CONTROL OF FOREIGN FISHERIES

RESEARCH REPORT

The Construction of a Model to Optimise Benefits to Costal State Developing Countries from the Control of Foreign Fishing

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NB Unfortunately, the figures in this report are no longer available.

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Project Framework

Globally, the entire fisheries sector remains dominated by fleets and companies from only a few maritime nations; Japan, USSR, Korea, Taiwan, USA, Spain and France, etc. These countries possess large domestic fleets that exploit their national fish stocks optimally (very often with major over-capacity) or at a lowered level resulting from over-exploitation. Combining their domestic demand and industry structure (and other factors), these countries have expanded their activities to almost all the world's oceans. There is little scope for major increases in catch beyond the 100 million tons currently produced.

The general movement towards unilateral extensions of marine zone sovereignty that began in the late 1970s and was finally embodied in the 1982 United nations Law of the Sea was a direct response to the threat by distant water fishing nations (DWFNs) to stocks of fish adjacent to countries which had their own domestic requirements or developing fishing industries. Open access to the then "common property" resources of the oceans, at least those resources close to countries which were not DWFNs thus came to an end.

The experience of all countries to controlled access fishing has been mixed and the benefits that were presumed would accrue bot to individual nations and to the general health and productivity of fish stocks has remained less than satisfactory.

At the outset of the 200 mile zone era there were few frameworks or planning horizons that could be used to take control of newly acquired fish stocks to ensure sustainable conservation while securing optimum benefits from their exploitation. Most countries have with a few exceptions proceed by trial and error, particularly developing countries.

This project proposes a major study of the ways in which distant water fishing fleets and developing coastal states have responded...

Control of Foreign Fishing

Fisheries management regimes may evolve in one of two ways; either through international agreement and cooperation or through extended fisheries jurisdiction of individual nation states.

History reveals that management of fisheries on an international scale is extremely complex and difficult. This has been exemplified in various international fisheries management bodies such as NEAFC, NAFO, and IWC, the performance of which has often been particularly poor primarily because of the related problems of voluntary membership and 'free riders' (Cunningham et al, 1985). Furthermore the situation of res nullius or res communes under which such management regimes exist make it almost impossible to enforce unpopular decisions.

Partly because of the inadequate performance of international management and partly due to various unilateral declarations of extended fisheries jurisdiction by a number of South American countries during the late 1940's, mainstream views of ocean resources being res nullius began to change and by the 1970's was moving rapidly in the direction of private ownership for the coastal state.

These actions stimulated a widespread move towards 200 mile limits which emerged from within the United Nations Conference on the Law of the Sea (UNCLOS), and which where finally confirmed by that Convention in 1982.

Essentially, six principles underlie the provisions set out in the Convention. The most important of which is the principle of extended jurisdiction over all living and non-living resources by the coastal state (CS) within an Exclusive Economic Zone (EEZ) of 200 miles and a territorial limit of 12 miles. The remaining principles cover management guidelines and access rights to surplus resources by geographically disadvantaged states and the management of resources in the 'high seas' beyond the EEZ's.

The move towards extended fisheries jurisdiction has had a wide-ranging set of economic impacts which are both complex and multidimensional. These include improved fisheries management, production, consumption and welfare of coastal states and their communities, as well as various trade effects. More immediately important, it provides various benefits through permitted access (usually restricted) of foreign vessels.

Permitted access and foreign fishing

Both the CS and the distant water state (DWS) benefit from permitted access. The CS through access fees and arrangements and the DWS in terms of an increases resource base available for exploitation.

Permitted access, usually involving transfer of income from the distant water state (DWS) to the CS is particularly valuable to a developing country, especially if the country is unable to exploit the resource itself. Other benefits may also be realised such as receipt of foreign exchange, increased local landings and local fishery development through joint ventures. Such a venture recently began in Mauritania where french fishermen, exploiting langoustine stocks, faced either substantial increases in access fees, or agree to joint ventures for investment in development of the CS fishing fleet. This situation, common to many developing countries arises, more often than not, when the allocation of access rights through licence fees, contributes little in the way of economic growth and development.

Study Rationale

Maximising benefits from resources contained with the EEZs of developing countries forms the backbone of the present study.

The study uses mathematical bioeconomic analysis and optimal control to investigate the relationship between the potential benefits of foreign vessel licensing and the prerequisites to effective fisheries resource management notably the cost of monitoring, control and surveillance. These findings are considered in relation to national fishery development.

BACKGROUND - CONTROL OF FOREIGN FISHING

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 many cases decisions about access will be taken for political reasons rather than economic ones. However, key decisions which are critical to the sensible use of both the marine resource and the scarce resources of capital in the country must be taken.

If the decision is taken to permit foreign fishing then a whole series of secondary decisions are required which involve deciding at what level to set licence fees, what amount of money to spend on policing and surveillance and what legal framework, especially the level of fines for illegal fishing, is sensible.

The project is aimed at developing a suitable framework based on modern mathematical bioeconomics that answers these questions for developing countries in a practical and rigorous way. The project has first reviewed the access of foreign fleets in a variety of different cases and, with the benefit of these data, developed realistic mathematical models which can be manipulated to assess what are the optimal management decisions.

The project has found that the data necessary to answer the questions are often available but not collected. A key result indicates that it is critically important to relate the fines for illegal fishing directly to the value or fishing power of the vessels concerned. This is so whether the decision is taken to spend large or small amounts on surveillance and seems perfectly general.

The models developed enable one to choose the optimal combination of levels of licence fees and investments in surveillance which will maximise the benefits to the coastal states, subject to necessary conservation restraints. These general models are now being applied to a wide variety of different types of fisheries. These vary from small island states dealing with heavily capitalised long-distance fishing fleets to coastal states who have a significant fishing industry and infrastructure of their own.

A vital aspect of this project is going to be the way in which it is disseminated to appropriate fisheries managers in the developing countries. It is intended that computer software in the form of a management game will be developed and used during the dissemination of the results of the project. Overseas experience has been that such games have proved very effective in getting difficult concepts across to managers.

A challenge to the project and its staff is to see the results utilised by developing countries. It is the firm belief of all those involved that this will happen, and prove of significant benefit.

**Coastal States and Distant Water Fishing Nations
: Conflicting Views of the Future.**

It has now been accepted that Extended Fisheries Jurisdiction, and the resultant 200 mile Exclusive Economic Zones, arising from the U.N. Third Conference of the Law of the Sea, constitute customary international law. It has also been generally agreed that the fishery resources within the 200 mile zones are, to all intents and purposes, property of the adjacent coastal states.

Coastal states opting to permit a distant water presence in their 200 mile zones are faced with several economic problems. One such problem is that of devising optimum terms and conditions of access to the coastal state Exclusive Economic Zones to be imposed upon the distant water fleets.

It has been argued (Munro 1981) that the decision to licence foreign fleets or not, is best viewed in the light of the relative costs of harvesting for domestic and foreign fleets. He showed that, in many cases, economic analysis will lead to a solution where all rights to exploit are either allocated to the domestic fleet or to foreign fleets.

In contrast, Beddington and Clark (1984) consider the allocation problem in the context of the stochastic nature of renewable resources and show that, in many situations, a mix of domestic and foreign fleets will be optimal.

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1Optimal control where developing countries should chose between developing their own fishing industry or licensing foreign fleets has been addressed. Allocation between foreign fishing fleets : The Falkland Island squid fishery.

2 Interplay between the level of surveillance and its cost, the level of fines for illegal activity and the level of licence fees and the value of a licence.

3 Empirical foundation derived from a set of case studies of foreign access. This work has not been done see E.J's study of BIOT.

4 Investigate, analyse and produce a general overview of the level of foreign fishing activity and their regulatory environments on a global scale in developing countries.

5 take examples of 3 or 4 developing countries fisheries and undertake detailed analyses of their bioeconomic characteristics, including the calculation of the marginal value of

2 MODEL DEVELOPMENT

The development process for the construction of the model for the Control of Foreign Fishing took a number of mathematical constructions from first principles and modified these step by step to accommodate increasingly complicated sets of different conditions to mimic the decision processes that fishermen and the state would take under a number of different scenarios.

These step by step constructions have been written up as a set of research notes these are available for examination but have been summarised here in this research report.

Where any assumptions have been made about conditions or patterns of behaviour these have clearly been stated.

First Principles

In the first stage, building upon the essential assumption that the coastal state had resources extending beyond the 200mile zone and that the catch rates of the resource were higher inside of the zone than outside of the zone, a number of simple situations were examined from both the fishermen / vessel owner's and the state's point of view. These models can be examined in more detail in Appendix 1.

First Principles - Model One

In model one it was determined in the simplest case that fishermen will want a licence if the value of the catch minus the probability of being caught for fishing illegally times the level of the fine is greater than the value of the catch minus the licence fee.

The state's income assuming that the number of licences or unlicensed vessels are not affected by the level of the licence fee or fine, will be either from licence fees and/or from fines. Making a further assumption that outgoings are only with respect to surveillance and that the cost of surveillance increases as the, probability of detecting illegal fishing increases, an expression was derived for income return to the state. The "control" variables in the expression are the licence fee, the probability of catching a poacher and the fine, see expression1 in Appendix 1. As the expression is linear for both the licence fee (L) and the fine (F), the maximum return will occur when both are set at a maximum amount. However, there are likely to be realistic levels at which both of these values can be set. This expression was solved mathematically in order to maximise the income return. The probability of catching any poacher (q) will tend towards a unitary value 1 as both the fine and a parameter k (determining how fast q increases with respect to increasing cost) increase. In reality it is unlikely that the probability of capture is close to one and there will be an upper limit for q say qmax. Likewise there is likely to be a lower limit for q say qmin, if there is no surveillance then there would be no incentive for the fishermen to take up a licence. A mathematical solution for this expression shows the conditions when q is likely to tend towards qmax.

First Principles - Model Two

In model two, the mathematical expression from model one was extended to include a fleet of size N which is interested in fishing in the area. The expression then contains the variables F, L, q and an additional control variable N, the number of licences. The function was then maximised with a number of realistic constraints relating to the other variables for the fine, licence fee and q. There are two possible solutions to the problem. When the two solutions are evaluated, the optimal solution is the one which gives the maximum expected income. This was done by considering the critical licence fee where the two maxima meet. The interesting feature of this model when the optimal solution is sought it recommends that the solution is either all licences or no licences and not a mixture of the two. However, it does make the assumption that the fishermen all respond in the same way and the levels of Lmax and Fmax have been set in a sensible way.

First Principles - Model Three

One of the limitations of model two is that it does not take into account the fishermen's response with respect to the taking up of licences. In model three this is modelled by assuming that the number of licences (n) that are taken up are directly related to the licence fee (L). Assuming a linear relationship between n and L then the mathematical expression developed from the previous models can be further developed to give an equation that is quadratic with respect to the licence fee, see equation 5 in Appendix 1. The unconstrained optimal solution for this equation is to set no licences.

Models with Decision Rules

From the first principles in the development of the model as outlined in Appendix 1, an approach was taken to develop the model further by examining the different areas of parameter space, outlined by the terms from the mathematical expression developed from the first principles, as they are likely to be constrained by different sets of decision rules that would be likely to govern the behaviour of the fishermen and coastal state in different conditions. An understanding of the interaction of the variables is sought in order to determine how best to optimise the benefits or revenue to the state under different sets of parameter conditions.

During the course of the research for this project there were several refinements to the development of the decision rules. These have been outlined in a series of research notes produced for this project.

The construction of a number of sets of decision rules and additional modelling of the parameters around these rules to account for factors such as 1) the relationship between probability of capture, surveillance costs and the expected penalty; 2) different classes of vessels; and 3) conservation constraints, was undertaken to provide the mathematical framework around which the model for the control of foreign fishing could be constructed. The technical details are considered in Appendix 2.

The overall approach to the model development undertaken that can be followed in the descriptions of the research process outlined below was to construct the model from the simplest possible situation, so that it increasingly took onboard more realistic situations, i.e from the simple decision to licence or not licence, to a situation that incorporated a risk prone attitude by the fishermen. In the next steps the relationship between probability of capture, surveillance cost and the expected penalty is explored. An expansion of the model is then undertaken to explore the likely optimisation process if more than one fishing vessel is considered i.e. a fleet of vessels and further expanded to consider optimisation outcomes if the vessels in the fishery were of different categories, size or otherwise. In a further step, conservation constraints are incorporated into the model through a linear programming approach.

ADD IN : E J s further modelling work incorporating game model approach to anticipate fishermens likely behaviour.

Version One of the Decision Rules - Fishermen are Risk Neutral

As a starting point a number of areas are defined mathematically from a set of parameters for the licence fee (L), expected penalty for fishing illegally E(F), the probability of being caught (q), and a non-zero surveillance cost (s) that coincide with a) fishing with a licence, b) fishing illegally and c) fishing legally without a licence. This is done by applying a simple set of decision rules that may be undertaken by the fishermen when deciding which of the three strategies to follow. It is assumed fishermen are prepared to pay as much as the marginal revenue in licence fees and as an expected penalty. The marginal revenue is the difference between the expected revenue from fishing with a licence and from fishing legally without a licence. The fishermen's decision rules summarised in words are :

FISHERMEN :

if the licence fee is less than the marginal revenue and less than the expected penalty then fish with a licence.
if the expected penalty is less than the marginal revenue and less than the licence fee then fish illegally.
if the licence fee and the expected penalty are the same and both are less than the marginal revenue then it doesn't matter - either fish illegally or with a licence.
in all other cases, either fish legally outside the zone or not at all.

In the third case, whatever the decision, the state does not receive any income from the vessels, i.e." no contribution".

The state may however, make a different set of decision rules. It assumes that there is a non-zero surveillance cost associated with the illegal fishing. The expected income to the state would then be expected fines minus surveillance costs. The decision rules for the state summarised in words are :

STATE:

Let the licence fee and expected penalty be less than or equal to the marginal revenue then,
if the licence fee is less than the expected penalty minus the surveillance cost per vessel then don't issue licences.
if the expected penalty minus the surveillance cost per vessel is less than the licence fee then issue licences.
if the licence fee and expected penalty minus the surveillance cost per vessel are equal then do either.

The overlap in parameter space between these two sets of decision rules, if one is placed over the other, is the area where the fishermen and state are both agreed on their strategy, i.e. the state wishes to issue a licence and the fishermen want a licence.

The optimal solution for the state in this simple model is to set both the licence fee and the fine equal to the level of the marginal revenue. If this were the case, however, in theory the fishermen would have no incentive to buy a licence. For the state, net revenue would be higher if all vessel were licensed, if licensing them all implied no surveillance costs. It is unrealistic to assume that fishermen would, however, take up licences if they knew that there would be no surveillance.

Appendix 2

Decision Rules

Version 1 of the Decision Rules - Fishermen are risk neutral

As a starting point, the areas of parameter space coinciding with (a) fishing with a licence, (b) fishing illegally and (c) fishing legally without a licence or not at all, are defined. This is done by considering the types of decision rules that fishermen and a coastal state may use to make their decisions, with respect to the parameters outlined below.

The decision rules for fishermen. Let MR be the marginal revenue, in other words the difference between the expected revenue from fishing with a licence (C_L.p) and from fishing legally without a licence (C_U.p). Here C is the catch, subscripts L and U signify 'licensed' and 'unlicensed' respectively and p is the unit price of the catch. Note that by definition $C_L > C_U$ and fishermen would fish illegally when unlicensed to try and push their catches up towards C_L.

In this simple version of the decision rules, it is assumed that fishermen are prepared to pay as much as the marginal revenue in licence fees and as an expected penalty.

Let L be the licence fee and E(F) be the expected penalty for fishing illegally. This term is the product of the fine, F, and the probability of being caught and charged (sometimes referred to as 'q').

These decision rules can be summarised as follows, first in words and then in terms of the parameters defined above:

FISHERMAN:

if the licence fee is less than the marginal revenue and less than the expected penalty then fish with a licence.
if the expected penalty is less than the marginal revenue and less than the licence fee then fish illegally.
if the licence fee and the expected penalty are the same and both are less than the marginal revenue then it doesn't matter - either fish illegally or with a licence.
in all other cases, either fish legally outside the zone or not at all.

[1a] FISHERMAN

> if L $\leq$ MR and L < E(F) then fish with a licence
> if E(F) $\leq$ MR and E(F) < L then fish illegally
> if L and E(F) $\leq$ MR and L=E(F) then do either (licence or illegal)
> if L > MR and E(F) > MR then fish legally (but unlicensed) or not at all

The areas of parameter space coinciding with the above decision rules are illustrated in figure 1a.

Figure 1a The parameter space defined by the fishermen's decision rules.

Note that in the third case, whatever the decision, the state does not obtain any income from these vessels. This is referred to as 'no contribution'. It is important to note that when conservation constraints are incorporated into the model, the decision of whether to fish legally without a licence or not at all becomes important. The expected penalty may also include an aspect of 'expected loss of catch' if the vessels is caught fishing illegally. This aspect is aimed at taking into account the fact that once a vessel has been caught it would not be allowed to continue fishing for the rest of the season. Note that this aspect of the expected penalty would affect the fishermen's decision but not the value of the income to the state.

State Decision Rules : Assume that there is a non-zero surveillance cost, s, associated with illegal fishing. (We assume that s is a 'per fishing vessel' surveillance cost at this stage). The net income to the state from a vessel that is caught fishing illegally is then E(F)-s. Now the following set of decision rules can be set up:

STATE:

Let the licence fee and expected penalty be less than or equal to the marginal revenue then,
if the licence fee is less than the expected penalty minus the surveillance cost per vessel then don't issue licences.
if the expected penalty minus the surveillance cost per vessel is less than the licence fee then issue licences.
if the licence fee and expected penalty minus the surveillance cost per vessel are equal then do either.

[1b] STATE

Let $L \leq MR$ and $E(F) \leq MR$ then
if $L < E(F)-s$ then issue no licences (i.e. let vessels fish illegally)
if $E(F)-s < L$ then issue licences
if $L=E(F)-s$ then do either (licence or illegal)

The areas of parameter space coinciding with this set of decision rules are illustrated in Figure 1b.

Figure 1bThe parameter space defined by the states decision rule's.

If the two sets of decision rules are considered together, it is clear that there is only one area of 'agreement' between the state and the fishermen. This area lies between the two lines where L=E(F) and where L=E(F)-s and coincides with fishermen wanting licences and the state wanting to issue licences (Figure 1c). At the 'edges' the state can do either (where L=E(F)-s) and fishermen would do either (L=E(F)).

Figure 1c The parameter space where the fishermen's and state's decision rules overlap.

It can be seen from this figure that for the state the optimal value for setting the licence fee, would be to set it equal to the marginal revenue, L*=MR. The optimal level of the expected penalty would also be at the marginal revenue, E(F)*=MR. This would imply (in theory at least!) that fishermen would be indifferent between having a licence and fishing illegally.

