, however, the lack of local expertise in developing countries and of frameworks that could be used to manage newly acquired fish stocks to ensure their conservation, while securing optimal economic benefits from their exploitation, has severely hampered developing coastal states. Most, with a few exceptions, have proceeded by trial and error. In particular, developing countries have a dilemma in deciding to what extent they should develop a fishing industry of their own, or to what extent they can obtain benefits from licensing foreign fleets and permitting access of these fleets to their fish resources.

Clearly, in most cases such decisions belong in the political arena, rather than the biological or economic one. However, if the decision is taken to permit foreign fishing, then it is essential that optimum terms and conditions of access to the coastal state be imposed upon the distant water fleets. Devising such terms and conditions involves a series of secondary decisions about what level of licence fees should be set, what amount of money should be spent on surveillance and enforcement, and what legal framework should be developed, especially what levels of fines for illegal fishing should be imposed.

The original Control of Foreign Fisheries research project (R. 4775, MRAG 1993) was aimed at developing a suitable framework, based on modern mathematical bioeconomics and optimal control theory, that answered these questions for developing countries in a practical and rigorous way. The results of the project revealed a number of principles underlying the optimal management of foreign fishing activities by a coastal state that had very general applicability. An important output of the project was a simple spreadsheet-based management "game" incorporating these principles. The game was designed to demonstrate both the problems of licensing foreign fishing vessels and potential solutions to fishery managers in developing countries. The primary recommendation of the project was that under a subsequent adaptive research initiative, further research should be undertaken, using a limited number of specific case studies, to determine the applicability of the methodology and results in the field. This report describes the results of the adaptive research project.

1.1 Organisation of the report

This section of the report covering the detailed results is organised as follows. First, the key principles and results of the theoretical studies obtained in the original Control of Foreign Fisheries research project are summarised in section 2. Section 3 describes how the case study areas were selected for the adaptive phase of the research and outlines the research strategy adopted and some modifications to aspects of the model.

The next six sections describe the analyses of each of the case studies. Each case study section has a similar format. To set the scene for unfamiliar readers, a background to the region is given, followed by a sub-section on the status of the fisheries, including short species profiles and descriptions of the fishing gears and methods. This is followed by sub-sections describing surveillance and enforcement aspects in the region and the extent of illegal fishing activities. The key problems that will be addressed using the Control of Foreign Fisheries methodology are then drawn out, followed by the analyses themselves. The six case study sections are designed to be read in isolation, so inevitably there is some overlap and repetition within them, particularly those that deal with similar fishing methods and species.

In the main final section, general conclusions are drawn from the case studies.

1.2 Confidentiality

Some of the data on which the analyses described in the later sections devoted to case studies were based, especially those relating to licensing and surveillance, were provided to MRAG on the basis that they were to be treated as strictly confidential. In a similar vein, it is obvious that many of the detailed recommendations relating to licensing and surveillance policy are equally sensitive.

Detailed confidential reports describing in full all the analyses and conclusions will be sent separately to the Governments concerned. However, for this report, which will have an unrestricted circulation, all confidential material has been omitted. Inevitably, this has led to a degree of vagueness in some of the concluding sections, but this has been unavoidable.

2 Optimal Control of Foreign Fishing

2.1 Background

The scenario examined in the research undertaken during the Control of Foreign Fisheries research project (R. 4775, MRAG 1993) was one in which a coastal state has declared a 200 nm EEZ containing a single exploitable fish stock. Provided they perceive a benefit in doing so, foreign fishing vessels will want to exploit this fish stock, and they approach the coastal state with a view to gaining access to the EEZ. They are prepared to pay a fee for that access. The coastal state wishes to maximize the net revenue it can accrue from granting access to the foreign vessels. At least initially, it is assumed that there is no alternative domestic fleet, nor any stock conservation problem associated with granting access to the foreign fishermen.

For the state, the principal potential source of revenue arises from licence fees charged to the foreign fishermen for access to the EEZ. Clearly, from this restricted point of view the larger the individual licence fee, the greater the revenue accruing to the state. However, if the licence fee is set too high, it will no longer be considered worthwhile by the foreign fishermen to try to gain access to the EEZ. Even if licence fees are set at levels such that gaining access to the EEZ is still attractive to the foreign fishermen, some vessels may opt not to pay the licence fee and rather to fish illegally inside the EEZ. To counteract this, the state must enforce the EEZ by detecting and penalising illegal fishing. However the surveillance and enforcement activity itself bears a cost, which may or may not be offset by the fines paid by illegally fishing vessels that have been detected.

Throughout this section, the benefits to either the coastal state or the foreign fishermen will be assessed in terms of net revenues. For the coastal state, the net revenues will consist of the total income from licence fees, less the cost of surveillance, plus the revenue from fines paid by foreign fishing vessels operating illegally that have been detected by the state's surveillance activities. For the foreign fishermen, the net revenue accruing from fishing within the zone is made up of the net increase in catch value attained by fishing within the EEZ as opposed to fishing elsewhere, minus the licence fee (if paid) or minus any fines if detected fishing illegally.

The first obvious conclusion from this very simple formulation is that the foreign fishermen will not seek to buy licences, nor will they have any incentive to fish illegally inside the coastal state's EEZ, unless the value of the catches that can be taken within the EEZ exceed those that could be taken elsewhere. It further follows that the incentive to fish within the zone will increase as the (perceived) value of fishing within the EEZ increases. The most obvious case in which there will be a net benefit in fishing within the EEZ is one in which the catch rates for the target species are higher within the EEZ than outside it.

Analyses carried out by MRAG (1993) showed that the choice the foreign fishermen would make regarding whether to seek a licence, fish illegally or fish elsewhere would be predicated on the values of three variables:

> MR, which is the marginal revenue available from fishing inside the EEZ as opposed to outside the EEZ;
>
> L, which is the licence fee charged by the coastal state for access to the EEZ; and
>
> $E(F)$, which is the expected fine the fishermen would face if they were caught fishing illegally within the EEZ.

In the simplest case, a risk neutral foreign fishermen will either

(i) purchase a licence and fish legally inside the EEZ if $L \leq MR$ and $L < E(F)$;

(ii) not purchase a licence and fish illegally within the EEZ if $E(F) \leq MR$ and $E(F) < L$;

(iii) not purchase a licence and fish legally outside the EEZ if $L > MR$ or $E(F) > MR$.

In the special case when $L=E(F)$ and both are less than or equal to *MR*, then the fishermen will be indifferent between fishing illegally and legally.

In MRAG (1993), all variables were effectively treated as being deterministic. For the current project, it is important to recognise that actually both *MR* and *E(F)* represent statistical expectations of random variables. Only the licence fee is fixed and certain. In some cases, mainly those where the EEZ contains the preferred habitat of the target species, it is reasonable to expect that it will always be preferable to have access to the EEZ to catch the target species, provided the licence fees are not set too high. In other circumstances this might not be the case. A typical example is one in which the EEZ lies near the migration route of a highly migratory species. In some years, the species may migrate through the EEZ, in which case it will be attractive to be able to fish within the EEZ, but in other years this may not occur. In MRAG (1993), it was assumed that the fishermen would base their decisions on their expected marginal revenues, which would take account of both the good years and the bad years.

The role of the statistical expectation is even clearer when considering the expected fine *E(F)*. This is made up of the product of two other variables:

q, the probability that an illegally fishing vessel is detected, and

F, the fine imposed by the coastal state.

While it is perfectly rational to base decisions on the expectation of the fine, it is important to recognise that there may be a considerable difference between the fishermen's perception of the probability of their being detected and the actual probability based on the real surveillance activities of the state. Furthermore, the fishermen's perception may change over time, depending on the coastal state's record in detecting illegal fishing. This distinction becomes important in later case studies.

In MRAG (1993), a simple theoretical model was assumed to relate the per vessel expenditure on surveillance (*S*) and the resulting probability of detection. This was

$$q = Q\,(1 - \exp(-KS)), \text{ where } Q \leq 1.$$

This model reflects the diminishing returns in terms of increased probability of per-vessel detection that arises as the expenditure on surveillance increases. It also allows for the possibility that it might never be possible to detect vessels with certainty, regardless of the expenditure. The model is illustrated in Figure 2.1.

As indicated above, the coastal state wishes to maximize its net revenues from foreign fishing activities. To achieve this, it has three control variables it can set:

L, the level of licence fee;

F, the fine to be imposed on illegal fishing; and *S*, the amount of money to spend on surveillance and enforcement.

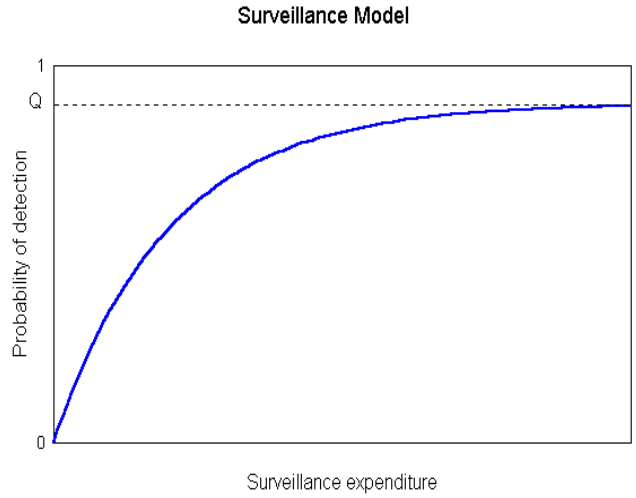


Figure 2.1 Surveillance Model

If there is a single fleet of N foreign fishermen wishing to gain access to the EEZ, then the total net revenue accruing to the state is given by

$$\text{Net revenue to state} = N\,L \;+\; N\,q\,F \;-\, N\,S.$$

The most basic decision rule for the state regarding the issuing of licences, in cases where the foreign fishing fleet does want to gain access to fish in the zone either legally or illegally, is

If $L < E(F)$ then refuse to issue licences even if fishermen want them.

If $L > E(F)$ then seek to issue licences.

If $L = E(F)$ then do either.

It may seem somewhat perverse that the coastal state may consider not issuing licences even when the foreign fishermen want them. This option arises because it is indeed possible with some combinations of parameters that the state could gain more revenue by detecting and fining illegal fishermen than by licencing legal ones. In practice, the state may be far more comfortable with having every fishermen fishing legally, and it may even be prepared to forego some revenue to ensure this. Under such circumstances, the first inequality could be replaced by

If $L < S$, then issue no licences.

If $S < L < E(F)$, then consider issuing licences.

These new conditions differentiate between two regions. In the first, the per vessel surveillance cost is greater than the licence fee, so issuing licences is unprofitable. It is almost inconceivable that the state could be in this position, unless fishermen are just not prepared to pay more for licences. In this case, the state would choose do nothing, i.e. not to issue licences and not to mount any surveillance operations. However, if the state had obligations to manage or conserve stocks it would have to accept that the fishery would run at a loss.

The second inequality describes a region where the state can afford to be more flexible. Issuing licences in this region would indeed be profitable for the state. However, the expected fine is greater than the licence fee so the state could actually make more by fining a vessel than by licencing it. This region could therefore be one within which licence fees are negotiated.

The objective of the analysis carried out in MRAG (1993) was to determine values of the three state control parameters (licence fee, fine, expenditure on surveillance) that maximize the state revenue. The next sections summarise the results of that analysis, while including a few modifications that were made to the model during the adaptive phase of the project.

2.2 Single fleet of foreign fishing vessels, risk neutral fishermen

The first principle that arises from analysis of this scenario is a powerful one, and it seems to have very wide generality.

While the licence fee enters the calculation of net revenue to the state in a very straightforward way, there is a clear interaction between the level of fine set and the amount spent on surveillance. If we consider the issue of optimal surveillance and penalty on its own, it can be shown (MRAG 1993) that if one wishes to maximize the net benefit from surveillance activities, the level of the fine for illegal fishing should be set at its maximum possible value.

A formal proof of this is given in MRAG (1993), but heuristically it is clear why this is true. The decision rules for the state and the fishermen depend on the parameter $E(F)$, which is the product of the fine F and the probability of detection, q, which itself is an increasing function of surveillance expenditure. Any given value of $E(F)$ can be attained by different pairs of values of q and F, such that $q\,F = E(F)$, but clearly the cost to the state is least when the surveillance expenditure is lowest, which can only occur when F is at its maximum.

In practice, the maximum fine is likely to be related to the value of the fishing vessel and its fishing gear, plus the value of the catch in its hold on arrest. In most cases, fishing vessels and gear have such a high value that the maximum fine is far larger than the marginal rate, i.e. $Q\,F_{max} > MR$. The following discussion will assume that this so, while the alternative case will be described later.

If the optimal value of the fine control variable is set as

$$F^* = F_{max}$$

MRAG (1993) then showed that the net revenue to the state is maximized in the limit by setting

$$L^* = MR, \text{ and } E(F)^* = MR.$$

That is, both the licence fee and the expected fine are set equal to the marginal revenue the fishermen would attain from fishing within the zone. In fact, at these parameter values the fishermen will actually be indifferent amongst their alternative decisions (buy licence, fish illegally or fish outside), so the true optimal policy would be to set L^* and $E(F)^*$ just fractionally below MR.

It is intuitively clear that this result holds in theory, but in practice if this policy were followed it would be extremely unlikely that any fishermen would seek to buy a licence. This is because the values of both MR and of $E(F)$ that would be attained in any one year can be highly uncertain, while the licence fee, L, is fixed. A rather more likely situation is one in which there is an effective maximum proportion of the marginal revenue the fishermen would be prepared to pay for a licence, say

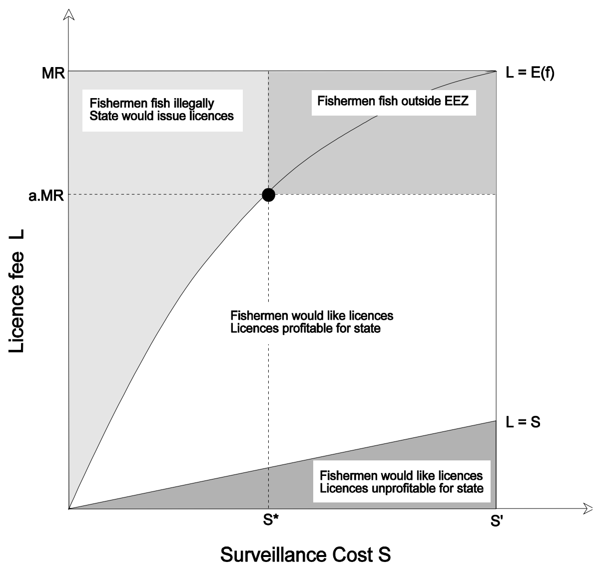
$$L \leq a\,MR, \text{ where } a \leq 1,$$

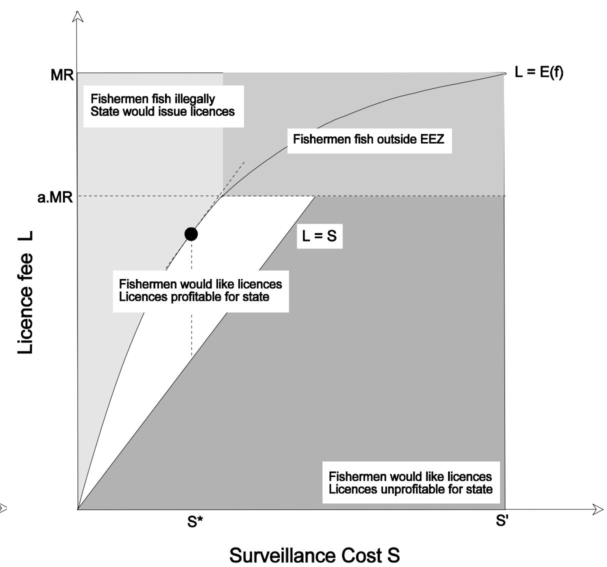
in which case the optimal policy is

$$L^* = E(F)^* = a\,MR \qquad \text{if } Q\,F_{max} - 1/K \geq a\,MR$$
$$L^* = E(F)^* = Q\,F_{max} - 1/K \text{ otherwise.}$$

The point $L = Q\,F_{max} - 1/K$ is the point at which the licence fee minus the surveillance cost per vessel is the greatest, i.e. where the state revenue is at a maximum. The optimum licence fee will thus be $a\,MR$ or $Q\,F_{max} - 1/K$, whichever is the smallest. The second option will arise only if K is quite small, which corresponds to a situation where surveillance is very ineffective. For example, this could be the case if fishermen manage to find out in advance when and where surveillance flights are to take place. If K becomes so small that $K \leq 1 / Q F_{max}$, then there is no profitable level of licencing at all.

