Shrimp Management

Final Report for the Overseas Development Administration

Fisheries Management Science Programme

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Final Report

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FINAL REPORT

1. Objectives of the project

(1) To develop a bio-economic model of tropical shrimp fisheries that takes account of (a) the different types of capture fishery and of collections for aquaculture, (b) the market responses to changes in demand and supply of shrimp from the capture fisheries and aquaculture and the resultant impact on fleet sizes and profitability, and (c) the possible effects of destruction of nursery areas through pond construction for aquaculture.

(2) To use the model to examine the potential effects of different levels of interactions between the different fishery types, the effects of changes in supply and demand in different market sectors, and to investigate possible management strategies that best meet different objectives.

(3) To analyse data from a selected case study (or studies) of shrimp fisheries in developing countries, using an applied version of the bioeconomic model. The output will be used to evaluate the effectiveness of current management practices and make proposals for changes where appropriate.

Work on this project was divided into two phases. The first phase consisted of a general investigation addressing issues under objectives (1) and (2), both biological and economic. The second phase was to address objective (3) as a specific case study or studies. A decision on whether to proceed to phase two was to be taken on completion of phase one.

As recorded in the quarterly progress report for July-September 1992, the lack of available shrimp supply and price data disaggregated by size made it clear that continuing to phase two would be impractical. Accordingly, objective (3) was abandoned for the purposes of this current project.

2. Work carried out in the period

A detailed work plan was developed on receipt of a report from an external consultant outlining biological and economic research issues in the management of wild shrimp stocks arising from the growing importance of shrimp aquaculture. The research project proposed by the consultant investigated optimum bio-economic management of shrimp stocks subject to removals by both a wild fishery and aquaculture.

A bio-economic computer model was developed to allow investigation of both biological and economic influences on a shrimp fishery in a developing country. Impacts of an artisanal fishery, an industrial fishery and an aquaculture industry on the stock can be investigated. The model allows evaluation of optimum management strategies to meet a variety of possible management objectives. In particular, it allows investigation of the effects of changes in market prices. Both static and dynamic optima can be examined using the model.

A review of current and future trends in markets and production from aquaculture and wild fisheries has been carried out, as well as an analysis of shrimp demand, both in terms of aggregated overall demand in the world market, and demand disaggregated by size category in part of the US market. Despite a wide search, it was only for the US market that suitable published data on supply and price disaggregated by size were found to be available on the public record.

The results of the review were used to predict the effects of increases in supply of medium sized shrimp from aquaculture on the different production sectors supplying the US shrimp markets. The bio-economic model was also used to predict the effects of price falls in medium sized shrimp on profitability and other performance indicators in the different segments of the shrimp fisheries. A general investigation of the properties of the bioeconomic model was also conducted.

Most planned inputs to the project relating to the first two objectives of the project have been achieved. However, the unavailability of fully representative supply and price data by size grade prevented reliable estimation of the own- and cross-elasticities needed for definitive evaluation of policy options in practical settings. Only a restricted data set for the US market between 1987 and 1989 were available in the necessary detail. As a result, the final phase of the project, involving detailed case studies, was abandoned.

During the course of the project, the scientists who developed the bio-economic model and who conducted the economic review resigned. Progress on the project was considerably hampered by the inevitable delays in appointment and familiarisation of new staff.

3. Results

3.1 Development of bio-economic model

A flexible bio-economic computer model for shrimp fishing in a developing country has been developed. Biological influences allowed for in the model include direct removals of juvenile and adult shrimp by capture fisheries, collections of post-larvae and mature females for aquaculture, and the possible effects on recruitment of destruction of nursery areas for juvenile shrimp. A stock-recruitment relationship is also included. Economic influences allowed for in the model include different cost structures for the fishing fleets (artisanal and industrial), and different prices obtained for different size grades of shrimp. The model allows evaluation of the impacts on optimum fleet sizes and profitability of changes in prices for the different size grades. Outputs include the net profitability of the fishing fleets, and other performance indicators such as inputs to national revenue, catch value and employment. In a departure from other bio-economic models of shrimp fisheries, both static and dynamic optimisations can be performed.

The predictions of the model were investigated using as an example estimates of biological and economic parameters published for the Suriname fishery for *Penaeus subtilis*. The sensitivity of predicted optimum fleet sizes and profitabilities to changes in these parameters was also determined.

The main results in terms of a single industrial fishery were as follows. As the maximum size or the growth rate of the shrimp species available for capture increases, the fleet size producing maximum profit was found to increase, as did the age and size at first capture. Shrimp recruitment can be highly variable, and it was found that as recruitment increases, again the optimum fleet size and age at first capture increases. Management implications of varying profitabilities between years were evaluated. Finally, the effect of a reduction in the price of medium-sized shrimp, such as might come about as a result of increased aquaculture supply in this size category, makes it less profitable to take shrimp of these sizes, so leading to pressure to increase the size at first capture and reduce profits for fleets accustomed to catching medium sized shrimp.

When both artisanal and industrial fisheries are included in the analysis, the economic parameters are such that the industrial fleet is only marginally profitable, but the size of the profits available from that fleet still dominates the profits of the artisanal fishery. Thus with the parameters used, if the objective were simply to maximise the total net profit from fishing, the policy would be to have essentially no artisanal fishing. Such a policy would probably be completely unacceptable to a developing country. However use of the model can demonstrate just how much potentially could be lost by allowing heavy artisanal fishing.

Rather different conclusions would be reached if objectives other than some form of maximum profit or revenue are considered. If the objective were simply to maximise the value of the catch landed, then the appropriate levels of fishing by the industrial fleet are much higher. Finally, if maximising employment were the primary objective, then this would be achieved at high fishing mortalities by both fleets.

If allowance is made for a stock-recruitment relationship, or degradation of nursery areas, optimal profits are now obtained at lower fleet sizes for both fisheries.

A more detailed outline of results obtained is appended to this final project report.

3.2 Analysis of supply and demand for tropical shrimp

With imports currently valued in excess of $US 4.4 billion, shrimp account for approximately 20 per cent of the total world trade in fisheries products. Direction of trade is dominated by developing country exports, which supplies around 90 percent of total shrimp imports by industrial countries. For many developing countries the shrimp production sector, which includes both aquaculture and capture fisheries, is an important source of foreign exchange earnings through exports. Furthermore it is a sector that can generate and sustain primary and secondary rural employment.

The analysis of current directions and volumes of trade reveals that there are three major import markets for tropical shrimp species; Japan, the USA and Europe. Total volumes of shrimp imports to each of the three markets increased dramatically during the 1980s, with tropical shrimp from developing countries now accounting for approximately 80% of total imports. The review of major sources reveals a lack of potential for large increases in capture fishery production and the dramatic increases in aquaculture production during the 1980s and early 1990s.

A good is elastic with respect to price if the quantity demanded increases more than proportionally with a decrease in price. It is inelastic of the demand increase is less than proportional. A review of existing aggregate demand analyses (i.e. ones not distinguishing between size grades) has identified shrimp as inelastic with respect to price and elastic with respect to income.

The price and quantity trends for each of the large, medium and small size categories in a segment of the US market between 1987 and 1989 were also examined. The large and medium size categories show inverse relationships between price and quantity supplied to the market vis a vis imports, with the relationship for large shrimp being stronger. The trend for the small size category does not indicate a clear relationship between price and quantity. The market shares of medium and small shrimp show a clear inverse relationship, but the market share of large shrimp does not relate in any simple manner to either medium or small market shares.

A variety of models were used in an attempt to estimate own- and cross-price elasticities for the small US market data set. The most suitable was a generalised choice model. Plausible price elasticities were obtained in most cases, though there still remained some inconsistencies. However, the price elasticity estimates were of too low a precision to transform into elasticities describing the affect of changing supply levels on price.