It is, however, clear that licensing all vessels would bring in a higher net income to the state than having all vessels fish illegally, if licensing all vessels implies no surveillance cost. In practice, this may not make sense since fishermen would not take up licences if they know there is no surveillance. This would therefore only make sense if there is surveillance (i.e. a non-zero probability of being caught fishing illegally) but with zero or very low cost associated with it.

At this stage it is also useful to note that if a conservation constraint needs to be imposed on the number of licences that are issued, vessels that do not get licences would be fishing illegally because they are assumed to be indifferent to the choice of licence or no licence. Note that this assumption implies a kind of risk neutral attitude by fishermen. In version 2 of the decision rules, a risk prone attitude is considered.

Version 2 of the Decision Rules - Fishermen are risk prone

It is worth considering the following question which leads to an alternative set of decision rules: what happens as L or E(F) approaches MR?

It is clear that if L=MR, fishermen may (or may not) bother to fish under licence, because they can get the same return by fishing 'legally' outside the zone. We can therefore assume that there would be some threshold level, say L=a.MR, which would constitute the maximum licence fee fishermen would be prepared to pay. Obviously a≤1 so that the more general case would include the above set of rules. It may also be that fishermen are prepared to take risks so that they are still prepared to fish illegally even if the expected penalty is larger than the maximum they would pay for a licence. This brings in an asymmetry into their decision-making process and the modified set of rules would be:

[2a] FISHERMAN

if L ≤ a.MR and L < E(F) then fish with a licence
if E(F) ≤ b.MR and E(F) < L then fish illegally
if E(F) and L ≤ a.MR and E(F)=L then do either
if L > a.MR and E(F) > b.MR then fish legally outside the zone or not at all

By implication, we assume that a≤b and therefore if L>a.MR but a.MR<E(F)<b.MR the fisherman would be prepared to fish illegally. Figure 2a illustrates this set of decision rules. The asymmetry associated with fishing illegally using the third set of rules is shown in the area where the licence fee is larger than a.MR and the expected penalty is larger than the licence fee but, since the expected penalty is still less than b.MR, fishermen are prepared to take the risk and fish illegally. There is of course the 'special case' when L=E(F). We assume that when L=E(F) with L≤a.MR and E(F)≤a.MR fishermen would be indifferent between fishing with a licence or fishing illegally.

As before, we now consider the set of decision rules a state may use to decide whether to issue licences or not. As in case [1], we assume a non-zero surveillance cost (per fishing vessel), s. The decision rules are then:

[2b] STATE

Let L≤a.MR and E(F)≤b.MR
if L < E(F)-s then issue no licences (i.e. let vessels fish illegally)
if E(F)-s < L then issue licences
if L=E(F) then do either

Figure 2b illustrates the areas of parameter space associated with the decisions for this set of rules. It is important to note that by definition of the fishermen's set of decision rules, if L=a.MR < E(F) ≤ b.MR, a fisherman would want a licence but if not offered one, he would fish illegally.

When figures 2a and 2b are put together, it is clear that the area of overlap is, as before, between the lines defined by L=E(F) and L=E(F)-s. In this case, however, the maximum level for a licence fee would be L*=a.MR and for an expected penalty it would be E(F)*=b.MR (see figure 2c).

The income to the state would then be:

Licensed: a.MR
Unlicensed: b.MR-s

If a=b, then the situation is the same as before in the sense that licensing all vessels would bring in a higher income if zero surveillance cost is implied by doing so. It has, however, been pointed out that this case may not be practical.

If $a<b$, then the optimal strategy would be as follows:

if $a.MR > b.MR-s$ then licence all vessels
if $a.MR < b.MR-s$ then issue no licences
if $a.MR = b.MR-s$ then do either

The main points can be summarised as follows:

1it is only worth being in the area of 'overlap' between fishermen and a state's decisions .
2there are advantages in being in the area where fishermen can decide either way - particularly when conservation constraints enter the game.
3some solutions may not be practical and there may be a need for reformulation of the problem or for further constraints on parameters.

Version 3 of the Decision Rules - Extended Penalties

In this section the decision rules are outlined for the situation where fishermen include the loss of future catches in their calculations of the expected penalty. Assume that the expected loss of future catches in the particular fishing season (due to being caught fishing illegally) can be expressed as a proportion of the expected penalty, E(F), so that the total expected penalty to the fisherman becomes:

$$(1+r)E(F)$$

Note that the state still only receives E(F) from a captured vessel. Also note that this case does not yet include any long term effects. It simply takes into account that fact that if a vessel is caught fishing illegally during the first month of a six-month fishing season, for example, it will not be allowed to continue fishing and will therefore loose the value of the catch he would have expected during the remaining 5 months.

The set of decision rules for the fisherman now becomes:

[3a] FISHERMAN

if $L \leq a.MR$ and $L < (1+r)E(F)$ then fish with a licence
if $E(F) \leq b.MR$ and $(1+r)E(F) < L$ then fish illegally
if $(1+r)E(F)$ and $L \leq a.MR$ and $(1+r)E(F)=L$ then do either
if $L > a.MR$ and $(1+r)E(F) > b.MR$ then fish legally outside the zone or not at all

The decision rules for the state remain as in version 2:

[3b] STATE

Let $L \leq a.MR$ and $E(F) \leq b.MR$
if $L < E(F)-s$ then issue no licences (i.e. let vessels fish illegally)
if $E(F)-s < L$ then issue licences
if $L=E(F)$ then do either

The Relationship between Probability of Capture, Surveillance, Cost and the Expected Penalty

In the section above the expected penalty, E(F), has been used without considering the two components: the probability of being caught fishing illegally, q, and the actual fine, F. Also the probability of capture was not related to the surveillance cost. In this section these two aspects are considered in more detail using version 2 of the decision rules.

We assume that the probability of detection, q, is a function of the total surveillance cost:

$$q = (1-\exp(-kS)) \qquad (1)$$

where k is the rate at which q increases with increasing S. Note that this function tends to 1 as S tends to infinity. This may be very unrealistic and a more general formulation would be:

$$q = d.(1-\exp(-kS)) \qquad (2)$$

where $d \leq 1$. This relationship is illustrated in figure 3 for different values of k and d.

In some cases it may be simpler to express q in terms of the 'per fishing vessel' surveillance cost, s (in which case the term kS would become kNs=Ks).

We also assume that there is some maximum possible fine, Fx, which can, for example, be the value of the boat plus its catch. Note that this is in addition to the constraint that $E(F)=q.F \leq b.MR$.

The constraints, from the state's point of view, are therefore:

$L \leq a.MR$ (if not, vessels won't take licences)
$q.F=E(F) \leq b.MR$ (if not, vessels won't fish illegally)
$F \leq Fx$ (if not, vessels won't be able to pay the fine)

The 'decision-area' that overlaps with that of the fishermen lies between:

$$L = q.F \quad \text{and} \quad L = q.F - s$$

which can be transformed into a constraint on the licence fee, L:

$$q.F - s \leq L \leq q.F \qquad (3)$$

If the licence fee is set between these bounds, it is in the state's interest to licence vessels and it is also in the fisherman's interest to take up a licence.

If the net income from a vessel is to be maximised, we need to maximise the following expressions:

a) If Licensed: max L subj. to $L \leq a.MR$

b) If Unlicensed: max qF-s subj. to $qF \leq b.MR$
and $F \leq Fx$

Part (a) is straightforward; L is maximised at L*=a.MR (where '*' indicates the parameter value at the optimum).

Part (b) is also straightforward with respect to F, the maximum being at F*=Fx. Write q in terms of s (see equation 2) then the objective function (with F set at Fx) becomes:

$$d(1-\exp(-Ks))Fx - s$$
$$\text{subject to } d(1-\exp(-Ks))Fx \leq b.MR$$

[see Appendix 2 FOOTNOTE 1]

There are now two possible solutions for s*, depending on the values of the parameters. The one solution is at the actual 'peak' i.e. where the first derivative is zero (see figure 3a). This solution holds when $b.MR \geq d.Fx-1/K$ and

$$s^* = 1/K.\mathrm{Ln}(dFxK) \text{ implying } q^* = d(1-1/dFxK)$$

The second solution is at the constraint (see figure 3b) and holds when $b.MR < d.Fx-1/K$:

$$s^* = -1/K.\mathrm{Ln}(1-b/d.MR/Fx) = 1/K.\mathrm{Ln}[dFx/(dFx-b.MR)]$$
$$\text{implying } q^* = d(b/d.MR/Fx) = bMR/Fx$$

To summarise, the two solutions are as follows:

SOLUTION 1:
If $b.MR \geq d.Fx-1/K$ then
$L^* = a.MR$
$F^* = Fx$
$s^* = 1/K.\mathrm{Ln}(dFxK)$
$q^* = d(1-1/dFxK)$

SOLUTION 2:
If $b.MR \leq d.Fx-1/K$ then
$L^* = a.MR$
$F^* = Fx$
$s^* = 1/K.\mathrm{Ln}[dFx/(dFx-b.MR)]$
$q^* = bMR/Fx$

Let's now consider how the two parts of the problem (licensed and unlicensed) compare when viewed from the fisherman and the state's point of view. The outcomes are summarised below. Recall that L^* is the licence fee paid by a vessel (and received by the state), q^*F^* is the expected penalty paid by a vessel fishing illegally and $q^*F^*-s^*$ is the expected 'net' penalty received by the state (i.e. after the cost of surveillance has been subtracted). (Note that (1) $q^*F^* > q^*F^* - s^*$ and (2) $L^*=a.MR$ and $q^*F^* \leq b.MR$)

		STATE	FISHERMAN
if a<b:			
	$L^* < q^*F^* - s^* < q^*F^*$	No Licences	Get Licence; will fish illegally
	$L^* = q^*F^* - s^* < q^*F^*$	Do Either	Get Licence; will fish illegally
	$q^*F^* - s^* < L^* < q^*F^*$	Licence	Get Licence; will fish illegally
if a=b:			
	$q^*F^* - s^* < L^* = q^*F^*$	Licence	Do Either

The decision for the fisherman is, in the first three instances, to get a licence. If not offered a licence, he would be prepared to fish illegally and hence be a potential source of revenue for the state. In the special case where a=b, the fisherman doesn't mind whether he fishes illegally or with a licence.

If the state is only interested in licensing vessels to optimise income, it will only do so in cases 3 and 4, when the expected return per licensed vessel is greater than that from a vessel fishing illegally. In case 3, fishermen would want licences if offered but if there is a limit on the number of vessels that can be given licences, the ones that do not get licences will fish illegally. In case 4, fishermen are indifferent to fishing with a licence or illegally and it is therefore assumed that if licences were offered, they will be taken up. (NOTE: if fishermen are risk prone they may decide to fish illegally when $L=q^*F^*$)

SUMMARY : single vessel or all vessels with same characteristic
To be added.

Different Classes of Vessels

(Using the Version 2 of the decision rules)

Marginal revenue to Maximum fine ratio the same for all categories of vessels

Before considering conservation constraints, we consider the extension from one group of similar vessels to many groups of vessels. Assume that vessels can be grouped together according to some characteristics. The simplest case is as follows:

For all groups 1...J: a, b are the same
For each group j: Fxj and MRj are different BUT MRj/Fxj = C i.e. constant for all j.

We also assume, as before, that a<b and that b.MRj<d.Fxj-1/K for all vessel categories (? note 1/K term entered the picture).
For fleet j, the objective functions are:

a) if Licensed: Max L_j
b) if Unlicensed: Max $q.F_j - s$

with constraints:

$L_j \leq a.MR_j$ j=1..J
$F_j \leq Fx_j$ j=1..J
$q.F_j \leq b.MR_j$ j=1..J

Two points need to be noted. First, we assume that the probability of being caught fishing illegally is the same for all categories. This is a sensible assumption although, in some fisheries, it may be possible for surveillance to 'target' a certain type of vessel. Especially if different types of vessels tend to fish together and in different areas; longliners vs. purse seiners for example). Second, we assume that the 'per vessel' surveillance cost is the same irrespective of the category.

The optimal solution for this case is relatively simple when $b.MR_j<d.Fx_j-1/K$:

$s^* = -1/K.Ln(1-(b/d).C)$
$q^* = b.C$
$F_j^* = q^*Fx_j$
$L_j^* = a.MR_j$

and the decision is made by comparing L_j^* and $q^*Fx_j - s^*$ for each group. Note, however, that this is a slightly strange approach because the surveillance cost is expressed as the same value per vessel in each category. This may mean that for some categories it is better to licence vessels than to let vessels fish illegally. The surveillance cost is in reality a total cost that should be subtracted from the sum of income from fines from all categories. This re- formulation is considered below, but it is worth noting the following points with respect to the above solution.

There are two reasons why this case is relatively simple. First, the fact that $b.MR_j<d.Fx_j-1/K$ implies that the maximum for each category with respect to s (or q) lies at the constraint, i.e. where $q^*Fx_j=b.MR$. Second, the fact that $MR_j/Fx_j=C$, implies that the 'optimal' q is the same for each category. This means that the problem is easily extended from one vessel to many vessels in one category and to many categories.

At this stage we still assume that the parameters are the same for every vessel in a group although there are differences between groups. This implies that the objective function for all vessels in category j can be written as follows:

a) If all vessels are licensed: Max L_jN_j
b) if all vessels are unlicensed: Max qF_jN_j - sN_j

where N_j is the number of vessels in category j. When we then sum over fleets, the objective function becomes:

a) If all categories are licensed: Max $sum_j\ L_jN_j$
b) if all categories are unlicensed: Max $sum_j\ qF_jN_j$ - sN_j
or Max [$sum_j\ qF_jN_j$] - S

where S is the total surveillance cost. The question that immediately arises is: what about a mixture of some categories licensed and others not?

First, if a<b then the maximum GROSS income is obtained by issuing no licences. The q-value at which this optimum occurs is the same for each fleet and is either at or below $b.MR_j/Fx_j$. The optimal q-value is given by:

$q^* = d(1-1/(dk.sumFx_jN_j))$

provided that this is less than $b.MR_j/Fx_j$ (else $q^*=b.C=b.MR_j/Fx_j$). This implies that a 'mixture' solution will not be optimal under this set of assumptions, except when the outcome is 'do either'.

3.2 Marginal revenue to Maximum fine ratio NOT the same for all categories.

The second case we consider is one where the ratios MR_j/Fx_j are not the same for all vessel categories. (We still assume that $b.MR_j < d.Fx_j$ for all categories). Let's ignore the licensing aspect for the moment and concentrate on unlicensed vessels.

The first question that arises is whether it is optimal to set fines for all vessel categories at Fmax? We look at this using an example. Assume there are two fleets with the following constraints:

	fleet 1	fleet 2
b.MR	100	300
Fx	300	600
fleet size	50	50
q~	0.33	0.50

where q~ is the value of q that satisfies the first constraint at equality with F=Fx, i.e q~Fx=b.MR. Now assume that q is set at the minimum of the q~ for the two fleets (or categories), then:

CASE A

	fleet 1	fleet 2	
F	300 (=Fx)	600 (=Fx)	
qF	100 (=b.MR)	200 (<b.MR)	
INCOME	5000	10000	TOTAL=15 000

Now compare the situation with q set at the maximum of the q~, i.e. q=0.5:

CASE B

	fleet 1	fleet 2	
F	200 (<Fx)	600 (=Fx)	
qF	100 (=b.MR)	300 (=b.MR)	
INCOME	5000	15000	TOTAL=20 000

Comparison of these two cases shows that the gross income from the two fleets can be increased by setting q higher and the FINE for fleet 1 below the maximum fine (Fx), although the expected penalty is the same in both cases. Moving from case A to case B implies an increase of 5000 income 'units'. The first point is : it is NOT necessarily optimal to set the fine level for all fleets at Fx. It may, however, be optimal to ensure that all constraints associated with b.MR are at the equality (REPHRASE).

We know, however, that there is a cost involved in increasing q. In short, if the gain associated with moving from the low q to the high q (the 5000 units in the above example) is MORE than the increase in surveillance cost, then it is worth increasing q. If, on the other hand, the gain is less than increase in cost, then it is not worth increasing q up to the maximum of the q~-values.

The trade-off between the gain in income and loss due to increased surveillance cost is further investigated using an example involving 4 fleets or categories. As before the four fleets are assumed to have the following constraints and characteristics:

	fleet 1	fleet 2	fleet 3	fleet 4
b.MR	100	200	500	1000
Fx	1000	1500	3000	7000
fleet size	10	10	10	10
q~	0.10	0.133	0.167	0.143

Further assume that (from q=1-exp(-kS)):

S = -1/k.Ln(1-q)

where S is the TOTAL surveillance cost. The first thing to note is that the maximum the state can receive from a vessel in each of the categories is b.MR, i.e. when q.F=b.MR for all categories. Recall that there is effectively a single q because we assume that the surveillance can not target one or another type of vessel.

The second thing to note is that, for a given q, the fine for fleet j will either have to be at Fx or below. In order to satisfy both constraints (F≤Fx and q.F≤b.MR) the fine is set as follows:

$F_j = \min[\ Fx_j,\ b.MR_j/q\ ]$

The gross income is always maximised when q is set at the maximum of the q~. This implies (in terms of the above example) that q*=0.167 with F=Fx for fleet 3. What about the other fleets? Since q*>q~ for the other fleets, the fines have to be less than Fx in order to satisfy the constraint for b.MR. In other words, if $q^* = \max_j [\ q\sim_j\ ] = q_I$, say (e.g. I=3 in our example) then:

$F_I = Fx_I$ so that $q^*.Fx_I = b.MR_I$

and

$(F_j = b.MR_j/q^*) < Fx_j$ so that $q^*.F_j = b.MR_j$ for $j \neq I$

What about the NET income? Figures 4a and 4b illustrate the gross and net income for our example, with two different levels of the surveillance cost. In figure 4a (k=5e-5) the surveillance cost is relatively small and the optimal solution is q*=0.167 (i.e. the maximum of the q~'s). Note that the gross (and hence net) income does not increase beyond the maximum q because the constraints for Amax have come into effect for all fleets.

Figure 4b (k=3e-5) illustrates the situation for a larger survey cost (for the same q as in 4a). Now the optimal solution lies somewhere between the minimum and the maximum (at about 0.145). This implies that, at the optimal, only fleets with q~-values greater than 0.145 have F=Fx and q*F ≤ b.MR. Fleets with q~<0.145 have q*F = b.MR but F<Fx.

In the above example I have assumed that each category contains the same number of vessels. If this assumption holds but the total number increases or decreases (from 10 to 50 or 10 to 5, for example), the optimal solution may also change. For example, with N between 4 and 13, the optimal is around 0.142 to 0.145, then at N=14, the optimal solution jumps to q=0.167 and then stays there for all $N \geq 14$.

If the fleet sizes for each category changes, the optimal solution may also change drastically. For example, if there are 50 vessels in category 1 and only 1 in each of the other fleet categories, then the optimal solution would be dominated by the values for fleet 1 (the optimal is likely to be at $q^*=q\sim_1$) (see figures 5a: N=50,1,1,1 and 5b: N=1,50,1,1).