The two situations described above are illustrated graphically in Figures 2 (a) and (b). The figures depict the state and fishermen's decisions for various combinations of licence fee and surveillance expenditure; the fine is assumed constant at its maximum value. S' is the level of surveillance required for the expected fine to be equal to MR. This is considered an upper bound for S since the fishermen will not risk more than the profit which they could make from fishing inside the zone.





a) Normal Surveillance ($FQ - 1/K \geq a\ MR$) b) Inefficient Surveillance

Figure 2.2 Decision rules and optima for state and fishermen

Note that the scale of the surveillance axes in the two figures is different. The L=S line always has a gradient of 1, but because K is smaller in figure 2.2(b) it takes much more surveillance expenditure for the L=E(f) line to reach MR. If the figures were drawn to the same scale, figure 2.2(b) would have to be far wider than it is.

Graphs such as these are useful to a fishery manager in that they portray the decision space in a manner that is easy to interpret. The white area in the figures represents a region of potential negotiation. Here, the fishermen are prepared to buy licences, although they would like the fees to be as low as possible, so they will try to negotiate to a point near the bottom of the region. The state is prepared to issue licences even though it could make more from fines, but the most profitable points are at the top of the region. The graphs assist the state by clarifying the extent of this region, e.g. for a given level of surveillance, one can read off the range of licence fees within which both parties requirements could be accomodated. This could be useful during subsequent negotiations.

The optimal point for the state in each of the two figures is marked with a black dot. In figure (a) the optimum licence fee is set at the maximum that fishermen are prepared to pay. The surveillance expenditure is then the minimum necessary to deter illegal fishing, given that fee. In case (b), where surveillance is inefficient, this licence fee would require a level of surveillance that is so expensive that the state's profits would be lower than could be otherwise obtained. Here, the optimum licence fee is lower than in (a), while the corresponding cost of surveillance is higher. Also, you can see that the height of the region of negotiation is considerably smaller. This means that the state's scope for negotiation on licence fees has been reduced.

If the actual optimal points were used, then in case (a) the fishermen would theoretically have no clear preference between fishing legally, illegally or outside the EEZ. In case (b) they would wish to fish within the EEZ, but would be indifferent between fishing legally or illegally. It is tempting to assume that when fishermen are, in principle, indifferent between fishing legally or illegally, they would actually opt to fish legally. There may well be some incentive to act lawfully when there is no benefit in acting unlawfully, but as already noted the licence fee is a certain cost to the fishermen, but it is by no means certain that the expected marginal revenue or the expected risk of detection when fishing illegally would actually be realised in any one year. Under these circumstances, it is quite likely that the fishermen may show risk prone behaviour. This is the subject of the next section.

2.3 Single fleet of foreign fishing vessels, risk prone fishermen

In the first case studied, it was assumed that there would be some threshold level $L = a\ MR$, with $a<1$, which would constitute the maximum licence fee fishermen would be prepared to pay to fish in the zone. Due to the uncertainty about whether they may or may not be detected when fishing illegally, or because their perceptions of the risk of capture might be optimistic, assume now that they are prepared to fish illegally when the expected fine $E(F) \leq b\ L$, where $b \geq 1$. This means that they are prepared to risk a fine greater than the current licence fee. For risk averse fishermen, $b \leq 1$, since they will not risk even as much as the licence fee. Risk averse fishermen are not considered in this analysis.

The above definition for risk aversion and risk proneness differs from that of MRAG(1993). The earlier work was primarily concerned with identifying optima rather than regions of potential negotiation. It was felt that the current model gives a better representation of risk proneness and aversion in such regions.

For ease of notation we define $c = 1/b$. The parameters a and c bring an asymmetry into the decision-making process and the modified set of decision rules for the fishermen is now:

If $L \leq a\ MR$ and $L < c\ E(F)$ then fish inside the EEZ with a licence

If $L > c\ E(F)$ and $c\ E(F) < a\ MR$ then fish illegally inside the EEZ

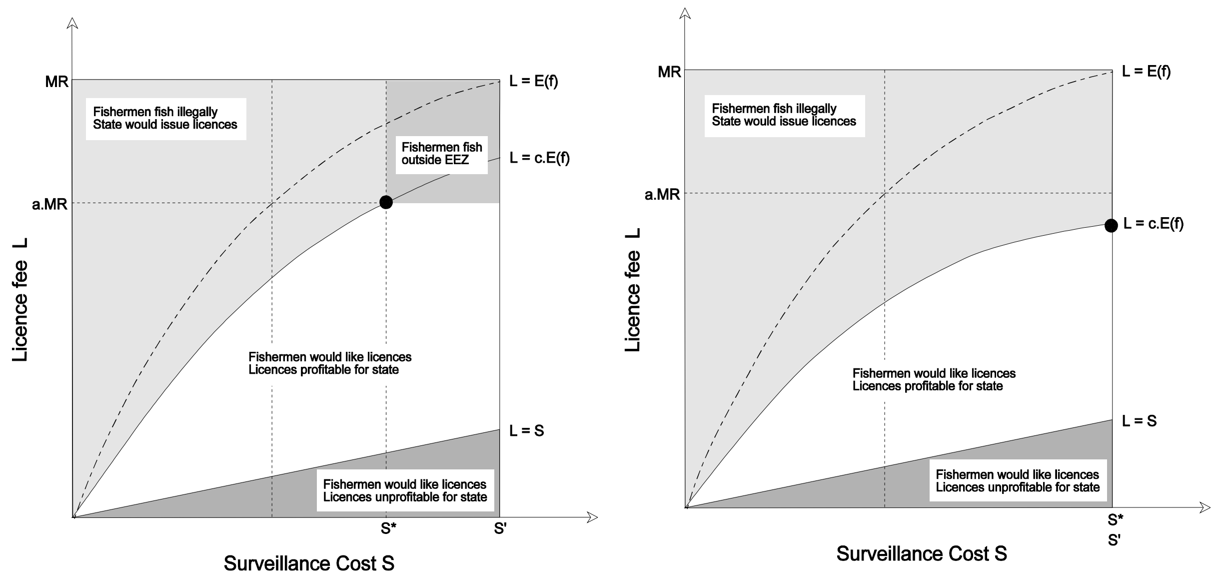
If $L > a\ MR$ and $c\ E(F) > a\ MR$ then fish legally outside the zone

The decision rules for the state remain as before.

The optimal point differs for the two cases $c > a$ and $c < a$:

Optimal licence fee:	$L^* = a\ MR$	if $c > a$
	$L^* = c\ MR$	if $c < a$
Optimal fine level:	$F^* = F_{max}$	
Optimal surveillance cost:	$S^* = -1/K\ ln(1- a\ MR / c\ QF_{max})$	if $c > a$
	$S^* = -1/K\ ln(1- MR / QF_{max})$	if $c < a$
Optimal detection probability:	$q^* = a\ MR / c\ F_{max}$	if $c > a$
	$q^* = MR / F_{max}$	if $c < a$

The combined rules for the fishermen and the state are depicted graphically in figures 2.3 (a) and (b) for the cases $c > a$ and $c < a$ respectively. Remember that c is an indicator of risk proneness; the smaller c is, the more risk prone the fishermen.



a) c > a　　　　b) c < a

Figure 2.3 Combined decisions for the state and fishermen

Notice that the original region of negotiation has become smaller. In the risk neutral case the upper boundary of the region used to lie along the line $L=E(f)$, but here it becomes lower as c decreases. The more risk prone the fishermen are, the smaller the area of negotiation will be. Points which were in the interior of the risk neutral region now become optimal in the risk prone case, and the state has to settle for points close to the new upper boundary.

Figure 2.3(a) is similar to figure 2.2(a) in that the optimum licence fee is the maximum that fishermen are prepared to pay. The surveillance expenditure needed to enforce the optimum fee is higher than in the risk neutral case, and the more risk prone the fishermen are, the greater the level of surveillance required. With increasing risk proneness, the stage is eventually reached where the level of surveillance is so high that the expected fine is greater that the potential profit from fishing inside the zone. Any further increase in surveillance merely forces the fishermen outside the EEZ. This point is therefore the optimum, and it corresponds to a lower licence fee than the maximum fishermen would otherwise have been prepared to pay for licences.

2.4 Low maximum fines

In section 2.2 we motivated the assumption that $Q F_{max} > MR$ by saying that the maximum fine is usually much higher than the potential annual profits to be made from fishing inside the EEZ. For example, the maximum fine is often of the same order of magnitude as the value of the vessels. In these cases, there will always be some level of surveillance which will lead to an expected fine greater than or equal to the potential profit, which is the maximum that fishermen are prepared to risk. This assumption will normally be valid, particularly for foreign vessels. However, there are two circumstances under which this may not be true. The one is when the marginal rate for the stock is very high, i.e. the potential profits from fishing in the zone are very large. The other is when the maximum fine is low due either to the vessels having low value or political considerations making it impossible for the state to set large fines. Under these conditions it may be that $QF_{max}<MR$. Then, for $c < a$,

Optimal licence fee:	$L^* = Q F_{max} - 1/K$
Optimal fine level:	$F^* = F_{max}$
Optimal surveillance cost:	$S^* = -1/K \ln(1 / KcQF_{max})$
Optimal detection probability:	$q^* = Q (1- 1 / KcQF_{max})$

The optimum for $c > a$ is the same as in the previous section, because under these circumstances $L=c E(f)$ does intersect $L=a MR$. The case $c < a$ is illustrated in Figure 2.4 below.

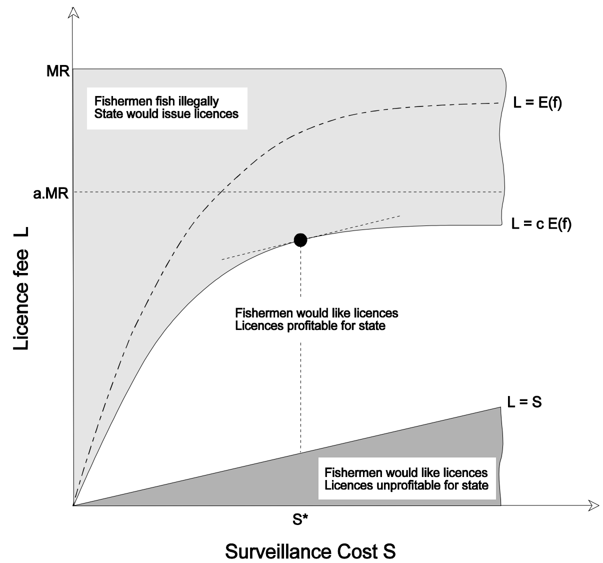


Figure 2.4 Combined decisions for the state and fishermen where F_{max} is low.

The figure has no right hand boundary because the expected fine can never exceed the potential profits to be made from fishing inside the zone. There is therefore no level of surveillance high enough to force fishermen to fish outside the zone. There is also no level of surveillance which could enforce a licence fee equal to ***a** MR*, which is the maximum that the fishermen would be prepared to pay for a licence if the expected fine were greater. This means that the optimum cannot be on a boundary or intersection point as happened in most of the previous instances. This case is rather more similar to that of figure 2.2(b), in that the optimum is merely the point where the licence fee minus the surveillance expenditure is the greatest. Graphically, this is where the slope of the curve *L=c E(f)* is the same as that of the line *L=S*.

The optimum point is designated by the black dot in the figure. As in some of the earlier cases, the optimal licence fee is lower than the maximum fishermen would be prepared to pay. The optimal surveillance expenditure cannot be said to be lower or higher than before; this is affected by the efficiency of surveillance and risk proneness of the fishermen as discussed in the previous examples.

2.5 Single fleet of foreign fishing vessels with a conservation constraint

The previous two cases assumed that the coastal state would in principle be willing to licence all foreign fishing vessels that applied for licences. This might be appropriate for a previously unexploited or under-exploited fishery, or for a highly migratory stock that spent only part of the year in the coastal state's EEZ. In a number of cases, however, it may well be inappropriate to issue licences to all the applicants, because to do so may lead to over-exploitation of the stock.

If the coastal state has a domestic fleet that already fishes the stock, then this would be a circumstance in which it might well be appropriate not to issue any licences at all to foreign fishermen. Such an action is entirely consistent with UNCLOS. However, there are other cases where there is no domestic fleet available but a conservation risk still exists. A classic example of this is the Falkland Islands squid fishery, where many fewer licences are issued for foreign fishermen, in order to ensure stock conservation, than there are applicants for licences.

In the previous cases, it was generally within the power of the coastal state to discourage illegal fishing, if it wished to, by setting licence fees at an appropriate level. Where it is not possible to issue licences to all who wish them, this is no longer an option, because those who are refused licences will have a strong incentive to fish illegally. The only solution here is to raise the expected fine for illegal fishing to such a level that illegal fishing is no longer attractive. On the basis of the previous analysis, that will occur when

$$E(F) = q\,F > min(a,c)\,MR.$$

Now more than ever it is necessary to set the level of the fine as high as possible. As indicated previously, it is normally considered that the maximum possible fine would be the value of the vessel and its fishing gear plus the value of the fish in its hold. An additional possibility raised in MRAG (1993) is that of extended penalties, in which the offending vessel is barred from being issued a licence for some period into the future. Once the fine has been set at the maximum possible value, the only response for the coastal state is to increase the probability of detection to exceed $min(a,c)\ MR / F_{max}$. This will of course mean increased surveillance expenditure, but that may be at least partly offset by revenue from fines.

It is worth making a final obvious but important point in this case. In the absence of a conservation constraint, as in the previous two cases, it was appropriate to consider only the current year in the calculations. When a conservation constraint applies, consideration of just the current year is appropriate only if the stock is in equlibrium; that is if the number of licences issued corresponds to a sustainable level of fishing effort and there is no illegal fishing. If there is excess fishing effort through illegal fishing, then the stocks will decline in future years, and if it continues unchecked eventually the state of the stock will become so poor that the incentive to fish illegally will disappear. The bad news, of course, is that the incentive to fish legally and pay for licences will also disappear, so the coastal state will be left with a badly depleted stock and no revenue until the stock recovers, if it does. The point here is that increased expenditure on surveillance now not only will produce more income in the current year from fines, but it will also contribute to future cash flows from fishing on a conserved stock.

2.6 Multiple fleets of foreign fishing vessels of different types

In the earlier cases, decision rules were formulated on the assumption that vessels fishing in the zone were all of the same size and fishing efficiency, and so the decision of a single vessel could be extrapolated to the whole fleet. This is often not true in real fisheries. In many cases, quite different vessel types may be interested in fishing in the zone. Even if the vessels are broadly similar, they may vary significantly in fishing power. In these cases, a state's licensing policy will impact differently on different categories of vessel, and so the fishermen's decisions will vary between category. The decision rules need therefore to be generalised to include the case of multiple fleets.

As soon as we move away from considering a single uniform fleet, it becomes much more difficult to obtain analytical results similar to those in the previous cases. In MRAG (1993), such results can be obtained in one special case, and this is described briefly below before moving to the more general case.

Ratio of marginal revenue to maximum fine is constant

Assume that vessels can be grouped together according to some characteristic, such as gross registered tons, country of origin, or fishing method, in such a way that it is reasonable to treat vessels in each category as effectively identical. Also make the simplifying assumptions that

(I) For all categories, the values of parameters a and c are the same

(ii) For each category i, the maximum fine $F_{max,\,i}$ and the marginal revenue MR_i are different, but their ratios $MR_i / F_{max,\,i}$ are constant and equal to R, say.

Also assume, as before, that fishermen are risk prone and that $a\ MR_i < Q\ F_{max,\,i}{-}1/K$ for all vessel categories.

While the marginal revenues and maximum fines are allowed to vary amongst vessel categories, it seems sensible to assume the probability of being detected fishing illegally is the same across each vessel category. In some fisheries, it may be possible for surveillance to 'target' a certain type of vessel. This might be true, for example, if different types of vessels tended to fish in different areas, such as longliners and purse seiners in a tuna fishery. This possibility is ignored in the analysis of MRAG (1993), not least because such possibilities will depend on the specific cases being examined, and the aim of the original Control of Foreign Fisheries research project was to seek generic results. In the same vein, it is assumed that the surveillance cost per vessel is the same irrespective of the vessel's category. Again, this seems a sensible first assumption.

With these simplifying assumptions, the optimal policy is directly analagous to that for a single fleet.

$$L_i^* = min(a,c)\ MR_i$$

$$F_i^* = F_{max,\,i}$$

$$S^* = -1/K\ Ln(1 - min(a/c,1)\ R\ /\ Q)$$

$$q^* = min(a/c,1)\ R$$

This special case is relatively simple because the assumptions guarantee that the optimal detection probability q^* is the same across vessel categories and that the optimal expected fine $q^* F_{max,\,i}$ is equal to $min(a,c)\ MR$.

Ratio of marginal revenue to maximum fine is not constant

The assumption that the ratio of marginal revenue to maximum fine is constant across fleets is far too restrictive and unlikely. In particular, different categories of fishing vessels are likely to differ considerably in their value and the value of their fishing gear, while differences in marginal revenue are much more a function of the relative densities of the fish inside and outside the zones. If the assumption that the ratio is constant is dropped, however, it is no longer possible to derive analytical solutions.

