Amazonian Fisheries: Socio Economic Issues and Management Implications

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Jaime Fernandez-Baca

ABSTRACT

Over the last three decades, the demand for fish in the Amazon basin has greatly increased due to population growth in the main cities of the region. While technological improvements in commercial fishing methods have made it possible to meet this growing demand, they have led to concerns about the possible extinction of certain fish species and to conflicts over the resource between commercial fishermen and rural communities. This study reviews the current state of inland fisheries in the Amazon in order to analyse policy options for fisheries management, and identifies key gaps in information on the economic, social and biological aspects of fisheries which constrain policy-makers.

Introduction

Fish has traditionally been a major source of protein for the people of the Amazon basin. This is not surprising, considering the extent of its river system and the large populations of fish species this system supports. The high biological productivity and biodiversity most commonly associated with the terrestrial ecosystems of the Amazon rain forests also apply to its rivers and lakes.

Over the last three decades, the demand for fish has greatly increased as a result of population growth in the main cities of the region. Technological improvements in commercial fishing methods have made it possible to meet this growing demand but have also increased pressure on the fishery resource. Many managers and conservationists claim that fisheries in the Amazon are reaching a state of over-exploitation, and are concerned about the possibility of certain species becoming extinct. Although there seems to be no conclusive evidence of such overfishing actually occurring, in some areas increasing competition for the resource has resulted in conflicts, usually between commercial fishermen and rural communities that also make use of the fishery resource. Such conflicts have been aggravated as several local riverine communities have claimed property rights over fishing grounds in order to exclude commercial boats from these areas.

Undoubtedly there is a need for adopting and enforcing policies that will guarantee a fair share of the resource to the different sectors of the population whose livelihood depends on fisheries. Such policies also need to consider the nutritional demands of a growing urban population. However, fisheries management is constrained by complex environmental and biological interactions whose mechanisms are insufficiently understood and whose outcomes are difficult to predict. Thus, a deeper understanding of the ecological processes that eventually determine the performance of the fishery is an important factor for achieving sustainability.

In Peru, the Amazon basin fisheries have received relatively little attention from central government, mainly because of their low value in economic terms when compared to the country's marine fisheries, which are some of the most productive in the world. Nevertheless, in terms of fisheries production for human consumption, the harvest from the Peruvian Amazon basin equals more than 50% of the marine fisheries' yield (Montreuil *et al* 1991). This reflects the high dependency of local populations on fish, given the fact that the Amazon is much less populated than coastal areas.

The purpose of the present study is to review the current state of inland fisheries in the Amazon basin and related policy issues, and to identify gaps in information on the economic, social and biological aspects of the fishery which may limit such an assessment. This is a desk study with the aim of identifying priority topics for further studies.

The main body of this work is divided into three sections. Section 1 reviews the key environmental and socio-economic characteristics of fisheries in the Amazon basin. Emphasis is placed, as much as possible, on the fisheries in Peru; however, reference to the whole basin is made when presenting general features. Section 2 introduces the main principles of fisheries management and presents several case studies of fisheries management around the world. Among these, several case studies are presented where local communities have played a major role in the design and implementation of the management system. Finally, Section 3 discusses how general fisheries management and economic principles would apply to the specific case of the Amazon basin. Policy options for the Amazon fisheries are also discussed, as well as the need for further information to assess them. In order to clarify key concepts that are used throughout the present study, some general principles and definitions of common property management as well as a review of the economics of fisheries management are given in two supporting annexes.

1 Inland Fisheries in the Peruvian Amazon

1.1 Introduction

A traditional activity in the Peruvian Amazon, fishing has provided cheap and easily accessible food for the population of the region, and today it is an important source of animal protein for fast-growing urban areas. Different aspects of the Amazonian fisheries are reviewed in this section in order to provide a background knowledge of their characteristics and current problems. An attempt is made to narrow the focus to the fisheries in the area of the Peruvian Amazon, mainly comprising the Amazonas and Ucayali regions, where the main landing ports are the cities of Iquitos and Pucallpa respectively[1].

This section first examines some of the socio-economic factors that determine the fishing activity in the Amazon, such as the demand for fish products and the commercial and subsistence fisheries that operate in the region. Subsequent sections describe the hydrological and biological factors that underpin the Amazonian fisheries, as well as their diversity. A discussion of whether there is overfishing in the Amazon follows, as well as the factors behind the conflicts that have arisen between commercial and subsistence fishermen.

1.2 Demand for fish

Inhabitants of the Amazon region have a high per capita consumption of fish compared to other types of meat. It has been estimated that 61% of the animal protein consumed by people in the Ucayali River valley comes from fish (Dourojeanni 1985; cited by Chapman 1989). In Iquitos, 32% of the population consumes fish three times a week, and the economically poorest (12% of the population), consume fish every day (Beuzeville 1973; cited by Chapman, 1989). Estimates of fish consumption based on household surveys range from 89g per day in the city of Pucallpa to 185g per day in rural areas (Haneck 1982; Eckman 1985; cited by Bayley and Petrere, 1989).