Qualitative analysis of the available long-run information suggests that between 1980 and 1992 the increase in world-wide supply of aquaculture shrimp has so far had little impact on the levels of prices in the US. However, it is not possible with the available data to predict if or when the US market will cease to be able to absorb even further increases in the supply of medium size shrimp. If demand does reach a plateau, then an increased supply of medium sized shrimp is likely to result in a drop in price for medium sized shrimp and an accompanying reduction in both quantity demanded and price of the large and small size categories. The result would be a reduction in revenues for both the aquaculture and capture fishery shrimp producing sectors. Reductions in revenues to aquaculture would result in a shift from intensive to semi-intensive aquaculture production.

The main recommendation is that the management strategies for tropical shrimp resources should explicitly take into account the international market forces which affect them. However, it will be very difficult to do so unless a much better system for recording supply and prices disaggregated by size category is instituted.

A more detailed outline of results obtained is appended to this final project report. The full report is also appended.

4. Implications of the results for achieving the objectives

The first objective of the project, development of a bio-economic model, has been achieved. The model developed has several features not normally found in similar such models: inclusion of a stock-recruitment relationship, and the ability to calculate dynamic optima.

The second objective has also been generally met, in that the model has been used to examine the potential effects of different levels of interaction between different fishery types, how these may change with different biological characteristics of the shrimp fished. However, the primary focus of the second objective was to examine the effects of changes in supply and demand, especially increases in supply of medium sized shrimp from aquaculture. As recorded above, despite an extensive search and a wide ranging study of production and market trends, insufficient size-disaggregated data could be found to address this question quantitatively.

Objective 3 was not met, having been formally abandoned during the course of the project.

5. Priority tasks for follow up

Before any further useful progress can be made on this aspect of shrimp management, it is essential that better data on supply and demand by size category of shrimp be obtained. This is the subject of recommendations in the economic sections of the report. However, it should be noted that collection of such information on a world-wide basis is not a task suitable for a research project under the ODA Fish Management Science Programme. It does appear that some of the information is contained in private commercial databases, and can be purchased. It may be worth investigating how expensive it would be to gain access to those data.

After completion of development of the bio-economic model, it was found the FAO were in the final stages of development and release of a software package BEAM 4, which was designed to allow a bio-economic simulation of space-structured multi-species and multi-fleet fisheries. In practice, it was a development of earlier software designed for application to shrimp fisheries. With the exception of the two previously-mentioned aspects in the model developed in this project (inclusion of a stock-recruitment relation and dynamic optima), BEAM 4 has the capacity to be used directly with detailed biological and economic data for a developing country shrimp fishery. Given the imminent release of this package, it would be quite inappropriate to spend the considerable extra time and funds on separate development of a package ready for practical application in the field, based on the MRAG bio-economic model. In principle, it would however be possible to develop modules to be added to the FAO package if this were considered desirable

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OUTLINE OF RESULTS OBTAINED

1. Background

For many years, shrimp taken in wild capture fisheries have provided a very valuable source of export earnings for developing countries in the tropics. More recently, the supply of wild-caught tropical shrimp on the world market has been supplemented by rapidly increasing production from aquaculture. This additional factor in the market for shrimp has exacerbated the already difficult policy and planning issues faced by fishery managers in such countries.

Many tropical shrimp stocks are subject to both artisanal and industrial capture fisheries for wild shrimp, with the artisanal fishery taking small shrimp (over 51 count per lb) and the industrial fishery normally taking shrimp in medium (26 - 50 count per lb) and large (up to 25 count per lb) categories. Generally, shrimp produced by aquaculture are in the medium size category. Thus the increasing aquaculture supply of medium sized shrimp will have a direct effect on those countries marketing wild-caught medium sized shrimp. However the complexity of shrimp supply and demand on the world market suggests that indirect effects on other size categories may be possible. In addition, there will be important direct biological interactions when more than one of these production methods is used in one country.

The life cycle and biology of tropical shrimp species has been extensively described by Garcia and Le Reste. The life cycle of a typical Penaeid shrimp begins with eggs laid demersally offshore. Larvae hatched from these eggs progress through several planktonic nauplius stages before transformation into post-larvae. These post-larvae migrate inshore to settle into estuarine or lagoonal nursery areas, often in shallow sea grass beds or in coastal mangroves. After several months, they begin an offshore migration as juveniles. Both while there are in the nursery grounds, and at the start of their offshore migration, they are available for catching by coastal artisanal fishermen. Having run the gauntlet of an artisanal fishery, the migration continues until they reach the deeper offshore grounds, where they can then be targeted by an industrial fishery. The life cycle in completed offshore, after mature shrimp have spawned.

In cases where there shrimp are cultured, this normally takes place in ponds, where they are grown either from eggs stripped from ripe mature females or from the post-larval stages. It can be notoriously difficult to complete the life cycle in cultured shrimp. Hence in both cases, mature females or post-larvae are collected from the wild. A recent practice (e.g. in Ecuador) has been to site ponds or enclosures for aquaculture near to or amongst nursery areas. While this makes the supply of wild shrimp easier, the consequent losses of available nursery grounds for the wild stock should not be ignored.

It follows that a wild shrimp stock can be subject to a wide variety of direct removals at different stages in their life cycle: post-larvae for aquaculture, juveniles in an artisanal fishery, sub-adults and adults in an industrial fishery, and mature females for aquaculture. As is clear, the direct removals act sequentially throughout the life cycle. Thus, for instance, increases in artisanal catches will directly reduce the stock available for catching by the industrial fleet. To these direct effects must be added possible degradation of nursery grounds through the siting there of aquaculture ponds. Officials wishing to manage the shrimp stocks effectively must take account of these potential biological interactions.

For the government of a developing country, however, there is more at stake than just ensuring that the wild stocks are not overexploited. As already noted, tropical shrimp sold on the world market provide an important source of foreign currency revenue. If prices paid for the different size categories of shrimp realign in response to the world-wide increase in aquaculture supply, then this will overall effects on future revenue, but more importantly these effects are likely to fall differentially on the various sectors. Appropriate planning of future development needs to take all of these factors into account.

Given this background, the shrimp management project was formulated with the objectives to examine interactions in tropical shrimp fisheries in developing countries between artisanal and industrial capture fisheries and shrimp aquaculture, and to evaluate possible management strategies to take account of these interactions and minimise deleterious outcomes.

It was originally intended that the project would be carried out in two phases. The first phase had two primary segments:

(i) development of a bio-economic model that takes account of the different types of capture fishery and of the impact of aquaculture, as well as market responses to changes in supply and the resultant impacts on fleet sizes and profitability; and

(ii) a comprehensive review of shrimp production and price trends, including a demand analysis aimed at obtaining quantitative estimates of the likely effects of changes in supply in the different size categories on prices in each category.

On completion of this first phase, a decision was to be made as to whether to proceed to a second phase, which would involve a detailed review of selected case studies and an evaluation of alternative management strategies.

As detailed in the Final Report, it proved unexpectedly difficult to obtain on the public record suitable data on supply and prices paid that were disaggregated by size category, despite considerable time and effort being spent in attempting to locate such data. Lacking these vital data for a substantial part of the world market, it was decided to abandon the second phase of the project.

This outline is therefore devoted to summarising the results obtained in the two segments of the first phase. It is presented in two sections. The first describes the bio-economic model in non-technical terms, and illustrates some of its properties. The second section summarises the review of production and price trends, and the analysis of the short data sets obtained for part of the US market for which disaggregated data by size were obtained. The full review of production and price trends is appended to the Final Report.