The simplest way of examining the effect of having marginal revenue to maximum fine ratios differing amongst vessel categories is first to look at each vessel category separately. If we retain the assumption that $a\ MR_i < Q\ F_{max,\,i} - 1/K$ for each vessel category, then the results obtained before suggest that for category i,

$$L_i^* = min(a,c)\ MR_i$$

$$F_i^* = F_{max,\,i}$$

$$q_i^* = min(a/c,1)\ MR_i\ /\ F_{max,\,i}$$

Because of our revised assumptions, the values of the optimal detection probability q_i^* calculated on an individual fleet basis will now differ for the different categories. But we have also assumed that in fact the same value of detection probability should apply across all categories because it is not possible to target different categories.

One obvious possibility is to see what happens if we select a constant q^* equal to the maximum of the individual q_i^* values. The problem now is that for all vessel categories other than that for which $q_i^* = q^*$, we have

$$\text{Expected fine} = q^*\ F_{max,\,i} > min(a/c,1)\ MR_i$$

which violates the constraints. It follows in this case that the optimum fine must be set at a level $(min(a/c,1)\ MR_i\ /\ q^*)$ which is less than the maximum fine for that vessel category. At the other extreme, we could have set q^* equal to the minimum of the individual q_i^* values. Now we find that for all but one vessel category, the expected fine is less than the constraint value even when the fine is set at its maximum for that category.

Simple numerical examples in MRAG (1993) demonstrate that

- It is not necessarily optimal to set the fine to its maximum value for all categories of vessel.
- The relative fleet sizes in each category affects the optimum value of q.
- For vessel categories with optimal expected fine $E(F)^* = min(a/c,1)\ MR_i$, one can licence these vessels, setting $L_i = min(a,c)\ MR_i$. That is, the licence fee is set equal to c times the expected fine. Since the state is assured the licence fee, whereas the fine income has an associated uncertainty, it is better to licence than to fine, all other things being equal. However, fishermen may prefer the high risk option of fishing illegally and not take up the licences offered to them. For these vessel categories it is also true that the optimum fine is less than the maximum fine. It is

therefore possible to set the fine higher, e.g. at $F_{max,\,i}$, which could imply that $E(F)^* > min(a/c,1)\ MR_i$. This would discourage vessels from fishing illegally.

- For categories with $E(F)^* < min(a/c,1)\ MR_i$, it would be necessary to let these vessels fish illegally, since with the licence fee set *at* $min(a,c)\ MR_i$, the fishermen would expect to gain more from illegal fishing than from legal fishing. Alternatively, of course, it would also be possible to reduce the licence fee for these categories (to $L_i = c\ E(F)$), but this may be seen to be unfair. In any case, it would not lead to any increase in income to the state.

2.7 Management game

The above discussion demonstrates that as soon as one allows for the possibility that there are several fleets with different characteristics wishing to fish in the EEZ, it is no longer possible to derive analytical results in all cases. Accordingly, a computer model was constructed, incorporating the decision rules for the coastal state and fishermen described in section 2.5. At the heart of this computer model was a procedure to determine the values of the control variables that maximized the net revenue to the coastal state.

Input data are required to describe fleet characteristics and the surveillance function. For each fleet, the user is asked to specify:

(i) Per-vessel catch rates inside the EEZ in tonnes per day,

(ii) Per-vessel catch rates outside the EEZ in tonnes per day,

(iii) Value of the catch ($/tonne),

(iv) Value of a vessel ($),

(v) Number of vessels in the fleet,

(vi) Expected EEZ catch per season (tonnes per vessel),

(vii) An estimate of the "honesty coefficient" for the fleet.

For each fleet, the length of the season is implicitly specified by the ratio of the expected EEZ catch per season to the inside EEZ catch rate. The season length is allowed to be different for each fleet, but it is assumed that the vessels pay a single annual licence fee, and that the probability of per-vessel detection is not altered by their having different season lengths.
A single parameter is needed to specify the surveillance function. In the game, that is the surveillance expenditure per vessel needed to ensure a 99% detection probability.

The purpose of all but one of these parameters is familiar from the preceding sections. The exception is the so-called "honesty coefficient". Previous sections have noted that for several reasons one might expect fishermen not to be risk neutral. In some circumstances one might expect them to be risk averse (normally in cases where the fine they may expect if caught illegally fishing is very high); in others they may be expected to be risk prone (e.g. where the expected fine is relatively low, or there is substantial inter-annual variability in the catch rates inside the EEZ).

The decision rules for fishermen outlined earlier characterised risk proneness by defining b as the proportion of the licence fee they are prepared to face as an expected fine ($b \geq 1$), and a as the maximum proportion of net revenue to the fishermen that they are prepared to pay as a licence fee. In the game, recognising that the parameters *a* and *b* may be very difficult to specify for each fleet, instead the user is asked to specify the probability that they will fish legally even if it is apparently in their interest to fish illegally. This probability is the "honesty coefficient", which can vary from 0 to 1. This parameter may be no easier to estimate than the parameters *a* and *b*, but at least now there is only one such parameter per fleet, and this makes sensitivity analyses rather easier to carry out.

The computer program then calculates the optimum combination of the licence fee charged (expressed as a proportion of the expected EEZ catch for each fleet), the optimum fine (as a proportion of the maximum fine, which is the value of the vessel plus its catch), and the optimum amount of money spent on surveillance.

The computer program was implemented in a Quattro Pro spreadsheet, to take advantage of the excellent graphical interface available. It was set up so that the way in which the fishermen's decisions in the different categories change with the state's decisions on licence fee and surveillance can be easily illustrated. It also allows rapid depiction of how these decisions change as the parameter values change. The primary objective was to allow the user of the game to explore both optimal and alternative policies for managing foreign fishing. A fuller description of the game is given in MRAG (1993).

2.8 Numerical examples

While at least in their simplest form the formulas given above for the decision rules and optimal control parameters are relatively easy to understand, a fuller appreciation of some of their implications is best gained by investigation of some numerical examples. All these examples consider the case of a single fishing vessel.

Consider a longline fishery for a tuna species taking place within a country's EEZ. To make it attractive to fish inside the EEZ, we will assume that the typical catch rates achieved inside the EEZ are greater than those outside the zone. Some typical values of fishery parameters for a single vessel then might be:

Season length = 100 days
Daily catch rate inside EEZ = 5 t/day
Daily catch rate outside EEZ = 4.9 t/day
Value of catch = $8000/t.

With these figures, the value of the expected catch inside the EEZ each year would be $4,000,000, and the gross benefit to the fisherman for fishing within the EEZ would be $80,000. This latter sum will also be the maximum he would be prepared to pay for a licence. This represents 2% of the EEZ catch value, which is actually somewhat lower than the normal rate at which licence fees tend to be set.

The assumed difference between catch rates inside and outside the EEZ is very small (0.1 t/day). The first obvious question is what would happen if the advantage for fishing inside the EEZ is increased. This, of course, is just a matter of arithmetic. Some results are shown in the following table, in which the catch rate inside the zone (and therefore the annual catch value) is kept constant, while that outside the zone is decreased.

Table 2.8.1

	Inside EEZ catch rate advantage (t/day)				
	0.1	0.2	0.3	0.4	0.5
Licence fee ($)	80000	160000	240000	320000	400000
fee as % of catch value	2	4	6	8	10

As the advantage of fishing within the zone increases, the maximum amount the fisherman would be prepared to pay for a licence fee naturally increases. Because our assumptions led the annual catch value within the EEZ to remain constant at $400,000, that means the percentage that the maximum licence fee is of the annual catch value increases from a low value of 2% to a high value of 10%. Licence fees of 10% of catch value are extremely rare in tuna fisheries, though this rate is presently being paid by the US purse seine fleet for licences in the South Pacific tuna fishery. The important point here is that in principle, the licence fee should be set as a proportion of the marginal revenue accruing to the fisherman, rather than as a proportion of the catch value. As the table illustrates, the standard rule of thumb that licence fees should be approximately 4 - 5% of the EEZ catch value will in some cases completely deter a fisherman from seeking a licence, while in others it will be far less than he would be prepared to pay. This may seem a trivial and obvious result, but differences in attractiveness to foreign fishing amongst different countries'

EEZs cause real problems when licence fees are set as a fixed percentage of catch value, as is the case amongst the South Pacific Forum Fisheries member governments.

The analyses in earlier sections stressed that a consistent optimal policy is to set the fine for illegal fishing at its maximum value. The highest possible value the fine could take in normal circumstances is the value of the vessel, its fishing gear and the catch in its hold. If the vessel involved is a modern purse seiner with a full hold of yellowfin tuna, or a longliner with a full hold of top grade sashimi tuna, this can amount to a lot of money. However, some coastal states will be reluctant to set fines at such large amounts. The effect of reducing the maximum fine is investigated next.

Assume now that the catch rate advantage in fishing within the EEZ reverts to 0.1 t/day. Then the maximum licence value will be $80,000. Also assume that the relationship between surveillance cost *S* and probability of detection *q* is given by $q = 1 - exp(-K S)$, where *K* = 3.0e-6. Recall that the optimal surveillance expenditure is such that the expected fine (probability of detection times fine) equals the licence fee. The effect of decreasing maximum fines is then shown in the next table. The base value of the maximum fine is taken to be $1 million.

Table 2.8.2

	Maximum Fine ($ millions)				
	1	0.8	0.6	0.4	0.2
Optimum surveillance cost ($)	27794	35120	47700	74381	170275
cost as % of licence fee	34.7	43.9	59.6	93	212.8

With the parameter value chosen for the surveillance function, even when the fine is at its maximum the expenditure needed to produce the required probability of detection (0.08) is quite a high percentage of the licence fee, which of course in this simple case is the income to the state. As the maximum fine decreases, the corresponding probability of detection needed increases, and thus so does the surveillance expenditure. In this numerical example, by the time it reaches $200,000 the surveillance expenditure greatly exceeds the licence fee (and thus the income to the state). Naturally, such a circumstance would be intolerable to the state, which would certainly not dream of spending so much on surveillance. However, the state cannot just reduce expenditure on surveillance, because if it did so the fishermen would find it more attractive to fish illegally in the EEZ and refuse to buy a licence.

One alternative is that it might be possible to use more cost-efficient surveillance methods. This can be mimicked by reducing the *K* parameter value assumed. The corresponding table follows

Table 2.8.3

	Maximum Fine ($ millions)				
	1	0.8	0.6	0.4	0.2
Optimum surveillance cost ($)	8338	10536	14310	22314	51083
cost as % of licence fee	10.4	13.2	17.9	27.9	63.9

This certainly has helped substantially, though if the maximum fine is very low, then there will still be a problem as the surveillance expenditure gets uncomfortably close to the licence revenue.

The possible response by the state of retaining the licence fee at its current level but only spending what can be afforded on surveillance was dismissed above, because it will only lead to illegal fishing and no licence revenue. Another alternative perhaps is to reduce the licence fee. Recall that the optimal expected fine is equal to the optimal licence fee. It follows in the case considered here that if the maximum the state is prepared to spend on surveillance is $27794 (the optimal level when the maximum fine was $1 million and *K*=3e-6), the maximum licence fee will be reduced from $80000 by the same percentage that the maximum fine is reduced from $1 million. That gives rise to the next table.

Table 2.8.4

	Maximum Fine ($ millions)				
	1	0.8	0.6	0.4	0.2
Maximum licence fee ($)	80000	64000	48000	32000	16000
surveillance cost % of licence fee	34.7	43.4	57.9	86.9	173.7

Comparing this with Table 2.8.2, there is an improvement, but not much. Essentially one trades off reduced licence fees with reduced surveillance expenditure, but this becomes impossible when the maximum fine is too low.

It has to be emphasised that these numerical examples are not based on "real" parameter values, so little should be read into the individual numbers themselves. However, it is clear that this strong interaction between surveillance costs, maximum fine levels and licence fees will definitely carry over to the real world. In particular, if the maximum fine is set too low, it may prove almost impossible effectively to deter illegal fishing.

If there really is a maximum amount that can be spent on surveillance, the state's best response is probably to reduce its expectations on licence fees (as in Table 2.8.4). At least that will get some licence revenue flowing in. However, that solution will not work if the fishery is operating under a conservation constraint, such that only a limited number of licences can be issued. Only maximizing the fine can then work to deter illegal fishing.

Many of the points raised here will arise again in the analysis of the case studies described in the later chapters.

3 Selection of Case Studies and Research Strategy

3.1 Selection of case studies

The objective of this adaptive research project was to apply the methodology and principles developed in the original Control of Foreign Fisheries project (MRAG 1993) to assess the extent that they can be used in practice by governments of developing countries in forming policies for controlling foreign fishing in their EEZs, and to make modifications as necessary. This was to be achieved by collaborative research with the fishery management authorities in selected case studies.

Potential case study sites were selected at the start of the project according to the following principal criteria:

(i) A fishery existed within the EEZ of a developing coastal state which was currently being exploited by foreign fishermen, either under an existing or potential future licensing scheme. Strong preference was given to cases where the potential revenue to the coastal state was substantial.

(ii) A reliable database of foreign fishing activities both inside and near to the EEZ of the coastal state existed, to which access would be made available. Information on existing or potential surveillance activities should also be available.

(iii) Subject to meeting the first two criteria, a variety of types of fishery and foreign fishing should be included.

Using these criteria, potential sites for case studies were identified to be the Seychelles (tuna purse seine and longline fisheries), the South Pacific (tuna purse seine, longline, and pole and line fisheries), Namibia (hake and horse mackerel fisheries) and the British Virgin Islands (sports fishery). As it turned out, substantial progress only proved possible in the first two of these initially selected case studies. Subsequently, two further short case studies were included: the British Indian Ocean Territory (tuna purse seine and longline fisheries in a newly declared EEZ) and South Georgia (toothfish longline fishery subject to a major conservation constraint).

For both the Seychelles and the South Pacific, there are major fisheries for several species of tunas by a number of foreign fishing fleets and there exists a detailed historical database of fishing activities. In both cases, the fisheries provide a very important source of revenue to the coastal states. At the start of the project, Namibia had only recently become an independent nation with a newly declared EEZ. The southwest African coast, including that off Namibia, is the site of a major international fishery for hake and other species that previously had been heavily over-fished. A large historical database existed, but a fishery development policy for Namibia was only in the process of formulation at the start of the project. As part of a separate project undertaken for ODA, MRAG had recently evaluated the potential for licensing of foreign longline fishing in the EEZs of British Dependent Territories in the Caribbean. While prospects for that appeared poor, the potential for licensing foreign sports fishing in the EEZ of the British Virgin Islands appeared highly promising.

During the term of this research project, fisheries management regimes have come into force in the British Indian Ocean Territory (BIOT) and around South Georgia and the South Sandwich Islands. The BIOT regime, in particular, had incorporated some of the lessons learnt from the original Control of Foreign Fisheries project. It therefore provided an excellent case study of the introduction of a new regime in waters that had previously been considered to be high seas and of the responses of foreign fishermen to it. The toothfish fishery in South Georgia is particularly interesting because it is a high value fishery where the maximum number of licences that can be issued is heavily restricted due to fears of over-fishing. Thus the potential for illegal fishing is very high.

Further details and characteristics of these case studies are given in the subsequent sections.

3.2 Research strategy

3.2.1 Revisions to decision model

The research strategy adopted in the original Control of Foreign Fisheries project was that a primarily theoretical approach should be taken, where initially analytical results were sought for a simple generic model in which a single foreign fleet was fishing a single stock of fish. This proved a highly successful strategy, and important general properties and principles were identified. However, extension to the case of multiple fleets had already revealed that optimal policies could only be determined numerically. The management game developed at the end of the project attempted to address this shortcoming while still retaining the ease of understanding of the basic model and its outputs. Again this proved successful, but it remained true that the underlying processes (essentially those of fishing and surveillance) were being modelled in a rather simplistic way.

In particular, with respect to modelling the fishery, it was assumed that

(i) The foreign fishing fleets were exploiting a single stock of fish.

(ii) Each fleet sought to fish in the zone either all year round, or at least in the same fixed fishing season each year, and they would spend the entire time either fishing within the zone (legally or illegally) or outside the zone.

(iii) Vessels within each fleet were identical. Furthermore, the differences amongst fleets lay solely in the catch rates and product values that could be achieved, and in the values of the vessel, gear and expected EEZ catch.

With respect to surveillance,

(iv) The entire zone was subject to random surveillance activity throughout the entire year (or season).

(v) All vessels in the zone were equally likely to be detected by the surveillance activity (no targeting was allowed).

(vi) A particularly simple functional relationship between surveillance expenditure and probability of detecting a vessel was assumed.

It was immediately clear that for the adaptive phase of the research it would be essential to inject more realism if quantitative results were to be derived. How this might best be achieved was less obvious, however.

One possibility was effectively to start from scratch in each case study, developing an bespoke integrated analysis that took basic fishery and surveillance data as inputs and produced the optimal control parameters as outputs. The advantages of this approach are obvious, in that from the start the special characteristics of each application can be taken into account from the design stage, and there is no need to try to "twist" some of these characteristics to fit a more generic but less flexible model. The disadvantage, however, is that much of the attractive generality of the original analysis will be lost, and it is likely to be quite difficult to identify the essential features that led to particular optimal policies.

