NATURAL RESOURCE MANAGEMENT AND POVERTY REDUCTION

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1. INTRODUCTION

The purpose of this paper is to improve our understanding of the relationship between the management of natural resources and poverty reduction by analysing a specific example: an inland fishery in Bangladesh. This analysis involves substantial extensions to standard fishery models in order to explain the observed pattern of fishing effort. The use of an example allows the choice of assumptions to be guided by direct empirical observation and ensures the relevance of the results to at least one practical situation. Nonetheless, the modelling techniques developed in the analysis can readily be adapted to other fisheries and perhaps even to other sorts of natural resource. As the main aim is to provide insights that can be applied more generally, the paper starts with a discussion of the general issues that are illustrated by the example, and concludes with an evaluation of the wider implications of its results.

There are important links between natural resource management and poverty. Many poor people, particularly in developing countries, rely on natural resources for their livelihood, and these people are very vulnerable to deterioration in the resource. This has been demonstrated tragically by the recent famines in sub-Saharan Africa, and less dramatically by the declining living standards of fishing communities in Britain and Canada. This observation suggests that government policy to conserve natural resources can be justified by a concern for poverty, in addition to the more commonly cited justifications of ensuring sustainable living standards and respect for Nature.

It is also possible to argue that there is another link between natural resources and poverty: poverty contributes to the degradation of natural resources. According to this argument, the desertification of parts of sub-Saharan Africa is not only due to drought but also to the actions of the local inhabitants, whose desperate poverty left them with no choice but to continue their exploitation of natural resources such as wood, despite the fact that this worsened their situation in the longer term. This possible link from poverty to resource degradation is not so well established as the link from resource degradation to poverty. However, to the extent that it does apply, it strengthens the poverty-based argument for policies to reduce resource degradation, because the alleviation of poverty through improvement in natural resources will benefit from the positive feedback from reduced poverty to further resource improvement.

The most obvious policy to reduce resource degradation is to limit activities that make use of the resource concerned. But such a policy would damage the people who rely on the resource, and for whose benefit the policy is partly designed. For example, the process of desertification can be slowed by reducing the amount of wood that people are allowed to gather for their fires, but such a reduction will reduce the ability of poor inhabitants to cook their food and so derive the fullest nutritional benefit from it. It looks as if the only way to reduce poverty in the next few years is to increase it now. It seems that the aims of poverty reduction and resource improvement cannot be achieved.

This example illustrates the fact that the design of policies to both manage natural resources in a sustainable manner and reduce poverty is very difficult, and it is unrealistic to hope for the quick realisation of a virtuous spiral of reduced poverty and better natural resource quality. However, the conflict between poverty alleviation and resource improvement may not be as direct and unavoidable as the previous paragraph suggests. There are a number of ways in which the conflict can be reduced:

1. There may be other partial causes of resource degradation that can be reduced, so that resource quality can be improved without reductions in resource use. For example, industrial pollution may be harming a fishery. The reduction in such pollution would allow the fish stocks to increase, even without a reduction in fishing effort.

2. There may be alternative occupations for some of the local inhabitants, so that resource use can be reduced without reducing the standard of living. For example, the employment of rural inhabitants in a nearby city would reduce the number of people relying on local natural resources.

3. There may be ways of managing the resource so that more local benefit is derived from it, but with a smaller destructive effect. For example, a change in crops on fragile soil might be able to increase farmers incomes and improve soil quality at the same time, as happened in the agricultural revolution with the introduction of crop rotation.

4. There may be ways of managing reduced resource use that ensure that most of the cost is carried by those who are not so poor. For example, banning the use of expensive fishing equipment may allow poorer fishermen a better livelihood, using traditional methods which do not deplete fish stocks.

The extent to which any of these factors can be used to achieve a simultaneous improvement in resource quality and poverty alleviation will depend very much on the specific situation of each community and the nature of the resource(s) available to it. It is therefore unwise to reach any general conclusions about how policies should be designed to overcome the twin evils of poverty and natural resource degradation. Progress in this area can only be achieved by developing methods that can be applied in specific circumstances to: (i) understand the current relationship between poverty and local natural resources, (ii) identify which factors can have a role to play in reducing the conflict between resource conservation and poverty alleviation, and (iii) evaluate the scientific, economic and social feasibility of policies that seek to exploit those factors to reduce poverty and resource degradation.

This paper contributes to this progress by analysing the fourth possibility listed above: the use of resource management in a manner that favours the poor, while maintaining the long-term sustainability of the resource. As stated above, this analysis is developed in the context of a particular fishery in Bangladesh. Section 2, therefore, provides a brief description of the aspects of the fishery that are most relevant to the analysis, and describes why there is a need to modify the standard models of fisheries. Section 3 develops a model of decision making in the fishery, taking account of the features discussed in section 2. Section 4 reports on the results of numerical simulations of the model, which demonstrate the effects of possible changes in the economic environment and possible fishing regulations. Finally, section 5 summarises the main results and discusses their implications for a wider range of fisheries and for other types of natural resources.

2. A DESCRIPTION OF THE FISHERY

The purpose of this section is to provide a brief description of the fishery in order to motivate the model described in the next section. The information is available as the fishery was one of the study sites used in a research project entitled “Poverty and sustainability in the management of inland capture fisheries in south and southeast Asia", funded by the UK's Overseas Development Administration. A much fuller description of the fishery is provided in Kremer (1994) and MRAG (1994)[1], and a description of the project is given by Heady, McGregor and Winnett (1995).

The MRAG (1994) report includes results from modelling the consequences of a range of management policies for the fishery at Hail Haor. The modelling approach used there incorporated more detail of the fish population and of the gear characteristics than the model discussed in this paper. However, it had the drawback that it contained no model of the behaviour of the people involved in fishing. It was therefore not possible to analyse the effects of changes in the economic environment, such as interest rates and wages, on the level of fishing effort. It also had to assume that policies which involved banning the use of a particular gear would not increase the use of other gears. The model discussed in this paper represents an attempt to remedy these drawbacks by including a model of fishery decision making. However, in order to keep the model tractable, some of the detail in the MRAG model had to be dropped.