2. Bio-economic model

The bio-economic model developed for the first phase of the project was deliberately kept relatively simple and general, and was intended to be used to illustrate the type and size of effects of the different interactions between the different fishery types and the effects of changes in prices for different size grades of shrimp. It was intended that a much more detailed model taking account of all the special features of the fishery, fishing gears and markets of case study shrimp fisheries would be developed in the second phase of the project.

2.1 The biological model

At the heart of the bio-economic model is a model of the dynamics of the shrimp stock. This was based on the dynamics equations originally developed by Beverton and Holt, and also used by Willman and Garcia to model interactions between artisanal and industrial shrimp fisheries. Using a time scale of one month, the population size of a cohort is reduced from its initial recruitment level as a result of age-specific natural mortality, and removals by the four possible fishery types:

i removals of post-larvae for aquaculture,
ii artisanal fishing,
iii industrial fishing, and
iv removals of mature females for aquaculture.

In its most general form, the fishing mortality rates exerted by each fishery can vary across months, though normally it is assumed that the fishing mortality rate for a given fishery is proportional to the available fleet size. In the results illustrated in this report, we will ignore removals of post-larvae and mature females.

On reaching sexual maturity, spawning occurs, with the number of recruits becoming available to the earliest fishery being assumed to be governed by a stock-recruitment relationship. It remains a matter of controversy whether or not tropical shrimp stocks exhibit a stock-recruitment relationship. Given their very high fecundity, it would perhaps not be unexpected that the spawning stock could be reduced to very low levels before any reduction of average recruitment might be detected. However, in at least two Penaeid fisheries in Australia, there does appear to be good evidence that recruitment can indeed be reduced by over-exploitation. Accordingly, we have included the possibility that the stock-recruitment relationship takes a Beverton and Holt form. Such a relationship allows the recruitment to remain virtually constant until low spawning stock levels, below which it falls. Most analyses (e.g. that of Willman and Garcia) assume constant recruitment.

An additional motivation for making allowance for reductions in recruitment comes from the increasing use of nursery grounds for siting of aquaculture ponds. Even if recruitment is on average constant when the nursery grounds remain untouched, sufficient degradation of nursery grounds must eventually lead to recruitment declines. As a first approximation, it is assumed that recruitment falls linearly (though not proportionally) with the size of the effective nursery grounds relative to their pristine size.

Both potential causes of reductions in recruitment are allowed for in the model, though we will only illustrate the effects of including a stock-recruitment relationship.

Other features of the biological model are standard. Growth in length and weight is assumed to follow the standard von Bertalanffy forms, for which estimates of growth parameters are available for many shrimp species.

2.2 The economic model

The principal variables to be set in the economic model are the prices received by each fishery for each size grade of shrimp, and the costs (both fixed and variable) experienced by each of the fishing "fleets". Naturally, the contribution of variable costs is directly related to the amount of fishing effort expended. Once estimates are available for these parameters, it is a simple matter to determine the net profitability, and the revenue obtained for each seasons' fishing. Throughout the study, we have calculated present values for each of economic variables of interest, using appropriate discount rates.

If the fishery being studied took place in a developed country, using modern industrial shrimp trawlers manned and owned by nationals of the country, it would be reasonable to restrict attention to the profits earned by the fishery, with a common management goals being to seek to achieve maximum economic yield. However, for developing countries there are often other important management goals.

Normally, artisanal fishermen exert much lower fishing pressures per fishing unit that do modern industrial fleets. Thus judged on simple economic efficiency, it will usually be far preferable to restrict fishing to industrial trawlers taking large shrimp. However, often the artisanal fishermen are based in coastal villages, and frequently in remote locations, with little other opportunity for alternative employment or income. On the other hand, the industrial fleet may well be foreign-owned. Benefits in terms of higher profits then may flow out of the country, balanced only by any licence fees or export levies imposed. Industrial trawlers may employ larger crews than artisanal vessels, but the proportion of locals employed as crew can be small.

It follows that there are likely to be many other economic variables of interest to shrimp fishery managers and policy makers in developing countries. In an attempt to make allowance for these, the economic model allows simple estimates to be made of the local employment generated, total revenue to the country, and total catch weight. As noted, the simple relationships used in the first phase would of course have to be replaced by more realistic ones estimated from data pertaining to a particular country and fishery in any practical application.

2.3 Static versus dynamic models

As will be seen more clearly in the next section, which illustrates some of the properties of the bio-economic model, models of the type described so far present only a static picture of the shrimp fisheries. While the sizes of the different fleets can be allowed to vary, the fishing patterns adopted by them are normally rather restricted. For example, it is usually assumed that the artisanal fishery operates only for a fixed short season, and that the industrial fishery operates over another defined fishing season, with adjustments available only for the starting date of the season.

By varying the different fleet sizes in separate runs of the model, the combinations of fleet sizes producing optimum performance in terms of chosen policy variables can then be determined for given biological and economic parameters. Further multiple runs can test the effects of using different biological or economic variables, but essentially this allows determination only of static optima.

This static approach is the one that has been taken in all similar previous studies of shrimp fisheries. In particular, it is the approach used by Willman and Garcia in their study of interactions between artisanal and industrial shrimp fisheries. It is also the approach used in the complex and detailed computer model BEAM 4, in the final stages of development by FAO. The difficulty is that only long-term equilibrium optima can be estimated. This is hardly a problem in the initial stages of policy development for a developing country. However, if a particular optimum mix of fleet sizes is rather different to the current one, it is unrealistic to assume that an instant switch can be made between the two. An alternative, dynamic, approach can introduce greater realism by allowing for changes in fishermen's strategy over time.

A dynamics model would be of great interest when attempting to evaluate a particular case study shrimp fishery. While here we concentrate on presenting static results, a computer model using the technique of dynamic programming has also been developed, initially to investigate optimum harvesting within a cohort.

3. Properties of the bio-economic model

We now present an illustration of the properties of the bio-economic model that has been developed. To give it some degree of realism, we have extracted relevant biological and economic parameters from the data presented for the Suriname fishery for *Penaeus subtilis*. It should be noted, however, that at this stage the model is not able to deal with the processing sector, and flows of revenue and employment to the country have been simplified. The aim here is a brief illustration of properties, rather than a detailed analysis of the fishery.

3.1 Biological and economic parameters

As recorded by Willman and Garcia, shrimp recruit to the artisanal fishery for *P. subtilis* at age around 2 months, and they are then taken by that fishery for another 1-2 months. The shrimp then migrate offshore and recruit to the industrial fishery at age 4 months. Within the industrial fishery, the natural mortality rate is constant at 0.2 month^{-1}, but higher natural mortality rates apply in the artisanal fishery. On average, the shrimp grow to a maximum total length of around 168 mm, corresponding to a weight of around 50 g. The growth rate is somewhat higher than the natural mortality rate.

The (then) current fishing mortality rate exerted by the industrial fishery was 0.13 per month, corresponding to a fleet of 160 vessels. The artisanal fishery entered a fishing mortality rate of 0.05, corresponding to 67 fishing units. Fixed and variable costs for the two fleets as recorded by Willman and Garcia were used. Twelve different size categories of shrimp were recognised, with prices obtained for these estimated from US market data. Annual discount rates of 10% were used throughout.

In order to look at employment effects, it was assumed that all artisanal fishermen should be counted towards national employment (measured in man-months), but only 5% of the crew (based on an estimate of 5% of wages) were locals. In order to allow a crude estimate of revenue accruing to the country, estimates of the proportions of fishing costs spent on imported goods and services were used.

3.2 Optimum age at first capture in the industrial fishery

One of the primary management tools used for industrial shrimp fisheries is control of the age (or size) at first capture. Because shrimp trawls are not very size-selective, especially for schooling species, these controls usually take the form of closed areas (to protect nursery areas and to prevent the capture of small shrimp) or closed seasons (allowing the season to open only when the shrimp have reached the appropriate size).