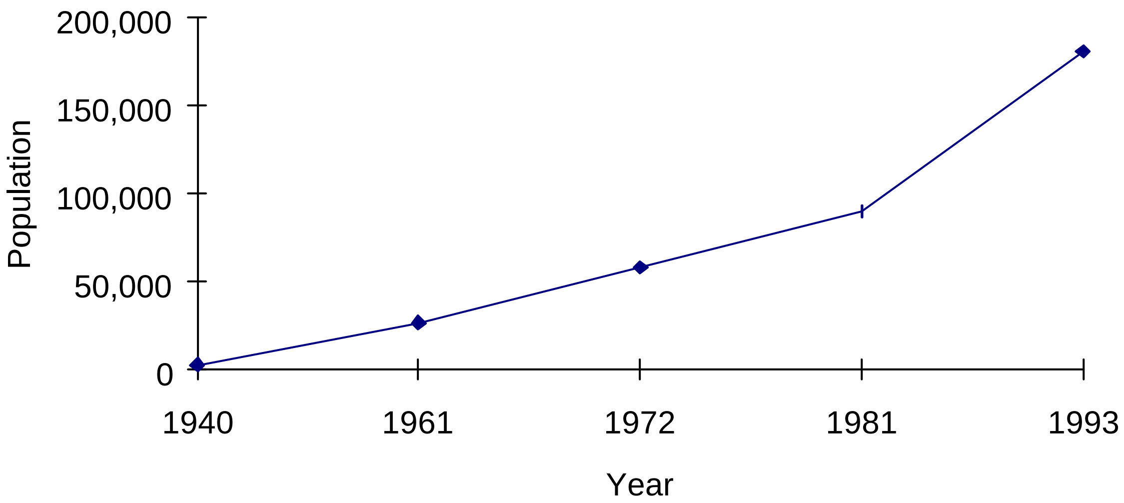
According to the Food and Agriculture Organization of the United Nations (FAO) (1995), there is a negative correlation between fish consumption and income in tropical countries. In other words, fish consumption falls as income levels rise. Bayley and Petrere (1989) have observed that this relation between income and fish consumption also holds in the Amazon basin, where fish consumption is higher in rural areas near the floodplains than in cities, and within the latter, fish consumption is lower in high income groups. There are no estimates of the income elasticity of demand for fish in the region.

Despite lower per capita demand for fish among urban residents, the total demand for fish is expected to increase due to the rapid growth of Amazonian cities. Over the period between 1972

[1] Information on the Amazon fisheries in Peru is provided in local publications which are difficult to find outside Peru. A compilation of this information was carried out by the Amazonian Cooperation Treaty (TCA, 1994), based on an article previously published by Guerra *et al* (1990). Much of the information given in the present section was obtained from these two works, although some general principles that apply to the whole basin were obtained from other sources. Among these, works by Bayley (1981, 1995) and Bayley and Petrere (1989) provide good insight into the current situation of the Amazonian fisheries.

and 1993, high birth rates and migration from rural areas resulted in a three-fold increase in the population of Pucallpa; such a rate of increase is expected to continue in the future (see Figure 1). Although in cities like Pucallpa there is a relatively large beef and poultry market, fish still forms an important part of the staple diet of lower income groups.

Figure: 1 Population growth in the city of Pucallpa, Peru.
(Source: Instituto Nacional de Estadística e Informática (INEI) 1994)



1.3 Fishing activity

There are two types of fisheries for human consumption in the Amazon: commercial and subsistence fisheries. FAO (1995) defines subsistence production as "fisheries which are essentially to yield food for the fishermen, their families and the immediate community". Commercial fisheries, on the other hand, "are capture fisheries where the stock is exploited for commercial gain".

Commercial fisheries operate around the largest cities of the region, such as Iquitos, Pucallpa and Yurimaguas (Box 1). The vessels used are relatively large, with the capacity to travel long distances, and are equipped with refrigerated chambers or ice boxes to preserve the fish. Commercial fisheries use equipment which is specifically designed for massive catches (Guerra *et al* 1990). Compared to subsistence fisheries, commercial fisheries also tend to concentrate on relatively few high-value species, owing to higher fishing costs and more selective markets (Bayley and Petrere, 1989).

Subsistence fisheries use small boats, usually canoes, which only allow them to travel short distances. Besides providing food for subsistence, this type of fishery also supplies fish to small, mainly rural markets. Subsistence fisheries are characterised by their wide dispersion (mostly in rural areas) and their use of simple fishing equipment. Based on several per capita consumption surveys, it is estimated that subsistence fisheries account for about 75% of the total fisheries production in the Peruvian Amazon (Bayley and Petrere, 1989).