Conclusion: From the above analysis it is clear that:
a) it is not necessarily optimal to set F=Fx for all fleet categories
b) The relative fleet sizes in each category affects the optimum value of q
c) the coefficient k that relates q to S affects the optimum value of q

This conclusion also starts suggesting some of the difficulties that will be encountered later. If we ignore the non-linearity between q and S or assume that we can approximate it by a linear function over the range of values we are interested in then we effectively have a linear programming problem with constraints. The problem is that we are trying to optimise with respect to the coefficients (L, q, F) AS WELL AS the 'allocation variables', i.e. how many of each fleet category to licence or not to licence.

What are the implications of having q*F*<b.MR for some fleets? (see above; the example where surveillance costs were relatively high and q*=0.145). If q*.F*<b.MR, a fisherman would 'gladly' fish illegally because the expected penalty is less than the maximum he is prepared to pay. Let us also, for the moment assume that a=b (see equation x). If the licence fee is set at b.MR, then he will not take up the licence but rather fish illegally.

Clearly, if the licence fee is set below b.MR, the fisherman would take the licence but the income to the state (from that vessel category) would be sub- optimal. The point is, however, that in order to get more income from this category, more money would have to be spent to increase q and the expected penalty and the solution to the 'unlicensed' sub-problem has shown that this is not worthwhile. This means that the maximum that can be obtained is q*F* and either these categories (for which q*F*<b.MR) should not be licensed or they should be licensed at the reduced licence fee of L=q*F*.

From the above, the following procedure for solving the general problem seems sensible. Optimise the 'unlicensed' problem w.r.t all fleets and find q*. For fleets with q*.F=b.MR, one can licence them, setting L=b.MR (recall we are assuming aMR=bMR). The main point is that one is assured the licence money whereas the 'fine' money has an associated uncertainty. Note however that although the expected penalty is equal to the licence fee, fishermen may prefer the 'high risk' option of fishing illegally and not take up the licences offered to them. For these categories it is also true that F<Fx. It is therefore also possible to set the fine higher, e.g. at Fx which would imply that q*.Fx > b.MR and which would therefore discourage vessels to fish illegally.

For fleets with q*.F<b.MR, it would be necessary to let them fish illegally outside the zone since with a licence fee set at b.MR, the fishermen would not be interested in licences. It would of course also be possible to reduce the licence fee for these categories (to L=q*F) but this may be seen to be 'unfair' and this would not imply any increase in income.

IF licensing all vessels implies NO surveillance cost then (as before) the optimal would be to set L=b.MR for all fleets and to licence all vessels. Common sense, however, suggests that there should be some non-zero probability of being caught and fined for fishing illegally before fishermen would be prepared to pay for a licence and usually this would imply a non-zero surveillance cost even if all vessels are licensed. (NOTE There may be examples, e.g. in the SE Pacific where this is not true).

Another little example - FLEET4.WQ1

Let's consider yet another simple example - mainly to show how one might explore the solutions given real data and information. Assume three fleets with the following characteristics:

	fleet 1	fleet 2	fleet 3
b.MR	100	200	500
Fx	1000	1500	2000
q~	0.10	0.133	0.25

Now note that if licensed, the best option is to set L=b.MR for each category. If we now assume a certain surveillance cost, say 2000 units (with k=1e-4), then this implies a q-value of 0.18. With this q, the implications for unlicensed vessels would be the following:

	fleet 1	fleet 2	fleet 3
F	555	1111	2000
(0.18)F	100	200	360

Note that for categories 1 and 2 qF=b.MR BUT F<Fx whereas for category 3 F=Fx but qF<b.MR. This implies that vessels in categories 1 and 2 would be indifferent to being licensed or fishing illegally whereas, with L=500=b.MR for category 3, these vessels would choose to fish illegally. It is also clear that there is a loss of 140 (=500-360) units per vessel at this level of q. If we assume for the moment that the number of vessels in each category is the same, N say, then the net income is given by:

N(100+200+360)-2000 = 660.N - 2000 (1)

This case can be compared with one where, say 3000 units are spent on surveillance. This implies a q-value of 0.259 with the following implications for each category:

	fleet 1	fleet 2	fleet 3
F	386	718	1930
(0.259)F	100	200	500

i.e. vessels in all three categories are indifferent to whether they fish with licences or illegally. In this case the net income is given by:

N(100+200+500)-3000 = 800.N - 3000 (2)

If we compare equations (1) and (2), it is clear that if N<7 then (1)>(2) (i.e. it would be more profitable to spend 2000 than 3000 on surveillance) whereas when N>7 then it would be more profitable to spend 3000 than 2000 on surveillance. Figure 6 illustrates the net income for a range of S-values and various values of N. This clearly shows how the optimum shifts from one level of surveillance cost (and implied q) to another as N changes.

It is also worth noting that the optimum is actually at the q implied by category 3 (i.e. b.MR/Fx=0.25) and that there is no point increasing q beyond that value.

As before, the comment stands that F can be increased to Fx for all three categories to try and discourage vessels from fishing illegally (if there are any independent reasons for doing so). Also note that if a vessels decides to fish illegally anyway (although q.Fx>b.MR) and gets caught and fined, the state would get more than they bargained on!

Conservation constraints for this particular problem

Conservation constraints on this problem can be treated relatively easily when the income from all fleets is b.MR at the optimum and vessels are therefore indifferent between fishing illegally or with a licence. The assigning of licences is quite easy. This can be done with a simple LP (linear programming) model (see Third.doc; there could be lots of linear combinations that could give the same answer, particularly if the relative 'catchabilities' are the same).

Also note that by setting the fine higher (e.g. at Fx so that q.Fx>b.MR) vessels would be discouraged to fish illegally and this could mean a 'saving' with respect to conservation.

When the optimum for 'unlicensed' vessels does NOT imply that the income is b.MR then what? Well, as indicated before, vessels in these categories will only accept licences if the fee is less than or equal to the expected penalty (i.e. L≤q*.Fx<b.MR). There are two possible options: 1) do not licence these vessels but allow them to fish illegally; 2) drop the licence fee to the value of the expected penalty (or just below) and licence them (recall that vessels would be indifferent to fishing with a licence or fishing illegally when L=q*Fx). There is a third option which is, however, not optimal from the state's point of view, and that is to increase the probability of capture even further.

Let us consider the two options. First, not to licence the vessels in this category. In such a case, the income from these categories would be q*Fx if they are caught fishing illegally and we have already seen that the net income would not increase if q is further increased above q*. The second option of dropping the licence fee to q*Fx and licensing vessels would give the same income as the situation where they are fishing illegally. There is therefore only the advantage of actually being sure of getting the money by licensing compared to not licensing.

There is, however, a further point which may come into play when allocating licences subject to a conservation constraint particularly when the 'certainty' factor of licence money is important/taken into account. If the vessels in a category with q*Fx<bMR are relatively inefficient, each vessel would contribute relatively little to the overall effort and it may be more profitable to licence these vessels rather than ones that are very efficient (see section x). This implies that when allocating licences it may be wise to include these categories in the problem with L=q*F.

Having said this, recall the comment on 'unfair' licence fee for some categories..

NOTE: we have not yet considered the case where a<b in detail.

LINEAR PROGRAMMING APPROACH TO ALLOCATING LICENCES WHEN THERE IS A CONSERVATION CONSTRAINT

In this section we consider a sub-problem of the main problem by focusing on the allocation of licences to vessels.

Think of the following scenario: we have already decided how much to spend on surveillance (i.e. S is known and so is the probability of detection, q), the levels of the licence fees and the levels of fines. We now need to decide how many and WHICH vessels to licence. We assume that there is a distribution of boats of different sizes.

Assume that there are J size classes (e.g. GRT categories). Also assume that there are N_j vessels in size class j indicates the total fleet size for each category. We assume that if x_j vessels in size class j is licensed it implies that N_j-x_j will be fishing outside illegally. This is because the licence fee and fines are set in such a way that they are not more than the marginal revenue for each category.

Let the licence fee in category j be α_j and the expected penalty β_j. The income to the state would then be given by :

$$\sum_{j=1}^{J} [\,\alpha_j x_j + \beta_j (N_j - x_j)\,] - S \qquad (1)$$

where S is the total surveillance cost. Note that it is also possible to replace the unlicensed vessels with variables y_j (this will be useful later).

Equation (1) is the objective function, the one that we want to maximise. There are, however, some constraints involved. The first set of constraints ensure that the number of licensed and unlicensed vessels does not exceed the total fleet in each category:

$$x_j + y_j = N_j \qquad j=1...J \qquad (2)$$

We introduce a second constraint here, referred to as the conservation constraint. At this stage we choose to limit only the effort in the licensed zone. Instead of just limiting the number of vessels, we limit the number of vessel 'units'. This takes into account the fact that vessels of different sizes or characteristics often have different degrees of efficiency. The constraint for licensed vessels is therefore:

$$\sum_{j=1}^{J} c_j x_j \leq X \qquad (3)$$

where c_j is the relative efficiency of vessels in class j. These three equations form a classical linear programming problem. We repeat them here to summarise:

Maximise:

$$\sum_{j=1}^{J} [\alpha_j x_j + \beta_j y_j] - S$$

Subject to :

$$x_j \geq 0,\ y_j \geq 0 \qquad j=1...J$$

$$x_j + y_j = N_j \qquad j=1...J$$

$$\sum_{j=1}^{J} c_j x_j \leq X$$

Note that the surveillance cost enters the objective function as a constant and can therefore be left out of calculations.

It may be possible to write the coefficients in terms of linear functions of the size category, i.e. j but this would not simplify the problem.

As indicated, this is a standard type of problem that is easily solved using the so-called simplex method. It is, however, worth thinking a bit about how the solution should 'work'. Intuitively one would feel that categories with large values for licence fee should be given licences. But this is only a good idea if their contribution to the conservation constraint is not too large. If, for example, the licence fee and expected penalty are the same for each category, i.e. $a_j=b_j$, then it doesn't really matter whether a vessel is licensed or not from the objective function's point of view. (We assume that not all vessels will be licensed and that there will be a surveillance cost anyway). From the conservation constraint's point of view, it would be best to licence those with relatively low efficiency.

It is therefore clear that the solution to this problem will be driven by the trade-offs between licence fees and expected penalties and the relative efficiencies of vessels.

In the case where the licence fee and expected penalty are equal (i.e. where a=b), it is mainly the relative efficiencies that 'drive' the solution. There is, however, a further interesting point to note with respect to this case. Because $L_j=q.F_j$ the income from a vessel would be the same irrespective of whether it is licensed or not. This means that there may be many different linear combinations of licensed and unlicensed vessels from the different categories that satisfy the conservation constraint and give the same total net income. As indicated above, it may be in the state's interest to ensure a certain amount of income from licences rather than from catching vessels fishing illegally. This can be done by optimising only the income from licensed vessels. That implies solving the following problem:

Maximise:

$$\sum_{j=1}^{J} \alpha_j x_j$$

Subject to :

$x_j \geq 0 \qquad j=1...J$

$x_j \leq N_j \qquad j=1...J$

$\sum_{j=1}^{J} c_j x_j \leq X$

The total net income is of course easily calculated since $y_j = N_j - x_j$, but as mentioned, it is the same for all combinations of licensed and unlicensed vessels for a given value of S and the coefficients a_j and b_j.

Using this approach, it is also possible to compare the income from licensed vessels for scenarios where a vessel category with q.F<a.MR (i.e. the expected penalty is less than the maximum fishermen are prepared to pay) can be included at the lower licence fee (L=q.F) or excluded.

(NOTE that these days QUATTRO has a linear programming option in its spreadsheet! see ALLOCATE.WQ1 in c:\poach; also see ALLOCAT3.wq1)

WHAT if a<b in the original problem?

****

The obvious question is how does this fit in with the more general problem of optimising with respect to the licence fee, fine and surveillance cost? First let's consider a single vessel. If the vessel were to contribute to the state at all, the licence fee and/or the expected penalty have/has to be less than some proportion of the marginal revenue. So assume that L≤a.MR and qF(1+r)≤b.MR. (Recall that (1+r) adjusts for lost catches due to being caught poaching, see second.doc; NB lost catches in that season only, not future catches as well). If L<qF(1+r) then he would want a licence; if L>qF(1+r) he would fish illegally. If the two are equal the fisherman is assumed to be indifferent.

Let us also make the realistic assumption that the maximum fine, Fx, is greater than the marginal revenue. As we have seen from previous analyses, the optimal solution is to set L=a.MR and qF(1+r)=b.MR. Then if a<b, the fisherman would want a licence and if a=b he doesn't mind. Note that if a<b but the fisherman is denied a licence, it is assumed that he will still fish outside illegally because he is prepared to 'take the risk'.

From the state's point of view, the cost of surveillance needs to be taken into account. Assume that 's' is the 'per fishing vessel' surveillance cost. If a>b/(1+r)-s/MR then the state should licence the vessel. If a<b/(1+r)-s/MR the vessel should not be licensed and if a=b/(1+r)-s/MR it doesn't matter.

Now note that we always have:

b/(1+r) - s/MR ≤ b   (most often strictly <)

Whether to licence or not therefore depends on where 'a' falls in this relationship (recall we have assumed a≤b). The decisions made by the state and the fisherman are summarised below.

	IF	STATE	FISHERMAN
1)	b/(1+r)-s/MR < a ≤ b	licence	licence (<); don't mind (=)
2)	b/(1+r)-s/MR = a ≤ b	do either	licence (<); don't mind (=)
3)	a < b/(1+r)-s/MR < b	no licence	licence (if possible)

As soon as a conservation constraint enters the system, the best situation to be in is one where the fisherman doesn't really mind whether he has a licence or fishes illegally and where he is prepared to fish illegally when he can't get a licence. This would include all 3 cases above.

There are some potential problems, however. For example, if the parameter 'b' has been over-estimated (or if fishermen's perception of the expected penalty is that it is larger than it really is), the state may be relying on income from vessels fishing illegally. These unlicensed vessels may in fact not be fishing illegally at all.

In both cases (1) and (2) the next step would be to solve the allocation problem. It is important to note that there is an implicit assumption here that the same relative relationship holds for all vessel categories (IS THIS CORRECT?). This would be valid if there is a linear relationships between vessel category (VC) and marginal revenue (MR) and between VC and maximum fine, Fx. A linear relationship is, however, not necessary (although it is sufficient). It seems sensible to assume that values of 'a', 'b' and 'r' would not be functions of vessel category. (This may, of course, prove to be wrong!)

In case (3), there is no need to solve any allocation problem, since the optimal income would be from catching vessels that fish illegally and the conservation constraint would (by definition of the problem) not come into effect. [footnote: there may of course be situations where it would be beneficial to conservation to offer licences if one could come to some sort of VRA-type arrangement. This is not discussed here.]

FOOTNOTE 1

The first step in solving the following problem:
MAX: d(1-exp(-Ks))Fx - s
SUBJECT TO: d(1-exp(-Ks))Fx $\le$ b.MR

is to write the objective function as:
MAX: F(s,V) = d(1-exp(-Ks))Fx - s + V.{ b.MR - d(1-exp(-Ks))Fx }
with constraints:
s $\ge$ 0, V $\ge$ 0

The (primary) Kuhn-Tucker conditions for an optimum are then:
deltaF/deltas $\le$ 0 s(deltaF/deltas) = 0
deltaF/deltaV $\ge$ 0 V(deltaF/deltaV) = 0

This then easily leads to the two solutions given in the text.
Also note that if we maximise with respect to the fine, F, as well, we effectively add the following conditions:
Fx-F $\ge$ 0 and lambda(Fx-F) = 0

Now if we assume that lambda=0, it leads to a contradiction because the following two equalities should hold:
d(1-exp(-Ks))(1-V)=0 implying V=1
and
dKFexp(-Ks)(1-V)=1

which cannot hold if the first condition is met. This implies that we cannot have lambda=0 and therefore (Fx-F)=0 so that F=Fx. The rest of the solution (with respect to s, follows as in the above case.

Appendix 1

FIRST PRINCIPLES

Model One

In the simplest situation, from the fisherman / vessel owner's point of view. He can either fish under licence or fish illegally. When fishing with a licence his income less outgoings (excluding the fixed cost of fishing) would be:

(1)C.p - L (where C=catch, p=price, L=licence fee)

When fishing illegally, we assume that he can, at best, get the same catch that he can achieve inside the EEZ. His expected return is:

(2) C.p - q.F (where C and p as before, q=probability of being caught and F the fine if caught)

The fisherman would want a licence if (1) is greater than (2) and vice versa. Because we assume that the catches are the same, it implies that he would only want a licence if L<q.F. (Note that when NOT fishing illegally, i.e. outside the EEZ all the time, his catch would of course be less than C. Say it is r.C where r<1. Then, obviously, if rC.p > (C.p- L) he won't be interested in a licence and if rC.p > C.p-q.F he won't be interested in fishing illegally.

From the coastal state's point of view, it can be assumed that the number of licences or unlicensed vessels are not affected by the level of the licence fee or fine. The state's income is going to be either from licence fees:

(unknown no. of licences).L = xL

and/or from fines:

(unknown no. of unlicensed poachers).qF = y.qF

Making the assumption that outgoings are only with respect to surveillance and that the cost of surveillance increases as q, the probability of detecting illegal fishing, increases. We assume that :

$$q = 1-\exp(-k.I)$$

where I is the cost of surveillance and k is a parameter which indicates how fast q increases with respect to increasing cost. It is also possible to rewrite I in terms of q :

$$I = -\ln(1-q)/k$$

The expected return to the state is therefore:

$$xL + y.qF + \ln(1-q)/k$$

where x and y are unknown. The 'control' variables in this expression are: L, q and F (the licence fee, probability of catching a poacher and the fine). In order to maximise this expression, it is sufficient to maximise L (the first term of the expression) and to maximise with respect to F and q in the second and third terms.

Since the expression is linear in L, the licence fee should be set as high as possible. In reality there would tend to be a value Lmax such that fishermen are not interested in licences if the fee is higher than Lmax. The fee should then be set equal to (or just below) Lmax.

The expression is also linear in F and, as before, this implies that the fine should be set as high as possible. There is again likely to be a value Fmax (e.g. the value of a vessel plus its catch) which can be set as a realistic fine and F should therefore be set equal to Fmax.

As for q, it is necessary to look at the first derivatives. Figure 1 illustrates the function ($qF + \ln(1-q)/k$) versus q for given k and F. The maximum, for given F and K occurs at $q=1-1/(Fk)$. It is clear that q will tend to 1 as F and k increase. In practice it is highly unlikely that the probability of capture could be close to one and there may be an upper limit for q, qmax, say. In such a case, q would be set equal to qmax if $1-1/(Fk)$ is greater than qmax.