The fishery on which the analysis is based is Hail Haor, an inland fishery in north-east Bangladesh. It is an egg-shaped body of water that is subject to seasonal flooding from the monsoon, which delivers about three-quarters of the annual rainfall between May and September. Its area is about 13,600 hectares at the height of the monsoon flood, reducing to 1,800 hectares at the end of the dry season with a fall of about 4 metres in water level. There are between 30 and 40 commercially exploited species of fish, with life-cycles well adapted to the flooding, so that spawning takes place at the beginning of the flood. The fish are very fast-growing but total mortality is very high, with typically less than 5% of any cohort surviving into their second year. Despite this, their fecundity is sufficiently high that recruitment (the number of new fish each year) remains stable.

The fishing gears used in Hail Haor can be divided into two groups. The first group consists of gill-nets, fish traps, push nets and small seine nets. These are all relatively low-cost, labour-intensive gears and can be used all year round. The second group, consisting of brush-piles and pump embankments, are very much more expensive and produce a much higher level of catch, but only during the dry season when fish are concentrated in depressions.

Although there is little control of fishing on flooded farmland at the peak of the flood, access to the most productive part of the fishery is tightly controlled by a system of leases. The fishing grounds are divided into more than 60 units (*jalmohols*) that are leased by the government to wealthy individuals (typically under the guise of a "Fishermen's Association"). These leaseholders, either directly or through sub-lessees, then charge tolls to fishermen for the right to fish in the lease-units.

The payment of a toll does not give the fisherman[2] freedom to fish as he likes. Rather, he is restricted to using a particular type of gear in a particular part of the lease-unit for a specific period of time. Thus, the important decisions about the level of fishing effort and the choice of fishing gear are made by the leaseholder, not the individual fisherman. The fisherman is therefore much like an employee, except that his income is derived from the value of fish sold minus direct costs and toll charges. However, even this difference is of limited significance, as

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[1] This report also includes descriptions of the other two fisheries that were studied in the project, one in Indonesia and the other in Thailand.

[2] All of the people fishing on Hail Haor at the time of the study (1992-4) were men.

the toll charges will have been set at the difference between the expected value of the fisherman's catch and his reservation wage.[3] Thus, the difference between this toll arrangement and standard wage employment is that it avoids the need for the leaseholder to monitor the fisherman's level of effort and it transfers the risk to the fisherman.

These considerations imply that the model of decision making in the fishery should focus on the interests of the leaseholders and the decisions that they make to advance those interests. In the interests of simplicity, and because data on the variability of catches are unavailable, the formal model does not take account of risk. This implies that the income of the leaseholder, which comes as tolls, can be regarded as equal to the value of the fish caught minus the non-labour costs and the reservation wages of the fishermen.

This concentration on the decision making of the leaseholder attempting to maximise net income is consistent with the standard idea of rent maximisation in the fisheries management literature. However, the nature of the fishery requires some important modifications to the standard model. First, the highly seasonal nature of the fishery makes the standard Schaefer (1957) model inappropriate, and it is necessary to use a dynamic pool model as developed by Beverton and Holt (1957). This type of model focusses on the history of a particular cohort of fish, born during a particular flood season, and takes account of variations in natural growth, natural mortality and fishing mortality over the year. This type of model is easier to analyse if successive cohorts of fish do not overlap, and the high rates of fish mortality suggest that this will not be too misleading for this fishery. The analysis will therefore consider the pattern of fishing over the year that will maximise the leaseholder's rent from the fishery, subject to the requirement that there are enough fish left at the end of one year to produce a cohort of similar size in the next year.[4]

Although a dynamic pool model appears to fit the basic physical description of the fishery, the standard results from analysing it do not reflect the observed behaviour of the fishermen of Hail Haor. In particular, Clark (1976) shows that the optimal solution for rent maximisation is "pulse fishing", in which fishing only takes place at a particular instant during the year, when the rate of return from allowing the fish to grow is exactly equal the market rate of interest. In contrast, there is a substantial (though varying) level of fishing effort at Hail Haor throughout the year. To some extent, this difference between theory and observation can be reduced by dropping Clark's assumption of constant marginal cost of fishing effort: increasing marginal cost would provide an incentive for fishing effort to be less concentrated. However, numerical simulation has shown that plausible rates of increasing marginal cost are not sufficient to predict fishing early in the year, and so it is necessary to introduce an additional factor into the model.

In the model developed below, fishing throughout the year is explained by the migration of fish between lease-units. This migration produces an externality, reducing the individual lease-holder's return from letting the fish grow, as some of the fish will have moved into other lease-units before the holder of their original lease-unit can benefit from their growth. This extension allows the model to approximately replicate the pattern of catches in Hail Haor, but its significance is also confirmed by direct observation: Beri Beel, a small water body near Hail

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[3] The research project found that the net income of fishermen after subtracting direct costs and tolls was very similar to the incomes of day-labourers in the locality.

[4] It would be possible to extend the analysis to allow a choice of year-end fish stock, taking account of the effect that this would have on the size of the subsequent cohort. However, scientific knowledge of the size of this effect is so limited for this sort of fishery that the empirical predictions of such a model would have little practical value.

Haor, constitutes a single lease-unit and so does not suffer from fish migration, and its lease-holder practices something very close to pulse-fishing, forbidding fishing for most of the year and then applying very high levels of fishing effort for a short period. Nonetheless, migration alone cannot explain the catch pattern at Hail Haor: with constant marginal cost, it would still predict pulse fishing, but earlier in the season. The model can only replicate the fishing pattern by combining migration with non-constant marginal costs.

The non-constancy of marginal costs arises for two reasons. First, there is the standard idea of increasing marginal costs: as additional fishing effort is applied to a limited body of water, the cost of catching extra fish rises, because fishing gears interfere with each other and additional gear will have to be placed at worse fishing locations. Second, the costs of fishing vary during the year because of changes in the size of the fish and the depth of the water. In fact, the relative costs of using different fishing gears will also change during the year, with some only becoming economic at low water levels. It is therefore necessary to model the choice of gears as well as the choice of fishing effort.

A final modification that will be made to the standard dynamic pool model is the introduction of newly born fish during the year. This modification is not introduced specifically to explain the observed pattern of effort, although it does help explain why there is fishing at the end of the year, but because the MRAG (1994) report needed to assume this in order to reconcile the observed catches with the observed data on effort levels. It is also consistent with the known reproductive behaviour of some of the smaller species of fish.

3. A MODEL OF DECISION MAKING IN THE FISHERY

The purpose of this section is to formulate an analytical model that captures the most important features of the Hail Haor fishery and that will be used as a basis for the numerical simulations reported in the next section. In order to keep the model tractable, a number of simplifying assumptions are made:

(i) There is no risk or uncertainty.