This disadvantage is rather more critical than it may first appear. Discussions with potential users early in the project, both in the Seychelles and in the South Pacific, revealed that the ease of understanding why a particular policy was optimal was a very attractive feature of the original management game. In contrast, the output from what was effectively an impenetrable black box was considerably less attractive. Another factor was that any change to the circumstances in a fishery would require modification, possibly substantial, to a complex computer program.

The alternative approach, which was the one adopted, was to seek a middle ground, in which the model of the fishery and surveillance was made more realistic, but still the essential simplicity of the determination of the optimal policy was retained. To do this, it was necessary to identify both changes to the model and revised input parameters.

The key to this was to return to the basic model and see precisely what were the parameters that were critical to the determination of the optimal policy. For the individual fisherman, the decision on whether to seek a licence, fish illegally or go elsewhere depends on his marginal revenue. In the simplest case, this is calculated as the product of three numbers: the value per tonne of fish caught, the length of the season, and the difference between the daily catch rates he would get from fishing inside the zone and fishing outside the zone. However, if different fishermen or fleets take different mixes of species over different fishing seasons at different catch rates, then apparently it will be necessary to perform separate calculations for each fleet and possibly each vessel. This is indeed unavoidable, but the critical question is at what stage this calculation need be done.

For the optimization, as the theoretical formulation in section 2.2 makes clear, the fishermen's decision is based actually on a marginal revenue calculated as the difference between the value of his expected catch over the year or season if he takes up a licence (or fishes illegally though it is unlikely that data will be available to estimate this directly for obvious reasons) and the value of his catch if he does not take up a licence. With one exception covered below, for the optimization it is irrelevant how this value is made up (e.g. species mix, number of days fished etc.) All that is required is that it can be calculated reliably and this can be done externally. Provided the marginal revenue input parameter is understood in this way, then only a single value per fisherman need be provided. Normally this would be averaged over a fleet, with fleets being split if there were too much variability within fleet. Note that this calculation may be quite complicated, but it is straightforward and it can be revised if circumstances change without adjusting the optimization model.

At least as far as the fishery is concerned, this effectively deals with points (i) and (iii) above. Dealing with point (ii), however, does require a change to the basic model. In the Seychelles, two types of fishing gear are employed to take tuna: purse seine and longlines. Historically, the purse seiners have tended to fish in or around the EEZ throughout the year, and thus they tend to pay a single annual licence fee that entitles them to fish at any time they wish throughout the year. Note that in any month they may spend more or less time in the zone, depending on which is better. In contrast, longliners tend to spend only part of the year in the Seychelles region, and to accommodate this they are offered the possibility of purchasing monthly licences. The situation is further complicated by the fact that different longline fleets have tended to seek licences in different months.

It follows in this scenario that in any one month, there will be purse seiners in or around the zone that either do or do not have licences, and there may also be longliners with or without licences in the area if that month coincides with their desired fishing season. There will be other months, however, when the longliners will be elsewhere and therefore not involved in the fishery at all. If the possibility of illegal fishing could be completely ruled out, this would still not pose real problems. However if it cannot be ruled out, it is obviously essential that proper account be taken of who is available to fish when during the year. The model therefore needs to be amended so that it deals individually with decisions on licensing and surveillance each month or season, while still maximizing overall annual net revenue to the coastal state. Dealing with licensing separately by month or season is clearly easy, however surveillance is more complex .

3.2.2 Revised surveillance model

The surveillance model used in the original project to relate the expenditure on surveillance (S) and the resulting probability of detection q was

$$q = 1 - exp(-KS)$$

when Q, the maximum possible probability of detection is equal to 1. Although not specifically stated in

MRAG (1993), the functional form chosen was based on the theory of random search proposed by Koopman (1980). In the simplest form of that theory, it is assumed that a surveillance vessel or aircraft searches an area of size *A* for a single vessel randomly placed within that area. If the search is conducted on a randomly chosen trackline within the area at speed *v* for a time *t*, and if the vessel lies within an effective search width *½W* either side of the trackline, then Koopman shows that the probability that the vessel is detected is given by the formula

$$q = 1 - exp(-W\, v\, t\, /\, A\,).$$

It is easily seen that the numerator within the exponential is simply the area searched in time *t*, so the exponent is simply the ratio of the area effectively searched to the overall area. Experience has shown that this model is surprisingly accurate (Mangel, 1984).

Koopman defined the effective search width as satisfying the equation

Pr [Not detecting the object within *½W* either size of the trackline]
= Pr [Detecting the object outside of *½W* either side of the trackline].

This definition takes account of the case when the probability of detection decreases steadily as the distance from the trackline increases.

Obviously, the surveillance expenditure enters directly through the time spent searching. Note, however, it is unlikely to be directly proportional to the time spent searching, since normally it will be necessary to steam or fly some distance from the home port before effective search activities can commence.

The great advantage of starting from the Koopman formulation is that the probability of detection is now a function of parameters that can readily be estimated, at least for directed surveillance from a platform such as an aircraft or a vessel. This is a great improvement over the rather awkward parametrization used in the management game.

It is convenient to treat the above probability of detection as relating to searching on a single day, so that it is highly likely that the proportion of the area searched on that day really is very small. Now suppose that searching is carried out on *N* days each season, and assume that the fishing vessels move randomly between days so that each daily search can be treated as being independent. Then it follows that the probability that the vessel will be detected at least once in the *N* days is

$$q = 1 - exp(-N\, W\, v\, t\, /\, A\,).$$

Again, provided the exponent is not too large, the probability of actually being detected more than once will be negligible. If searching takes place on *N* days during the season, and if vessels that decide to fish illegally do so for the entire season (or at least until they are detected), then we have returned to the original formulation, except now each of the parameters is easily specified.

As noted earlier, however, it is quite unreasonable to assume that the fishing seasons are necessarily the same for each fleet. Further, available data on vessel movements also suggest that frequently even licensed vessels do not spend their entire season within the zone. Thus on different days, it is likely that there will be different numbers of vessels available to be detected inside the zone. We therefore need to take account of the possibility that an illegal fishing vessel may not always be fishing illegally (and so available to be detected) on the days on which flights are made.
Consider a vessel that spends a proportion θ of the days in a season fishing illegally inside the zone. We

$$\lambda = \theta\, (1 \;\; \exp(\;\; \frac{Wvt}{A} \;))$$

treat this as equivalent to the probability that the vessel was fishing illegally on the day of a flight. Then, if

$$Pr[i\ detections\ during\ season] = \binom{N}{i} \lambda^{i}\, (1 \lambda\ )^{N i}$$

it follows that

$$Pr[\text{Detected at least once during season}] = 1\ (1\ \lambda\ )^N$$

and

If $\theta = 1$, so that the vessel was always fishing when the surveillance was undertaken, this formula reduces to the one before. Generalisations to allow, for example, each month of the year to be considered separately are straightforward.

With this formulation, the control variable for the coastal state is now the number of surveillance flights or cruises undertaken each month (or season). The probability of detection is no longer a continuous variable; it rises in steps coinciding with an additional flight or cruise that month or season, and it may vary between fleets. The total cost of surveillance will be the cost of the total number of flights or cruises undertaken during the year.

Until now, we have been attempting to model the detection of a single vessel, whereas there may be several fleets of many vessels. We take the same approach to this extension as was used in MRAG (1993): we assume that the expected number of vessels detected is just the product of the number of vessels available to be detected and the probability of detection of a single vessel. This does still assume a random distribution of vessels within the zone (or a well defined part of it). This is almost certainly strictly incorrect, but taking account of clumped distributions of vessels would be extremely difficult, and the effect could go either way.

Potentially rather more serious is the fact that only the event of vessel detection (usually by radar) has been considered so far. What is really wanted is to calculate an expected fine resulting from surveillance activities. This has loosely been treated as the product of the probability of detection and a fixed fine, which is a control variable set by the coastal state. In practice, a sequence of events must occur before a fine is actually levied. The illegal fishing vessel has to be detected, then closed upon by the surveillance platform, evidence of illegal fishing collected, an arrest made, a successful prosecution made under the relevant legislation, and finally the fine collected.

Most examples of fishery legislation we have seen at least envisage different fines for different offences, which in turn require different types of evidence. Maximum fines invariably require unequivocal evidence that the unlicensed vessel was actually fishing at the time an arrest was made. If, for example, a vessel was illegally fishing when first detected on radar, but by the time a patrol vessel came alongside it had been able to retrieve and stow its fishing gear, then there is most unlikely to be any unequivocal evidence of illegal fishing that would satisfy a court. At best a lower fine might be imposed, and at worst the vessel may even get off scot free.

In the case studies that follow, where information allowed it account has been taken of the problem of the need to arrest a vessel with its gear still in the water (purse seiners in BIOT), but otherwise it has generally been assumed that a single certain fine applies in base case analyses. To allow for this element of unrealism, especially since the optimal policy generally is to set the fine at or near its maximum, we also consider sensitivity analyses where the maximum fine is reduced to much lower levels.

A final point relates to a criticism raised of the surveillance model at initial discussions with Forum Fisheries Agency staff. This was that there was assumed to be a direct connection between surveillance expenditure and detection probability. In the South Pacific, as in other areas, the fishery surveillance activities are undertaken, often by the military, as part of wider customs and immigration surveillance activities. In such cases, it is very difficult to relate directly fishery detections to the costs of surveillance. In the South Pacific, the costs of these wider surveillance activities are generally met out of development funds and they are commonly carried out by vessels or aircraft operated by donor countries. In such cases, this can simply be treated as generating a baseline probability of detection that is free to the coastal state. Taking this as a given, the only surveillance issue then is to determine whether it is worthwhile for the coastal state to spend additional money of its own on supplementary surveillance to supplement this free surveillance. Taking account of two different types of surveillance activities in the model is again straightforward.

3.2.3 Implications of the research strategy

With the changes described above, the model used in the optimization process remains relatively simple and easy to interpret. The price paid is in considerably more routine analysis of basic data to calculate values of input parameters, but such analysis has to be done one way or another. Within each case study, the analyses to produce parameter values as input for the revised model are described in detail before proceeding to analysis of the model and determining optimal policies.

4 Seychelles

4.1 Background

The Seychelles is made up collectively of over 100 islands. The main island, Mahe, is centred on 4 30' S and 55 30' E in the Western Indian Ocean. The Seychelles has an EEZ of over 1,370,000 km^2, compared to a total landmass of 455 km^2. The principal offshore fishery in the Seychelles EEZ is for tuna, which are taken almost exclusively fished by foreign vessels.

Since 1984, administration, surveillance and enforcement of fisheries within Seychelles waters has been the responsibility of the Seychelles Fishing Authority. The main objective of its fisheries strategy is to maximise potential benefits from resource management through job opportunities, maximisation of foreign exchange earnings, creation of linkages with other sectors of the economy, ensuring industry stability and resource conservation. These goals are pursued through a mixture of domestic exploitation, licensing of foreign fleets and joint venture operations. The Seychelles Fishery Authority maintains a comprehensive database on all fishing vessel activities, catches and transshipments.

The Seychelles has also encouraged the use of their port facilities by fishing vessels and they are attempting to expand the range of services that Port Victoria can offer to distant water fishing nations. The port may be used for transshipment on payment of a fee, both for vessels fishing inside and outside the EEZ, and it is also visited regularly by other fishing vessels operating in the region. These activities lead to harbour fees, bunkering fees, port dues, ship chandling fees, and other sources of revenue associated with the fisheries, accruing to the Seychelles economy.

4.2 The status of the Seychelles tuna fisheries

The two main fishing methods for tuna in Seychelles waters and the surrounding western Indian Ocean are longlining and purse seining. Longlining, primarily carried out by the far-eastern fleets of Japan, Korea and in recent years Taiwan, involves setting thousands of baited hooks on long branched lines. These lines are usually set quite deep to catch individual deep swimming tuna. The fish that are caught by this method have a high value, because the fish taken are large and the fishing method inflicts very little damage to the flesh. On the Japanese sashimi markets, where most of these fish are sold, they can fetch prices of over $10, 000 per tonne.

Purse seine fishing in the western Indian Ocean is primarily carried out by French and Spanish vessels. The purse seiners tend to operate in groups, targeting the surface schools of skipjack and yellowfin tuna. They fish by extending a large net around a school of fish, closing the bottom of the net like a purse string. The net is then hauled in until the fish can be taken from the purse by smaller nets, called brails, operated from the fishing vessel. The fish are transferred directly from the sea to the hold. Because of the size of the species involved and the damage to the flesh that can occur during capture, the price paid for tuna caught in this manner is much less than from the longline fishery. Purse seine caught fish are normally marketed in cans, and the fish reach prices of around US$ 1,200 per tonne at market. The dominant market in the case of the Western Indian Ocean purse seine fishery is Italy.

The data discussed below originates from the Seychelles Fishing Authority Annual Reports and from analyses of Seychelles logbook data reported in MRAG (1994). Annual time series data published by the Seychelles Fishing Authority currently runs to 1993, however data pertaining to longline catches have only been published to 1992.

The Longline Fishery

Between 1980 to 1991, the numbers of licensed longline vessels operating in and around the Seychelles EEZ has varied widely (MRAG, 1994). For example, between 1980 and 1983, the Korean fleet operated between 16 and 60 vessel months per year. There then followed a dramatic increase in effort, both inside and outside the zone, peaking in 1988 with 188 vessel months inside and 232 vessel months fishing outside the EEZ). By 1991, the Korean fleet fished only two vessel months, but since 1991 the monthly licences issued to the Korean fleet have risen again (see below). The Japanese fleet mirrored the trends seen in the Korean fleet, although total fleet size was significantly smaller. Fleet size peaked in 1988 but was much reduced in 1992 and had only shown a small increase in size by 1993. The only other longline vessels operating in the Seychelles zone during the last 15 years, were several Russian vessels active during 1981, 1984, 1989 and 1990, a Spanish longliner that fished in the area between 1983 and 1985 (MRAG, 1994), a French longliner licensed in 1993 and of course the Taiwanese. Since 1991, there has been an increase in the number of Taiwanese longline vessels operating in the Seychelles EEZ.

The MRAG (1994) analysis, based on database logbook returns, revealed that during the period 1980 to 1991, the longline fleets operating in and around the Seychelles EEZ spent a higher proportion of time inside the Seychelles EEZ than outside it. On average over that twelve year period, 60% of the fishing days were inside the Seychelles EEZ. This is in contrast to the fishing patterns of purse seine vessels described below. Longline fishing effort is greater inside the EEZ than outside it between the months of November and April. Based on number of hooks set per month, December is by far the most significant longline fishing month. In the majority of years, the highest catches were made in the months September to December.

The total catch from the longline fishery peaked at nearly 5000 MT in 1988, 2100 MT of which came from inside the Seychelles EEZ. Between 1988 and 1991, catches decreased as the majority of the Korean and Japanese longline vessels departed from the area. Catches have historically been dominated by these two nations. Japan has a slightly higher catch per vessel than Korea, due to their higher catch per unit effort, both inside and outside the EEZ, but for most years the total catch recorded for Korea exceeds that for Japan because of the larger Korean fleet.

The longline catches for all fleets have similar catch compositions, the catch being dominated by bigeye tuna (approximately 50%) and yellowfin tuna (approximately 40%), with the other 10% being made up of assorted marlin and other species. Catches by country by species for the latest two years of data available are shown below.

Bigeye tuna - *Thunnus obesus*

Bigeye tuna have a worldwide distribution throughout tropical and subtropical waters down to a depth of 250 m. Bigeye feed on a variety of fish, cephalopods and crustaceans, depending on availability. They grow to a maximum fork length approaching 285 cm, and weigh up to 450 kg. However, individuals of that size are now quite uncommon. Fish of 175 cm and about 115 kg are believed to be at least 8 years old. They are thought to mature after 4-5 years. Spawning is known to occur throughout the year in the tropical band from 15^{o}N to 15^{o}S.

In 1992 (REF), the maximum sustainable yield for bigeye tuna in the Indian Ocean was estimated to be 37,850 t, which, if accurate, suggests that the Indian Ocean bigeye stock is at, or close to, an optimal level of exploitation. There are, however, some questions over unrecorded longline catches. If these are substantial, then current harvests may be in excess of the maximum sustainable yield.

Yellowfin tuna *- Thunnus albacares*

Yellowfin tuna are found in tropical and subtropical waters of the Indian, Pacific and Atlantic oceans. The yellowfin is a fast growing species. At around seven years of age a yellowfin may attain a maximum fork length of 170 cm and a corresponding weight of 70kg, but such specimens are not common. Of the two main commercial species taken by purse seine, the yellowfin is considered potentially to be more vulnerable. However, there is not considered to be excess pressure being placed on yellowfin populations by the purse seine or longline fisheries in the western Indian ocean.

Purse seine vessels harvest younger schooling yellowfin, which often congregate with skipjack schools.