Traditionally, calculations leading to the selection of an optimum size at first capture have been based around the idea introduced by Beverton and Holt of maximising yield per recruit. In a bio-economic setting, the equivalent is maximising value per recruit, or net profit per recruit. Such calculations are simply done using the bio-economic model developed during this project.

In this section, we present illustrative results for the standard sets of biological and economic parameters, and examine their sensitivity to changes in these parameters.

3.2.1 Standard set of parameters

For the standard set of biological and economic parameters used, the results are shown in panel (b) of Fig. 1. Four fishing mortality rates in the industrial fishery are shown (0.04, 0.10, 0.16 and 0.22) corresponding to industrial fleet sizes of approximately 48, 120, 192, and 264.

As the fishing mortality rate increases, the optimum size at first capture decreases. For F=0.04, it is approximately 38 count per pound (corresponding to an age at first capture of just over 4 months). When F=0.1, the optimum size at first capture has fallen to just over 25 count per pound (5 months) and therefore very close to the boundary between the medium and large size categories. For F=0.22, the optimum size is 19 count per pound (nearly six months).

The interplay between prices and variable costs also imply that there is a single fleet size that will produce the maximum overall profit. Considering the restricted set of fishing mortality rates used, the optimum fleet size is 120. Fishing at rates substantially higher than that will lead to reductions in profit, and for F much greater than 0.22, the fleet will make a net loss, regardless of adjustments to the opening date of the season.

Thus use of the bio-economic model allows calculation of both optimum ages at first capture for any given fleet size, and also of an optimum fleet size. In this example, the overall optimum is obtained for fleet sizes over about 120, with fishing being delayed until the shrimp have reached the large size category.

We now proceed to examine how these conclusions change as biological and economic parameters vary.

3.2.2 Varying maximum size of shrimp

If larger shrimp have higher value than smaller shrimp, then all else being equal species with greater maximum length should produce greater profits. This is indeed the case, as illustrated in the other panels in Fig. 1.

Panel (a) shows results for a case where the species being harvested has a maximum asymptotic length 20% lower than the standard case. As it must, the trend for higher optimum sizes at first capture as F increases remains, but now the greatest profit is obtained for the smallest fleet sizes, with fishing commencing when the shrimp have reached only 36 count per pound.

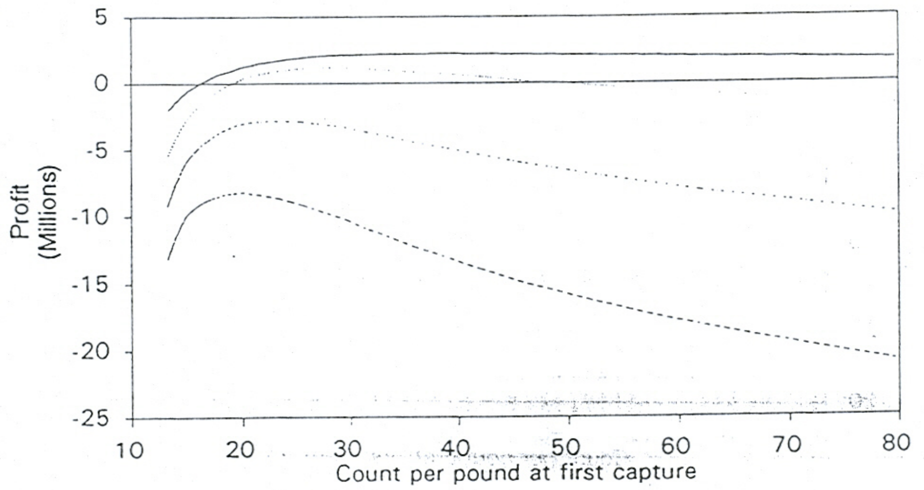
The variable costs of the industrial fleet are sufficiently high that it is at best only marginally profitable to fish at all. If even smaller shrimp were the only ones available, no fishing would be profitable.

On the other hand, of the maximum size of the available shrimp were larger than the standard, then overall profit increases at all fishing mortality rates. Panel (c) indicates that the optimum fleet size now is around 192, with fishing being delayed until the shrimp have reached just under 17 count per pound.

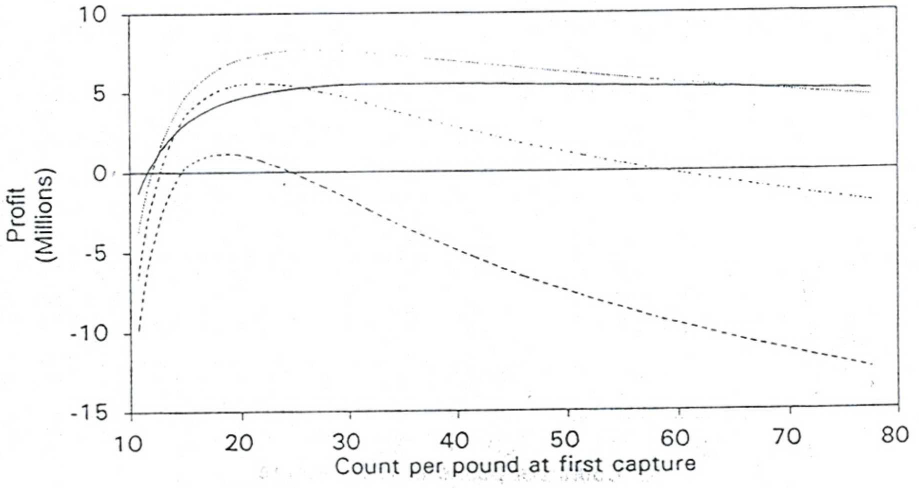
The general conclusion is that as the maximum size of the shrimp available for capture increases, the fleet size producing maximum profit increases, and the age and size at first capture also increases.

Figure 1. Effect of changes in asymptotic weight

a) Winf = 0.4



b) Winf = 0.5 (standard)