(ii) There is only one species of fish.

(iii) Each cohort of fish only lasts one year.

(iv) All lease units are identical.

These assumptions were not made in the MRAG (1994) modelling, but are necessary here because of the complications required by incorporating human decision making.

The model is concerned with two types of decision: the level of fishing effort and the choice of gear. The first part of this section considers the choice of fishing effort over the year with a given seasonal pattern of gear choice, and thus a given (but time-varying) relationship between effort and cost. The second part then looks more closely at the issue of gear choice.

3.1 The Choice of Fishing Effort

As explained in the previous section, the focus is on the decisions made by the leaseholder. It is assumed that these decisions are made to maximise the leaseholder's present discounted value of net income over the year:

$$\int_{t=0}^{12} (P_t \cdot E_t \cdot S_t - C_t(E_t)) \cdot e^{-rt}\, dt \qquad (3.1)$$

where: P is the price of fish per unit weight;
E is the fishing effort, measured so that the catch is equal to the product of E and S;
S is the fish stock, measured by weight;
C(E) is the total cost of the fishing effort, including the reservation wage of the fishermen;
r is the instantaneous interest rate, on a monthly basis;
t is time, measured in months from the beginning of the flood.

This integral is maximised subject to the dynamics of the fish stock:

$$\dot{S} = (g_t - E_t - m_t) \cdot S_t + m_t \cdot S_t^* + F_t \qquad (3.2)$$

where: a dot over a variable indicates its time derivative;
an asterisk indicates a value for the other lease-units;
g is the natural net growth rate of the fish stock (growth minus natural mortality);
m is the rate of fish migration between lease-units;
F is the (exogenous) rate at which new fish are born during the year.

As is usual for dynamic pool models, equation (3.2) states that the growth in the fish stock depends on the natural growth rate minus the fishing mortality. However, there are three new terms connected with the fish migration: the first gives the exit of fish from the lease-unit, the second gives the entry of fish from other lease-units and the third provides for new fish to be born during the year.

There is also the requirement that the fish stock at the end of the year should be at least as great as the final stock that is necessary for the reproduction of the cohort:

$$S_{12} \geq S_{final} \qquad (3.3)$$

The first-order condition for maximising (3.1) subject to (3.2) and (3.3) can be obtained by the standard Euler-Lagrange method. However, this can be simplified if it is assumed that other leaseholders are facing the same problem, and that a symmetric equilibrium holds, so that:

$$S_t^* = S_t \tag{3.4}$$

An optimum will therefore have the following growth, obtained by substituting (3.4) into (3.2):

$$\dot{S} = (g_t - E_t)\cdot S_t + F_t \tag{3.5}$$

This cannot replace (3.2) in the formulation of the maximisation problem, as it would imply co-operation between the lease-holders. However, (3.5) can be substituted into the first-order condition to obtain[5]:

$$\dot{\mu} = (m_t + r + f_t)\cdot \mu_t + P_t \cdot S_t \cdot \{\hat{P} + g_t - m_t - r\} \tag{3.6}$$

where: a ^ represents a proportional rate of change;
μ is the marginal cost of effort;
f is equal to F divided by S.

Equation (3.6) represents the local optimality condition of the intertemporal maximisation problem and can be combined with (3.2) and (3.4) to compute the optimal paths of effort and fish stock. It is therefore interesting to examine the intuition that lies behind it and to consider the way it reflects the impact of two novel features of the model: fish migration and non-constant marginal costs.

First, consider the case where marginal cost is constant, so that the left hand side of (3.6) is zero. The right hand side consists of variables that cannot be immediately chosen by the leaseholder, and so cannot be expected to be zero for every time period. Thus (3.6) will only be satisfied on isolated occasions and pulse fishing results. This is most clearly understood in the case that marginal cost is zero, so that equation (3.6) requires the expression in braces to be zero. This requirement is the standard Hotelling condition that the return from postponing exploitation of the resource (price rise plus growth minus migration) is equal to the rate of interest. As all four of these variables are independent of the lease-holder, they will normally not satisfy (3.6). A typical fishery will start with a high rate of growth, so that the expression is positive and no fishing is desirable (because the return to postponement is greater than the rate of interest). As the growth rate falls, the expression becomes zero so that fishing is allowable, and then it becomes negative, so that the fish should be caught as quickly as possible (infinitely quickly if the marginal cost is really zero everywhere). This is pulse fishing.

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[5] This is obtained on the assumption of an interior solution. It therefore only holds in time periods where fishing effort is finite and non-zero.

The intuition behind pulse fishing must be modified in the case where marginal cost is positive and constant. Equation (3.6) now includes the first term on the right hand side, although the left hand side is still zero. This allows (3.6) to be solved for the fish stock:

$$S_t = -r \cdot \mu_t \Big/ \left\{ P_t \cdot \left(\hat{P} + g_t - m_t - r \right) \right\} \qquad (3.7)$$

As with the case of zero marginal cost, equation (3.7) shows that an interior solution is not possible while the return to postponement is greater than the rate of interest. Indeed, fishing will not start until some time after the rate of price increase plus the natural rate of growth falls below the rate of interest: the time at which the right hand side of equation (3.7) (all of which is outside the control of the leaseholder) equals the value of the stock, which has been increasing at its natural rate. The reason for this postponement is that it reduces the present value of the fishing costs.

Once fishing has started, equation (3.7) shows that the stock will decline as the absolute size of the denominator of the right hand side increases in absolute size: as the rate of price increase plus natural growth falls further below the rate of interest. The level of fishing effort required to satisfy the stock trajectory specified by (3.7) can be calculated from equation (3.5). Fishing will stop once the stock has reached such a low level that its full natural growth is required in order to satisfy the terminal condition (3.3). Thus, fishing effort is spread out to some extent, depending on the size of marginal costs, but this cannot explain the observation of fishing throughout the year because fishing starts later.