To summarise: in order to maximise the return, let

$L=L_{max}$
$F=F_{max}$
$q=\min$ of $[q_{max}, 1-1/(Fk)]$

Note there may also be a lower constraint for q, qmin, say. If there is no surveillance, there would be no incentive for fishermen to take up licences. In such a case q would be set at $1-1/(Fk)$ only if:

$q_{min} < 1-1/(Fk) < q_{max}$

if $1-1/(Fk) < q_{min}$ then $q=q_{min}$
if $1-1/(Fk) > q_{max}$ then $q=q_{max}$

Model 2

In the second model we assume that there is a fleet of size N which is interested in fishing in the area. If n vessels are licensed, it implies that (N-n) vessels are unlicensed. The function that we are now interested in maximising is :

$nL + (N-n)qF + \ln(1-q)/k$ (3)

N and k are assumed known and the control variables are therefore as before but with the addition of n, the number of licences. As indicated above, there is not much sense in leaving the parameters unconstrained. The following constraints are therefore imposed:

$L \leq L_{max}$
$F \leq F_{max}$
$q_{min} \leq q \leq q_{max}$

It is also obvious that all parameters need to be positive.

This non-linear optimisation problem can be solved formally but it is useful to consider the unconstrained maximisation problem to get some idea of how equation (3) behaves. We consider one parameter at a time.

Equation (3) is linear in L and in F and, in order to maximise the expression, both parameters should be as large as possible, implying that L=Lmax and F=Fmax. We need to consider n and q together and here a plot of the income function for different values of n and q is helpful.

Figure 2 shows that there are two local maxima, one at $n=N$ and $q=0$ and another at $n=0$ and $q=q^*$. This optimal value of q, q^*, can easily be calculated by setting the first partial derivative of (3) with respect to q equal to zero and solving for q with $n=0$. This leads to :

$$q^* = 1-1/(kNF)$$

A further important point to note is that when $q=L/F$, the value of the income function is equal at all values of n (see Figure 3). Let's first assume that $q^*>L/F$ then, for values of $q<L/F$, the income function increases (linearly) as n increases with a local maximum at the 'corner' where $q=0$ and $n=N$. For values of $q>L/F$, the income function decreases (linearly) as n increases and the second local maximum is therefore at $n=0$ (where $q=q^*$).

When $q^*<L/F$ the local maximum at $q=0$, $n=N$ must be greater than the one at $q=q^*$, $n=0$ (see figure 4).

There are, in other words, two possible solutions to the problem:

(a)either $q=q_{min}$ and $n=N$ or
(b)$q=q^*$ or $q=q_{max}$ and $n=0$

The appropriate solution (i.e. which local maximum is the largest) is found by comparing the relative values of q_{min}, q_{max}, q^* and $q\sim=L_{max}/F_{max}$.

If $q^* \leq q\sim$ then $q=q_{min}$, $n=N$ else

if $q^* \geq q\sim$ then (1) if $q_{max} < q^*$ -> MAX of (a) $q=q_{min}$, $n=N$
(b) $q=q_{max}$, $n=0$

(2) if $q_{max} > q^*$ -> MAX of (a) $q=q_{min}$, $n=N$
(b) $q=q^*$, $n=0$

Clearly for solutions (1) and (2) the two alternatives marked (a) and (b) have to be evaluated and the optimal solution is the one that gives the maximum expected income.

Evaluation of the two maxima can also be done by considering the licence fee. If we assume that $F=F_{max}$ is given then it is possible to calculate the critical licence fee value, L^*, where the two local maxima would be equal. This is given by:

$$L^* = (Nq^*F + \ln(1-q^*)/k)/N$$

If $L=L_{max} > L^*$ then the optimal solution is $n=N$, $q=q_{min}$. If $L=L_{max} < L^*$ then the optimal solution is $n=0$, $q=q^*$ or $q=q_{max}$ (as appropriate; see full solution above). Figures 2 and 5 illustrate these two cases.

The interesting feature of this model is that the solution is either all licences or no licences and not a mixture of the two. This model, however, assumes the same response by all fishermen and assumes that levels of L_{max} and F_{max} have been set in a sensible way. Note for example that if $F_{max}=L_{max}$ then $q\sim=1$ and the optimal solution would be to licence all vessels and to set q as low as possible (i.e. $q=q_{min}$). This makes sense from the state's point of view but, most fishermen are likely to go for illegal fishing because their expected return would be higher i.e. $q_{min}.F_{max} < L_{max}$.

On the other hand, if $F_{max} >> L_{max}$, $q\sim$ would tend to be small and, provided that a relatively high level of q can be achieved in practice, it would be optimal not to issue licences. Again, however, the fishermen may leave the area and not even take the risk of fishing illegally if the fines and the probability of being caught get very high.

Model 3

One very simple way of taking the fishermen's response into account, is to assume that the number of licences that would be taken up are directly related to the licence fee. If the licence fee is equal to the expected cost of fishing illegally (i.e. q.F) then no one would want a licence. We assume a linear relationship between n and L:

$$n = N - (N/qF)L \qquad (4)$$

This is illustrated in figure 6. Note that when L=0, n=N and when L=qF, n=0. Also note that one could use some parameter other than qF as the point where n=0 to describe a more general relationship. It is now straightforward to replace n with equation (4) into equation (3):

$$2NL - (N/qF)L^2 + \ln(1-q)/k \qquad (5)$$

The most obvious difference between the two equations (3 and 5) is that equation (5) is quadratic in the licence fee.

Again, F occurs only in one term and, with other parameters fixed, F has to be set as large as possible to minimise that term (which enters as a negative term in eq.5).

Figure 7 illustrates income as a function of q and L, for fixed F. Note that n is implicit in equation (5) and has to be determined from equation (4). For each value of L there is a maximum at some value of q, say, q* (the '+' root of a quadratic in q).

Figure 8 illustrates the income at q* for a range of values of L. This is the 'view' along the ridge in figure 7 where the ridge coincides with values of L=q*F. Clearly this ridge is also a parabola with a maximum at some value of L, L* say. It turns out that this overall optimum is at :

$$q^{**} = 1-1/kNF \quad \text{and} \quad L^* = q^{**}.F$$

This implies that

$$n^* = N-N/(q^{**}F).(q^{**}.F) = 0$$

The UNCONSTRAINED optimal solution is again, no licences with F=Fmax and q=q**=1-1/kNF.

Figure 9 shows the parabola at the ridge (i.e. at q* for various values of L) and parabolas at equal distances from the ridge.

Figure 10 shows contours of income for fixed F=Fmax over ranges of L and q. The outer contour coincides with values of Income=0, the inner contour with values of Income = 0.9 times the maximum income.

It is now necessary to consider the constrained problem where $q_{min} < q < q_{max}$. The solution would depend on the relationship between qmin, qmax and q**.

Appendix 2

An Extension of the Control of Foreign Fisheries Model with Constraints

A different approach from that given in the first document is used. As a starting point, the areas of parameter space coinciding with (a) fishing with a licence, (b) fishing illegally and (c) fishing legally without a licence or not at all, are defined. This is done by considering the types of decision rules that fishermen may use to make their decisions.

Let MR be the marginal revenue, in other words the difference between the expected revenue from fishing with a licence (C_L.p) and from fishing legally without a licence (C_U.p). Here C is the catch, subscripts L and U signify 'licensed' and 'unlicensed' respectively and p is the unit price of the catch. Note that by definition $C_L > C_U$ and fishermen would fish illegally when unlicensed to try and push their catches up towards C_L.

Let L be the licence fee and E(F) be the expected penalty for fishing illegally. This term is the product of the fine, F, and the probability of being caught and charged (sometimes referred to as 'q').

Now the following decision rules can be set up:
[1]
- if L < MR and L < E(F) then fish with a licence
- if E(F) < MR and E(F) < L then fish illegally
- if L > MR and E(F) > MR then fish legally but unlicensed or not at all

Note that in the third case, whatever the decision, the state does not obtain any income from these vessels. This is referred to as 'no contribution'. It is important to note that when conservation constraints come into the model, the decision of whether to fish legally without a licence or not at all becomes important. The expected penalty may also include an aspect of 'expected loss of catch if the vessels is caught fishing illegally. This aspect would affect the fishermen's decision but not the value of the income to the state. (see later)

In the next section (for the first simple model) we shall use the above set of decision rules. It is, however, worth considering the following question which leads to an alternative set of decision rules now: what happens as L or E(F) approaches MR?

It is clear that if L=MR, fishermen may (or may not) bother to fish under licence. We can therefore assume that there would be some threshold level, say L=a.MR, which would constitute the maximum licence fee fishermen would be prepared to pay. Obviously $a \leq 1$ so that the more general case would include the above set of rules. It may also be that fishermen are prepared to take risks so that they are still prepared to fish illegally even if the expected penalty is larger than the maximum they would pay for a licence. This brings in an asymmetry into their decision-making process and the modified set of rules would be:
[2]
- if L < a.MR and L < E(F) then fish with a licence
- if E(F) < b.MR and E(F) < L then fish illegally
- if L > a.MR and E(F) > b.MR then fish legally but unlicensed or not at all

Figures 1a and 1b illustrate the first and second set of decision rules by mapping out the areas of parameter space (L and E(F)) for each of the three alternatives. The asymmetry associated with fishing illegally using the third set of rules is shown in the area where the licence fee is larger than a.MR and the expected penalty is larger than the licence fee but, since the expected penalty is still less than b.MR, fishermen are prepared to take the risk and fish illegally. There is of course the 'special case' when L=E(F). We assume that when L=E(F) with L<a.MR and E(F)<b.MR fishermen would be indifferent between fishing with a licence or fishing illegally.

Let us now consider the net income to the state, for the first set of decision rules. The net income consists of three components: income from licences, income from fines and expenses for surveillance.

Let N = fleet size (number of vessels that would potentially fish)
 S = surveillance cost

Also assume that the probability of detection, q, is a function of the surveillance cost:

$q = (1-\exp(-kS))$

where k is the rate at which q increases with increasing S. Note that this function tends to 1 as S tends to infinity. This is quite unrealistic and a more general formulation would be:

$q = d.(1-\exp(-kS))$

where $d \leq 1$.

The net income (NI) (in one year, say) can now be written as:
[4]

i) if $L < MR$ and $L < E(F)$ then $NI = L.N$
ii) if $E(F) < MR$ and $E(F) < L$ then $NI = E(F).N - S = F.(1-e^{-kS}).N - S$
iii) if $[L=E(F)] < MR$ then $NI = LN - S = E(F)N - S$

iv) if $L > MR$ and $E(F) > MR$ then $NI = 0$

Case i) coincides with all vessels licensed, case (ii) with all vessels fishing illegally, case (iii) with a mixture of licensed and illegally fishing vessels and case (iv) with some or all vessels fishing legally but unlicensed.

The next step is to consider the decision variables. It is clear that if one or both of L and E(F) is less than MR then the state would get some income from the fishery. We assume that parameters such as MR, N and k are known to the state and they have to decide on the level of the licence fee, L, the fine, F and the expenditure on surveillance, S.

We also assume that there is some maximum possible fine, Fx, which can, for example, be the value of the boat plus its catch.

In order to maximise the net revenue to the state, we need to maximise each of the items in equation set [4]:

(i) max. $NI=L.N$, subject to $L \leq MR$
(ii) max. $NI=F(1-e(-kS))N - S$ subject to $F \leq Fx$
 and $F(1-e(-kS)) \leq MR$
(iii) identical to (ii) but with $L^*=F^*.(1-e(-kS^*))$
(The '*' indicates the value of the parameter at the optimal solution.)

We shall consider the full, formal solution for a more general case below and at this stage it is sufficient to note the following. First, the net income in case (i) is linear in L and the maximum is obtained by setting $L^*=MR$.

Second, the net income in case (ii) is linear in F so that the maximum is obtained by setting $F=Fx$. The maximum with respect to S is found in the standard way (setting the first partial derivatives equal to zero) with $F^*=Fx$, but note that we need to take the constraint $F(1-e(-kS)) \leq MR$ into account.

If $MR > Fx$ then the optimal solution is at $S^*=1/k.Ln(Fx.k.N)$. In this situation the constraint is not 'operational' since it holds for all values of S and the maximum is therefore at the point where the first derivative of the objective function (with respect to S) is zero. If $MR < Fx$ then the optimal solution is at $S^*= -1/k.Ln(1-MR/Fx)$, which coincides with the largest value of S for which the constraint holds.

Figure 2 illustrates the unconstrained function for the net income in case (ii) as S increases and for three values of Fx. When the constraint becomes operative (i.e. when MR<Fx) then the curve would effectively be truncated at some value below the maximum of the curve.

In the next set of figures, the two 'halves' of the problem, the licensed and unlicensed parts, are put together. Figure 3 should be looked at with figures 4a and 4b. The net income, as a function of L and E(F) is shown in Figure 3 (only part of the 'surface' is shown due to software limitations! but this is not a problem as long as we assume that MR= or > 80). The values along the E(F) axis can also be replaced by values of S because F has been fixed. Note, however, that E(F) is not linear in S (also see below, Figure?). Figure 4a illustrates the view along the L-axis at two values of E(F). Figure 4b illustrates the view along the E(F)-axis at two values of L. The 'lower' part of the curve (i.e. at small values of E(F)) coincide with the parabola shown in figure 1 (for Fx=110), i.e. all vessels fishing illegally. At E(F)=L, however, the system switches to all vessels licensed, i.e. L.N. which is a constant (horizontal line) for a given value of L.

In order to find the overall maximum, one is effectively comparing cases (i) and (ii), i.e

$$Lx.N \quad \text{and} \quad Fx.N.(1-e^{-kS}) - S$$

It is clear that when both Lx=MR and E(F)=MR, the net income will always be greater when all vessels are licensed (and none fish illegally) because, under this model, we have assumed no surveillance cost when all vessels are licensed. The values plotted in the graphs do, however, assume that some vessels will decide not to take a licence and there will therefore have to be a surveillance cost.

MAY NEED REWRITING
Now consider what happens as Fx increases. First look at figure 5 (Fx=80) then at Figure 3 (Fx=110) and finally at Figure 6 (Fx=1000). The first thing to note in figure 5 is that when E(F) > 80, there is no income. (There is in fact no solution for S in E(F)=Fx(1-e(-kS)) because E(F)>Fx). Along the E(F)-axis, the maximum is at E(F)=60. In all cases, however, the optimal is in the region where all vessels fish with a licence.

In figure 3 this is still the case (the optimal is in the region where all vessels have a licence) but now the maximum along the E(F)-axis is at a value of E(F)>80. In figure 6, it seems as if both solution lead to the same net income. The actual numbers, however, show that it is still slightly better to licence all vessels. As Fx increases further the two solutions do tend to equality. In order for E(F)<L at high Fx, S has to become very small and therefore starts having a negligible influence on the net income.

In general the results from this model suggest the following: if the value of a vessels (Fx) is small relative to the marginal revenue (MR), then the optimal solution would be to licence all vessels with the licence fee set as close to the marginal revenue as possible. On the other hand, if the value of a vessel is much larger than the marginal revenue, a mixture of licensed and unlicensed vessels can be considered. This interpretation is based on the assumption that the maximum fine would be set at something like the value of a vessel and the assumption that surveillance costs can be kept quite low.

<u>On to a slightly more complicated case</u>

As indicated above, fishermen may perceive a higher penalty for fishing illegally than the value received by the state, when they include the loss in catch due to the loss of their vessel(s). This is quite easily incorporated in the above model. Let the total penalty perceived by the fisherman be (1+r)E(F)=(1+r)F(1-e(-kS)), where r>0. Note that the expected penalty received by the state is still $E(F) \leq (1+r)E(F)$. The set of decision rules are as above but with E(F) replaced by (1+r)E(F) and the income equations stay as in [4].

Let us now combine this aspect with the third, more general, set of decision rules:

[6]
if L < a.MR and L < (1+r)E(F) then fish with a licence
if (1+r)E(F) < b.MR and either (1+r)E(F) < L or L>a.MR then fish illegally
if L > a.MR and (1+r)E(F) > b.MR then fish legally but unlicensed or not at all

As indicated above, the parameter space coinciding with the decisions is illustrated in Figure 1b.

It is possible to go through a formal solution of this problem and this is indeed done in Appendix A. The alternative solutions are presented here only in summary form.

In terms of licensing, the optimal solution is always to set the licence fee at its highest, L*=a.MR. In terms of the 'unlicensed' part of the problem, F*=Fx but there are two possible solutions for S:

(1) if b.MR>Fx(1+r) then S* = 1/k.Ln(FxNk)
(2) if b.MR<Fx(1+r) then S* = -1/k.Ln[1-b/(1+r).MR/Fx]

The first is at the actual maximum (i.e. where the first derivative is zero) whereas the second is at the constraint (i.e. b.MR=Fx(1-e^{-kS})(1+r)). The overall maximum is obtained by comparing the two cases: all vessels licensed or all vessels unlicensed for the appropriate case, (1) or (2). Recall that when the licence fee and the expected penalty are both equal, a mixture of licensed and unlicensed vessels would also be optimal.

In practice it seems more likely that the marginal revenue (in one year, say) would be less than the maximum penalty or value of a vessel. In considering how the optimal surveillance cost changes with changing parameters we have therefore focused on case (2) above. Note that 'k' is simply a scaling factor and instead of looking at S*, it is simpler to look at k.S*. Figure 7 illustrates kS* as a function of the ratio between the marginal revenue (MR) and the value of a vessel (Fx) for different values of b and r. Two values of b (1, the maximum value b can have, and 0.75) were used. Two values of r (0, the minimum value for r, and 1) were used. Note that one may expect r to be small, i.e. close to 0, rather than close to 1.

Figure 7 shows that the optimal surveillance cost is largest when the ratio between MR and Fx is large. The curve is steepest when fishermen are prepared to pay as much as the marginal revenue in a penalty and when the expected 'additional' loss of catches is low.

RESULTS revisited

All this seems very complicated and confusing but the next paragraph should show just how simple it really is! Let us take the first example where the maximum licence fee and the maximum expected penalty can be equal to the marginal revenue. At the optimum, when MR<Fx, L*=MR and E(F)*=MR. If MR>Fx, we have L*=MR and E(F)*<MR. In terms of net income we either have:

All licensed	or	All unlicensed or a mixture	MR.N	MR.N - S*
OR				
MR.N		(<MR).N - S*		

where (<MR) means a terms that is less than MR.

It is clear from the above that licensing all vessels will always be a better option than giving no licences. If the 'all licences' case involves a surveillance cost anyway, then if E(F)*=MR a mixed solution will also be optimal.