c) Winf = 0.6

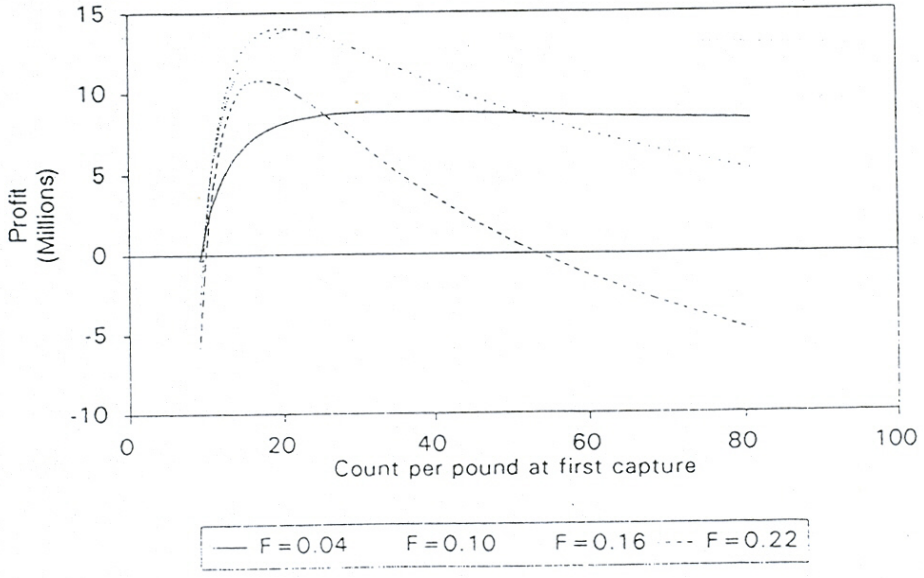
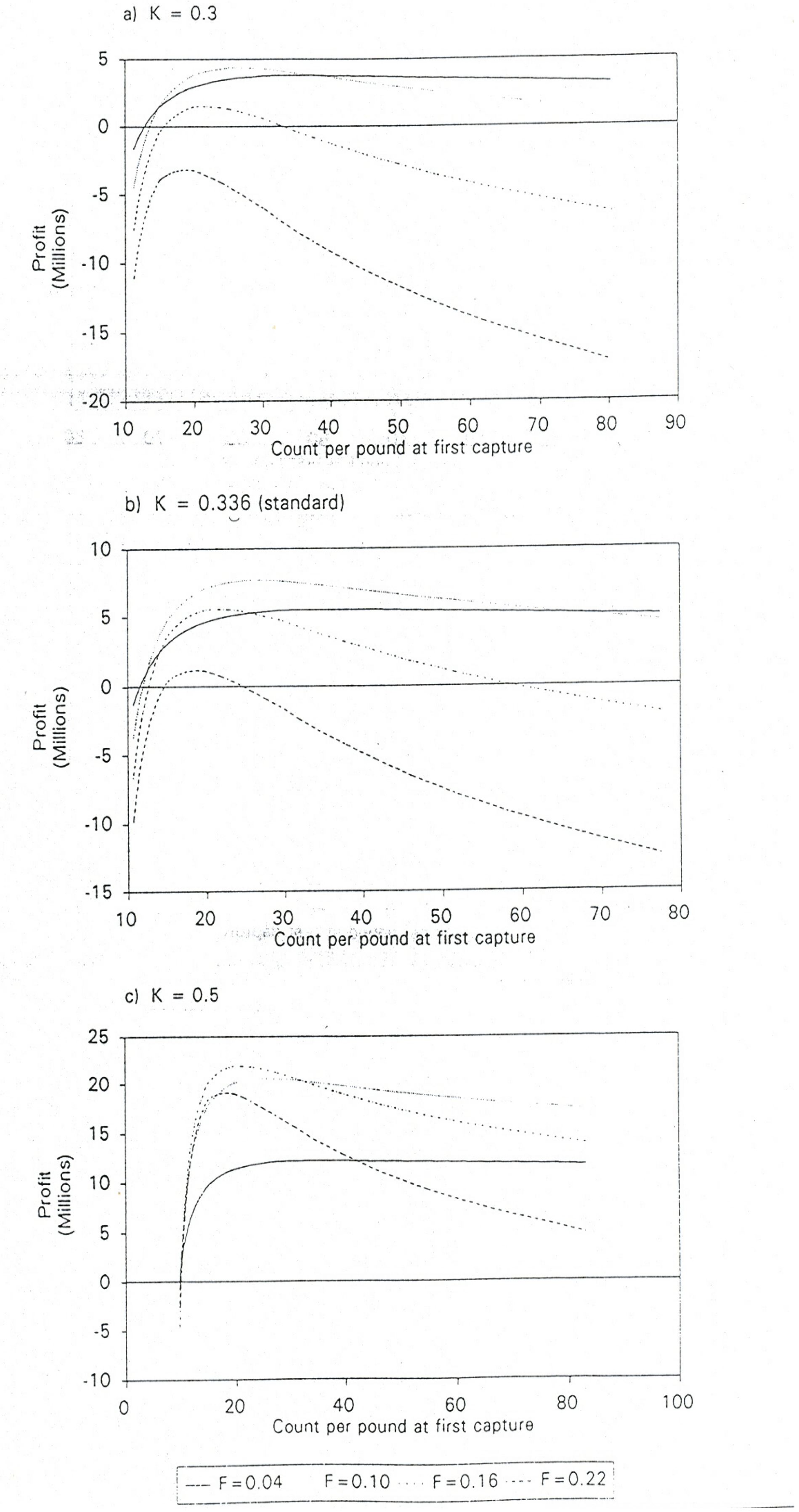


Figure 2. Effect of changes in growth rate



3.2.3 Varying growth rates

Shrimp species can also show considerable variability in growth rates. An increase in growth rate when the maximum length remains the same implies that the shrimp will on average reach greater sizes at any one time of the year than those with a smaller growth rate. Thus when viewed throughout the season, they will appear to larger than shrimp with a slower growth rate. Not surprisingly, therefore, the effects of varying growth rate are similar to those of varying maximum size.

The effects of changes in the von Bertalanffy growth parameter K are illustrated in Fig. 2. There are subtle differences between the effects of varying K and varying maximum length, introduced by differing interactions with the natural mortality rate (it not only takes longer for a shrimp with smaller K or smaller maximum length to reach a given size, but also fewer of them do so because of the greater length of time they have been exposed to natural mortality). However, as expected, the optimum fleet size still increases with increasing K, as does the optimum size at first capture.

3.2.4 Varying recruitment and mortality

With their high fecundity, shrimp species often show considerable variation in recruitment. Comparison of panels (a) and (b) of Fig. 3 illustrates the effects of profitability of changes in recruitment (in this case an increase by 50%).

With more shrimp available to be caught, not surprisingly an already profitable fishery will become more profitable. Now, the optimum fleet size has increased to around 264, with an optimum age at first capture of 5.6 months (20.7 count per pound). What is not so clear from the figure is that the optimum sizes and ages for each F are in fact slightly lower than those in the standard case. Not shown in the figure is the case with reduced recruitment. The results there are obvious: the fishery was marginal at the standard level of recruitment, and substantial drops in recruitment will make no fishing profitable.

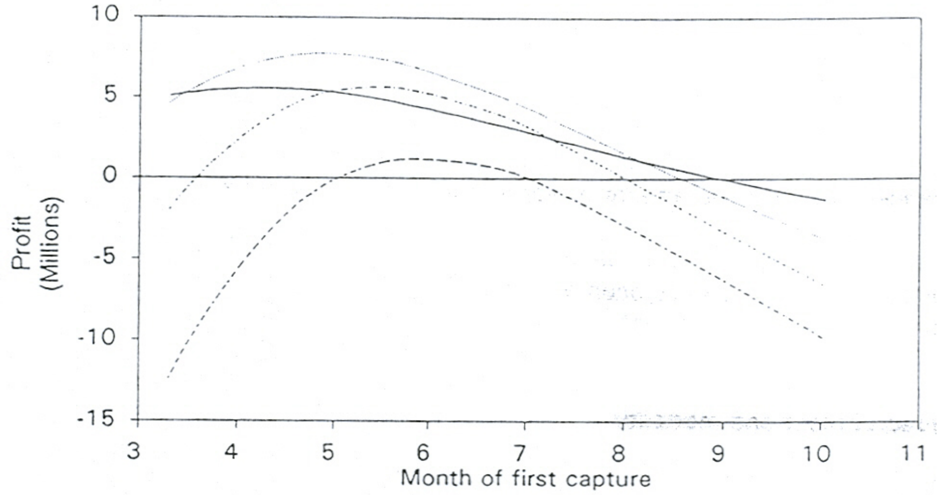
One implication of these results is that the profitability of a fixed fleet may vary substantially between years. Years of poor recruitment will produce losses, and years of high recruitment will produce windfall profits. Management implications of this will vary with the types of management scheme in place and with the characteristics of the fleet. For a locally owned and crewed fleet, employment benefits might outweigh any temporary losses. However if the fleet is a licensed foreign fleet, with benefits accrued through license fees, there may be a strong case for using pre-season surveys to measure the recruitment each year and to adjust the fleet size and license fees accordingly.

Another biological parameter that will affect optimum fleet sizes and sizes at first capture is the natural mortality rate. As this increases, fewer shrimp will survive to reach larger sizes, suggesting that it would be necessary to reduce the size at first capture to compensate. That this is the case is illustrated by panel (c) of Fig. 3. The case shown here also has recruitment doubled, because increased natural mortality also brings lower profits, and for the standard recruitment no fishing is profitable.