When variable marginal costs are admitted, the interpretation of equation (3.6) is that marginal cost should be increasing when the right hand side is positive and falling when the right hand side is negative. Concentrating initially on the case where there is no seasonality in fishing costs, marginal cost is an increasing function of effort and so (3.6) can be seen as determining the rate at which effort should change in order to maximise the return from the fishery. Effort should be increasing in periods when the right hand side of (3.6) is positive and should be declining in periods when the right hand side is negative. The overall level of effort for the year is restricted by the requirement to leave enough fish at the end of the year, condition (3.3). Thus a factor which causes effort to increase through time according to (3.6) will lead to a reduction in earlier fishing effort and an increase in later fishing effort. For example, a higher rate of price increase will increase the right hand side of (3.6), requiring effort to increase through time. It would therefore result in less fishing early in the year and more fishing at the end of the year. Similar effects would result from an increase in the rate of growth of the fish stock. In contrast, an increase in either the rate of migration or the rate of interest would reduce the right hand side of (3.6), because the marginal cost of fishing (μ) will always be less than the value of its marginal product (P.S).[6] Therefore an increase in either of those variables would increase fishing earlier in the year and reduce it later in the year. This justifies the claim, made in section 2, that fish migration is important in explaining why there is substantial fishing effort expended early in the year.

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[6] This is a necessary condition for rent maximisation.

These comparative dynamic results are quite intuitive. An increase in the rate of price increase or the rate of growth of fish stocks has two effects: (a) it increases the relative attraction of postponing fishing effort, and (b) it increases the value of the fish stock in the future and therefore justifies greater fishing effort in the future. Both of these effects lead to an increase in the rate of increase of fishing effort. In contrast, increases in the rate of interest or in the fish migration rate will reduce the rate of increase of fishing effort, but only by reducing the relative attraction of postponing fishing, the reverse of (a). The reverse of (b) does not apply because neither of these forces reduces the actual value of the fishing stock in future periods and so do not justify lower fishing effort in the future. This is straightforward to see for interest rates: even from a present value point of view, increased interest rates reduce future costs just as much as future benefits. It also applies to migration, because the fish stock leaving the lease-unit is offset by new fish stock entering. This means that the rate of change of fishing effort is less sensitive to changes in migration and the interest rate than it is to changes in the rates of price increase or fish stock growth. It is reflected in (3.6) by the first term on the right hand side, which partially offsets the effects of m and r that are included in the second term.

In contrast, the introduction of new fish (represented by f) only has an effect analogous to (b): increasing the value of the fish stock in the future. It does not have an effect analogous to (a), as the arrival of an exogenously determined quantity of new fish has no influence on the marginal return to postponing fishing effort.

The introduction of seasonality into fishing costs complicates the picture somewhat, and tends to move fishing effort to periods when fishing costs are low. This can be seen by considering (3.6), with a given value of the right hand side: declining fishing costs will reduce the value of the left hand side, and so increasing levels of effort are required to bring (3.6) back into equality. However, the basic intuition of the effects of changes to the rate of price increase, the rate of growth of the fish stock, the rate of fish migration and the rate of interest remains unchanged. The overall observed pattern of fishing effort will be the result of a combination of these four factors with seasonal variations in fishing costs.

3.2 Gear Choice and Cost Structure

In order to model the gear choice of the leaseholders and the resulting relationship between cost and effort, it is assumed that fishing effort at any one time can be represented by a constant elasticity of substitution (CES) function of the levels at which the gears are used:

$$E_t = \left(\sum_i \beta_{it} \cdot G_{it}^{\rho}\right)^{\frac{\gamma}{\rho}} \tag{3.8}$$

where: i is an index that runs over the gear types;
β represents the productivity of the ith gear in time period t;
G is the quantity of the ith gear used in time period t;
ρ is the standard CES parameter that is related to the elasticity of substitution;
γ represents the returns to scale.

The specification of (3.8) allows for diminishing returns to scale (γ less than 1), which is required to produce marginal costs that increase with effort. The variation of the β parameters through time captures the fact that both the absolute and relative effectiveness of fishing gears varies through the year. It is this that is required to explain the changes in the mix of fishing gears over the year. As some fishing gears are not used in all time periods, it is necessary to assume that the elasticity of substitution is greater than 1 (that ρ is positive) to allow positive fishing effort when some G are zero.

Fishing costs will include both fixed and variable costs, but it is the variable costs that enter into the marginal decisions on gear use.[7] The variable costs of producing fishing effort can be divided into labour and non-labour costs. Variable labour costs are assumed to be linear in gear use, but with gears differing in their labour needs:

$$W_t . L_t = W_t \cdot \sum_i l_{it} \cdot G_{it} \tag{3.9}$$

where: W is the wage rate;
L is total variable labour use;
l is the labour requirement to operate gear i at unit level in time period t.

Similarly, variable non-labour costs are given by:

$$N_t = \sum_i n_{it} \cdot G_{it} \tag{3.10}$$

where: N is total variable non-labour costs;
n is the non-labour cost to operate gear i at unit level in time period t.

It is assumed that levels of gear use at any time is decided by minimising the sum of labour and non-labour costs. This gives rise to the following variable cost function:

$$C_t = E_t^{(\frac{1}{\gamma})} \cdot \left(\sum_i \beta_{it} . \{[W_t . l_{it} + n_{it}] / \beta_{it}\}^{\frac{\rho}{\rho - 1}}\right)^{\frac{\rho - 1}{\rho}} \tag{3.11}$$

It is the differentiation of this cost function with respect to effort (E) that produces the marginal cost used in the analysis of the choice of fishing effort. This is increasing in fishing effort at any one time, provided that γ is less than 1. Seasonal variations in total and marginal cost arise from variations in the wage rate (W) and the productivity parameters (β).

4 NUMERICAL RESULTS

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[7] Fixed costs will enter into the decision of whether a particular gear will be used at all. Data limitations mean that this decision could not be modelled in this study.

The purpose of this section is to present the results of numerical simulations of the model described in section 3 and so obtain a greater understanding of the behaviour of the fishery. The simulations illustrate the response of the fishery to changes in the economic environment, to changes in model parameters and to government imposed management policies.

As explained in the introduction, our interest is in government policies that are designed to reduce poverty without damaging the resource. The idea that governments might have a role in poverty alleviation is widely accepted. However, it is worth considering why the government should have a role in ensuring proper management of the resource. After all, this is a fishery that is characterised by private ownership and competitive markets, and so might be expected to achieve efficiency automatically. Any role for government would arise from market failure, and it should be noted that there are several possible market failures in this model:

1. The migration of fish between lease-units represents an externality.

2. The leaseholder might choose the wrong value for the final fish stock either because of ignorance or because the finite length of the lease gives an inadequate incentive to manage the resource sustainably.