Purse seining provides fish largely for the canned market and the quality of fish is considered inferior to quality from longline vessels. This is partly because of the size of fish (smaller) and partly because of the damage caused to flesh during harvest. Mature yellowfin tuna are targeted by longline vessels and usually enter the more valuable fresh and frozen fish markets. These fish are individual swimmers, and are located in deeper waters than the schooling juveniles.

Billfish: Indo-Pacific Blue Marlin - *Makaira mazara*, Indo-Pacific Sailfish - *Istiphorus platypterus*, Swordfish - *Xiphadias gladius*

Billfish are oceanic, epipelagic species inhabiting tropical and temperate waters, and in certain seasons even the cold waters of all oceans. They can occur at depths below 800 metres but are usually found above the thermocline. There are twelve species of billfish currently recognised, from four genera and two families. Like tuna, billfish undergo seasonal migrations, typically involving a journey into temperate or cool waters for feeding, followed by a return to subtropical waters to spawn and to overwinter, however distances travelled do not compare with those of larger tuna.

Billfish are a desirable commercial species, especially for the Japanese sashimi markets, where fish over 20 kg are sold. Billfish can apparently withstand longer periods of transportation than tuna and their flesh has a longer shelf life, further enhancing their commercial desirability. Globally, 90% of billfish harvests come as a bycatch to tuna longline fisheries. Billfish are also considered a key target for sports fishermen - waters around the Seychelles are renowned as one of the world's best billfish sport fishing grounds.

Makaira mazara is the most tropical species of billfish, often being found in equatorial waters. Its range is thought to extend from the northern coastline of the Indian Ocean to between 35 and 45 S in the south of the Indian Ocean. It is thought to be particularly abundant around Mauritius and of the east coast of Africa between April and October. It feeds near surface waters and, like other billfish, is a voracious predator.

Istiphorus platypterus is a widely distributed, epipelagic and oceanic species, usually found above the thermocline and also near coasts and islands. Their flesh is not as desirable as that of the marlin, but is still of a quality suitable for the sashimi market, particularly when caught in the summer.

Xiphadias gladius is primarily a warm water species but has a greater temperature tolerance than other billfish. Swordfish are opportunistic feeders and are largely caught incidentally, however in the Atlantic they are a primary target species. They are also a prized sport fish.

The Purse Seine Fishery

The number of licensed purse seine vessels in and around the Seychelles EEZ has remained relatively steady over the three year period 1990 - 1992, increasing from 62 in 1990 to 64 in 1992 (MRAG, 1994). In 1993, there were 56 licensed purse seine vessels (Seychelles Fisheries Authority, 1993). In 1990, the purse seine fleet consisted mainly of Spanish and French vessels, along with a few Japanese and others. Between 1990 and 1992, the Japanese fleet in the area increased to eleven vessels, but by the end of 1993 only two Japanese purse seiners remained. Mauritius and the former USSR operate between 3 and 4 vessels, and other flag states such as Iran, Liberia and India have recently commenced purse seine operations.
The purse seine fleets operate both inside and outside the Seychelles EEZ, virtually all year round, however the majority of fishing takes place outside the Seychelles EEZ. Of an average of about 1000 fishing days recorded in each month, only about 25% of these are recorded as being inside the Seychelles EEZ (MRAG, 1994).

Total annual catches for the period 1989 - 1993 have varied between 199,500 MT and 278,218 MT. Around 80% of this catch is taken outside of the EEZ. The largest catches are taken by the Spanish and French purse seiners, but the Japanese share of the catch has increased steadily with their fleet size to 1992. The highest catches inside the EEZ occurred in March and July. Outside the zone, the highest catches occurred in December. Recent purse seine catches are shown below.

French and Spanish purse seine catches consist of yellowfin tuna (45%) and skipjack tuna (55%), with a small bycatch of bigeye and albacore. The Japanese vessels target skipjack more than the Spanish and

French, with skipjack forming the bulk of their catch (70%), the remainder being made up of yellowfin (20%) and bigeye tuna, which are commonly found in mixed schools with the skipjack. The other fleets have catch compositions somewhere between those of the European and Japanese vessels. Larger purse seiners can target the large schools of yellowfin, while the smaller vessels, such as the Mauritian fleet, tend to target mixed schools of small fish associated with logs and other flotsam.

Skipjack tuna - *Katsuwonus pelamis*

Skipjack tuna is a cosmopolitan species, occurring in tropical and warm temperate seas. The maximum size observed for skipjack from all oceans is about 110 cm, corresponding to a weight of about 34 kg, however fish in the range of 80 cm or less and up to 10 kg are most common. Skipjack are thought to spawn first at about 45 cm or about 1 year old. They are opportunistic feeders and mature at an earlier age and have a higher natural mortality rate than either yellowfin or bigeye tuna.

Skipjack tuna are attracted to floating logs and flotsam. In order to enhance catches, fishermen sometimes mark logs with radio beacons and return to them on a regular basis. Purse seine fishing fleets have come to depend more and more on log-associated tuna schools. Since these schools consist principally of skipjack (70%), records show an increasingly high skipjack catch.

Current indications are that the skipjack stock in the Indian Ocean is in a good condition.There are no suggestions that limitations should be placed on effort directed at this species. Skipjack tuna's resilience stems from an ability to spawn at small sizes, an extended spawning area, rapid turnover and large population. Skipjack are usually marketed as canned tuna, and they do not command as high a price as larger species.

4.3 Transhipment

An important feature of purse seine fishery is transhipment of the catch. Transhipment fees, levied on a per tonne basis, are an important source of foreign exchange for the Seychelles. Transshipment involves periodic steaming to Port Victoria to transfer the catch in the hold to another carrier vessel, which then takes the catch to markets at home or abroad. Statistics on transhipments carried out in Port Victoria in 1992 and 1993 are shown in the table below.

Tuna Caught By Purse Seiners and transhipped in Port Victoria, 1991-93 (Metric tonnes)

	Jan	Feb	Mar	Apr	May	Jun	Jul
1991	16694	20281	9574	608	5906	8219	17059
1992	14842	16638	775	10467	5545	4868	8050
1993	18293	17751	14122	11829	6111	9554	12782

	Aug	Sep	Oct	Nov	Dec	Total
1991	16509	16590	25764	21580	12573	171360
1992	9879	13318	23220	26932	11741	160275
1993	17701	21420	24224	15936	19234	188957

Source: SFA Annual Report, 1993

Transhipment In Port Victoria By Flag State, 1993

Nation	MT	%
France	75143	40
Spain	54227	29
Japan	36778	19
Russia	6286	3
Mauritius	3346	2
Panama	8731	5
Others	4446	2
Total	188957	100

Source: SFA Annual Report, 1993

4.4 Licensing

The Seychelles Fishing Authority is responsible for negotiating licence fees, issuing licences, and for ensuring that the terms and conditions attached are adhered to. Separate licensing schemes apply to purse seine and longline vessels, with annual licences generally being issued to purse seiners and monthly licences to longliners.

Licence fees paid by foreign fishing vessels are an important source of revenue for the Seychelles economy. Different licence agreements have been made with the different fleets. Under an agreement reached with the EC, French and Spanish vessels pay licence fees that vary with the amount caught in the EEZ, and as part of the same agreement, EC support is given for scientific programmes, training and travel. Licensing agreements with other fleets can involve both fee payments that may vary with the size of the vessel and a requirement to land part of the catch for onshore processing at the canning factory in Port Victoria.

Up to 56 purse seine vessels were licensed in 1993, a similar number to 1992, although the Japanese purse seine fleet was smaller in 1993 than in 1992. Longline activity decreased between 1992 and 1993, with Korean vessels failing to renew a total of 99 monthly licences in 1993. Information on monthly licences for both purse seiners and longliners published by the Seychelles Fishery Authority is shown in the next table. Note that the 'others' category in the longline table refers almost entirely to Taiwanese vessels, with the exception of the one French vessel mentioned earlier.

Purse Seine Licences Issued Each Month in 1992 and 1993

	1992												1993											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EC	29	29	29	29	29	31	32	30	32	32	32	32	32	33	32	31	31	31	32	32	34	35	35	35
Private	5	5	5	5	5	5	5	5	5	5	6	6	6	4	5	5	5	5	6	6	5	6	6	6
Mauritius	3	3	3	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Japan	8	10	10	10	9	9	10	10	7	4	7	11	11	10	9	9	9	8	7	6	6	6	6	2
CIS	1	3	3	3	3	3	3	3	3	3	3	3	3	2	4	4	4	2	3	3	3	1	1	1
Others	1	2	4	4	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	-
Total	47	52	54	53	50	52	54	52	50	48	52	56	56	53	54	53	53	50	52	51	52	51	52	47

Source: Seychelles Fisheries Authority Annual Report

Longline Licences Issued Each Month in 1992 and 1993

	1992												1993											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Japanese	1	1	-	-	-	-	-	-	-	1	6	5	3	-	-	-	-	-	-	-	4	1	8	4
Korean	8	2	3	-	-	19	6	34	23	25	18	15	10	1	-	-	-	4	-	4	16	4	10	5
Others	11	2	3	-	-	1	-	1	2	10	54	41	19	13	-	-	-	1	3	-	3	30	44	23
Total	20	5	6	-	-	20	6	35	25	36	78	61	32	14	-	-	-	5	3	4	23	35	62	32

Source: SFA Annual Report, 1994

4.5 Surveillance

The Seychelles Fishery Authority maintains a monthly record of information for all vessels licensed to fish in their zone, consisting of weekly positions and catch radio reports. It is mandatory for vessels to provide this information only while fishing inside the EEZ, but often it is also provided while outside the EEZ as a matter of course.

The Seychelles Coastguard operates a patrol boat, the *Gemini*, which is capable of undertaking long-range patrols of up to two weeks covering the nation's EEZ. The 26.6 metre long vessel can carry a crew of twelve. She is appropriately armed to carry out fisheries protection duties and has radar detection equipment and an advanced communications system. She has a maximum speed of 38 knots, a range of 2000 nautical miles and a cruising speed of 15 knots.

Airborne surveillance is also undertaken in the protection of Seychelles marine resources. Aircraft used for this purpose carry sophisticated camera equipment. Thus, in addition to aiding waterborne surveillance, the aircraft can obtain evidence of illegal activities in the course of reconnaissance flights.

4.6 Illegal Fishing

There have been some recent reports of illegal fishing by Spanish purse seiners. Vessels owned by the companies OPAGAC and ANABAC were apprehended using purse seine nets within the Seychelles 12 mile restricted zone. When requested by the coast guard to enter Port Victoria, the vessels refused and left the area. After negotiations with the owners, each vessel (eight in total) was fined R250,000[1] (amounting to R2 million) and 50 tonnes of tuna per vessel was to be sold to *La Conserverie de l'Ocean Indien* (COI), the only canning factory in the Seychelles. Finally, the vessels were each to supply 5000 tonnes of tuna to the COI for a period of three years in a joint venture operation. A Taiwanese vessel was also found fishing illegally in a restricted zone in 1994, this time in an area of water prohibited to foreign fishing lying 30 nautical miles south of Mahe. It was fined a total of US$ 150,000.

In both cases, the vessels in question were actually licensed to fish within the Seychelles EEZ, but they were fishing waters where additional restrictions applied. Had they also been unlicensed, considerably greater penalties would have applied.

4.7 Application of Control of Foreign Fisheries methodology

During 1994, initial analysis of the extensive logbook data for foreign tuna fishing activities in the Seychelles EEZ was completed by MRAG and a report on the estimation of net state benefits from foreign fishing was presented to the Seychelles Fishing Authority. Most of the calculations had been carried out using a slightly modified version of the management game described in section 2.6. Subsequent discussions with staff at the Seychelles Fishing Authority indicated that estimates of some of the parameters used in the analysis were rather uncertain, and also that some of the assumptions made were unrealistic. To address some of the parameter uncertainties, sensitivity analyses were carried out and reported to the Seychelles Fishing Authority. These revealed that the results were insensitive to many of the parameter uncertainties, but they did indicate that further work was needed in some areas. The principal difficulty lay in the treatment of relative levels of catch rates inside and outside the Seychelles EEZ. Much of the following analysis has been devoted to resolving this issue.

[1] The exchange rate is approximately 0.11 pounds sterling to one Seychelles Rupee.

4.7.1 Estimates of fleet parameters

A comprehensive tuna fishery database was provided to MRAG by the Seychelles Fishing Authority for use on this project. The database contains, amongst other things, daily catch and effort data with geographical position for longliners fishing from 1980 to 1991 and purse seine vessels operating between 1990 and 1992. Details of individual purse seine trips and transshipments have also been recorded. Data are available for vessels fishing in the area but outside the zone as well as inside, for it is collected from vessels visiting the port as well as those licensed to fish.

It was decided to include five fleets in the analysis: the French, Spanish and Japanese purse seine fleets and the Japanese and Korean longline fleets. These were the most active over the period for which data were available. This may not be an accurate representation of the current fleet composition; for instance there is now a sizeable Taiwanese fleet operating in the Indian Ocean for which there was no data in the database available to MRAG. Nonetheless, these fleets with their associated data will be adequate for the purpose of this study. The analyses made use of the complete purse seine data (1990 - 1992 for all fleets) and a subset of the longline data comprising the years 1987 - 1991, which were the main years when both the Korean and Japanese fleets were active.

Number of vessels per fleet

The following table lists the numbers of vessels by fleet and year recorded in the database.

Gear	Flag	80	81	82	83	84	85	86	87	88	89	90	91	92	Ave
PS	Fre											21	18	18	19
	Spa											26	22	20	23
	Jap											5	10	15	10
LL	Jap				3	6			8	19	21	5	6		10
	Kor	12	24	22	6	31	18	30	59	84	46	25	1		30

Table 4.7.1.1 Number of vessels by fleet and year in the Seychelles database.

As already indicated, only data for the years 1987 - 1991 were used in the subsequent analyses of longline data. Even during this period, however, the numbers of vessels have changed dramatically. In particular, far fewer Japanese vessels were recorded as fishing in the Seychelles area in 1990 and 1991 than in the previous three years. Even more dramatic is the decline in the Korean longline fleet to a single recorded vessel in January 1991.

Vessel value

The vessel values used were discussed in the previous report to the Seychelles Fishing Authority. They were estimated after extensive discussions with people in the industry. French, Spanish and Japanese purse seiners were valued at 17.5, 20 and 10 million US dollars respectively, while Japanese and Korean longliner values were set at 2.5 and 1.5 million dollars respectively.

Hold value

If a vessel is caught fishing illegally, the penalty may include confiscation of the catch as well as a fine. To account for this in the model, an estimate must be made of the average value of fish that a vessel would have on board at any one time. Long liners generally have holds large enough to hold the entire annual catch, so the average value of the hold contents was taken to be half of the average catch value over the study years. This amounted to $907,000 for the Japanese longliners and $460,000 for the Korean ones.

Purse seiners, on the other hand, catch far more in a year than their holds can contain, so consequently tranship their catch regularly. From the database, it was possible to ascertain that the average catch per purse seine trip was also greater than the average hold size, showing that transhipment at sea must be occurring. The value of a hold full of fish was calculated by using the average catch composition for a trip to calculate an average price per ton of catch and then multiplying this figure with the average hold size. The value of the hold contents on an average day was then taken to be a half of the value of a full hold. The purse seiner results are summarised in the following table.

Fleet	Hold size (MT)	Hold value	Ave value on board
France	842	1080	540
Spain	1326	1670	835
Japan	842	922	461

Table 4.7.1.2 Average value of purse seine hold contents in thousands of US$

Honesty coefficient

The honesty coefficient was set to zero throughout. This mimics the least complicated case where a fisherman's choice is based solely on which behaviour will bring him the greatest profit.

4.7.2 Value of a licence

Catch rates

A good first indication of the relative value of fishing inside or outside of the zone is given by the catch per unit effort (CPUE) or catch rate. For purse seiners, this is measured in metric tons per day, while longliner catch rates are measured in kg per hook. Tuna longliners allow their lines to soak for a approximately constant length of time each day, so number of hooks is regarded as a good measure of effort for these fisheries.

The Seychelles fishery is strongly seasonal, so it was anticipated that annual aggregated catch rates might not show any advantage to fishing inside the zone. In fact, the annual data showed that the overall yellowfin catch rates for longliners were higher inside the zone than outside, but that the reverse was true for bigeye. For purse seiners, annual aggregated catch rates were generally lower inside the EEZ, except for yellowfin in certain years, particularly for the French fleet.

A theoretically better comparison uses catch rates calculated by aggregating data from only those days when a fleet had vessels fishing both inside and outside the zone simultaneously. The trends in these catch rates were not much different to those in the first series, while a good deal of data was lost, so this method was not pursued further.

A clearer picture emerges when the catch rates are examined separately by month; these data are shown in table 4.7.2.1. To provide a context for these catch rates, corresponding effort levels are listed in table 4.7.2.2.