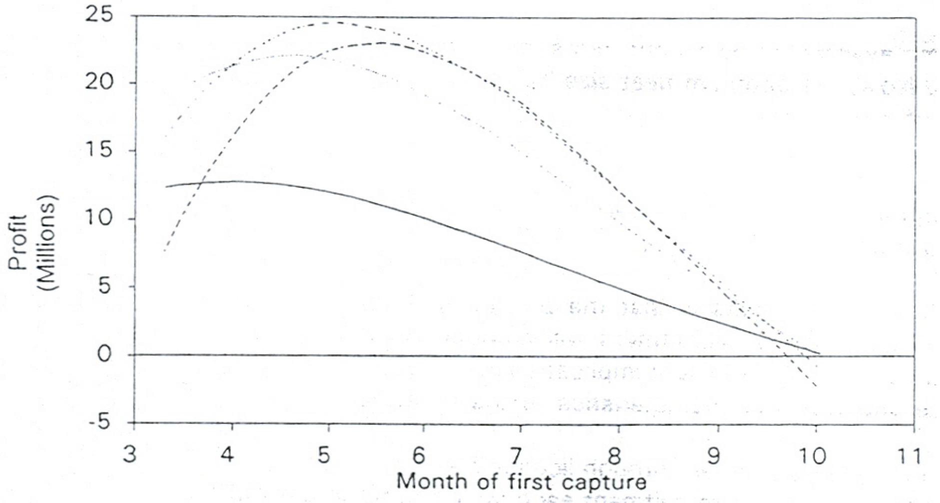
Comparing panels (b) and (c), we see that for each F, the optimum age at first capture is lower for the higher natural mortality rate. Concomitantly, the optimum fleet size has decreased.

Figure 3. Effect of recruitment and mortality changes

a) Standard



b) Recruitment increased by 50%



c) Natural mortality increased by 50%; recruitment doubled

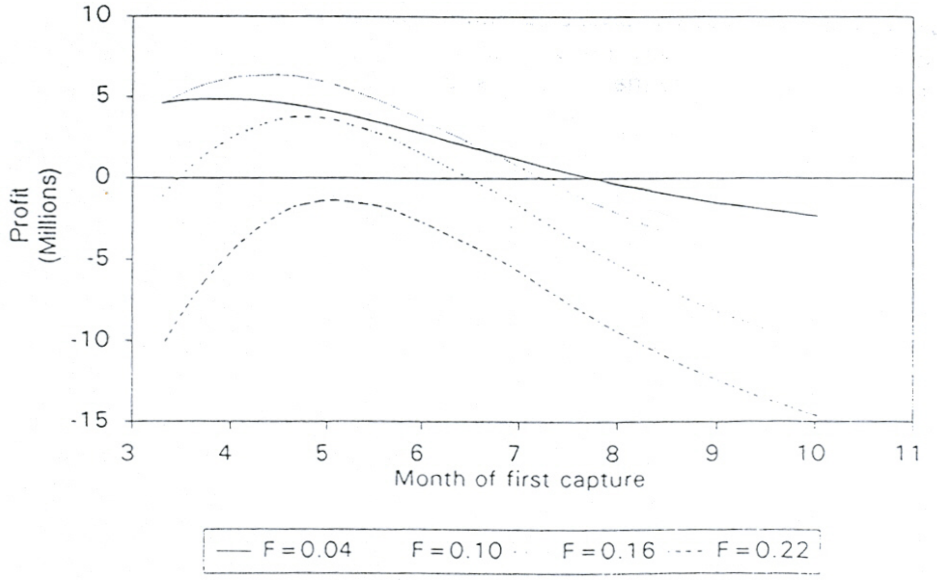
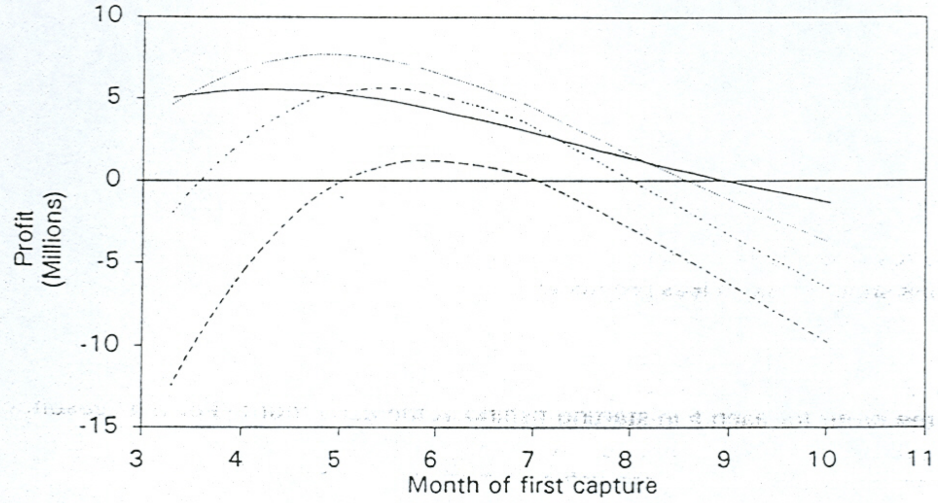
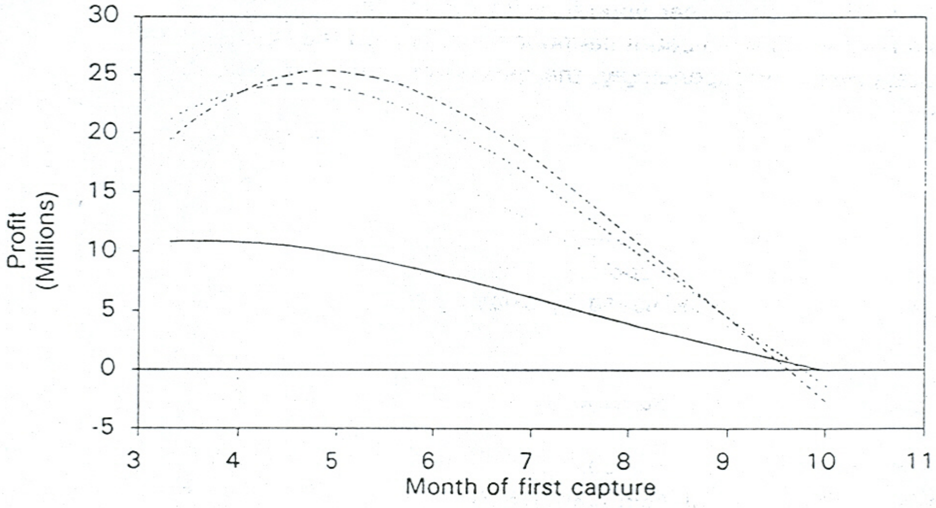