Let us now consider the more complicated case in a similar way. If b.MR<Fx(1+r) then the optimal

solutions are $L^*=a.MR$ and $E(F)^*=b/(1+r).MR$. If $b.MR>Fx(1+r)$ then the optimal solutions are $L^*=a.MR$ and $E(F)^*<b/(1+r).MR$. In terms of the net income we either have:

All licensed	or	All unlicensed or a mixture
$aMR.N$		$b/(1+r)MR.N - S^*$
OR		
$aMR.N$		$(<b/(1+r)MR).N - S^*$

This implies that all vessels should be licensed if (for the first case):

$$aMR.N > b/(1+r)MR.N - S^*$$

It is useful to rewrite this as follows (note $MR.N>0$):

$$a > b/(1+r) - (S^*/N)/MR$$

Recall that 'a' is the maximum proportion of the marginal revenue that fishermen are prepared to pay for a licence. Similarly, b is the maximum proportion they're prepared to 'pay' for the expected penalty when caught fishing illegally. {And it seems reasonable to assume that $a \leq b$} The term $(1+r)$ adjusts this for the expected loss of catches that fishermen may include in their penalty calculations. In general one would expect r to be small, and hence $(1+r) \simeq 1$. Also note that S^*/N is the surveillance cost per vessel fishing and $(S^*/N)/MR$ is the ratio of the 'per fishing vessel' surveillance cost to the marginal revenue.

Let $S^*/N=s$, the 'per fishing vessel' surveillance cost. For any vessel then, if $a>b/(1+r)-s/MR$ then the state should licence the vessel. If $a<b/(1+r)-s/MR$ the vessel should not be licensed and if $a=b/(1+r)-s/MR$ it doesn't matter.

Now note that we always have:

$b/(1+r) - s/MR \leq b$ (most often strictly <)

Whether to licence or not therefore depends on where 'a' falls in this relationship (recall we have assumed $a \leq b$). The decisions made by the state and the fisherman are summarised below.

	IF	STATE	FISHERMAN
1)	$b/(1+r)-s/MR < a \leq b$	licence	licence (<); don't mind (=)
2)	$b/(1+r)-s/MR = a \leq b$	do either	licence (<); don't mind (=)
3)	$a < b/(1+r)-s/MR < b$	no licence	licence (if possible)

If a=b then it will always be better to licence all vessels IF the surveillance cost can be ignored in such a case. If 'b' is only slightly larger than 'a' then the outcome will depend on the magnitude of the surveillance cost to marginal revenue ratio. If S^*/N is small relative to MR then the outcome may be in favour of licensing but if not, it is likely that the optimal solution would be not to licence vessels.

This result gives a 'neat' little test that is quite easy to perform assuming that some information about the relevant parameters is available. One can, for example determine the levels of surveillance cost where the system would 'switch' from all licensed to all unlicensed. This is given by:

$$S = N.MR\{ b/(1+r) - a \}$$

Alternatively, for a given level of surveillance cost, one can calculate what the critical number of vessels and/or marginal revenue ought to be (etc. etc.)

APPENDIX 1

The full set of equations and solutions for the general problem.

THE DECISION RULES:
[A1]
if L < a.MR and L < (1+r)E(F) then fish with a licence
if (1+r)E(F) < b.MR and either (1+r)E(F) < L or L>a.MR then fish illegally
if L > a.MR and (1+r)E(F) > b.MR then fish legally but unlicensed or not at all

THE INCOME EQUATIONS:
[A2]
i) if L<a.MR and L<(1+r)E(F) then NI = L.N
ii) if (1+r)E(F)<b.MR and either (1+r)E(F)<L or L>a.MR
then NI = E(F).N - S = F.(1-e^{-kS}).N - S
iii) if [L=(1+r)E(F)]<MIN(a.MR,b.MR) then NI = LN - S = E(F)N - S

iv) if L>MR and E(F)>MR then NI = 0

There are basically two maximisations required:
(a) Max. LN
subject to L≤a.MR (A3)

and
(b) Max. F(1-e(-kS))N - S
subject to F≤Fx and (1+r)F(1-e(-kS))≤b.MR (A4)

The optima for these two parts of the problem are then compared and the objective function with the highest net income is the desirable solution.
The first part of the problem is easy since the objective function (LN) is linear in the control variable, L. The maximum is therefore obtained when L is as large as possible. In order to satisfy the constraint, this implies setting the licence fee at:
L* = a.MR (A5)

The second part of the problem is somewhat more complicated since the objective function is non-linear in the surveillance cost S and there are two constraints in the form of inequalities. There is, however, a standard technique for dealing with such problems (see e.g. REF).

The first step is to incorporate the constraints into the objective function by introducing two new variables, V1 and V2. We rewrite the two constraints as follows:
Fx-F ≥ 0
b.MR - F(1-e(-kS)).(1+r) ≥ 0 (A6)

The objective function to maximise now becomes:

G = F(1-e(-kS))N - S + V1(Fx-F) + V2(b.MR-F(1-e(-kS))(1+r)) (A7)

with the only constraints that all parameters (F,S,V1,V2) must be positive.

The next step is to calculate what is known as the Kuhn-Tucker conditions. These can be summarised as follows:
[A8]
1a dG/dF ≤ 0 2a F(dG/dF) = 0
1b dG/dS ≤ 0 2b S(dG/dS) = 0

3a $dG/dV1 \geq 0$ 4a $V1(dG/dV1)=0$
3b $dG/dV2 \geq 0$ 4b $V2(dG/dV2)=0$

REWRITE, INCLUDE OR NOT?
A brief explanation of how these conditions 'work' may be useful. Consider condition 2a, which implies:
$F = 0$ and/or $dG/dF = 0$

If $dG/dF = 0$ the maximum is at an 'interior' point, i.e. a point where $F>0$. If
$F=0$, the first condition must also hold, so that $dG/dF < 0$, implying that the maximum is at a corner point.
****

In terms of equation A7, the Kuhn-Tucker conditions are:
[A9]
1a $dG/dF = (1-e^{-kS})N - V1 - V2(1-e^{-kS}) \leq 0$

1b $dG/dS = FNke^{-kS} - 1 - V2Fke^{-kS} \leq 0$

3a $dG/dV1 = Fx - F \geq 0$

3b $dG/dV2 = b.MR - F(1-e^{-kS})(1+r) \geq 0$

2a, 2b and 4a, 4b are easily constructed from the above equations and are not given in full.

We know that the fine and the surveillance cost have to be strictly positive (otherwise the problem is trivial!), so that $F>0$ and $S>0$. This implies that, from conditions 2a and 2b, conditions 1a and 1b have to be equal to zero.

Let us now consider the dummy variables V1 and V2. First assume that both are zero. This would imply (from 1a) that:
$(1-e^{-kS})N = 0$

This is impossible since $S>0$ (and of course k and $N>0$).

Secondly, assume that only $V1=0$. This would imply (from 1a) that $V2=N$ which, in turn, would imply that equation 1b has a value of -1. This would violate the condition that 1b is strictly equal to zero (see above).

Thirdly, assume that only $V2=0$. This would imply that (from 1a)
$V1 = N(1-e^{-kS})$
which in turn implies that $F=Fx$ (from 4a).

Condition 1b is then:
$FNke^{-kS} - 1 =0$
i.e. $F = 1/NKe^{-kS}$

But we have already seen that $F=Fx$ so that V2 can only be 0 if
$Fx = 1/NKe^{-kS}$
implying that
$S = 1/k.Ln(FxNk)$

Note, however, that for condition 3b to hold, we also need that:

$b.MR - Fx(1-1/FxNk)(1+r) \geq 0$

Finally, we assume that V1,V2>0. This implies:

$F=Fx$ and $b.MR=Fx(1-e^{-kS})(1+r)$

which means that

$S = -1/k.Ln[1 - b/(1+r).MR/Fx]$

Note that this solution is only possible when $b.MR<Fx.(1+r)$

In summary therefore, the optimal solution is at F* and S* which are determined as follows:

(1) $F^* = Fx$

(2a) if $b.MR>Fx(1+r)$ then $S^* = 1/k.Ln(FxNk)$
(2b) if $b.MR<Fx(1+r)$ then $S^* = -1/k.Ln[1-b/(1+r).MR/Fx]$

Solution 2a is at the maximum, i.e. where dG/dS=0 whereas solution 2b is at the constraint. This is illustrated in figure Xa and Xb (to be done).

As indicated above, the optimal solution for the 'licensing' part of the problem is:

$L^* = a.MR$

Let us now put these two together.
[i] if $b.MR > Fx(1+r)$ then
If $(L^* = a.MR) < Fx(1-1/FxNk)(1+r)$
$NI = L^*.N = a.MR.N$
else
$NI = Fx(1-1/FxNk).N - 1/k.Ln(FxkN)$

[ii] if $b.MR < Fx(1+r)$ then
If $(L^* = a.MR) < Fx(1-b/(1+r).MR/Fx)(1+r)$
$NI = L^*.N = a.MR.N$
else
$NI = Fx(1-b/(1+r).MR/Fx).N + 1/k.Ln(1-b/(1+r).MR/Fx)$

REWRITE TO MAKE CLEAR
If we compare the 'licensed' with the 'unlicensed' case, we find that as Fx tends to infinity, the slope between (a.MR) and Fx for equality between licensed and unlicensed tends to one.

NOTE the two bits can be combined using a 'trick' variable x, where x=1 when all are licensed and x=0 when all are unlicensed. (SEE NOTES).

Third set of notes on poaching - Linear programming

In this section we consider a sub-problem of the main problem by focusing on the allocation of licences to vessels.

Think of the following scenario: we have already decided how much to spend on surveillance (i.e. S is known and so is the probability of detection, q), the levels of the licence fees and the levels of fines. We now need to decide how many and WHICH vessels to licence. We assume that there is a distribution of boats of different sizes.

Assume that there are J size classes (e.g. GRT categories). Also assume that there are N_j vessels in size class j - this indicates the total fleet size. We assume that if x_j vessels in size class j is licensed it implies that N_j-x_j will be fishing outside illegally. This is because the licence fee and fines are set in such a way that they are not more than the marginal revenue for each category.

Let the licence fee in category j be α_j and the expected penalty β_j. The income to the state would then be given by :

$$\sum_{j=1}^{J} [\, \alpha_j x_j + \beta_j (N_j - x_j) \,] - S \qquad (1)$$

where S is the total surveillance cost. Note that it is also possible to replace the unlicensed vessels with variables y_j (this will be useful later).

Equation (1) is the objective function, the one that we want to maximise. There are, however, some constraints involved. The first set of constraints ensure that the number of licensed and unlicensed vessels does not exceed the total fleet in each category:

$$x_j + y_j = N_j \qquad j=1...J \qquad (2)$$

We introduce a second constraint here, referred to as the conservation constraint. At this stage we choose to limit only the effort in the licensed zone. Instead of just limiting the number of vessels, we limit the number of vessel 'units'. This takes into account the fact that vessels of different sizes or characteristics often have different degrees of efficiency. The constraint for licensed vessels is therefore:

$$\sum_{j=1}^{J} c_j x_j \leq X \qquad (3)$$

where c_j is the relative efficiency of vessels in class j. These three equations form a classical linear programming problem. We repeat them here to summarise:

Maximise:

$$\sum_{j=1}^{J} [\alpha_j x_j + \beta_j y_j] - S$$

Subject to :

$$x_j \geq 0,\ y_j \geq 0 \qquad j=1...J$$

$$x_j + y_j = N_j \qquad j=1...J$$

$$\sum_{j=1}^{J} c_j x_j \leq X$$

Note that the surveillance cost enters the objective function as a constant and can therefore be left out of calculations.

It may be possible to write the coefficients in terms of linear functions of the size category, i.e. j but this would not simplify the problem.

As indicated, this is a standard type of problem that is easily solved using the so-called simplex method.

It is, however, worth thinking a bit about how the solution should 'work'. Intuitively one would feel that categories with large values for licence fee should be given licences. But this is only a good idea if their contribution to the conservation constraint is not too large. If, for example, the licence fee and expected penalty are the same for each category, i.e. $a_j=b_j$, then it doesn't really matter whether a vessel is licensed or not from the objective function's point of view. (We assume that not all vessels will be licensed and that there will be a surveillance cost anyway). From the conservation constraint's point of view, it would be best to licence those with relatively low efficiency.

It is therefore clear that the solution to this problem will be driven by the trade-offs between licence fees and expected penalties and the relative efficiencies of vessels.

(NOTE that these days QUATTRO has a linear programming option in its spreadsheet! see ALLOCATE.WQ1 in c:\poach)

The obvious question is how does this fit in with the more general problem of optimising with respect to the licence fee, fine and surveillance cost? The answer is relatively simple! First let's consider a single vessel. If the vessel were to contribute to the state at all, the licence fee and/or the expected penalty have/has to be less than some proportion of the marginal revenue. So assume that $L \le a.MR$ and $qF(1+r) \le b.MR$. (Recall that (1+r) adjusts for lost catches due to being caught poaching, see second.doc; NB lost catches in that season only, not future catches as well). If $L<qF(1+r)$ then he would want a licence; if $L>qF(1+r)$ he would fish illegally. If the two are equal the fisherman is assumed to be indifferent.

Let us also make the realistic assumption that the maximum fine, Fx, is greater than the marginal revenue. As we have seen from previous analyses, the optimal solution is to set L=a.MR and qF(1+r)=b.MR. Then if $a<b$, the fisherman would want a licence, if $a>b$ he would fish illegally and if a=b he doesn't mind. Note that if $a<b$ but the fisherman is denied a licence, it is assumed that he will still fish outside illegally because he is prepared to 'take the risk'. Although not required in the formulation, it also seems reasonable to assume that $a \le b$, in other words, the fisherman is never prepared to pay more for a licence than he is to pay for an 'expected' penalty.

From the state's point of view, the cost of surveillance needs to be taken into account. Assume that 's' is the 'per fishing vessel' surveillance cost. If $a>b/(1+r)-s/MR$ then the state should licence the vessel. If $a<b/(1+r)-s/MR$ the vessel should not be licensed and if $a=b/(1+r)-s/MR$ it doesn't matter.

Now note that we always have:

$b/(1+r) - s/MR \le b$ (most often strictly <)

Whether to licence or not therefore depends on where 'a' falls in this relationship (recall we have assumed $a \le b$). The decisions made by the state and the fisherman are summarised below.

	IF	STATE	FISHERMAN
1)	$b/(1+r)-s/MR < a \le b$	licence	licence (<); don't mind (=)
2)	$b/(1+r)-s/MR = a \le b$	do either	licence (<); don't mind (=)
3)	$a < b/(1+r)-s/MR < b$	no licence	licence (if possible)

As soon as a conservation constraint enters the system, the best situation to be in is one where the fisherman doesn't really mind whether he has a licence or fishes illegally and where he is prepared to fish illegally when he can't get a licence. This would include all 3 cases above.

There are some potential problems, however. For example, if the parameter 'b' has been over-estimated (or if fishermen's perception of the expected penalty is that it is larger than it really is), the state may be relying on income from vessels fishing illegally. These unlicensed vessels may in fact not be fishing illegally at all.

In both cases (1) and (2) the next step would be to solve the allocation problem. It is important to note that there is an implicit assumption here that the same relative relationship holds for all vessel categories. This would be valid if there is a linear relationships between vessel category (VC) and marginal revenue (MR) and between VC and maximum fine, Fx. A linear relationship is, however, not necessary (although it is sufficient). It seems sensible to assume that values of 'a', 'b' and 'r' would not be functions of vessel category. (This may, of course, prove to be wrong!)

In case (3), there is no need to solve any allocation problem, since the optimal income would be from catching vessels that fish illegally and the conservation constraint would (by definition of the problem) not come into effect. [footnote: there may of course be situations where it would be beneficial to conservation to offer licences if one could come to some sort of VRA-type arrangement. This is not discussed here.]

Fourth set of notes on poaching
10/3/92

Notes on long and short term trade-offs between taking licence or poaching, including and excluding the effects of loss of future catches if caught fishing illegally.

Until now we have considered a one-year scenario. The fisherman's decision whether to take a licence or not was based on a comparison between L, the licence fee and qF, the expected penalty if caught poaching. (We assume for the moment that both these values are less than the marginal revenue).

The first extension considered here is the cost of poaching due to the loss of future catches if caught. Assume that once a fisherman has been caught, he loses his vessel and therefore all future catches. The expected value of future catches can be formulated as follows:

$$qQ.\ \mathrm{sum}_{t=2}^{inf}\ a^{t-1} = q.Qa/(1-a) \qquad (1)$$

where q is the probability of being caught in the first year, Q is the average value of the catch (e.g tonnage of catch times price per tonne) and a=1/(1+i) where 'i' is the discount rate. The discounted value of the catch from year 2 to infinity are summed. Realistically speaking, the sum should probably only be taken over a finite time horizon but the sum to infinity does reflect the general behaviour of the system.

The total expected cost associated with fishing illegally is now:

$$q[\ F + Q.a/(1-a)\ ] \qquad (2)$$

instead of only qF when the loss of future catches are ignored. (Recall that F is the fine and we have assumed that it is something like the value of the vessel). Note that if a~0 (i.e. the discount rate, i, tends to infinity) then the expected cost tends to qF. At a realistic value of i, say 0.1, the term a/(1-a) is of the order of 10. One can write Q=b.F and then the expected cost becomes:

$$qF(1+b.a/(1-a)) \qquad (3)$$

which tends to qF only if b~0 (i.e. the value of the catch in any one year is small relative to the value of the vessel) or if a~0 (i.e.a very high discount rate).

The second extension we consider here is the long term situation. First consider the licence fee. The cost in any one year is assumed to be L. Over the long term, the discounted sum of licence fees becomes:

$$L/a = L(1+i) \qquad (4)$$

(where, as before, 'i' is the discount rate and a=1/(1+i)).

The long term expected penalty is somewhat more complicated. Let's start by looking at the expected fine:

Year 1 $\quad q.F$ = P(being caught in yr1).Fine
Year 2 $\quad (1-q)q.F$ = P(NOT caught in yr1).P(caught in yr2).Fine
Year 3 $\quad (1-q)^2q.F$

and in general, in year t, the term is :

$$(1-q)^{t-1}q.F$$

If we now form the sum of the expected penalties, we get:

$$qF.\ \mathrm{sum}_{t=1}^{inf}\ (1-q)^{t-1}a^{t-1} = qF/[1-(1-q)a] \qquad (5)$$

The expected loss of catches can be treated in the same way:

Year 1 $qQa/(1-a)$ = P(being caught in yr1).Value of catch yr 2+
Year 2 $(1-q)q.Qa^2/(1-a)$ = P(not caught in yr1).P(caught in yr1).
Value of catch yr 3+

In general, in year t, the term is:

$$(1-q)^{t-1}q.Qa^t/(1-a)$$

The sum of these terms becomes:

$$qa/(1-a).Q/[1-(1-q)a] \qquad (6)$$

and the total expected cost is given by the sum of expressions (5) and (6):

$$q/[1-(1-q)a].\{ F + Qa/(1-a) \} \qquad (7)$$

The above expressions are summarised in Table 1.