Table 4.7.2.1 Catch rates for purse seine fleets (measured in metric tons per day), and longline fleets (measured in kg per hook).

French	90				91				92			
Purse-seiners	Yfin		Skj		Yfin		Skj		Yfin		Skj	
Mth	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
1	6.16	3.02	4.20	0.85	17.43	27.73	1.16	0.45	10.13	13.47	8.00	1.95
2	13.35	1.15	5.20	1.22	18.93	24.87	0.77	1.12	9.73	9.44	9.68	5.25
3	14.85	12.98	3.04	2.92	16.35	18.18	5.72	2.88	8.53	6.66	3.73	4.76
4	6.47	6.08	9.19	1.10	0.96	3.95	8.41	3.96	3.60	7.51	16.58	5.75
5	1.12	0.10	12.43	2.21	8.62	0.00	7.62	1.46	9.34	9.00	12.77	3.40
6	8.82	9.84	1.53	1.39	13.39	14.69	3.45	2.89	5.80	1.75	11.22	5.33
7	12.78	13.94	1.36	0.46	9.92	10.13	3.41	8.81	9.58	18.52	5.22	1.69
8	2.37	2.23	9.15	7.17	4.82	3.67	8.29	14.87	4.00	11.83	6.12	2.62
9	2.88	2.19	18.01	9.80	3.13	4.38	19.53	12.51	5.24	5.26	28.96	18.88
10	2.29	6.40	12.13	24.79	3.71	2.06	23.91	18.47	4.64	8.36	28.79	17.76
11	6.24	6.90	10.40	3.40	2.41	3.84	16.09	15.89	9.59	14.51	18.67	9.73
12	26.23	3.67	3.01	1.33	5.29	1.90	9.67	2.50	10.00	0.00	0.00	0.00

Japnese	90				91				92			
Purse-seiners	Yfin		Skj		Yfin		Skj		Yfin		Skj	
Mth	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
1	3.06	0.00	17.02	0.00	6.26	0.56	10.80	2.78	5.61	2.74	13.76	10.86
2	2.33	1.00	11.46	5.67	5.10	0.00	14.57	0.00	4.15	5.56	18.69	21.82
3	3.26	0.00	15.82	0.00	3.55	0.00	16.77	13.33	3.29	5.53	14.86	17.90
4	3.51	0.00	16.59	0.00	5.19	3.46	17.60	9.18	4.69	3.35	19.12	16.22
5	1.82	0.00	5.27	0.00	3.39	0.00	12.43	0.00	3.55	3.59	15.10	16.44
6	3.56	0.00	9.75	0.00	2.05	0.00	5.71	0.00	2.03	0.40	7.64	1.37
7	6.13	0.00	20.51	0.00	4.21	0.00	16.19	0.00	3.07	4.46	11.75	11.40
8	5.06	0.00	15.75	0.00	4.01	0.00	13.07	0.00	4.93	3.22	13.58	11.56
9	5.71	0.00	15.22	0.00	3.52	1.00	10.55	10.89	4.90	2.24	10.26	16.29
10					2.17	0.00	7.41	0.82	4.97	6.93	11.76	9.29
11	1.39	0.00	2.91	0.00	2.09	2.20	6.25	10.45				
12	5.60	0.00	7.92	0.00	2.81	2.76	9.22	8.88				

Spanish	90				91				92			
Purse-seiners	Yfin		Skj		Yfin		Skj		Yfin		Skj	
Mth	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
1	7.16	2.35	4.36	2.55	21.16	0.00	1.16	0.00	6.72	7.90	5.89	3.65
2	16.36	6.94	5.48	2.69	39.40	14.17	4.75	1.54	17.92	6.43	6.67	7.79
3	3.53	2.79	22.34	6.38	15.14	16.76	13.85	6.86	5.30	6.73	20.47	3.25
4	2.69	3.46	24.79	7.07	1.47	2.61	12.56	9.30	2.77	0.00	25.91	0.00
5	2.22	1.92	13.02	1.52	2.80	3.15	17.38	10.69	1.70	0.16	11.21	2.61
6	15.84	6.84	1.76	0.55	13.04	4.17	9.21	2.16	6.19	7.06	2.87	0.89
7	12.74	16.41	7.46	1.25	13.81	4.82	5.14	3.07	25.67	17.96	9.29	1.01
8	3.91	3.36	16.49	9.92	8.85	2.49	7.83	0.79	8.52	13.75	12.69	1.96
9	3.57	0.38	23.30	4.62	3.58	3.03	17.56	12.71	5.85	1.22	21.20	9.91
10	10.98	0.61	14.26	6.44	9.00	1.32	25.34	7.77	10.61	4.80	35.70	16.89
11	2.14	1.58	9.14	9.45	4.53	0.25	15.75	6.82	4.87	1.83	8.78	5.49
12	25.75	0.12	2.76	0.73	6.17	1.13	5.74	10.21	8.93	11.22	3.95	2.33

Japanese	87				88				89				90				91			
Longliners	Yfin		Beye		Yfin		Beye		Yfin		Beye		Yfin		Beye		Yfin		Beye	
Mth	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
1					0.48	0.30	0.10	0.16	0.35	0.26	0.28	0.28	0.37	0.20	0.16	0.19	0.46	0.22	0.25	0.13
2	0.29	0.45	0.36	0.36	0.07	0.42	0.13	0.33	0.23	0.17	0.28	0.14	0.27	0.30	0.15	0.16	1.09	0.44	0.17	0.12
3	0.08	0.28	0.41	0.49	0.39	0.52	0.22	0.41	0.08	0.08	0.28	0.13								
4	0.12	0.19	0.68	0.36	0.38	0.60	0.57	0.45	0.05	0.04	0.20	0.19								
5					0.21	0.41	0.43	0.69												
6					0.17	0.20	0.35	0.12												
7													0.05	0.07	0.30	0.28				
8																				
9					0.30	0.25	0.32	0.26												
10	0.00	0.00	0.00	0.00	0.20	0.05	0.34	0.07					0.31	0.23	0.16	0.19				
11	0.01	0.01	0.00	0.01	0.10	0.03	0.42	0.24					0.25	0.20	0.41	0.28	0.32	0.88	0.41	0.28
12	0.41	0.19	0.28	0.10	0.15	0.37	0.13	0.35					0.09	0.49	0.43	0.16	1.02	0.58	0.06	0.08

Korean	87				88				89				90				91			
Longliners	Yfin		Beye		Yfin		Beye		Yfin		Beye		Yfin		Beye		Yfin		Beye	
Mth	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
1	0.21	0.17	0.14	0.16	0.18	0.23	0.30	0.20	0.11	0.09	0.18	0.15	0.12	0.11	0.20	0.18	0.10	0.15	0.26	0.27
2	0.24	0.15	0.23	0.12	0.14	0.20	0.20	0.17	0.06	0.05	0.17	0.14	0.22	0.08	0.10	0.08				
3									0.16	0.04	0.08	0.12								
4					0.21	0.18	0.57	0.26	0.13	0.09	0.22	0.27								
5													0.18	0.13	0.15	0.32				
6	0.12	0.08	0.19	0.22	0.16	0.06	0.05	0.15	0.15	0.09	0.12	0.12	0.15	0.07	0.15	0.12				
7	0.08	0.06	0.24	0.25	0.10	0.18	0.11	0.08	0.07	0.07	0.09	0.12	0.10	0.03	0.12	0.09				
8	0.10	0.09	0.28	0.30	0.17	0.17	0.18	0.14	0.10	0.09	0.16	0.16	0.07	0.03	0.29	0.24				
9	0.17	0.17	0.17	0.22	0.11	0.10	0.14	0.13	0.09	0.08	0.15	0.11	0.04	0.05	0.15	0.15				
10	0.17	0.22	0.24	0.22	0.17	0.04	0.15	0.16	0.06	0.04	0.09	0.11	0.09	0.05	0.26	0.17				
11	0.17	0.30	0.31	0.22	0.09	0.11	0.18	0.18	0.07	0.06	0.17	0.15	0.06	0.10	0.29	0.16				
12	0.18	0.21	0.24	0.20	0.15	0.12	0.23	0.22	0.16	0.12	0.31	0.16	0.13	0.13	0.29	0.28				

Table 4.7.2.2 Effort levels for purse seine fleets (measured in days fishing), and longline fleets (measured in hooks set).

French PS Mth	90 Out	90 In	91 Out	91 In	92 Out	92 In
1	440	97	303	11	221	239
2	378	82	198	76	205	183
3	264	194	183	113	179	221
4	341	83	191	79	286	59
5	276	52	248	79	325	10
6	191	133	218	106	254	55
7	76	206	285	109	67	287
8	172	138	309	104	122	269
9	336	54	311	102	277	69
10	263	141	278	119	263	72
11	349	20	313	90	159	84
12	326	15	384	20	11	3

Japanese PS Mth	90 Mth	90 In	91 Out	91 In	92 Out	92 In
1	96	8	70	9	177	43
2	87	3	63	7	155	68
3	90	6	66	6	150	87
4	70	3	63	11	130	65
5	78	3	56	3	118	94
6	64	2	83	3	165	57
7	61	5	68	8	174	50
8	51	3	100	5	111	41
9	73	6	88	9	57	17
10			162	11	74	14
11	33	1	241	20		
12	79	7	163	49		

Spanish PS Mth	90 Out	90 In	91 Out	91 In	92 Out	92 In
1	447	118	431	27	230	222
2	444	48	269	65	152	223
3	383	165	92	369	251	122
4	399	28	273	111	339	11
5	243	234	344	72	349	43
6	298	146	278	155	267	147
7	197	266	324	120	189	242
8	338	145	403	101	343	95
9	475	45	388	73	414	23
10	537	23	415	34	276	35
11	366	60	346	100	150	35
12	512	26	426	56	57	9

Japanese Longliners Mth	87 Out	87 In	88 Out	88 In	89 Out	89 In	90 Out	90 In	91 Out	91 In
1			28,500	60,396	249,762	453,227	7,500	25,000	144,580	10,858
2	7,224	44,316	114,030	82,744	389,845	116,283	17,500	35,000	90,597	80,530
3	12,760	177,020	89,080	101,700	342,166	61,251				
4	2,500	27,098	154,250	51,160	21,480	4,920				
5			161,860	11,940						
6			145,528	35,870						
7							34,810	19,760		
8										
9			102,619	49,379						
10	7,200	9,600	167,137	16,040			48,070	38,870		
11	45,600	4,800	28,829	5,360			135,075	118,605	22,500	2,500
12	24,000	127,300	5,760	57,842			142,510	41,030	19,388	47,750

Korean Longliners Mth	87 Out	87 In	88 Out	88 In	89 Out	89 In	90 Out	90 In	91 Out	91 In
1	188,640	772,399	210,264	1,064,964	572,272	1,074,465	45,764	218,149	4,700	38,300
2	70,616	64,610	240,811	409,432	166,447	183,978	67,125	46,669		
3					207,903	120,512				
4			178,306	154,394	67,895	29,200				
5							43,610	17,965		
6	75,206	295,705	141,721	153,153	34,065	143,420	162,287	198,164		
7	281,291	235,334	438,275	477,024	132,147	170,715	275,037	227,933		
8	270,531	1,565,583	376,503	1,335,813	70,334	410,986	60,913	93,322		
9	395,004	1,038,226	501,728	982,116	192,177	96,065	170,901	134,728		
10	318,928	940,117	187,861	296,409	61,710	97,710	16,005	47,123		
11	312,085	1,019,359	454,835	618,300	34,370	99,800	35,734	271,602		
12	535,993	632,104	667,799	784,868	102,950	30,805	10,218	146,483		

The tables show that purse seine catch rates of yellowfin tuna are the highest early in the year, while those of skipjack increase towards the latter half of the year. French purse seiners seem to obtain higher catch rates of yellowfin inside the zone towards the middle and end of the year, but this is offset by better skipjack catch rates outside of the zone for most of the year. An exception to this trend is the Japanese purse seiners, which seem to target skipjack tuna and thus have higher catch rates for them than for yellowfin all year around. Japanese vessels exerted very low effort in the zone during 1990 and 1991, resulting in low inside catch rates there. During 1992, however, their effort levels were much higher, and relative catch rates inside and outside the zone displayed similar patterns to the French purse seiners.

Trends in the longline catch rates are far harder to spot; there is a lot of variation in effort distribution as well as catch rates. In general, catch rates of yellowfin are higher inside the zone towards the end of the year while bigeye catch rates are lower at these times. The Korean longliners seem to do better inside the zone for both species during the middle months of the year, while the Japanese, at least in early years, did even better for the two species during the first months of the year.

Although the catch rates provide a good indication of the behaviour of the fishermen, they are not sufficient to evaluate the worth of the zone, because different species fetch different prices. A small catch rate of a high value species may thus be worth much more that a high catch rate of a low value one. It was therefore necessary to incorporate this price into the calculation, in such a way that the revenue from fishing with a licence could be compared to the revenue that would have been obtained had the fleet not been able to fish within the zone at all.

Catch value

Suppose a fleet spent N_I days fishing inside the zone with a catch rate R_{SI} for a species S, and N_O days outside with a catch rate R_{SO} for the same species. The catch that was taken of species S is then $C_S = N_I$

$$V_L = \Sigma_S \left(N_I R_{SI} + N_O R_{SO} \right) P_S$$

$R_{SI} + N_O R_{SO}$, and the total catch value V_L, given that the fleet was licensed, is
where P_S is the price of species S. Although a license entitles a vessel to spend all its time fishing inside the zone, the above equation describes what the fishermen actually did; they had licences but chose to operate this way. If the fleet had not been licensed, it would have spent the total number of days $N_I + N_O$ fishing outside the zone, at a catch rate R_{SO}. The total catch value V_U, given that the fleet was unlicensed, would then have been

$$V_U = \Sigma_S \left(N_I + N_O \right) R_{SO} \; P_S$$

$$V = V_L \quad V_U$$

The value of having a licence is then given by
For longliners the effort is measured in number of hooks rather than days, but the calculation is otherwise the same.

The above calculation can be performed using historical catch rate and effort data aggregated over a number of different periods. It is therefore possible to determine the value that the licence brought to fishermen per fleet and year or month, or even over certain seasons.

The fish prices used in the following analysis were estimated using data from Infofish. Prices for the relevant fleets were not always available, so some assumptions had to be made, especially regarding the proportion of a longliner catch destined for fresh or canning use. The prices used are given below. Note that the assumed catch values were smaller for the Korean than for the Japanese longline fleets. This has implications for the relative levels of profits calculated later.

Gear	Fleet	Yellowfin	Skipjack	Bigeye	Albacore
PS	All	1.66	0.93	0.95	1.69
LL	Japanese	20.15		50	
LL	Korean	16.53		36.67	

Table 4.7.2.3 Tuna prices used in the modelling ($/kg).

Figures 4.7.2.1 (a) and (b) show the value V calculated from annual aggregated data for the purse seine and longline fleets respectively. As discussed before, the seasonal nature of the fishery means that catch rates inside the zone are not good throughout the whole year, so the annual aggregated V is usually negative. It was therefore necessary to look at these same values V on a monthly basis. These are depicted in figures 4.7.1.2 (a) to (e).

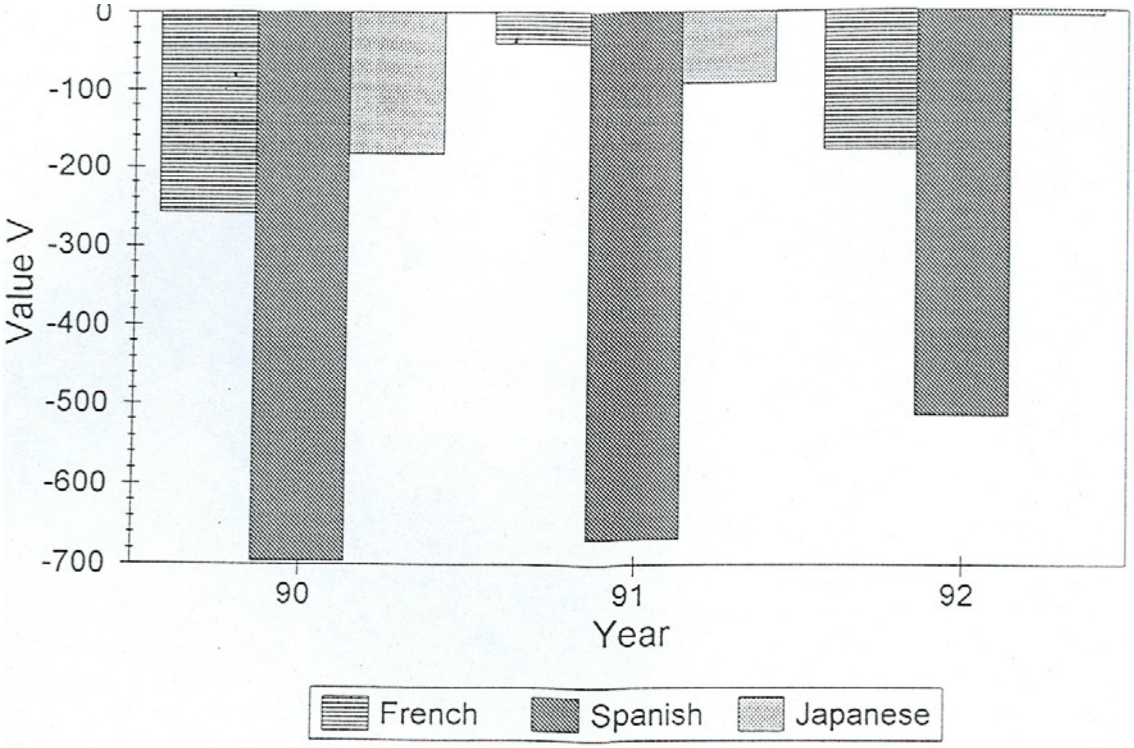


Figure 4.7.2.1 (a). Annual value V for the purse seine fleet, in thousand dollar units.