3. The interest rate faced by the leaseholder might differ from the social rate of discount. In particular, it could be substantially higher, thus encouraging the catching of fish too early in the year.

4. The wage rate of the fishermen may misrepresent the social opportunity cost of labour. In particular, it may be too high in view of the widespread unemployment and underemployment in Bangladesh.

The simulations investigate the importance of these issues by looking at the consequences of assuming that migration is zero, of lowering the interest rate, of increasing the end of period fish stock and of lowering the wage (perhaps by providing an employment subsidy). In addition the consequences of banning capital intensive gears are simulated in order to test the idea that this could help the poor without harming the resource. It also has the benefit of not involving any subsidy from the government. In considering the outcomes of the simulations, the efficiency of the fishery is reflected by the total catch value and the effect on poverty is reflected in the quantity of employment that is provided.

Table 4.1 contains the simulation results. They are obtained from applying the model described in section 3 with numerical values chosen to approximately replicate the observed pattern of fishing in Hail Haor. The calibration process which produced these values is described in the appendix. The calculations were made by taking a very large number of very short time periods (approximating continuous time), but are aggregated in the table to give monthly figures. Column (1) represents the “Base Case”, with parameters chosen to approximate the observed catches. The remaining columns show the effects of altering particular parameters from their Base Case values. For each simulation, table 4.1 shows the value of the catch for each month, starting at the beginning of the fishing year: June. Four summary measures are also shown: the total undiscounted catch value (TOTAL), the total catch value discounted at the rate of interest (REVENUE), the total variable costs discounted at the rate of interest (COSTS), and the total variable labour use valued at the Base Case wage rate and discounted at the interest rate (LABOUR). The labour is measured at a constant wage rate to indicate the effect of the change on employment.

A comparison of column (2) with column (1) shows the effect of assuming that there is no migration between lease-units. As one would expect, this has the effect of substantially reducing catches in the first four months and increasing catches later in the year. The total value of fish caught is increased and the cost of fishing is substantially reduced, including a large reduction in employment. This illustrates the importance of the externality created by migration. A comparison of column (3) with column (2) shows the effect of lowering the fishermen’s wage when there is no migration, without allowing the choice of fishing gear to alter (assuming a zero elasticity of substitution). This shows a reduction in catch at both the beginning and the end of the year. The interpretation of this result is discussed below, along with the discussion of columns (6) - (8).

A comparison of column (4) with column (1) shows the effect of reducing the interest rate from 10% per month[8] to 5% per month. As expected, this reduces the early fishing effort and increases the catches later in the year. This increases the total catch, but not by very much. The migration externality can, therefore, be seen as a much greater cause of inefficiency than any distortion in the capital market.

A comparison of column (5) with column (1) shows the effect of increasing the required final fish stock by 20%. This has almost no effect on the level of fishing in the first few months, but produces substantial reductions in catch towards the end of the year. The reduction in total catch, at 1544, is slightly larger than the increase in required fish stock (1512) because of a larger reduction in fishing effort, as reflected in the reduction in discounted fishing costs. As with interest rates, this factor is much less important than fish migration.

Comparisons of columns (6), (7) and (8) with column (1) all show the consequences of lowering the fishermen’s wage by 20%, under three different assumptions. In column (6), the wage reduction is assumed to have no effect on gear choice (assuming a zero elasticity of substitution between gears), so that the only effect is on the levels of marginal cost in (3.6). At first sight, this appears to reduce the right hand side of (3.6) and so reduce the rate at which marginal costs, and hence effort, increase through the year. However, the impact has to be interpreted more carefully than that, because the change in the wage rate has affected the relationship between marginal cost and effort. There are two aspects of this: (i) marginal costs at given effort levels have been reduced throughout the year, thus altering the relationship between changes in marginal cost and changes in effort; and (ii) marginal costs have declined relatively more in time periods when more labour-intensive gears are chosen, thus increasing effort and catch in those periods.

To deal with aspect (i), it is necessary to look at the impact of the change on the proportional rate of increase in the marginal cost, whose relationship with the proportional rate of change of effort is not altered by a change in the wage rate[9], provided that gear choice is constant. Thus, (3.6) needs to be rewritten as:

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[8] This was the informal market rate of interest in the area surrounding Hail Haor.

[9] This is because the wage rate has equal proportionate effects on the numerator and the denominator of the fraction that defines the proportional rate of change of the marginal cost.

$$\hat{\mu} = (m_t + r + f_t) + \frac{P_t . S_t}{\mu_t} . \{\hat{P} + g_t - m_t - r\} \qquad (4.1)$$

Equation (4.1) shows that a reduction in marginal cost, produced by a reduction in the wage, increases the weight that is placed on the second term. This second term is negative throughout the year because the high rates of growth at the beginning of the year are offset by high rates of fish migration. Thus, the reduction in the wage rate can be expected to reduce the proportional rate of increase in marginal cost and thus the rate at which effort increases. This is what appears from a comparison of column (6) with column (1): the proportional catch increases from June to July and from April to May are lower in column (6). Overall, the total catch is lower but the discounted revenue is slightly larger because the catch has moved to earlier in the year.

At the same time, aspect (ii) means that effort has moved towards months in which more labour intensive gears are used. Thus, column (6) shows that catches have increased in early months and are reduced in middle and later months, reflecting the fact that more capital-intensive gears are used later in the year, when water levels are lower. This reinforces the effects of aspect (i), which also shifted catch towards earlier months. The shift towards periods when labour-intensive gears are used is reflected in the increased use of labour over the year: an increase that is larger than the increase in discounted revenue.

It is interesting to compare the change from column (1) to column (6) with the change from column (2) to column (3). There is no fish migration in the cases depicted by columns (2) and (3), so that the second term on the right hand side of (4.1) is positive in the early months of high growth, only becoming negative as growth falls towards the end of the year. This means that the lowering of the wage increases the rate at which effort, and hence catch, grows over the first few months, in contrast to the case where there was no migration. The pattern of more rapid catch decline at the end of the year is unchanged, because fish migration is only significant in the early months.