Table 1

A) Excluding the cost of loss of future catches

	Licensed	Fishing Illegally
short term	L	qF
long term	L/a	qF/[1-(1-q)a]

B) Including the cost of loss of future catches

	Licensed	Fishing Illegally
short term	L	q{F+Qa/(1-a)}
long term	L/a	q/[1-(1-q)a].{F+Qa/(1-a)}

It is useful to consider under which circumstances the long and short term situations are similar. In case A, for example, assume that L=qF. The two costs (for fishing under licence and fishing illegally) would then also be equal in the long term if:

$$a = 1-(1-q)a, \text{ i.e. when } q=(1-2a)/a \text{ or } a=1/(2+q)$$

or, in terms of 'i', when

$$q=1-i \text{ or } i=1-q$$

This implies the following:
If L=qF then

if $q=1-i$, $L/a = qF/[1-(1-q)a]$
if $q<1-i$, $L/a < qF/[1-(1-q)a]$
if $q>1-i$, $L/a > qF/[1-(1-q)a]$

The similarity between the long and short term expressions for cost in case A and B suggest that the same relative relations hold in case B. This is indeed so, when the initial assumption is that L=q(F+Qa/(1-a)).

There are two important points with respect to these calculations. The first important point is that if the state makes its decision to licence or not to licence on the basis of short-term calculations whereas the fishermen base their decisions on long-term calculations, problems would arise. This is because the short-term decision may be to take a licence (i.e. L<qF) whereas the long-term decision may be to fish illegally (because L/a>qF/[1-(1-q)a]).

The second point is that if the state makes its decisions in the absence of the 'cost of lost catches' whereas fishermen include that in their calculations, problems would arise. The state would be under the impression that vessels would fish illegally whereas vessels will not be prepared to do so.
Note that Table 1 can also be given in terms of the discount rate, i, rather than a=1/(1+i) (see Table 2).

This makes it much clearer to see how the system behaves with respect to the discount rate.

Table 2

A) Excluding the cost of loss of future catches

	Licensed	Fishing Illegally
short term	L	qF
long term	L(1+i)	qF(1+i)/[i+q]

B) Including the cost of loss of future catches

	Licensed	Fishing Illegally
short term	L	q{F+Q/i}
long term	L(1+i)	q{F+Q/i}(1+i)/[1+q]

Fifth document with notes on licensing or poaching
(Variation on Second.doc)
12/3/92

As a starting point, we define the areas of parameter space coinciding with (a) fishing with a licence, (b) fishing illegally and (c) fishing legally without a licence or not at all. This is done by considering the types of decision rules that fishermen and a coastal state may use to make their decisions.

First we consider the decision rules for fishermen. Let MR be the marginal revenue, in other words the difference between the expected revenue from fishing with a licence (C_L.p) and from fishing legally without a licence (C_U.p). Here C is the catch, subscripts L and U signify 'licensed' and 'unlicensed' respectively and p is the unit price of the catch. Note that by definition $C_L > C_U$ and fishermen would fish illegally when unlicensed to try and push their catches up towards C_L.

Let L be the licence fee and E(F) be the expected penalty for fishing illegally. This term is the product of the fine, F, and the probability of being caught and charged (sometimes referred to as 'q').

Now the following decision rules can be set up:
[1a] FISHERMAN
if L $\leq$ MR and L < E(F) then fish with a licence
if E(F) $\leq$ MR and E(F) < L then fish illegally
if L and E(F) $\leq$ MR and L=E(F) then do either (licence or illegal)
if L > MR and E(F) > MR then fish legally (but unlicensed) or not at all

The areas of parameter space coinciding with the above decision rules are illustrated in figure 1a.

Note that in the third case, whatever the decision, the state does not obtain any income from these vessels. This is referred to as 'no contribution'. It is important to note that when conservation constraints come into the model, the decision of whether to fish legally without a licence or not at all becomes important. The expected penalty may also include an aspect of 'expected loss of catch if the vessels is caught fishing illegally. This aspect would affect the fishermen's decision but not the value of the income to the state. (see later)

Now consider the decision rules a state may use. Assume that there is a non-zero surveillance cost, s, associated with illegal fishing. (We assume that s is a 'per fishing vessel' surveillance cost at this stage). The net income to the state from a vessel that is caught fishing illegally is then E(F)-s. Now the following set of decision rules can be set up:
[1b] STATE
Let L$\leq$MR and E(F)$\leq$MR then
if L < E(F)-s then issue no licences (i.e. let vessels fish illegally)
if E(F)-s < L then issue licences
if L=E(F)-s then do either (licence or illegal)

The areas of parameter space coinciding with this set of decision rules are illustrated in figure 1b. If the two sets of decision rules are considered together, it is clear that there is only one area of 'agreement' between the state and the fishermen. This area lies between the two lines where L=E(F) and where L=E(F)-s and coincides with fishermen wanting licences and the state wanting to issue licences. At the 'edges' the state can do either (where L=E(F)-s) and fishermen would do either (L=E(F)).

It is now also quite simple to see what the optimal solution from the state's point of view would be. The optimal value for setting the licence fee, is to set it equal to the marginal revenue, L*=MR. The optimal level of the expected penalty would also be at the marginal revenue, E(F)*=MR. This would imply (in theory at least!) that fishermen would be indifferent between having a licence or fishing illegally.

It is, however, clear that licensing all vessels would bring in a higher net income to the state than having all vessels fish illegally, if licensing all implies no surveillance cost. In practice, this may not make sense since fishermen would not take up licences if they know there is no surveillance. This would therefore only make sense if there is surveillance (i.e. a non-zero probability of being caught fishing illegally) but with zero or very low cost associated with it.

At this stage it is also useful to note that if a conservation constraint needs to be imposed on the number of licences that are issued, vessels that do not get licences would be fishing illegally because they are assumed to be indifferent to the choice of licence or no licence. Note that this assumption implies a kind of risk neutral attitude by fishermen. In the next section, a risk prone attitude is considered.
It is worth considering the following question which leads to an alternative set of decision rules: what happens as L or E(F) approaches MR?

It is clear that if L=MR, fishermen may (or may not) bother to fish under licence. We can therefore assume that there would be some threshold level, say L=a.MR, which would constitute the maximum licence fee fishermen would be prepared to pay. Obviously $a \leq 1$ so that the more general case would include the above set of rules. It may also be that fishermen are prepared to take risks so that they are still prepared to fish illegally even if the expected penalty is larger than the maximum they would pay for a licence. This brings in an asymmetry into their decision-making process and the modified set of rules would be:

[2a] FISHERMAN
- if $L \leq a.MR$ and $L < E(F)$ then fish with a licence
- if $E(F) \leq b.MR$ and $E(F) < L$ then fish illegally
- if E(F) and $L \leq a.MR$ and E(F)=L then do either
- if $L > a.MR$ and $E(F) > b.MR$ then fish legally but unlicensed or not at all

By implication, we assume that $a \leq b$ and therefore if $L > a.MR$ but $a.MR < E(F) < b.MR$ the fisherman would be prepared to fish illegally. Figure 2a illustrates this set of decision rules. The asymmetry associated with fishing illegally using the third set of rules is shown in the area where the licence fee is larger than a.MR and the expected penalty is larger than the licence fee but, since the expected penalty is still less than b.MR, fishermen are prepared to take the risk and fish illegally. There is of course the 'special case' when L=E(F). We assume that when L=E(F) with $L < a.MR$ and $E(F) < b.MR$ fishermen would be indifferent between fishing with a licence or fishing illegally.

As before, we now consider the set of decision rules a state may use to decide whether to issue licences or not. As in case [1], we assume a non-zero surveillance cost (per fishing vessel), s. The decision rules are then:

[2b] STATE
- Let $L \leq a.MR$ and $E(F) \leq b.MR$
- if $L < E(F)-s$ then issue no licences (i.e. let vessels fish illegally)
- if $E(F)-s < L$ then issue licences
- if L=E(F) then do either

Figure 2b illustrates the areas of parameter space associated with the decisions for this set of rules. It is important to note that by definition of the fishermen's set of decision rules, if $L=a.MR < E(F) \leq b.MR$, a fisherman would want a licence but if not offered one, he would fish illegally.

When figures 2a and 2b are put together, it is clear that the area of overlap is, as before, between the lines defined by L=E(F) and L=E(F)-s. In this case, however, the maximum level for a licence fee would be L*=a.MR and for an expected penalty it would be E(F)*=b.MR.

The income to the state would then be:

Licensed: a.MR
Unlicensed: b.MR-s

If a=b, then the situation is the same as before in the sense that licensing all vessels would bring in a higher income. It has, however, been pointed out that this case may not be practical.

If a<b, then the optimal strategy would be as follows:

if a.MR > b.MR-s then licence all vessels
if a.MR < b.MR-s then issue no licences
if a.MR = b.MR-s then do either

Figure 2b illustrates a situation where a.MR > b.MR-s and figure 2c illustrates a situation where a.MR < b.MR-s.

point 1: it is only worth being in the area of 'overlap' between fishermen and a state's decisions.
point 2: there are advantages in being in the area where fishermen can decide either way - particularly when conservation constraints enter the game
point 3: some solutions may not be practical i.e. need for reformulation of problem (or further constraints, e.g. Smin etc.)

MOVE*****
What about conservation constraints? A conservation constraint, in this context, implies that not all vessels that are interested in fishing in the EEZ can be allowed to do so because that would 'endanger' the stock. In the simplest, but also most realistic case, we assume that effort can only be controlled in the EEZ. In other words, if licences are issued, not all vessels that want licences would get them. Those that do not get licences would, however, be at liberty to fish outside the EEZ. It is also important to note that those vessels that decide to fish outside the EEZ and not poach do contribute to the overall level of effort even though they do not contribute to the income of the state.
MOVE*****

In the previous section we have simply used the expected penalty, E(F), without considering the two components: the probability of being caught fishing illegally, q, and the actual fine, F. We have also not related the probability of capture with the surveillance cost. In this section these two aspects are considered in more detail.

We assume that the probability of detection, q, is a function of the total surveillance cost:

$$q = (1-\exp(-kS))$$

where k is the rate at which q increases with increasing S. Note that this function tends to 1 as S tends to infinity. This may be very unrealistic and a more general formulation would be:

$$q = d.(1-\exp(-kS))$$

where $d \leq 1$.

It may be simpler to express q in terms of the 'per fishing vessel' surveillance cost, s (in which case the term kS would become kNs=Ks).

We also assume that there is some maximum possible fine, Fx, which can, for example, be the value of the boat plus its catch. Note that this is in addition to the constraint that $E(F)=q.F \leq b.MR$.

The constraints, from the state's point of view, are therefore:

$L \leq a.MR$
$q.F=E(F) \leq b.MR$
$F \leq Fx$

The 'decision-area' that overlaps with that of the fishermen lies between:

$L = q.F$

and

$L = q.F - s$

This can be transformed into a constraint:

$q.F - s \leq L \leq q.F$

OR .... $L \leq \min[q.F, a.MR]$??

If the net income from a vessel is to be maximised, we need to maximise the following expressions:

a) Licensed: max L subj. to $L \leq a.MR$
and $q.F\text{-}s \leq L \leq q.F$

b) Unlicensed: max qF-s subj. to $qF \leq b.MR$
and $F \leq Fx$
and $q.F\text{-}s \leq L \leq q.F$

Section a) is straightforward, L is maximised at L*=a.MR.

Section b) is also straightforward with respect to F, the maximum being at F*=Fx. Write q in terms of s then the objective function (with F set at Fx) becomes:

$d(1-\exp(-Ks))F - s$

subject to $d(1-\exp(-Ks))F \leq b.MR$

There are now two possible solutions for s*, depending on the values of the parameters. The one solution is at the actual 'peak' i.e. where the first derivative is zero. This solution holds when b.MR > d.Fx and

$s^* = 1/K.Ln(dFxK)$

implying $q^* = d(1-1/dFxK)$

The second solution is at the constraint and holds when b.MR < d.Fx:

$s^* = -1/K.Ln(1-b/d.MR/Fx) = 1/K.Ln[dFx/(dFx-b.MR)]$

implying $q^* = d(b/d.MR/Fx) = bMR/Fx$

To summarise, the two solutions are as follows:

SOLUTION 1:

If b.MR > d.Fx then

$L^* = a.MR$
$F^* = Fx$
$s^* = 1/K.Ln(dFxK)$
$q^* = d(1-1/dFxK)$

SOLUTION 2:

If b.MR < d.Fx then

$L^* = a.MR$
$F^* = Fx$
$s^* = 1/K.Ln[dFx/(dFx-b.MR)]$
$q^* = bMR/Fx$

The case b.MR > d.Fx seems somewhat unrealistic. First consider the situation when b=1 and d=1. The inequality then implies that the marginal revenue is greater than the maximum fine level or, for example, the value of the vessel and its catch. (I shall concentrate on the situation where b.MR < d.FX)

Let's consider how the two cases compare when viewed from the fisherman and the state's point of view. (Note that (A) $q^*F^* > q^*F^* - s^*$ and (B) $L^*=a.MR$ and $q^*F^* \leq b.MR$)

	STATE	FISHERMAN
$L^* < q^*F^* - s^* < q^*F^*$	No Licences	Get Licence; will fish illegally

$L^* = q^*F^* - s^* < q^*F^*$	Do Either	Get Licence; will fish illegally
$q^*F^* - s^* < L^* < q^*F^*$	Licence	Get Licence; will fish illegally
$q^*F^* - s^* < L^* = q^*F^*$	Licence	Do Either

The decision for the fisherman is, in the first three instances, to get a licence. If not offered a licence, he would, however, be prepared to fish illegally and hence be a potential source of revenue for the state.

DIFFERENT CLASSES OF VESSELS

Before considering conservation constraints, we consider the extension from one group of similar vessels to many groups of vessels. Assume that vessels can be grouped together according to some characteristics. The simplest case is as follows:

For all groups 1...J: a, b are the same

For group j: Fxj and MRj are different BUT MRj/Fxj = Constant for all j.

The constraints now become:

$L_j \leq a.MR_j \quad j=1..J$

$F_j \leq Fx_j \quad j=1..J$

$q.F_j \leq b.MR_j \quad j=1..J$

The optimal solution for this case is relatively simple if $b.MR_j<d.Fx_j$ for all J (note that this will be true for all j if it is true for one j, given the assumption that $MR_j/Fx_j=C$ is constant):

$s^* = -1/K.Ln(1-(b/d).C)$

$q^* = b.C$

$F_j^* = q^*Fx_j$

$L_j^* = a.MR_j$

and the decision is made by comparing L_j^* and $q^*Fx_j - s^*$ for each group. Note again, that because of the assumption $MR_j/Fx_j=C$ the same relative relation will hold for all groups (i.e. the outcome will be licence all groups or do not licence any group or, of course, 'do either').

If $b.MR_j>d.Fx_j$ then, if one were to consider each group separately, the optimal solution for s would be a function of Fx_j. This would imply different optimal values for q and s and this is clearly impractical.

Assume for the moment that all groups are treated in the same way. Thus, if licences are issued, the income would be the sum of the products $L_j.N_j$ where N_j is the number of vessels in group j. Similarly, if none are licensed, the net income (that we want to maximise) would be:

$$d(1-\exp(-kS))(\text{sum}_j\ F_j.N_j) - S$$

where S is now the total surveillance cost. Because $b.MR_j>d.Fx_j$, the third constraint (in eq.x) is not needed and to maximise the function, $F_j^* = Fx_j$. When maximising with respect to S, we find that the optimal solution is at:

$S^* = 1/k.Ln(dk.\text{sum}_j\ Fx_j.N_j)$

$q^* = d(1-1/[dk.\text{sum}_j\ Fx_j.N_j])$

Now we need to compare

$\text{sum}_j\ a.MR_j$ and $d.\text{sum}_j\ Fx_jN_j - 1/k(1+Ln(dk.\text{sum}_j\ Fx_jN_j))$

to decide whether to licence or not.

(As indicated above, this is not a very realistic situation.)

16/3/92
Next section NOT directly linked to previous
CASE: i) b.MR/Fx not the same for all categories, (ii) b.MR < d.Fx for all categories.

The problem we consider in this section is related to the problem of setting fines and determining the optimal q (Prob. of catching) with associated surveillance cost, S, when there are many categories of vessels AND when the ratios between $b.MR_i/Fx_i$ is not the same for all categories. Let's ignore the licensing aspect for the moment and concentrate on unlicensed vessels.

The first question that arises is whether it is optimal to set fines for all vessel categories at Fmax? We look at this using an example. Assume there are two fleets with the following constraints:

	fleet 1	fleet 2
Amax=q.F	100	300
Fmax	300	600
fleet size	50	50
q~	0.33	0.50

where q~ is the value of q that satisfies the first constraint (qF=Amax) where F=Fmax. In other words, q~.Fmax=Amax. Now assume that q is set at the minimum of the q~ for the two fleets, then:

	fleet 1	fleet 2	
F	300 (=Fmax)	600 (=Fmax)	
qF	100 (=Amax)	200 (<Amax)	
INCOME	5000	10000	TOTAL=15 000

Now compare the situation with q set at the maximum of the q~, i.e. q=0.5:

	fleet 1	fleet 2	
F	200 (<Fmax)	600 (=Fmax)	
qF	100 (=Amax)	300 (=Amax)	
INCOME	5000	15000	TOTAL=20 000

Comparison of these two cases shows that the gross income from the two fleets can be increased by setting q higher and the FINE for fleet 1 below Fmax, although the expected penalty is the same in both cases. Moving from case A to case B implies an increase of 5000 income 'units'. The first point is : it is NOT necessarily optimal to set the fine level for all fleets at Fmax. It may, however, be optimal to ensure that all constraints associated with Amax are at equality (REPHRASE).

We know, however, that there is a cost involved in increasing q. In short, if the gain associated with moving from the low q to the high q (the 5000 units in the above example) is MORE than the increase in surveillance cost, then it is worth increasing q. If, on the other hand, the gain is less than increase in cost, then it is not worth increasing q up to the maximum of the q~-values.

The trade-off between the gain in income and loss due to increased surveillance cost is further investigated using a slightly more complicated example involving 4 fleets. As before the four fleets are assumed to have the following constraints and characteristics:

	fleet 1	fleet 2	fleet 3	fleet 4
Amax=q.F	100	200	500	1000
Fmax	1000	1500	3000	7000

fleet size	10	10	10	10
q~	0.10	0.133	0.167	0.143

Further assume that (from q=1-exp(-kS)):

S = -1/k.Ln(1-q)

The first thing to note is that the maximum the state can receive from a vessel in each of the categories is Amax, i.e. when q.F=Amax for all categories. Recall that there is effectively a single q because we assume that the surveillance can not target one or another type of vessel (** This assumption has not been mentioned before; in some fisheries it may be possible to target vessel-types).

The second thing to note is that, for a given q, the fine for fleet i will either have to be at Fmax or below. In order to satisfy both constraints ($F \leq Fmax$ and $q.F \leq Amax$) the fine is set as follows:

$F_i = \min[\, Fmax_i, Amax_i/q \,]$

The gross income is always maximised when q is set at the maximum of the q~. This implies (in terms of the above example) that q*=0.167 with F=Fmax for fleet 3. What about the other fleets? Since q*>q~ for the other fleets, the fines have to be less than Fmax in order to satisfy the constraint for Amax. In other words, if $q^* = \max_i [\, q\sim_i \,] = q_j$, say (e.g. j=3 in our example) then:

$F_j = Fmax_j$ so that $q^*.Fmax_j = Amax_j$

and

$(F_i = Amax_i/q^*) < Fmax_i$ so that $q^*.F_i = Amax_i$ for $i \neq j$

What about the NET income? Figures xa and xb illustrate the gross and net income for our example, with two examples of the surveillance cost. In figure xa (k=5e-5) the surveillance cost is relatively small and the optimal solution is q*=0.167 (i.e. the maximum of the q~'s). Note that the gross (and hence net) income does not increase beyond the maximum q because the constraints for Amax have come into effect for all fleets.