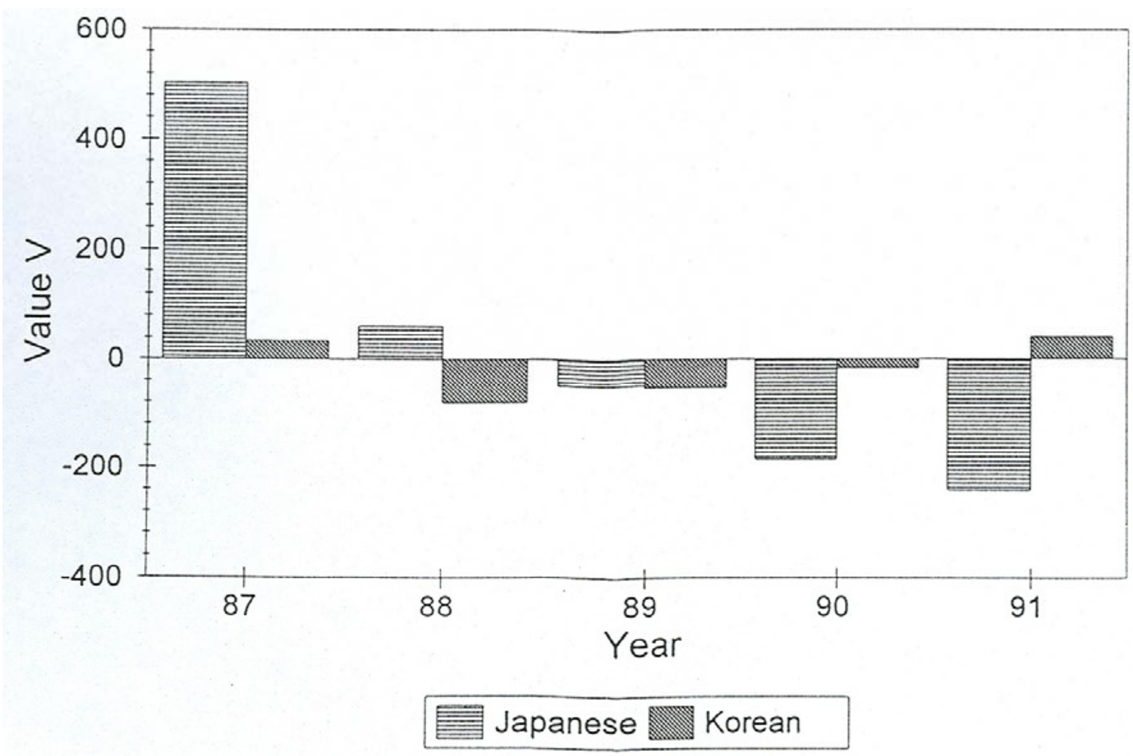


Figure 4.7.2.1 (b). Annual value V for the longline fleet, in thousand dollar units.

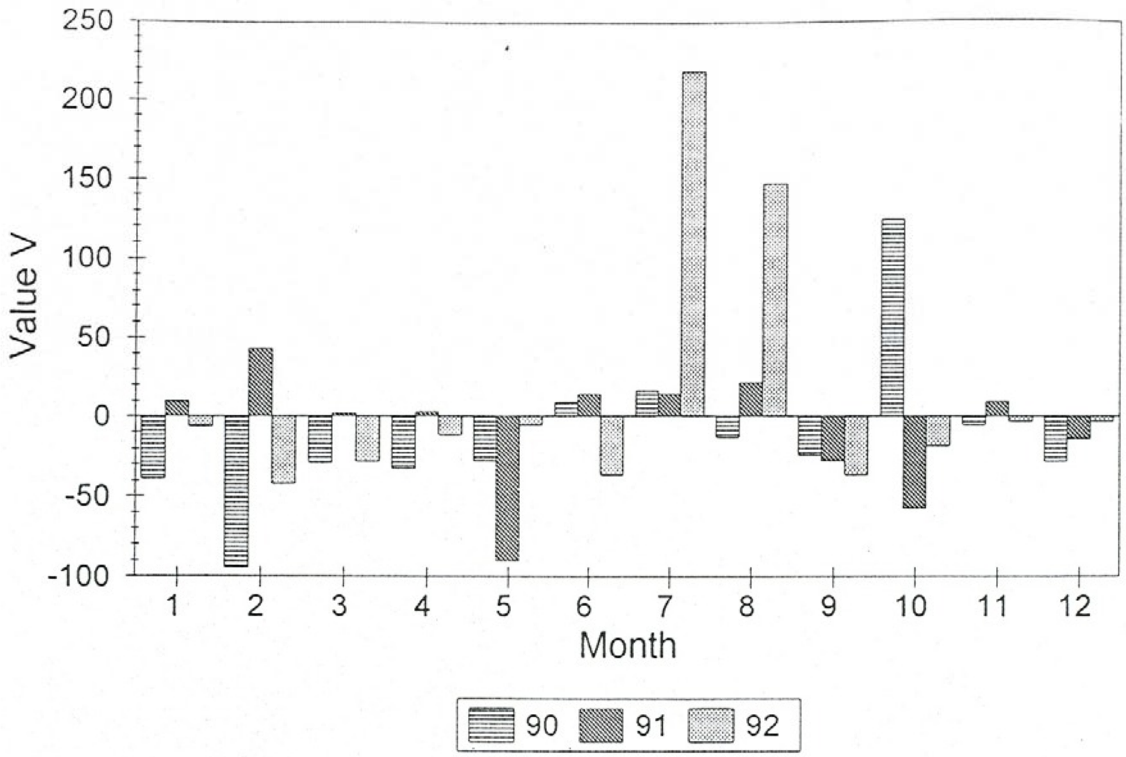


Figure 4.7.2.2 (a). Monthly values V for the French purse seine fleet, in thousand dollar units.

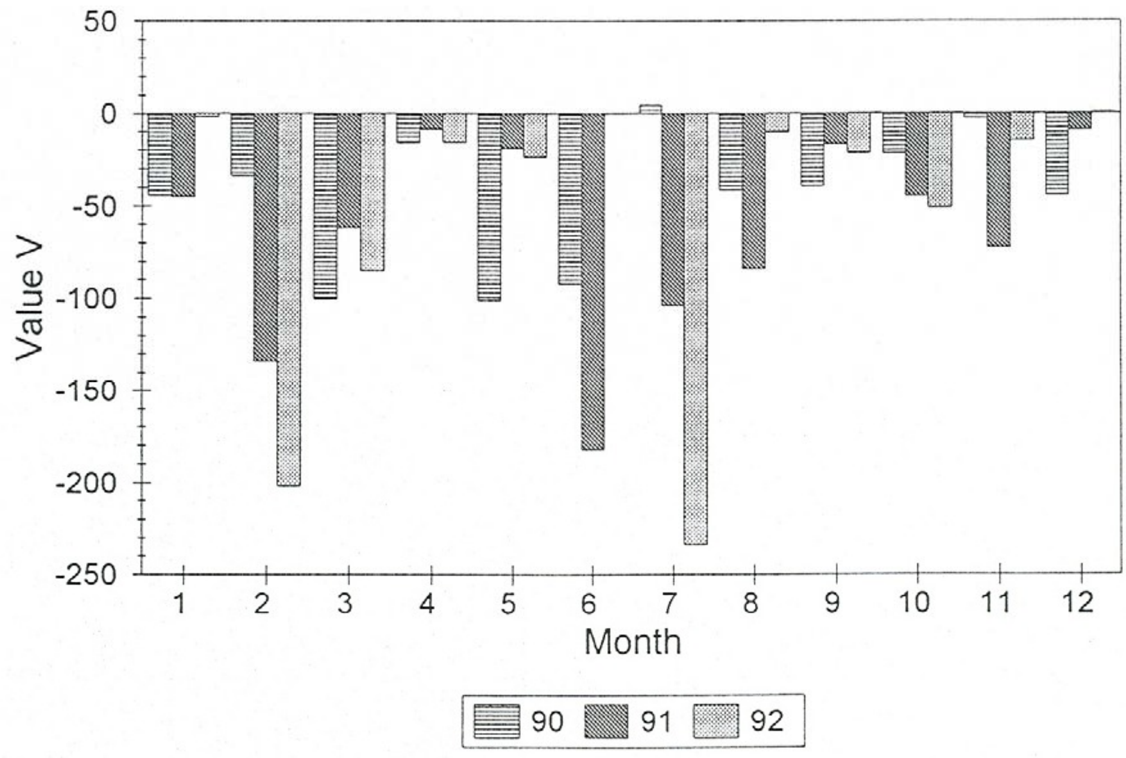


Figure 4.7.2.2 (b). Monthly values V for the Spanish purse seine fleet, in thousand dollar units.

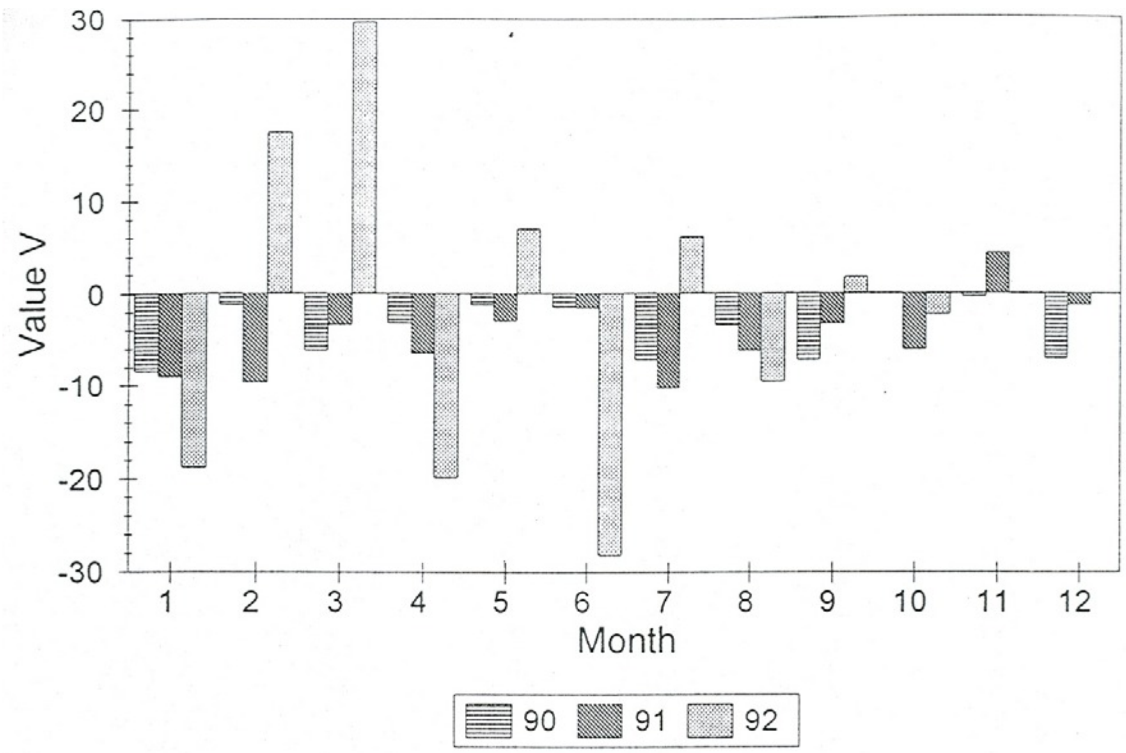


Figure 4.7.2.2 (c). Monthly values V for the Japanese purse seine fleet, in thousand dollar units.

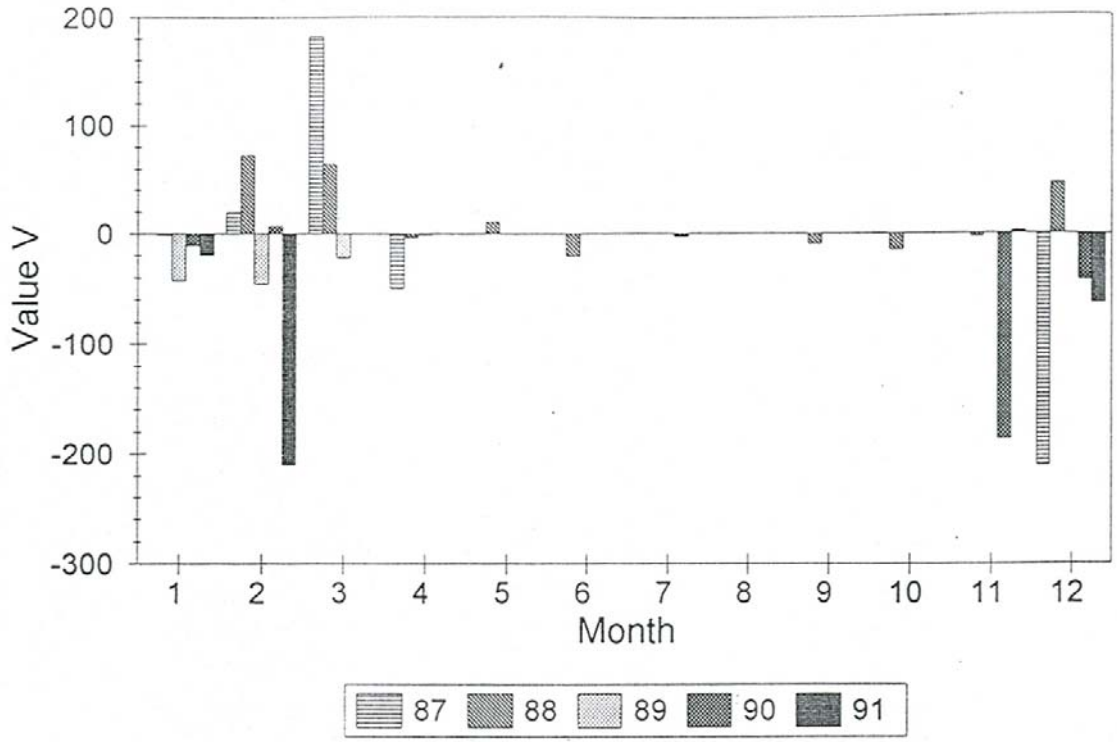


Figure 4.7.2.2 (d). Monthly values V for the Japanese longline fleet, in thousand dollar units.

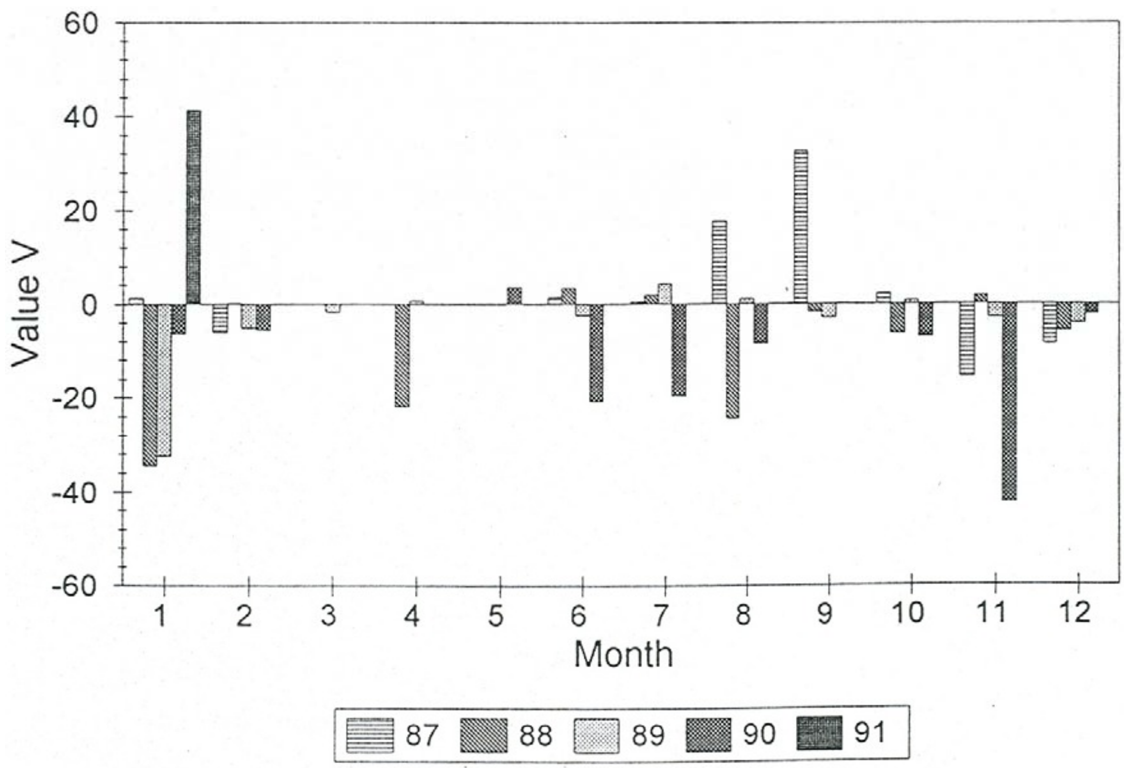


Figure 4.7.2.2 (e). Monthly values V for the Korean longline fleet, in thousand dollar units.