Columns (7) and (8) show the results of dropping the assumption of no change in gear choice: column (7) corresponds to an elasticity of substitution between gears of 2, and column (8) corresponds to an elasticity of 10. The existence of substitution allows an even greater reduction in marginal cost in each time period, as fishermen substitute more labour-intensive gears. This strengthens aspect (i), as is illustrated by smaller increases in catch from June to July as one moves from column (6) to column (8). However, higher elasticities of substitution mean a reduction in the high capital-intensity of gears used during the middle to late part of the year, reducing the extent to which they experience an increase in relative costs. This reduces the impact aspect (ii), as is illustrated by the higher catches in column (8) than column (7) for December, January and February. Overall, higher elasticities produce slightly smaller total catches. As far as employment is concerned, higher elasticities reduce the impact of aspect (ii) but also allow more labour to be used in every period. The net effect is that lowered wages create more employment if the elasticity of substitution is higher.

Finally, a comparison of columns (9) and (10) with column (1) show the effect of preventing the use of the two most capita-intensive gears: brush-piles and pump embankments. This reduction in gear choice increases the costs of fishing, particularly in the months of January and February, when the capital-intensive gears are used most heavily. The general increase in costs is similar to the reverse of aspect (i) from the case of a wage reduction, and results in greater increases in catch from June to July and from April to May. The fact that the cost increase is particularly marked in January and February is similar to the reverse of aspect (ii), as is shown by the reduced catch in those months. However, the higher elasticity of substitution for column (10) means that the differential cost increase is much smaller, and the reduced catch in those months is much less significant. Overall, the reduction in catch, both discounted and undiscounted, is very small. However, the increase in labour use is more appreciable, especially with the lower elasticity of substitution. This suggests that restrictions on capital-intensive gears can create additional employment with fairly low efficiency costs, in terms of reduced output.

TABLE 4.1: SIMULATION RESULTS

Monthly Catches	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
June	1824	0	0	1761	1824	2130	2196	2212	1799	1822
July	2578	105	73	2406	2574	2882	2934	2941	2567	2577
August	2700	835	823	2362	2688	2865	2899	2901	2724	2703
September	2647	2161	2333	2199	2622	2710	2710	2709	2714	2655
October	2457	3522	3830	1984	2416	2445	2420	2417	2558	2469
November	2192	4247	4573	1787	2134	2124	2111	2103	2333	2209
December	2269	4595	4830	2043	2191	2165	2078	2087	1923	2231
January	2324	4324	4373	2374	2230	2167	2033	2059	1584	2231
February	2281	3913	3852	2580	2157	2096	1995	2010	1764	2222
March	2260	3626	3427	2787	2079	2008	1994	1983	2288	2270
April	2186	3340	3027	2952	1891	1855	1880	1846	2711	2245
May	2560	3791	3204	3790	1931	1963	1994	1949	3254	2638
TOTAL	28280	34459	34346	29024	26736	27409	27245	27216	28219	28272
REVENUE (dc)	16469	16885	17101	21243	15861	16531	16503	16510	16312	16451
COSTS (dc)	4927	3191	2936	5337	4638	4870	4880	4873	5031	4940
LABOUR	3541	2310	2463	3857	3326	4064	4639	5051	4097	3995

Note: (dc) indicates that the measure is a discounted sum.

Columns: (1) Base Case (Approximately replicating observed catches).
(2) No Migration.
(3) No Migration and lowering wage by 20%, with fixed gear choice.
(4) Reducing the interest rate to 5% per month (from 10%).
(5) Increasing final fish stock by 20%.
(6) Lowering wage by 20%, with fixed gear choice.
(7) Lowering wage by 20%, with elasticity of substitution of 2.
(8) Lowering wage by 20%, with elasticity of substitution of 10.
(9) Banning capital-intensive gears, with elasticity of substitution of 2.
(10) Banning capital-intensive gears, with elasticity of substitution of 10.

5. CONCLUSIONS

This paper has been concerned with the issue of how to manage fisheries in a way that protects the resource and benefits poor people, particularly by creating employment. The analysis has focussed on a particular fishery, Hail Haor, in northeast Bangladesh and the standard models have been extended to make them consistent with the observed pattern of fishing behaviour. In particular, the recognition of non-constant marginal costs and of fish migration between lease units were shown to be essential. This modified model was then calibrated to approximately replicate the observed pattern of fishing behaviour, and the consequences of several parameter changes were calculated.

These numerical results are of considerable interest. They show that the externality produced by fish migration is substantial, and of considerably greater importance than two other possible distortions: an interest rate that is too high and a final fish stock requirement that is too low. However, the correction of the migration externality would seriously reduce employment, and would thus be expected to worsen poverty.

The other numerical simulations were concerned with looking at ways that policy could be used to create additional employment. It was shown that a lowering of the wage, perhaps through wage subsidies, would increase employment, although the undiscounted catch would fall. The size of the employment increase would be larger if the elasticity of substitution between gears were larger. An alternative policy, not involving subsidies, would be to prevent the use of capital-intensive gears. This was shown to also have an appreciable effect on employment although, in this case, the benefit was reduced by an increase in the elasticity of substitution.

The precise numbers shown in the simulations should not be given too much importance, because they relate to only one fishery and are based on parameter values that involve some degree of guesswork. Nonetheless, they do raise policy issues that could be looked at in other tropical inland fisheries and, perhaps to a wider range of natural resources. Also, the modelling reported here, and the detailed fieldwork upon which it is based, provides an important illustration of a methodology that can be applied to other fisheries and, indeed, to other natural resources where decisions are made about both the timing and the technique of exploitation. As a next step, it would certainly be valuable to apply this methodology in other locations and compare the nature of the empirical conclusions.

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APPENDIX

The Calibration of the Numerical Model

The purpose of this appendix is to describe how the numerical parameter values in the model were chosen to approximately replicate the observed pattern of fishing at Hail Haor.

The data used in the calibration were all collected as part of the research project, “Poverty and sustainability in the management of inland fisheries in south and southeast Asia”, as described in Heady, McGregor and Winnett (1995) and MRAG (1994). Briefly, these consisted of: (i) regularly collected fishermen’s reports of catches, gear use, time use and costs; (ii) surveys of fish prices, interest rates and wage rates; and (iii) the results of fish sampling exercises to establish growth rates, mortality rates and gear selectivity. In MRAG (1994), these data were used as the basis of a multi-species, multi-gear model of the fishery using BEAM4, software initially developed by FAO. Suitable choice of initial fish stocks, together with some fine-tuning of estimated parameters, allowed the model to approximately replicate the catch and effort data reported by the fishermen. Both the direct survey results and the parameters used to fit the BEAM4 model are used in the calibration procedure.