Figure xb (k=3e-5) illustrates the situation for a larger survey cost (for the same q as in xa). Now the optimal solution lies somewhere between the minimum and the maximum (at about 0.145). This implies that, at the optimal, only fleets with q~-values greater than 0.145 have F=Fmax and $q^*F \leq Amax$. Fleets with q~<0.145 have q*F = Amax but F<Fmax.

In the above example I have assumed that each category contain the same number of vessels. If this assumption holds but the total number increases or decreases (from 10 to 50 or 10 to 5, for example), the optimal solution may also change. For example, with N between 4 and 13, the optimal is around 0.142 to 0.145, then at N=14, the optimal solution jumps to q=0.167 and then stays there for all $N \geq 14$.

If the fleet sizes for each category changes, the optimal solution may also change drastically. For example, if there are 50 vessels in category 1 and only 1 in each of the other fleet categories, then the optimal solution would be dominated by the values for fleet 1 (the optimal is likely to be at $q^* = q\sim_1$) (see figures xx1a N=50,1,1,1 and xx1b N=1,50,1,1).

[footnote: when putting together lic and unlic - at first 'glance' it seems sensible to optimise w.r.t all fleets lic separately from unlic. But what if fleet 1 then comes down in favour of licensing (for whatever reason)? is it then not necessary to re-optimise the unlic-section w.r.t the remaining fleets? It DOES seem, intuitively, best to be where both the fisherman and state can decide which (i.e if L=qF when a=b, i.e. aMR=bMR)]

Conclusion: From the above analysis it is clear that:

a) it is not necessarily optimal to set F=Fmax for all fleet categories
b) The relative fleet sizes in each category affects the optimum value of q
c) the coefficient k that relates q to S affects the optimum value of q

This conclusion also starts suggesting some of the difficulties that will be encountered later. If we ignore the non-linearity between q and S or assume that we can approximate it by a linear function over the range of values we are interested in then we effectively have a linear programming problem with constraints. The problem is that we are trying to optimise with respect to the coefficients (L, q, F) AS WELL AS the 'allocation variables', i.e. how many of each fleet category to licence or not to licence.

What are the implications of not having q*F*=Amax for all fleets? (see above; the example where surveillance costs were relatively high and q*=0.145). If q*.F*<Amax, a fisherman would 'gladly' fish illegally because the expected penalty is less than the maximum he is prepared to pay. If the licence fee is set at Amax, then he will not take up the licence but rather fish illegally. Clearly, if the licence fee is set BELOW Amax, the fisherman would take the licence but the income to the state (from that vessel category) would be sub- optimal. This suggests that, either the licence and unlicensed parts of the problem should be considered together or that those vessel categories for which the above is true, should not be licensed. *** CHECK THIS ****
(Assumed for the moment that a=b in Lmax=aMR, Amax=(qF)=bMR)

The following seems sensible. Optimise the 'unlicensed' problem w.r.t all fleets and find q*. For fleets with q*.F=Amax, one can licence them, setting L=Amax (recall we are assuming aMR=bMR=Amax). The main point is that one is assured the licence money whereas the 'fine' money has an associated uncertainty. Note however that although the expected penalty is equal to the licence fee, fishermen may prefer the 'high risk' option of fishing illegally and not take up the licences offered to them. For these categories it is also true that F<Fmax. It is therefore also possible to set the fine higher, e.g. at Fmax which would imply that q*.Fmax > Amax and which would therefore discourage vessels to fish illegally.

For fleets with q*.F<Amax, it would be necessary to let them fish illegally outside the zone since with a licence fee set at Amax, the fishermen would not be interested in licences. It would of course also be possible to reduce the licence fee for this category (to L=q*F) but this may be seen to be 'unfair' and this would not imply any increase in income.
IF licensing all vessels implies NO surveillance cost then (as before) the optimal would be to set L=Amax for all fleets and to licence all vessels. Common sense suggests that there should be some non-zero probability of being caught and fined for fishing illegally before fishermen would be prepared to pay for a licence and usually this would imply a non-zero surveillance cost even if all vessels are licensed.

Another little example - FLEET4.WQ1

Let's consider yet another simple example. Three fleets with the following characteristics:

	fleet 1	fleet 2	fleet 3
Amax=q.F	100	200	500
Fmax	1000	1500	2000
q~	0.10	0.133	0.25

Now note that if licensed, the best option is to set L=Amax for each category. If we now assume a certain surveillance cost, say 2000 units (with k=1e-4), then this implies a q-value of 0.18. With this q, the implications for unlicensed vessels would be the following:

	fleet 1	fleet 2	fleet 3
F	555	1111	2000
(0.18)F	100	200	360

Note that for categories 1 and 2 qF=Amax BUT F<Fmax whereas for category 3 F=Fmax but qF<Amax. This implies that vessels in categories 1 and 2 would be indifferent to being licensed or fishing illegally whereas, with L=500=Amax for category 3, these vessels would choose to fish illegally. It is also clear

that there is a loss of 140 (=500-360) units per vessel at this level of q. If we assume for the moment that the number of vessels in each category is the same, N say, then the net income is given by:

N(100+200+360)-2000 = 660.N - 2000 (1)

This case can be compared with one where, say 3000 units are spent on surveillance. This implies a q-value of 0.259 with the following implications for each category:

	fleet 1	fleet 2	fleet 3
F	386	718	1930
(0.259)F	100	200	500

which implies that vessels in all three categories are indifferent to whether they fish with licences or illegally. In this case the net income is given by:

N(100+200+500)-3000 = 800.N - 3000 (2)

If we compare equations (1) and (2), it is clear that if N<7 then (1)>(2) (i.e. it would be more profitable to spend 2000 than 3000 on surveillance) whereas when N>7 then it would be more profitable to spend 3000 than 2000 on surveillance. Figure x illustrates the net income for a range of S-values and various values of N. This clearly shows how the optimum shifts from one level of surveillance cost (and implied q) to another as N changes.

It is also worth noting that the optimum is actually at the q implied by category 3 (i.e. Amax/Fmax=0.25) and that there is no point increasing q beyond that value.

As before, the comment stands that F can be increased to Fmax for all three categories to try and discourage vessels from fishing illegally (if there are any independent reasons for doing so). Also note that if a vessels decides to fish illegally anyway (although q.Fmax>Amax) and gets caught and fined, the state would get more than they bargained on!

[Note that this example again assumes that Fx>MR]

Conservation constraints on this problem can be treated relatively easily because at the optimum the income from all fleets is Amax and vessels are indifferent between fishing illegally or with a licence. First therefore, the assigning of licences is quite easy. This can be done with a simple LP model (see Third.doc; there could be lots of linear combinations that could give the same answer, particularly if the relative 'catchabilities' are the same).

Also note that by setting the fine higher (e.g. at Fmax so that q.Fmax>Amax) vessels would be discouraged to fish illegally and this could mean a 'saving' with respect to conservation.

3 GAME DEVELOPMENT

Control of Foreign Fishing

Progress Report

18 February 1992

I have done a simple model of the system in Turbo Pascal and come up with the following results:-

It is a fairly straightforward system as far as I can tell, even with a distribution of boat sizes. If licence fees and penalties can vary with the mass of the boat, then the results are the same for one as for a distribution of boats, since the fine and the licence can be varied to obtain optimum revenues for each. If some things must stay constant, then clearly some decision about which sub-optimal solution is required, needs to be made. I have kept to a one-boat model for now. A stock constraint would make things much more interesting and I shall go onto that next.

Assumptions

Marginal revenues and revenues per day from fishing in the territorial waters follow diminishing returns to boat size (Fig. 1a), while the value of the boat increases linearly with size. The penalty is (value of boat = k * revenues per day), increasing almost linearly with size (Fig. 1b). The probability of detection increases linearly with the number of patrol boats, as do surveillance costs. In symbols:-

Marginal revenues $MR = 600{,}000 * (1 - e^{-0.005M})$

Revenues/day $R = 40{,}000 * (1 - e^{-0.005M})$

Boat size $M_{max} = 1{,}000$

Boat value $V = kM$
$V_{max} = 3{,}000{,}000$

Detection $d = 0.1 * 0.08 * N$ $d_{max} = 1$

Capture if detected = 0.1
Proportion of area covered by 1 boat in 1 day = 0.8
N = number of patrol boats

Surveillance costs $S = 3{,}000 * 90 * N$

Cost per patrol per day = 3,000
Days in season = 90

Penalty $F = V = (20 * R)$ $E(F) = V * d$

State Revenues $Rev = L - S$ (legal)
$Rev = Vd - S$ (illegal)
L = licence fee

Decision of Fisherman

If MR < E(F) and MR < L Don't fish

If L < MR and L < E(F)   Fish legally
If E(F) , MR and E(F) , L   Fish illegally

Results

Licence fees, number of patrol boats and boat size were varied and the licence fee and patrol number giving the optimal revenues found for each boat size, as well as the decision made by the poacher at the optimum.

The key determinant of the optimal decision is that E(F) includes an element of implied cost not received as revenue by the manager. If it didn't the optimal solution would be L = E(F). Since the perceived E(F) is higher than the revenues gained from a fine, L should be as near as possible to perceived E(F) and above the revenue gained by the manager from a fine [ie the optimal solution is for the fisherman to take a licence of the value Vd < L < E(F)].

The other major factor is the cost of surveillance. The results here are of course a bit misleading, because only one fishing boat is involved so the costs are not spread around several users of the resource. Making more users would just lower costs per fishing boat proportionally to the number of fishing boats present. Anyway, if surveillance costs are low, the optimum is for the licence fee to be as near as possible to the marginal revenue of the fishing boat (Fig. 1a). At the high surveillance costs given in the data, the optimum is to have patrols at a minimum (1 boat) and to keep the licence fee as close as possible (but just below) the expected fine. Although the expected fine increases dramatically if more patrols are used, the high surveillance costs make this sub-optimal (Fig. 1b).

Ignoring surveillance costs for a moment, you can get a graph of the fisherman's decision faced with variation in the licence fee and the number of patrol boats (Fig. 2). All three possibilities can be encountered. The number of patrol boats is here linearly related to the expected fine so can be seen as a proxy for it. If you look at the state's revenues for the same range of licence fees and patrol boats, the optimal revenues vary substantially with the surveillance cost assumed, as does the optimal policy in terms of the amount of surveillance carried out (Fig. 3). Fig. 3b is near the cost taken from the Falklands data, Fig. 3d shows the limit situation with no cost to surveillance and Figs. 3a and 3c are intermediate values. The optimum is marked with a cross in each graph.

Looking first at Fig. 3d, as the licence fee approaches the value of the expected fine, revenues increase to a peak. They drop suddenly once the licence fee exceeds E(F) and illegal fishing starts to occur. Revenues are zero if both E(F) and L exceed MR, and are maximised when L is almost exactly equal to MR. When surveillance costs are low but non-zero the picture is the same, except that revenues decline at surveillance rates higher than optimal because of the expense of the unnecessary patrol boats (Fig. 3a). At very high costs of surveillance (such as pertained in the data), the optimum is at the minimum surveillance cost (Fig.3b). Finally there are a very few intermediate surveillance costs where the number of patrol boats is neither that producing revenues near the fisherman's MR nor the minimum, but on the line dividing the legal and illegal fishing (Fig. 3c).

3 April 1992

Progress Report

I thought you might like to know how I'm getting on with the law enforcement work. I've taken the idea of a game between the fishermen and the state as discussed in our meeting. I have used it in two ways:-

1 The Individual Fisherman. By reference to the proceedings of a workshop on law enforcement in the fisheries of the USA, the penalty structure in the USA is:-

First infringement	small fine
Second infringement	larger fine
Third infringement	fine and confiscation of assets
Fourth infringement	banned from fishery

It is politically and administratively impossible to impose large fines for first violations. They won't be paid so will need lots of court appearances, where they may be ruled unreasonable. Also, after 5 years without infringement, all previous infringements are removed from the books.

This can be modelled from the viewpoint of an individual fisherman, moving through a matrix of "penalty states" and fishing decisions under state imposed parameter values. Clearly the fisherman's attitude to risk could be included in the model. However, as it stands, it's not a very exciting model, since it would be very complicated to expand to a whole fishery and for an individual fisherman, the optimum strategy is to infringe once or twice, wait for 5 years ad then do it again, etc.

2 The Whole Fishery. There has been some work done using game theory for modelling fishing by two separate states, each maximising their own profits from the same fish stock. Kennedy (*Marine Resource Economics 1987*) uses dynamic programming and has the players making alternate harvesting decisions. this can be applied to the law enforcement problem by having the state making decisions about the licence fee and the surveillance costs on the basis of the expected reaction of the fishing fleet to the values chosen. A distribution of boat sizes in the fleet is included, along with a stock/harvest rate relationship. The stock size, state revenues and fishing revenues can be traced over time. The state decides on the licence fee charged and the money spent on surveillance, the fleet decides whether a boat of a particular size will fish legally, illegally or not at all.

At present, I have modelled this in the following way:-

Assumptions

- licence fee is constant over time;
- penalty is maximal - ie confiscation of boat and catch;
- probability of detection is related to surveillance costs by a negative exponential, as discussed when we met;
- a boat's catchability coefficient is related to the value of the boat by a negative exponential;
- Stock growth follows a logistic function.

Thus: $N_{t+1} = N_t [1 + r(1 - N_t/K)] - qN_t$

where qN_t is the revenues for a boat in a season and q is related to the value of the boat.

1 For a given surveillance cost and licence fee in each year, each size of boat decides whether to fish legally or not. The state then chooses the surveillance cost to maximise its short-term profits, given the decisions of the fishermen. This is basically an expansion of the model I showed you before, but including a stock constraint over time and interaction between the state and the fishermen.

2 The same, except that the fishermen co-operate to maximise their joint short-term profits. This is thus

much more like a 2-person alternating game between the state and the fleet. Obviously, the results are rather different if the fleet is maximising jointly rather than individually.

The next step is to keep the fishermen at the most realistic scenario, short-term non-cooperative maximisation, and to have the state maximising long-term profits. Also to relax the assumptions of a constant licence fee over time and a maximal penalty. However, since this dynamic programming type of simulation takes a very long time on my PC, I haven't got very far with exploring the above models yet. I would first like some feedback from you on how your like this approach, before embarking on more complicated simulations. It seems to me to be flexible enough to be quite useful for an expert system.

E J Milner-Gulland

Control of Foreign Fisheries

Surveillance Project

Report 15.4.92 - 25.6.92

Task: To read literature on tuna fisheries in the Indian and South Pacific oceans, and to use data gleaned from the literature to improve the general model presented at the meeting on 15.4.92 and to make it specific to tuna. To incorporate into the model a classification of fisheries by the degree to which stocks are sedentary or migratory.

Methods: The best example of a tuna fishery for which political constraints are less severe than, for example, in the South Pacific, is the newly regulated BIOT fishery in the Indian Ocean. The model is therefore run using data predominately from BIOT, though other fisheries have supplied some qualitative data. The following major points are addressed in the model.

1 The data are fragmented and not very informative, especially with respect to stock dynamics. There are neither good estimates of stock sizes nor of the effects of fishing on them. The general consensus (see Sibert 1991) is that no tuna stocks are in danger of collapse at present. Since a short-term model is considered to be the most realistic characterisation of a tuna fishery, the model assumes that the stock is adequate for the present fleet, and that the fleet currently present in the Indian Ocean remains constant. This assumption will obviously have to be modified at some point, though it seems an adequate characterisation of the current situation.

2 Several sources working on fisheries in the USA (eg Sutinen and Gauvin 1989) have shown a significant law-abiding section of the fishing fleet, who will not fish illegally despite the economic incentives. The model is able to simulate the situation with any proportion of law-abiding fishermen.

3 A classification of fisheries into sedentary and migratory is best carried out by varying the proportion of the catch obtained in the fishery that can be obtained elsewhere, either on the high seas or in another fishery. Thus the baseline profit below which the boat leaves the fishery can be varied. A sedentary stock has a baseline of zero, a highly dispersed, a high baseline. A stock such as tuna may be concentrated within a fishery on a seasonal basis, or may be concentrated within a harmonised management zone like the South Pacific, or a fishery may only have a slight advantage over the high seas at certain times of the year, as appears to be the case for BIOT. Thus this formulation, though crude, is a very flexible way of characterising a wide range of fisheries, although, as Paul Medley states (1991), the exact quantity to which the profits made from a fishery should be compared, is not always straightforward to calculate.

4 A major feature of the tuna fishery is its division into two very different sectors, purse seiners and longliners. These vary in their operating costs and revenues, as well as in the effects of GTR on catch. (There is a positive relationship between GTR and catch for purse seines, but no clear relationship for longliners.) The model divides the fishery into these sectors and can calculate the optimal strategy for each sector and for the fishery as a whole. Since stock size is not included as a variable in the model, the interaction between the catches of the two sectors is not considered (Paul Medley 1991).

Results: The graphs show the results of preliminary runs of the model. There are a large number of factors that can be varied, so in the preliminary runs no fishermen are assumed to be intrinsically law-abiding and only one high and one low fine, and a high catch and no catch outside the zone are considered. The fine is expressed as a proportion of the annual operating cost of a boat, and confiscation of the catch is assumed to occur at each capture. Thus a fine of zero means that the catch is confiscated but no extra penalty is given. The licence fee (as a percentage of the total catch) and the surveillance cost are varied and the revenues to the state are calculated, given a rational decision by the fishermen to optimise profits.

The two sectors behave very differently because the longliners are marginal fishermen who soon cease fishing as both the licence fee and surveillance effort increase. The purse seiners continue to fish at much higher costs because of their high catch rates. If the gains to be made elsewhere are assumed to be half the gains to be made in the fishery itself, the longliners do not fish even at very low licence fees or surveillance costs. The optimum strategies for both the fishery as a whole and for each sector are marked on the first graph, and occur at a much lower level for the longline fleet than for the purse seiners. Both optima occur (for the example with a low fine) when all boats are fishing illegally and there is a medium amount of surveillance. If the optimum for the whole fishery is reached, longliners will be excluded from the fishery, which may be an undesirable social consequence of maximising profits. However, if longliners and purse seiners can be treated differently in terms of the licence fees charged, although the surveillance cost will be the same, the maximum revenues, while keeping both fleets in the fishery will be made when the longliners are fishing legally at a low licence fee and a high surveillance, while the licence fee for purse seiners is high and they are fishing illegally. If the fine is very high, then the optima occur when fishing legally. Finally the graphs show that the GRT-catch rate relationship for purse seiners has little overall effect, but leads to smoother transitions between the three states (fish legally, fish illegally and don't fish). Greater differentiation between purse seiners in this respect will lead to even smoother curves.