Figure 4. Effect of cost and price changes

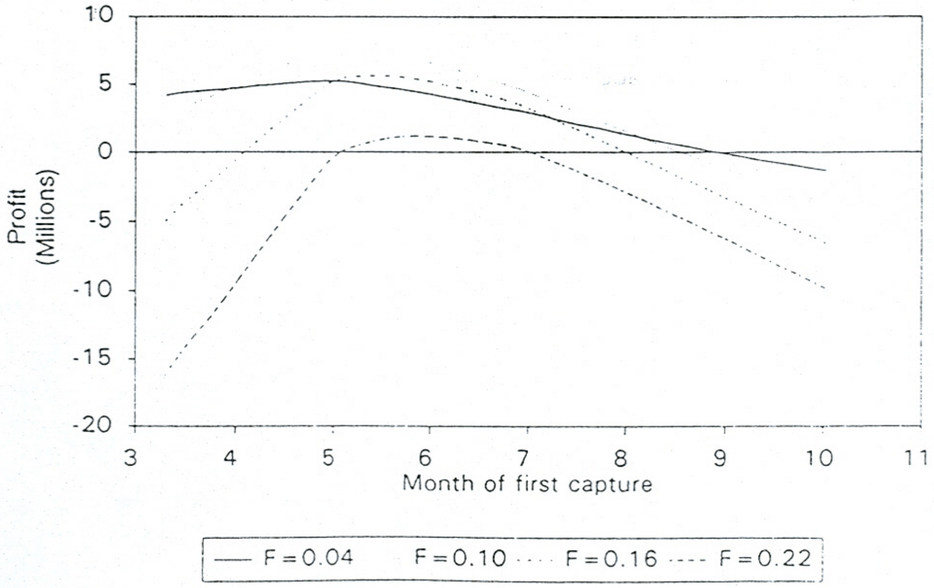
a) Standard



b) Variable costs reduced by a factor 10



c) Price of medium shrimp reduced by 50%



3.2.5 Effect of cost and price changes

The final sensitivity analysis for the industrial fleet examines the effects of cost and price changes.

One of the reasons for the industrial fleet being apparently only marginally profitable is because of relatively high variable costs. Panels (a) and (b) of Fig. 4 illustrate the effects of reducing the variable costs (by a factor of 10). A more cost-efficient fleet should produce better profits, and this is seen in the figure with increased profits for each F. The optimum age at first capture also decreases for each F, reflecting the greater marginal profitability of catching smaller, lower value shrimp. The optimum fleet size also increases.

Finally, we examine the effect of a reduction in the price of medium-sized shrimp, such as might come about as a result of increased aquaculture supply in this size category. A reduction in price in these categories should make it less profitable to take shrimp of these sizes, so one might expect that the optimum size at first capture to fall.

Panel (c) of Fig. 4 demonstrates that this is so. Comparing with the standard panel (a), there is a marked drop in the profit for each F in starting fishing in the early months of the season. For large F values, the optimum size at first capture in the standard case fell into the large size categories, and the figure confirms that lowering the value of medium shrimp has no effect.

However, for the lowest F value, it was optimal to commence fishing when the shrimp were medium-sized (at nearly 38 count per pound). With a price fall, this optimum size at first capture has increased to a fraction over 25 count per pound; i.e. just on the boundary between the medium and large size categories. Correspondingly, the maximum profit available for the lowest fleet size has also fallen slightly. The optimum fleet size has not changed.

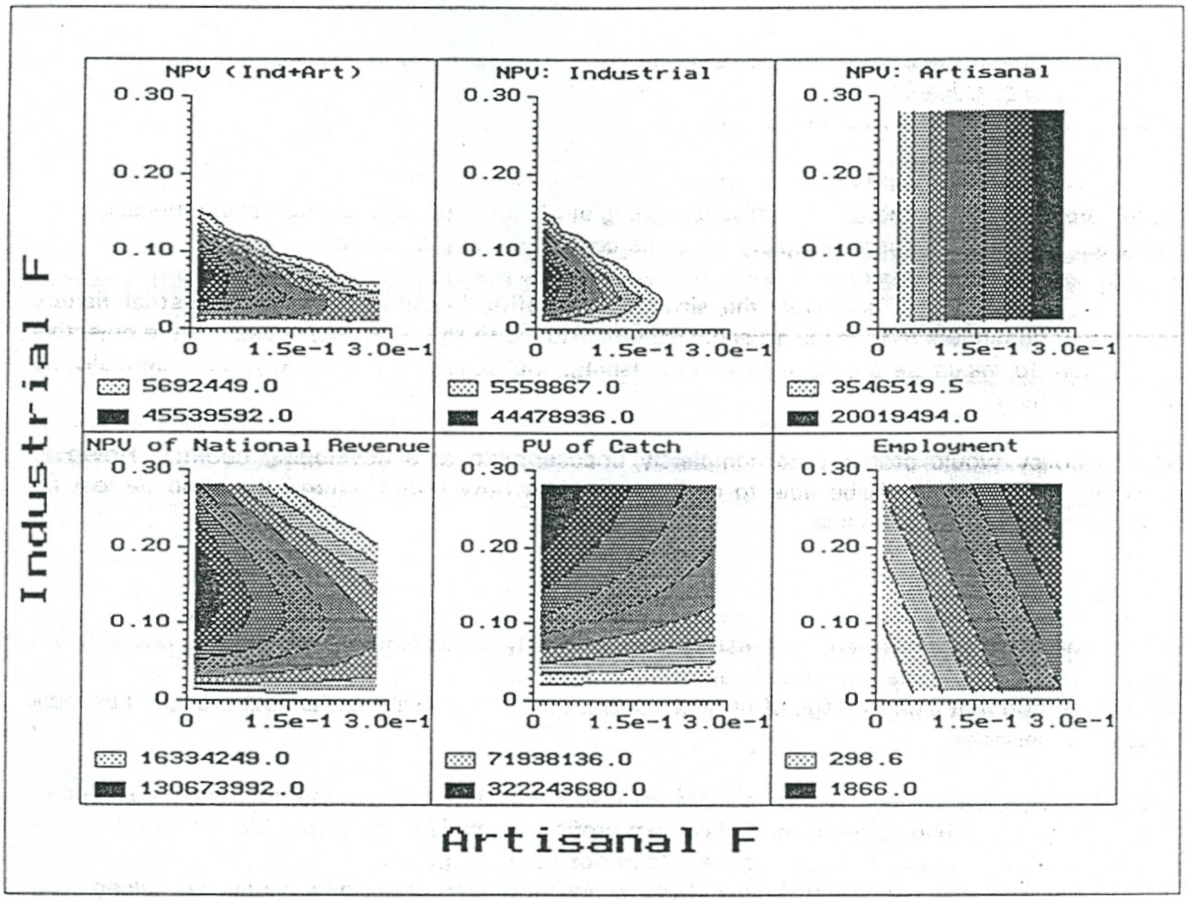
It now becomes clearer what effect a change in the price paid for medium sized shrimp would have on the profitability of an industrial fleet. If the biological and/or economic parameters are such that the optimal size at first capture of shrimp lies in the medium size category, then reductions in price will reduce profit, and there will be economic pressures to increase concentration on catching the large size category. This could be achieved by delaying the start of the season.

3.3 Interactions between the artisanal and industrial fleet.

So far we have ignored the interaction between the artisanal and industrial fleet, which in fact operate sequentially; the artisanal fleet catches shrimp aged 2-3, while the youngest shrimp available on the offshore grounds are aged 4 months.

The results in this section are presented in the form of contour plots of selected performance indicators: net present value (NPV) of the artisanal fishery alone, of the industrial fishery alone and of the two combined; NPV of revenue accruing to the nation; present value (PV) of the catch; and local employment. See section 3.1 for further description of how these were measured.

Figure 5. Interaction between artisanal and industrial fisheries: with constant recruitment.



3.3.1 Assuming constant recruitment

The net present values of the two fleets are illustrated in the top three panels of Fig. 5.

Turning first to the artisanal fishery, we see that its NPV is unaffected by the size of the industrial fleet. This occurs because of the sequential nature of the fishery -- the artisanal fleet gets first chance to catch the shrimp and the two fleets do not overlap in sizes of shrimp caught -- and because for the moment we have assumed that there is no stock-recruitment relation or degradation of the nursery grounds.

Another interesting feature of the contour plot for the artisanal fishery is that the NPV increases with increasing artisanal fishing mortality rate. This occurs because of the very low fixed and variable costs incurred by these fishermen.