As with the development of the theoretical model in section 3 of the paper, the calibration procedure can be described as two components: (i) the choice of parameters to replicate the observed pattern of catches; and (ii) the choice of parameters to replicate the observed pattern of gear use.

Simulating the Pattern of Catches

This corresponds mainly to the model of sub-section 3.1 in the paper. The following parameters are required to calculate catch patterns: fish prices, the cost of fishing as a function of effort, the interest rate, the growth rate of the fish stock, the initial fish stock, the final fish stock, the rate of fish migration and the rate at which new fish are born.

The growth rate of the fish stock, the initial fish stock, the final fish stock and the rate at which the new fish are born are all based on the BEAM4 analysis. In that analysis, described in greater detail in MRAG (1994), the fish were divided into five guilds, the basic parameters for which are shown in table A.1. The length of the fish in each guild was assumed to follow the standard von Bertalanffy growth function, and the parameters for that were estimated from fieldwork observations. The relationship between the length and weight of fish in each guild was also estimated from fieldwork observations, as was the (exponential) rate of natural mortality. The maximum length of life for fish in each guild was chosen so that the number of surviving fish at that age were too small to be worth continued modelling. Finally, the number of recruits in each month were chosen to produce the level of catch that was observed. As can be seen from table A.1, most of the recruitment was at the beginning of the fishing year, but some later recruitment was included in order to allow BEAM4 to replicate the observed pattern of catches. Most of the BEAM4 analysis was carried out in time periods of three months, but the analysis of this paper is concerned with the monthly pattern of fishing, and this is reflected in table A.1 by splitting the BEAM4 post-June recruitment into monthly figures (each of which is a third of the corresponding BEAM4 quarterly figure), which are assumed to relate to the beginning of each month.

In order to obtain the growth rate of the fish stock for the analysis in the present paper, the figures in table A.1 were first used to simulate the growth of the total mass of one cohort of each guild over its maximum life length, on a monthly basis, assuming there is no fishing. In order to calculate the growth of total fish mass in one year, the results of this exercise had to be modified to take account of the fact that, in any one year, the fish stock would include fish that had survived from earlier cohorts. This was done by taking the mass of fish recruited that year, and adding the mass of fish recruited in the previous year (if T was at least as large as 2) and in the year before that (if T equalled 3). As the fish mass from earlier years would have been depleted by fishing, these additional masses were reduced by the rate of fishing mortality assumed in the BEAM4 calibration (which was an annual exponential rate of 2.0). This procedure produced figures for the stock of each guild at the beginning of each month and at the end of the fishing year (the end of May). These figures for each guild were then aggregated using the market prices of each guild in Taka per Kilo (carps, 40; predators, 27; medium blackfish, 20; small whitefish, 20; small shrimps, 20). This produced a measure of fish stock in value terms[10], which is used in the remainder of the analysis. The use of the value measure means that the price of fish can always be taken as unity.

The growth rate of the fish stock, as reported in the first column of table A.2, was computed from the movements of this aggregate fish stock measure. It was obtained by calculating the proportional increase in the fish stock from the beginning of one month to the beginning of the next, subtracting the effect of the new recruitment that month (which is excluded from the definition of g in equation (3.2)).

This aggregate fish stock measure was also used to obtain the initial fish stock (value at the beginning of June) and the final fish stock (value at the end of May). The values of new fish, F in equation (3.2), are reported in the second column of table A.2 and are obtained by assuming that the new recruitment that is reported in table A.1 as occurring at the beginning of any month actually takes place uniformly during the previous month. This assumption is made so that F is a continuous variable for the solution of the model in continuous time.

The remaining parameters, relating to the cost of fishing and the migration rate, were then chosen so that the solution of the optimisation problem discussed in section 3.1 would approximate the observed fishing pattern, in terms of the proportion of the annual catch that is landed each month. In principle, there are many different combinations of parameter values that will produce this result, and so there is some arbitrariness in the result. However, the choices were constrained to fit in with some prior knowledge, particularly that the cost of fishing should decline gradually over the year and that the migration should be very high at the beginning of the year and reduce rapidly as water levels fall. This led to a choice of the returns to scale parameter, γ, as 0.6 as this allowed choices of the fishing cost factor (which is the expression in parentheses in equation (3.10)) and migration that met these requirements and allowed a fairly good match between actual and simulated catch patterns, as is shown in table A.2. The extent of returns to scale implied by this value was also considered reasonable, implying substantially diminishing returns to scale but not to such a great extent that fishing effort could not be re-allocated between months.

One aspect of the simulated catch that could not replicate observation is the total annual catch, which is 22% below the observed level. The reason for this is probably the neglect of gear

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[10] The actual units of the stock and catch figures are thousands of Taka, where 60 Taka is worth about 1 pound sterling.

selectivity in this simplified model. In reality, many of the gears will only catch fish that have reached one year old, thus allowing the younger fish to grow and increase the eventual yield of the fishery. As explained in section 2, this factor had to be omitted from the model in order to allow the introduction of the other important features without losing tractability.

Another aspect of the simulated results that conflicts with observation of the fishery is the fishing costs: the simulated results have costs that are about 30% of revenue, while Kremer (1994) suggests that the actual value is over 90%. The difference could not be removed by increasing the cost factors, as this soon led to a situation where the return from extra fishing became negative (which is inconsistent with rent maximisation). This leaves two possible explanations of the phenomenon: (i) as explained in sub-section 3.2, it is only the variable costs that are included in the equations, and so the fixed costs may account for the difference between the model's variable costs and the observed total costs[11]; (ii) it is possible that the leaseholders place a positive value on creating employment (from social concern or a wish for political influence) and so make decisions on the basis of a lower wage than that actually paid.

Simulating Gear Use

This corresponds to sub-section 3.2 of the paper, and the choice of the parameters in equation (3.11). As the value of γ was determined by the catch pattern, as explained above, the parameters of interest are the β, the (W.l)[12] and n.