Further work: The model is now sufficiently large for time to be a major constraint on the production of results. This could be solved by my being able to use the vacation once term is over and I can obtain advice in setting up a program to run on it. Alternatively, I could had the model over to Simon in its present form for him to revise it as he wishes and run it on RAG's machines. Once it is running, the model can show the different policies needed towards the two fleets under many combinations of variables, and what the best management strategy for BIOT might be. However, the model is basically the same simple decision process as the one first presented, with a few tweaks to improve the realism. I am unsure as to the value of continuing to refine it further. There are a few areas which it might be interesting to explore:-

1 The most comprehensive data on violation rates and the effects of enforcement come from Sutinen and Gauvin's work in the USA. They used both patrol data and surveys to build up a more rounded picture of detection rate, and came to the conclusion that there are two types of offender - habitual violators and very occasion violators. The majority of illegal profits are made by a small minority of fishermen (this is a similar conclusion to those of studies of burglary and other crimes, and also rhino poaching). If the habitual offenders were targeted, enforcement success would be greatly increased. They also show that psychological and social factors are important in the incentives to violate fishery laws. It seems very unlikely that we can get data on these kinds of factors for foreign tuna fishing vessels, but it would be excellent if we could.

2 The world tuna fishery seems a difficult one to use as an example because of the many political factors involved in compliance. For example, the regional register of the South Pacific seriously distorts any economic study of the relationship between penalties, enforcement effort and compliance. However, this seems to be less of a problem for BIOT.

There are a lot of data on the economics of the tuna fish market, although how tractable these data are, is debatable. Paul Medley (1991) did a preliminary analysis of the economics of the tuna market, but further data could perhaps be found for another more rigorous econometric analysis to be done. For example, an economic component could be crucial, if the tuna fishery were to be modelled with a stock constraint.

E J Milner-Gulland

INTRODUCTION

SUITABILITY OF FISHERIES MANAGEMENT FOR EMBODIMENT IN AN EXPERT SYSTEM

4 PROTUNA DESCRIPTION

INTRODUCTION

SYSTEM DESCRIPTION

5 CONCLUSIONS AND RECOMMENDATIONS

SHORT TERM

LONG TERM

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CONTROL OF FOREIGN FISHING

MRAG REFERENCES

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APPENDIX 1 : THEORETICAL CONSIDERATIONS

ODA Narratives

R 4775 Control of Foreign Fisheries

May 1991

Preliminary work on this project has started. There is nothing to report at present.

Management

During much of the last year, management time has been put into developing extended programme structure to take into account the increased level of funding. This is an exciting if somewhat arduous task. It is expected that a number of projects will be able to be brought forward but, because of the planning horizon, are not expected to start until the second half of the year.

August 1991

Using techniques of optimal control the problem of the situations where developing countries should choose between developing their own fishing industry or licensing foreign fleets has been addressed. Some preliminary results were presented by Dr Beddington at a conference in honour of Professor Colin Clark (the founder of Mathematical Bioeconomics) in Vancouver in July.

It is intended that the project will concentrate on the production of decision methods and management guidelines that will assist in policy formulation towards maximisation of benefits. It will:

*investigate, analyse and produce a general overview of the level of foreign fishing activity and their regulatory environments on a global scale in developing countries;

*take examples of 3 or 4 developing countries fisheries and undertake detailed analyses of their bioeconomic characteristics, including the calculation of the marginal value of licence fees (plus other benefits).

November 1991

Due to illness of the Senior Researcher (Professor Beddington) work on this project has been less extensive than planned. Research has been limited to constructing an initial bioeconomic framework for investigating the optimal control of illegal fishing. This provides the tools for analysing the relationships between licence fees, probability of detection, cost of surveillance, levels of penalties and the value of illegal fishing,. Substantial work on this problem is planned for the next quarter.

January 1991 ODA Annual Report

The objective of this project is to use the methods of mathematical bioeconomics and optimal control and apply them in a rigorous way to the practical problems faced by Fisheries Managers in developing countries in dealing with foreign access. The work will not involve any field work but a review of foreign activity will be conducted. Much of the work involves quite sophisticated mathematics, but will be written up in a form to make it readily accessible to fisheries managers in developing countries. Two central problems are addressed: first, the choice of licensing foreign fleets as opposed to developing local industry and the second, the interplay between the level of surveillance and its cost, the level of fines for illegal activity and the level of license fees and the value of a licence.

This work will build on a substantial empirical foundation derived form a set of case studies of foreign access.

Work on the project has been satisfactory, but the illness of Professor Beddington meant that some substantive analytical work planned for the third quarter of 1991 had to be postponed to the first quarter of 1992. A paper on the choice of whether or not to licence foreign vessels was presented at an International Conference in Canada in August. A paper to be submitted to the Journal Marine Resource Economics is in the final stages of preparation.

February 1991

Excellent progress has been made on the analytical investigation of the optimal control of illegal fishing. Some computer programmes have already been written to investigate for different scenarios what is the optimum mix of surveillance, the level of penalties and the level of licence fees. It is expected that manuscripts covering some of these aspects will be prepared for publication during the next quarter.

Work is planned on extending the analytic work to cover more detailed case studies during the next financial year. The ultimate aim is to provide a computer programme that can be linked in with the Experts System which will enable users to appropriately decide on alternative strategies for controlling foreign fisheries. Included in this will be a methodology for estimating licence fees from catch data.

June 1992

There is little to report on this project. Work is continuing along the lines previously set out.

August 1992

The main work on this project during this quarter has been orientated to building some detailed models of the operation of fleets of different types. In particular tuna purse seiners and long line fleets have been modelled and work on demersal trawl fisheries is planned.

As indicated in the narrative, there is a plan to extend this project and to use some of its interim results as part of a field based project to assess the responses of some individual client countries to the problems of the control of foreign fishing.

November 1992

Relatively little work has been done on this project during this quarter. Some software development to provide the optimisation computer programmes in a user-friendly manner has been continuing. Data collection for detailed model fitting continues.

January 1993 ODA Annual Reports

<u>Objectives</u>

The objectives of this project are to use the mathematical apparatus of optimal control to investigate the ways in which developing countries can assess the manner and extent to which they allow foreign vessels to fish in their EEZs.

This project is reaching the end of its active period of research. Results have been pleasing, some general methodology has been developed to assess the levels of licence fees. The detailed interrelationship between level of fees, degree of surveillance and the level of fines imposed for illegal fishing has been laid bare.

Much of the work in the last year has been involved with elaborating case studies and developing computer software that can appropriately demonstrate the power of the techniques and solutions used.

The results of the project are being applied in the Adaptive Research Project R.5049CB, described in Appendix XVII. This has presented certain logistical problems in finding sufficient time for key personnel to work on projects. To solve these problems it has been decided to slightly extend the duration of the project. There are no financial implications of this change.

March 1993

This project is due to finish in April and it is expected that there will be no problems in meeting this deadline. Very little work other than report writing and software finalisation has taken place during this quarter.

ODA Fisheries Management Science Programme

PROGRESS REPORT 1 **DATE** 27 / 05 / 92

TITLE OF PROJECT Control of Foreign Fishing : Optimal Benefit Management in Licensed Fisheries

ORGANISATION MRAG Ltd

REPORTING PERIOD FROM 01 / 04 / 92 **TO** 31 / 06 / 92

1OBJECTIVES

To develop methods for the assessment of optimal net benefits from the licensing of foreign fishing vessels in national fisheries jurisdiction and to prepare software for decision making in the planning of surveillance and enforcement and the quantification of licence fees and penalties.

2WORK CARRIED OUT IN THIS PERIOD

There are three thrust's in progress during the current quarter, modelling, literature search and review and information collection.

Modelling :

The two different conceptual approaches are undergoing redefinition that will include variation in some of the input parameters e.g. changes in fish stock size. These models are now being tested with some sensible ranges of values such as fish catch value, marginal licence value, and vessel value. A major problem is encountered in obtaining appropriate vessel values in relation to the size / carrying capacity of the vessel. Some ways to avoid this problem are being investigated.

Literature Search and Review :

A review of the Aquatic Science and Fisheries Abstracts database for key references has revealed an extremely large literature on surveillance and enforcement. Only a very small number of these investigate the bio-economics of the issue, none investigate the operations control modelling and testing that this project is attempting. Nevertheless, the fisheries literature has revealed useful sources of information, though little hard data, which are being followed up directly.

Information Collection :

As a result of the literature review and through personal contacts the project is compiling information directly from sources, including the Scottish Fisheries Protection Agency, the Sea Fisheries Inspectorate, the Canadian Department of Fisheries and Oceans, the South Pacific Forum Fisheries Agency and others.

3RESULTS

Extensive interviews have been undertaken with the Scottish Fisheries Protection Agency. Significant general information was obtained on surveillance and enforcement costs although the level of detail, at first attempt, was somewhat less than had been hoped. A detailed information request is now being prepared to which the SPFFA will respond where possible. There are significant problems encountered with obtaining surveillance costs. Firstly, in many places these costs are subsumed within general military spending and extraction of direct costs is difficult to measure. Secondly, in some places, e.g. Scotland, England/Wales, Australia, New Zealand, a considerable proportion of surveillance costs, particularly the aerial aspects, are not publicly available for reasons of commercial confidentiality; aircraft, pilots etc are used through private contract and for general security reasons. Lastly, full enforcement costs are difficult to measure; they are not simply the surveillance costs (in all its different forms) but also include the administration costs consisting of general management costs (say associated with quota calculation and monitoring) and prosecution costs (case preparation, lawyers, judiciary etc).

4IMPLICATIONS

The implications of failure to obtain the necessary data are that the real values cannot then be input to the models. Other approaches may need to be sought , perhaps even generating some of the costs from indirect information.

5PRIORITY TASKS DURING JULY-SEPTEMBER 1992.

Modelling:Modify the existing models to allow for gross parameter values to be used, rather than the detailed requirements say, of vessel value.

Literature in Review	:	Expand the literature review to investigate the same issues other areas of enforcement e.g. environmental monitoring, forestry and general criminology.
Information sources. collection	:	Continue with direct data collection from co-operating

6AUTHOR

NameDavid Evans

Signature ____________________

ODA Fisheries Management Science Programme

PROGRESS REPORT 2 **DATE** 04 / 09 / 92

TITLE OF PROJECT Control of Foreign Fishing : Optimal Benefit Management in Licensed Fisheries

ORGANISATION MRAG Ltd

REPORTING PERIOD FROM 01 / 07 / 92 **TO** 31 / 09 / 92

1OBJECTIVES

To develop methods for the assessment of optimal net benefits from the licensing of foreign fishing vessels in national fisheries jurisdiction and to prepare software for decision making in the planning of surveillance and enforcement and the quantification of licence fees and penalties.

2WORK CARRIED OUT IN THIS PERIOD

The theoretical modelling work has come to a halt during the quarter. A number of features of the simulation model have been altered and the project is awaiting data for further input and model testing. Attempts are being made to obtain surveillance and enforcement costs through a number of cooperating institutions. This has involved preparation of a detailed questionnaire on matters that it may be possible for informants to supply. Responses to these questions and compilation of data is awaited before resuming model testing.

3RESULTS

The priority tasks outlined in the previous progress report have not been addressed directly since we await data. Its availability may well alter the structure of the models.

4IMPLICATIONS

It may be that, if detailed information is not forthcoming the overall approach to the modelling and programming might need to be changed.

5PRIORITY TASKS DURING OCTOBER-DECEMBER 1992.

1 Continue with attempts to obtain data.

2 Adjust modelling to cope with data paucity.

6AUTHOR

NameDavid Evans

Signature ________________________

ODA Fisheries Management Science Programme

PROGRESS REPORT 3 **DATE** 18 / 11 / 92

TITLE OF PROJECT Control of Foreign Fishing : Optimal Benefit Management in Licensed Fisheries

ORGANISATION MRAG Ltd

REPORTING PERIOD FROM 01 / 10 / 92 **TO** 31 / 12 / 92

1OBJECTIVES

To develop methods for the assessment of optimal net benefits from the licensing of foreign fishing vessels in national fisheries jurisdiction and to prepare software for decision making in the planning of surveillance and enforcement and the quantification of licence fees and penalties.

2WORK CARRIED OUT IN THIS PERIOD

The practical application of the project has been further investigated and the development of a form of fisheries management game has been decided as an appropriate method for individual country implementation. Other aspects of work this quarter consist of:

a Data Collection

Information on the costs of aerial surveillance and the modalities of small scale aircraft deployment have been collected. Calculations of costs for area coverage have been developed.

bImplementation of Management Game

Various options were investigated for the implementation of the management game and it was decided to use the Quattro Pro for Windows software package. We will be able to program this to model each of the different fisheries under consideration whilst maintaining a consistent interface between models.

cTheoretical Modelling

Most of the theoretical modelling has been completed to the current position. More data is now required for simulations and this is being collected.

3RESULTS

The priority tasks outlined in the previous progress report have not been addressed directly since we await data. Its availability may well alter the structure of the models. A clear idea of the ways in which the project and theoretical results can be implemented has now been developed. Sourcing of information supply has been achieved (South Pacific, Australia, Namibia and Seychelles).

4IMPLICATIONS

It may be that, if detailed information is not forthcoming the overall approach to the modelling and programming might need to be changed.

The ways and means for incorporating this data into an implementation scheme are now being developed. The project has been chosen as an appropriate one for the implementation of the adaptive research strategy now being adopted under the Fisheries Management Science Programme. Direct connections with Namibia and Seychelles have now been made with a number of implications for the project and the next steps forward.

5PRIORITY TASKS DURING JANUARY - MARCH 1993.

1 Continue with attempts to obtain data.

2 Continue with theoretical modelling.

3 Begin development of management game software.

4 Interface with overseas countries and adaptive research project of this project.

6AUTHOR

NameDavid Evans

Signature ________________________

■ Objectives of the Project and Adaptive Research

The objectives of the general *'Control of Foreign Fishing'* Project (XCF) are to develop a suitable system, based on modern mathematical bioeconomics, for developing countries to help them make critical decisions concerning the level of licence fees, surveillance costs, and illegal fishing penalties. Such decisions are needed to assist in maximising the revenue from their fisheries whilst maintaining the resource.

Preliminary work has been done to develop the modelling techniques (and graphic presentation) of the problem - the interaction of the three principle parameters of revenues, management costs and penalties.

The problem of management of foreign fishing is particularly acute in those developing countries where they are now taking serious steps:

* to control the activities of vessels from Distant Water Fishing Nations (DWFNs) and neighbouring state fleets (NSFs); and

* to restructure their fishing industries to meet national policy requirements such as private sector participation through joint ventures and direct ownership; creating employment, ancillary industries and commerce; and meaningful means for sustainable exploitation and management.

Following ODA decisions under the RNRRS to include 'Adaptive Research' within the scope of programmes, including the Fisheries Management Science Programme, it was decided by the Programme Manager (Professor John Beddington) to extend the CFF project into an adaptive phase; to take the results of the general CFF project and adapt this to particular countries or fisheries.

Efforts are thus being made to undertake the research in a wide variety of developing country fisheries circumstances. These include the South Pacific Tuna Fisheries (through the Forum Fisheries Agency), the South West Indian Ocean Tuna Fisheries (through the Seychelles Fishing Authority), the British Virgin Islands (where foreign sports and tuna fishing is a problem) and in Namibia where considerable changes have taken place in recent years and a policy of complete control is developing.

■ Government Management and Private Sector Restructuring

In the three years since independence and the declaration of the 200 mile EEZ, Namibia has made significant moves in taking control of their rich and diverse fisheries by:

* effectively prohibiting the activities of foreign fleets except under strict exploitation rights and licensing conditions, including a requirement to land fish in country, surveillance and inspection; and

* a policy of Affirmative Action which is now providing 'newcomers' with quotas in order to force the pace of restructuring and limiting foreign involvement in 'local' companies.

■ Suitability of Namibia for the project

Namibia is suitable for the adaptive phase of the Control of Foreign Fishing Project for a number of reasons:

* The highly-centralised management of the fishery and the emphasis on local participation means that the data required for adaptive research will be available directly from the Ministry of Fisheries and Marine Resources.

* The structured nature of revenue generation from research and quota levies presents a relatively simple way of modelling this aspect of the adaptive research.

* The Government has also taken steps to introduce significant surveillance enforcement capabilities, including the purchase of a helicopter, three patrol boats and a number of aircraft. An Operations Communications Centre has also been set up together with an extensive programme to train surveillance officers (NORAD funded).

DATA AVAILABILITY

■ Fleet Characteristics

All vessels fishing inside the Namibian EEZ are licenSed by the Government and must submit full vessel characteristics as part of the licence application process. We have already obtained a full list of vessels that have been licenced for the 1993 season (see Annex A which contains a subset of the most important fleet characteristics).

■ Total Allowable Catches

TACs are set annually for all of the main species except Anchovy and are published in the Government Gazette. The TACs for 1993 are as follows:

■ Quotas and Quota Management

Access to the fishery is granted to individual companies by means of a 'Right of Exploitation', which generally last for one, five, or ten years. All companies holding a current right of exploitation are then able to apply for quotas on an annual basis. Quotas are allocated according to both historical participation and the policy of Affirmative Action. See Annex B for a full list of 1993 quotas.

■ Licence Fees, Quota Levies and Fund Levies

All Government revenue from the fishery is generated via licence fees, quota levies and research levies. The licence fee is minimal and intended only to cover administrative costs. The main sources of income are the two types of levies. Quota levies are payable per tonne of quota allocated, with different rates set per species. Quota levies are payable in quarterly instalments, irrespective of how much fish is actually landed. Research levies, on the other hand, are raised per tonne of fish actually landed. Each fishing company sends in a monthly payment to the Ministry. See Annex C for levy amounts and methods of calculation.

■ Catches and Catch Rates

Comprehensive catch data is available as all landings of fish are documented by the Ministry Inspectorate and are processed centrally for the calculation of research levies. All vessel captains are required to fill in a daily log of fishing activities which are then submitted on landing. These logs contain effort data. Some catch data has been processed onto a database and a printout is available. See separate document.

■ Fleet Costs

Fleet costs are difficult to ascertain, but given the detailed knowledge of fleet characteristics that we have, some sort of estimate could now be made. However, this will be difficult for the Russian fleet that still remains in the horse mackerel fishery and which it will take a very long time to replace.

■ Surveillance Capabilities and Costs

These are available and will be supplied by the Ministry, both at the general overall budget level and by individual surveillance platform.

■ Legal Aspects

The surveillance operations have met with considerable success since independence, confiscating ten Spanish vessels that were fishing illegally during this time. The penalty for unlicensed fishing is confiscation of both the vessel and catch, but we have not yet ascertained the penalty for lesser infractions such as dumping or over-catching. The Government would be able to provide more detailed information regarding legal aspects.