In contrast, the industrial fleet is affected by the operation of the artisanal fishery. Its maximum profits are made when there is no artisanal fishing at all, and as the artisanal fishing mortality rate increases the industrial fishery rapidly becomes completely unprofitable.

When viewed together, however, the size of the profits available from the industrial fishery completely dominates that of the artisanal fishery. Thus with the parameters used, if the objective was simply to maximise the total NPV from fishing, the policy would be to have essentially no artisanal fishing.

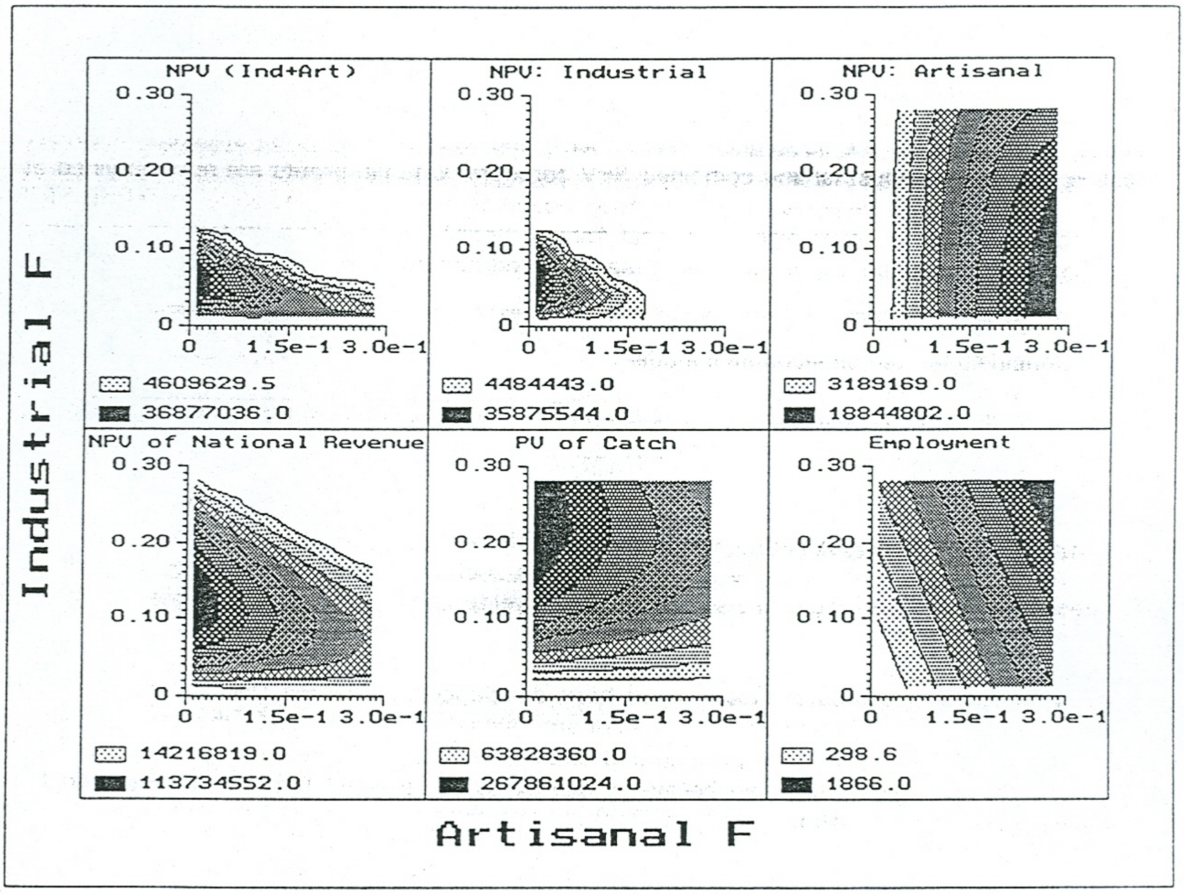
Such a policy would probably be completely unacceptable to a developing country. However analyses such as this will be able to demonstrate just how much potentially could be lost by allowing heavy artisanal fishing.

The picture is not so gloomy when one considers the NPV of national revenue. Because not all the industrial profit enters the national economy, combinations of higher artisanal and industrial fishing effort can be tolerated. In fact, interestingly but probably unrealistically, substantial benefits still accrue to the nation when the industrial fishing is at a rate that is unprofitable. This is because of the assumption that a percentage of variable costs incurred by the industrial fleet are spent on local goods and services.

The last two panels are included to illustrate the rather different conclusions that would be reached if objectives other than some form of maximum profit are considered. If the objective were simply to maximise the value of the catch landed, then not surprisingly, the appropriate levels of fishing by the industrial fleet are much higher. Note again, however, that they would be making very substantial losses. Finally, if maximising employment were the primary objective, then this would be achieved at high fishing mortalities by both fleets.

Clearly, the same levels of artisanal and industrial fishing cannot maximise the different performance objectives illustrated in the figure. This is not a particularly startling finding. What analyses using bio-economic models such as these do, however, is allow the tradeoffs between the different objectives to be examined quantitatively, thus assisting greatly in developing policies appropriate for developing countries.

Figure 6. Interaction between artisanal and industrial fisheries: with stock recruitment relationship.



3.3.2 Inclusion of a stock-recruitment relationship

The results in Fig. 5 were for the commonly examined situation in which the average recruitment to the fishery was unaffected by declines in mature stock size. In section 1, it was argued that on the available evidence it may not be safe to make that assumption. There is some evidence that shrimp stocks can display symptoms of recruitment over-fishing, and the increasing degradation of nursery grounds cannot be ignored.

For the illustrative purposes of this summary of results obtained, we combine these two possible effects by assuming that there is a real stock-recruitment relationship that will lead to lowered recruitment at high fishing mortalities. As we saw in section 3.2.4, reduced recruitment will lead to reduced profits, so we would expect to see additional penalties for high Fs.

The results are shown in Fig. 6. One obvious effect is shown in the NPV for the artisanal fishery. Previously, the amount of industrial fishing effort expended had no effect on the artisanal profits. Now, however, at sufficiently high industrial fishing mortality rates the spawning stock has been reduced sufficiently for the subsequent recruitment, and thus profits, to be affected. A similar effect is seen in the industrial and combined NPV contours. Optimal profits are now obtained at lower F values for both fisheries. Note that now, however, the areas of positive combined NPV have been extended to cover higher artisanal fishing mortality rates. The effects on the other performance measures are slight, but still in the expected direction.

4. Conclusions from bio-economic model

Results of an illustrative application of the bio-economic model developed during this project using data from the Suriname P. subtilis fishery have demonstrated the utility of the model and allowed some important general principles to be drawn. The specific conclusions about optimum fleet sizes are of course completely dependent on the parameter values used. Different fisheries may have completely different characteristics, and have quite different optimal mixes of fleets. However, provided the appropriate data can be collected, models such as this one can be used to examine the effects of different management strategies and develop appropriate policies to meet different management objectives.

A variety of different computer models have been developed to simulate the bio-economics of shrimp fisheries. Of particular note is the series of programs developed by FAO, the latest of which (BEAM 4) allows an extremely complicated and detailed simulation of the fishing and processing of shrimp. This program, which we believe is shortly to be released formally, is designed for immediate practical application.

In form, therefore, it covers all the practical and fishery-specific details that would be needed for the case study that was initially intended in this project. However, it does not allow for inclusion of a stock-recruitment relation, and it remains a static analysis. Although not illustrated here, the possibility in our bio-economic model of undertaking a dynamic analysis would allow a more realistic evaluation of the likely effects of changes in policy. That said, however, it does not seem sensible to undertake an independent development of the existing bio-economic model to attempt to match that developed by FAO. It would be possible, though would still take considerable time, to develop specific modules incorporating our extensions to the FAO model into their program.