The data used in their estimation is given in table A.3. The bottom panel of the table gives values for the labour cost, (W.l), and the non-labour costs, n.[13] These are based on data in Kremer (1994, p.14), identifying his capital outlay as non-labour costs and making some modifications. The table shows the data as "Computed from..." when the only modification is the multiplication of the hours of labour by the wage (4 Taka per hour) to obtain the labour cost. The table shows the data as "Modified from..." when Kremer gives a non-labour cost of zero. This is regarded as meaning very small, and the arbitrary value of 30 is used. Finally, the table shows data as "Assumed to be..." in those cases where Kremer provides no data. In such cases, a judgement is made about the most similar fishing gear, and its values are used.

The value of ρ, indicating the elasticity of substitution between gears, could not be estimated from the data, as there were no observations of the effect of cost changes on gear use. It is for this reason that section 4 of the paper presents results for two different values of ρ.

With these data, the values of β for each gear and time period is simply obtained by calculating those values that produce a proportional relationship between gear use, G, and the observed

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[11] The cost survey did not distinguish between fixed and variable costs. It is hard to see how the questions could have been phrased to illicit such a distinction.

[12] It is only the product of the wage rate and the labour requirement that is required, not their individual values.

[13] It should be noted that it is only the relative size of the labour and non-labour costs that are relevant, as the issue of scale is taken account of through appropriate choice of the β.

catches shown in the top panel of table A.3. This requirement only fixes the relative values of the β: the absolute values are fixed by the requirement that the term in parentheses in equation (3.11) for each month should equal the values of the cost factors given in table A.2.

TABLE A.1: BASIC PARAMETERS FOR FISH GUILDS

	(1)	(2)	(3)	(4)	(5)
von Bertalanffy Growth[14]					
L_∞ (cm)	75	70	30	15	4
K (per year)	0.3	0.7	0.7	0.7	1.0
t_0 (years)	-0.3	-0.2	-0.3	-0.3	-0.3
Wt/Length Relationship[15]					
a (10^{-6}: Wts in kg)	16	7	10	15	10
b	3.01	3.06	3.00	3.00	3.00
Natural Mortality					
M (per year)	0.6	0.9	2.4	3.0	3.0
Maximum Life Length					
T (years)	3	3	3	2	1
Number of Recruits (10^6)					
June	0.869	0.529	56.627	679	2367
July	0	0.176	18.876	0	1829
August	0	0.176	18.876	0	1829
September	0	0.176	18.876	0	1829
October	0	0	0	0	2348
November	0	0	0	0	2348
December	0	0	0	0	2348
January	0	0	0	0	1309
February	0	0	0	0	1309
March	0	0	0	0	1309

Note: The description of the fish guilds are as follows:
(1) Carps
(2) Predators
(3) Medium Blackfish
(4) Small Whitefish
(5) Small Shrimps.

Source: Adapted from MRAG(1994, Table 13a). See text for details.

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[14] The von Bertalanffy growth equation gives the length of each fish at time t as:

$$L_t = L_\infty \cdot \left\{1 - e^{K.\left(t - t_0\right)}\right\}$$

[15] The weight of each fish is given by: $W = a \cdot L^b$

TABLE A.2: CALIBRATION OF FISHING PATTERN

MONTHS	GROWTH RATE	NEW FISH	COST FACTOR	MIGRATION	CATCH PATTERNS (%) SIMULATED	CATCH PATTERNS (%) ACTUAL
June	0.27	1129	40,000	1.00	6.4	6.4
July	0.23	1129	36,500	0.95	9.1	9.3
August	0.19	1129	35,000	0.50	9.5	9.6
September	0.15	523	34,000	0.30	9.4	9.3
October	0.12	523	33,000	0.20	8.7	8.8
November	0.08	523	32,500	0.10	7.8	7.5
December	0.05	292	29,500	0.00	8.0	7.7
January	0.03	292	26,500	0.00	8.2	8.3
February	0.01	292	23,000	0.00	8.1	8.3
March	-0.01	0	18,000	0.00	8.0	8.4
April	-0.03	0	13,000	0.00	7.7	7.4
May	-0.04	0	7,500	0.00	9.0	9.0

OTHER VARIABLES

Returns to scale (γ) = 0.6
Interest Rate (r) = 0.10
Initial Fish Stock = 11,983
Final Fish Stock = 7,558
Simulated Total Catch = 28,280
Actual Total Catch = 36,091

TABLE A3: USE AND COSTS OF GEARS

Catch by gear and month from sample fishers

GEAR	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Bosni Trap	2.4	2.3	2.5	5.5	8.6	3.6	3.5	3.0	2.8	3.7	3.9	4.2
Brushpile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.1	25.3	16.6	0.5	0.0
Dori Trap	11.0	15.9	21.7	27.0	34.3	24.6	32.4	15.6	15.8	26.5	35.2	28.5
Dry Fishin	1.8	1.8	1.9	1.3	1.3	1.6	1.6	13.5	13.6	13.1	4.4	1.8
Faron Trap	11.7	1.0	1.0	1.3	4.9	5.7	5.8	21.7	21.6	18.6	12.3	11.5
Pushnet	21.4	27.7	30.0	25.7	12.3	5.7	4.6	7.9	7.9	12.1	21.2	50.6
Gill Net	28.5	27.3	27.3	26.7	32.7	36.2	35.3	16.1	15.9	17.1	24.2	28.5
Small Hook	24.2	42.2	42.2	40.3	23.9	22.2	22.2	18.4	18.4	18.6	22.7	24.2
Large Hook	0.0	10.4	10.4	10.4	14.1	14.1	14.1	0.0	0.0	0.0	0.0	0.0
Seine Net	9.3	25.0	21.8	16.6	14.4	9.3	8.3	6.2	5.7	4.0	3.7	7.3
TOTALS	110.3	153.6	158.8	154.8	146.5	123.0	127.8	127.5	127.0	130.3	128.1	156.6

Estimates of Labour and Non-Labour Costs

GEAR	LABOUR	NON-LABOUR	BASIS OF ESTIMATE
Bosni Trap	500	617	Assumed to be the same as faron trap
Brushpile	32	339	Computed from data in Kremer (1994)
Dori Trap	664	128	Computed from data in Kremer (1994)
Dry Fishin	32	339	Assumed to be the same as brushpile
Faron Trap	500	617	Computed from data in Kremer (1994)
Pushnet	800	30	Assumed to be the same as hooks
Gill Net	592	380	Computed from data in Kremer (1994)
Small Hook	800	30	Modified from data in Kremer (1994)
Large Hook	800	30	Modified from data in Kremer (1994)
Seine Net	640	211	Computed from data in Kremer (1994)