It is clear from the figures that for most of the year there is no apparent merit in being inside the zone. Nonetheless, for most fleets there have been some months in which it was highly profitable for the fleet to be able to fish inside the zone. Good months are not consistent over the years, however, so it is worthwhile for vessels to do small amounts of exploratory fishing inside so that they can exploit a good month when it arrives. A number of apparently poor months are based on very small catches due to low effort inside the zone, so it possible that this was such exploratory fishing. Generally, fleets expend a good deal of effort inside the zone when the catch rates are favourable whereas months showing negative profits are those with most activity outside the zone. That said, this is not always the case; in a few months fishermen appear to have behaved irrationally, spending large amounts of time on one side of the EEZ boundary while reporting the best catch rates on the other.

Special mention should perhaps be made here of the Spanish purse seiners, which appear never to have derived any benefit from the licences that they have continued to buy. There are other benefits to having a licence which will be discussed later, and perhaps these are prompting this fleet to buy licences. An alternative explanation is that the data are not as accurate as would be desirable.

It is fair to assume that what the fleets did in the past was in their best interests, so that where the value of the licence is negative, there was a reason for their fishing in the zone rather than spending all their time on the outside. Thus we regard the negative months as neutral, and concentrate on those months in which the licence enabled a fleet to make more that they would have otherwise. We define the average profit to

$$P = \max(0, V)$$

be made from fishing inside the zone as
Where V, the value of fishing in the zone, is averaged over the years, and calculated from either monthly or annual data. The average profits P, in thousand dollars, are listed in the following table.

Month	Purse seiners			Long liners	
	French	Spanish	Japanese	Japanese	Korean
1	0	0	0	0	0
2	0	0	2.3	0	0
3	0	0	6.8	75	0
4	0	0	0	0	0
5	0	0	1	10.8	3.7
6	0	0	0	0	0
7	82.8	0	0	0	0
8	51.6	0	0	0	0
9	0	0	0	0	7
10	16.1	0	0	0	0
11	0.3	0	2	0	0
12	0	0	0	0	0
Sum	150.8	0	12	86.7	10.7

Table 4.7.2.4. Profits P calculated per fleet from average monthly V values (k$).
It is also of interest to consider the profits P determined for each individual year for which there are data. These numbers are listed at the end of this section.

If a license could be useful for exploratory fishing or other reasons, it might well be desirable to have one, provided it is not too expensive. It is therefore worth considering how high the current licence fees are in relation to the value of catches that are taken.

The current value of a licence

Purse seiners

The Seychelles has a number of different licensing schemes for different purse seine fleets. These vary from fixed fees to a combination of fees proportional to catch and agreements for fish supply to the local cannery. The cost of these licences ranges from 2% to 20% of the value of the catch reported within the EEZ.

The following table lists the average catch value per day reported inside the EEZ by the various purse seine fleets.

Fleet	Catch value per day in EEZ	Catch value per set in EEZ
French	$21,000	$30,000
Spanish	$16,000	$37,000
Japanese	$16,000	$31,000

Table 4.7.2.5. Value of the purse seine catch per day and per set.

The licence fees are equivalent to the value of between 0.5 and 3.6 sets, or 1.1 and 6.5 days.

Purse seine vessels make a number of trips to port every year. At the start of a new fishing trip, having a license would enable a vessel to fish while steaming towards the fishing grounds, whereas an unlicensed vessel would have to spend a day steaming to outside the zone before commencing fishing. This means that, over the year, a license will allow the fleets a number of extra days fishing. Using the catch values per day listed above, the value of these extra days is listed in the following table.

Fleet	No of trips to port per year	Value of extra 1 day per trip
French	9	$192,000
Spanish	7	$117,000
Japanese	5	$83,000

Table 4.7.2.6. Annual value attached to being able to fish during port visits.

This value is a good deal more than the average licence fee in the case of the EU vessels, and a sizeable proportion of the fee for Japanese ones.

Longliners

Longlining licences are issued on a monthly basis and are a fixed amount per GRT. The licence fee amounts to between 5 and 7.5% of the EEZ catch during a good month.

Japanese longliners' catch value is on average $48,000 per day, while the Koreans run at an average of $27,000 per day. The monthly licence fee is thus covered by a small fraction (7-15%) of a single day's fishing. Longliners do not need to tranship during a trip, which may last for more than a year. They make fewer port calls than purse seiners and cover larger distances, calling at different ports. Therefore, the benefit of being able to fish *en route* out of port is negligible.

Model inputs for licence value

The profit to a fishing vessel of being able to fish inside the zone is one of the inputs to the Control of Foreign Fishing model. For the purse seiners, an annual value is required, since this is the period for which licences are bought. The profit used for the purse seiners is a combination of the average annual profits P described (and tabulated) above and the value of being able to fish *en route* from the port as listed in the previous table. These parameters were simply summed to become the values tabulated below.

Purse seiners	French	Spanish	Japanese
Average annual profit	342	117	95

Table 4.7.2.7. Purse seine average annual profit (thousands of dollars) from fishing inside the zone.

Profits for individual years were also calculated so that the effect of variability in the fishery could be investigated. These figures are listed in the following two tables and were used as inputs for part of the analysis, the results of which will be discussed in the next section. Note that the average results in the tables above are not direct averages of the annual ones listed below, but rather profits calculated from averaged values V, which comprise both positive and negative numbers.

Purse seiners	French	Spanish	Japanese
1990	341	122	83
1991	308	117	88
1992	557	118	146

Table 4.7.2.8. Purse seine annual profit per year (thousands of dollars) from fishing inside the zone.

The longliners buy their licences by month, so the model used the monthly profits P. Port trips for longliners are not considered. The following table lists the average monthly profits, which are of course the same as listed in Table 4.7.2.4.

Longliners average monthly profit	J	F	M	A	M	J	J	A	S	O	N	D
Japanese	0	0	75	0	11	0	0	0	0	0	0	0
Korean	0	0	0	0	4	0	0	0	7	0	0	0

Table 4.7.2.9. Longline average monthly profit (thousands of dollars) from fishing inside the zone.

As with the purse seiners, it is also important to consider the monthly profits for individual years. These are given in Table 4.7.2.10 below. Note that for each month, the averages in Table 4.7.2.9 were calculated from the differences in average values across years, including both positive and negative values, and so these will not be equal to the simple average of the entries in Table 4.7.2.10.

Longliners	Year	J	F	M	A	M	J	J	A	S	O	N	D
Japanese	87	0	20	182	0						0	0	0
	88	0	73	65	0	11	0			0	0	0	46
	89	0	0	0	0								
	90	0	7					0			0	0	0
	91	0	0									2	0
Korean	87	1	0				1	1	18	33	2	0	0
	88	0	0		0		4	2	0	0	0	2	0
	89	0	0	0	1		0	4	1	0	1	0	0
	90	0	0			4	0	0	0	0	0	0	0
	91	41											

Table 4.7.2.10 Longline monthly profit per year (thousands of dollars) from fishing inside the zone.

Table 4.7.2.10 reveals starkly the extent of variability in estimated profits for the longline vessels. With the exception of 1991, where the database records only one Korean vessel fishing in January (ironically producing the largest monthly profit), there were reasonably large numbers of Korean vessels operating in the period 1987 - 1991. Even so, it was only for August and September 1987 that substantial monthly profits were estimated.

For the Japanese fleet, however, it is very difficult to summarise monthly estimated profits. In 1987, 8 Japanese longliners were recorded as fishing around the Seychelles, and substantial profits were estimated for February and especially for March. The fleet increased to 19 in 1988, with good profits estimated for February, March, May and December. In 1989, the fleet had increased again to 21 vessels, but despite fishing in the first four months, in no month was a profit estimated. Perhaps in response to that, the fleet dropped to 5 vessels in 1990 and 6 in 1991. In only two of the ten months fished over those two years was a profit estimated.

4.7.3 Optimal policies

In this section, the results of applying the Control of Foreign Fishing methodology to the Seychelles data will be described. Section 4.7.3.1 describes the results of the analysis for the various purse seine fleets, both individually and in combination. Similar results for the longline fleets are discussed in section 4.7.3.2. Finally, section 4.7.3.3 expands on the conclusions that can be drawn.

As noted earlier, many details must remain confidential, especially those that relate to surveillance issues. These details will be submitted in a separate, confidential report to the Seychelles Fishing Authority.

Purse seiners

Given the type and structure of airborne surveillance in the Seychelles zone, the probability of detecting a vessel given that it is in the zone could be estimated. The probability of a vessel being in the zone on the day of a surveillance flight is calculated using the average number of days per year that purse seiners spend fishing inside the zone. As explained in section 3.2.2, this enables the probability of detecting an offending purse seiner during one surveillance flight to be estimated. This detection probability was used in all the purse seine calculations that follow.

<u>French purse seiners</u>

The profits associated with fishing inside the zone amount, on average, to $342,000, as discussed above, and listed in table 4.7.2.7. Theoretically, vessels should be prepared to pay up to that amount for a licence, provided that this is less than the expected fine. The vessel value is estimated at $17,500,000, and the average hold contents at $547,000. The maximum possible fine that could be levied is confiscation of both the vessel and the catch, i.e. a fine of about $18,000,000. With fines at this level, the amount of surveillance needed to keep expected fines greater than the licence fee would be minimal, even with fees set at the maximum level of $342,000. Of course, this is a far higher licence fee than is reasonable to charge, but it is a useful figure for comparison with current fee levels.

A problem with the above argument is that setting fines to these maximum possible levels would be unthinkable. In practice, a more reasonable fine level would be 10% of the total value of the boat, plus confiscation of the catch. For purse seiners this would amount to approximately the value of the fishing gear. If fines are set at these levels, clearly more surveillance is necessary than when fines are at their maximum. The number of surveillance flights required is that number which just ensures that the expected fine exceeds the expected profit to be made from fishing inside the zone. In this case, considerably more flights would be required than before.

Another issue to be considered is that the profits associated with fishing in the zone can vary considerably from year to year. Thus, it was also necessary to look at the profits for individual years, as calculated in the previous section and tabulated in table 4.7.2.9. From this it can be seen that the actual annual profits ranged from $308,000 to $557,000, so the ideal number of surveillance flights can be calculated for each year. In reality, licence fees are much lower than these profits might suggest is possible, so the amount of surveillance required to match the expected fine to the licence fee is much less than it would be otherwise. The number of flights required in such circumstances is once again minimal.

For the rest of this discussion, maximum fines will be considered to be 10% of the total value of the boat, plus confiscation of the catch.

<u>Spanish purse seiners</u>

The only profit that the Spanish purse seiners seem, on average, to make out of fishing inside the zone is due to the value of fishing during port trips. This amounts to $117,000, which is then the theoretical maximum licence fee. The maximum fine that could be imposed is around $2,000,000 and, with such a fine, relatively little surveillance is needed even to match the theoretical maximum fee. Again, setting the fees below the maximum, as is currently the case, would reduce the need for surveillance even further.

There has been little inter-annual variation in the estimated profits due to having a licence.

Japanese purse seiners

The average profit due to fishing in the zone by Japanese purse seiners was estimate to be $96,000. The maximum fine for this fleet is $1,050,000, and the highest possible fee is $96,000. The licence fee currently paid by this fleet is much closer to this maximum that was the case for the other fleets. Even so, the surveillance levels required are about the same as for the Spanish fleet.

The average profit quoted above is a slightly misleading figure, since the effort levels in 1990 and 1991 were very low indeed, while 1992 showed larger effort and correspondingly greater profits. Considering 1992 alone, with its estimate profit level of $146,000, would lead one to believe that higher licence fees could in principle be possible. This would, or course, require greater levels of surveillance to enforce.

When considering the three fleets simultaneously, the licence fees can be specific to each fleet (as is the current Seychelles policy), so need not differ from the single fleet cases. The number of surveillance flights required should be set at the maximum of the three fleets' requirements, taking into account the fine proportion chosen.

Longliners

Longliner calculations were done on a monthly basis because longline licences are bought month by month. This has an impact on the probability of detecting a longliner on a surveillance flight. The probability of detecting any vessel during a flight, given that the vessel is in the zone, is the same as for the purse seiners, but the probability of a longliner being in the zone varies amongst months. This means that the overall probability of detecting an offending longliner during one surveillance flight varies monthly and depends on the level of activity inside the zone during that month.

The longline input data was derived in section 4.7.2, and the main profit inputs were listed in table 4.7.2.9 and 4.7.2.10. Trips to port are not as important or as regular for longliners as for purse seiners, so the advantage of fishing during trips to port was not included in these estimated profits.

Japanese longliners

Following a similar procedure to that used for the purse seiners, calculations are first based on average monthly profits using the estimates in Table 4.7.2.9. For Japanese longliners, only two months were profitable on average, March and May, in which estimated profits amounted to $75,000 and $11,000 respectively. It follows that, if the licence fee was set at $11,000 per month or less, vessels would see benefit in buying licences during both months. However the theoretical maximum profit to the state would result from a fee of $75,000 per month, with vessels only buying a single monthly licence. One surveillance flight in each of the two months would be more than sufficient to deter illegal fishing.

As noted earlier, however, the use of monthly averages for the Japanese longliners may be particularly misleading. For example, in only 3 of the 31 months for which profits could be estimated for the Japanese longline fleet was the estimated profit close to or above $75,000, and all three of these occurred in 1987-88. The highest individual monthly profit estimated for 1989-91 was $7000. On these data, reasonably substantial monthly licence fees may have been justified for the first two years, but almost certainly not for the last three years of data.

The individual monthly estimates of profits also indicate that it is difficult for both the state and the Japanese fishermen to predict for which (if any) months it will be worth buying a licence. The principal season for Japanese longliners now appears to be November to February, though in earlier years March has produced substantial profits. This lack of predictability also has implications for the setting of licence fees.

Korean longliners

Based on monthly averages across years, Korean longliners show average profits of $4,000 and $7,000 in May and September. In part, these are smaller than those for the Japanese because of the assumed lower prices obtained by the Koreans for their fish. In this case, the licence fee that maximises state revenue is

$4,000, with licences being bought in both months. One surveillance flight in each of the two months will ensure an expected fine far greater than the potential profits from illegal fishing.

Year on year variation is also high for Korean longliners, though not as marked as in the Japanese case. Monthly profits were as high as $41,000 on one exceptional occasion (though this was from just one vessel) and all years had at least one month with an estimated profit of $4,000 or more. However, the profits also suggest that with a fee of $4,000, vessels would only have found licences worthwhile in 6 months out of the five years studied.

4.7.4 Conclusions

Depending on the fleet, the estimated values of fishing in the Seychelles zone are comparable to and in some cases greater than the current, rather modest, licence fees. Estimation of maximum possible fees for purse seiners based on average profits appears reasonable, with inter-annual variability not being too large. Availability of estimates of the theoretical maximum fees is important, because it indicates the extent to which it might be possible to negotiate changes in existing licence fees. A further factor in the setting of appropriate fees is the level of surveillance that can be carried out.

For longliners, variability is much more of a problem. Although some months can produce very high estimated profits from fishing in the zone, these are relatively rare. In the presence of such uncertainty, it is sensible to keep fees at relatively modest levels, to encourage licensing in as many months as possible.

An ideal system would have some level of surveillance in any month where there could potentially be a profit. With potentially profitable months being so difficult to predict for longliners, this poses some problems. As with all the other case studies, the need for surveillance reduces as the fines that can be imposed increase. Targeted surveillance, perhaps based on intelligence, can also increase the probability of detection on a single flight, and thereby also increase the perception of risk among fishermen.

The analysis in section 2 indicates that licence fees should be proportional to the expected profits. In the Seychelles tuna fishery, the estimated profits vary among fleets and it is thus appropriate for different fleets to be charged different fees. The Seychelles Fishing Authority currently does charge different fees for each purse-seine fleet and long-line vessel category. The results obtained in this study allow advice to be given on possible amendments to these fees.