During the last 30 years, commercial fisheries have grown considerably in importance. A series of developments revolutionised fishing technology and the transportation and storage of fish. The most significant of these was the use of synthetic material in nets, which increased fishing efficiency, and the introduction of diesel engines, which by the 1970s had totally replaced sails in the lower Amazon (McGrath *et al* 1993). This last development made it possible to travel faster and further than before, and was complemented by the introduction of insulating boxes in which fish could be stored for longer periods. Nowadays it is estimated that the maximum distance travelled by commercial boats in Manaus is 2,500 km; such long voyages are usually undertaken during the high-water season and may take several weeks (Bayley and Petrere, 1989).

Box 1: Profile of Commercial Fisheries in Ucayali, Peru

According to official statistics, the commercial fisheries in Ucayali comprise about 700 fishermen, while for the Peruvian Amazon as a whole, Hanek (1982; cited by Bayley and Petrere, 1989) estimated that there were 828 motorised boats and 694 canoes, supporting 2,600 full-time fishermen.

Of the estimated 700 commercial fishermen in the Ucayali region, 385 belong to three fishermen's associations. Through them, members have been able to obtain credit from the government to finance the purchase of new boats, engines and fishing equipment. Only 163 of the fisherman are registered with the port authority, and none with the Fisheries Ministry, making it difficult to control fishing effort.

One of the reasons that fishermen prefer to stay in the informal sector is to avoid the tax which has to be paid when registering a boat. This tax appears quite high relative to the scale of operations of inland fisheries and could be more suited to marine fisheries. In this respect, the law states that, for marine fisheries, boats with a capacity exceeding 30 tonnes must pay a certain tax in order to formalise their status with the Ministry of Fisheries. Exactly the same level of tax applies to inland fisheries, but in this case for boats with a capacity of five tonnes or more.

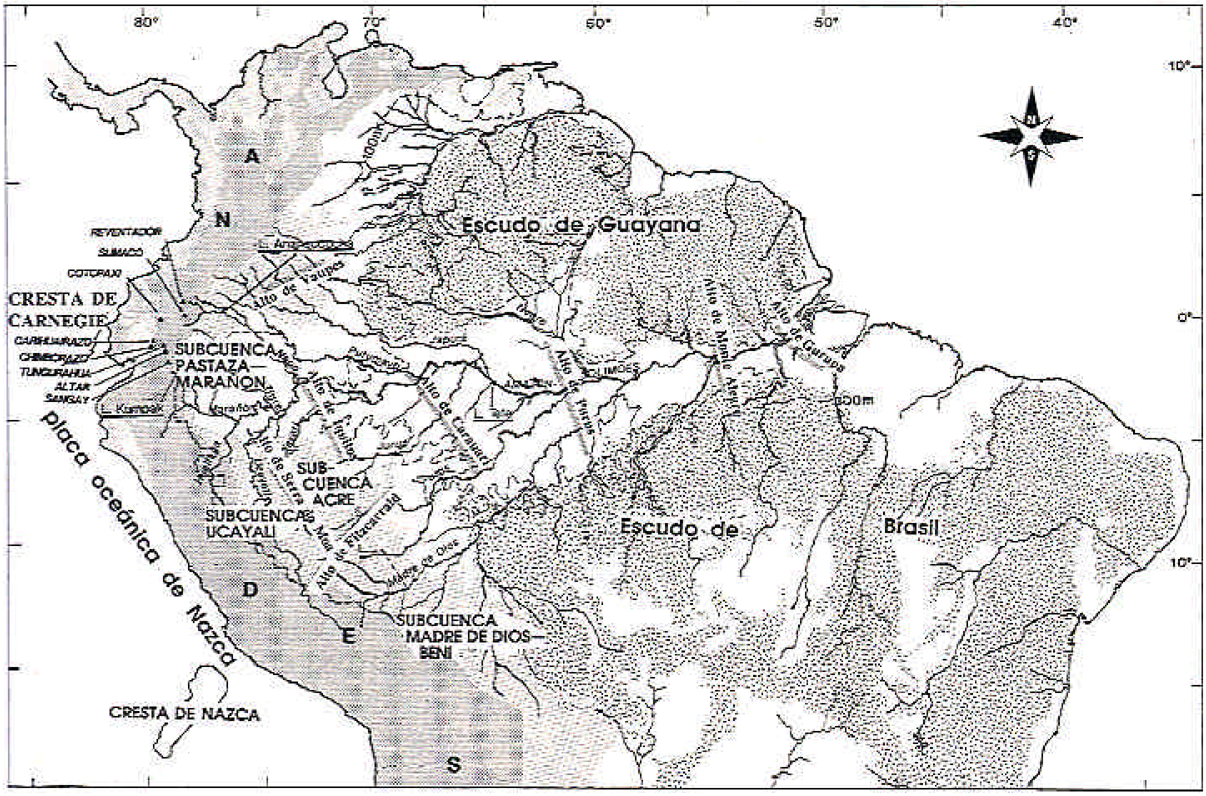
The fishing fleet in Ucayali is characterised by the use of obsolete fishing equipment, a situation which has made the activity unprofitable for many fishermen. However, there have been attempts by the government to upgrade the fishing equipment used in the region. For example, in 1991 the Government gave credit to one of the fishermen's associations for the purchase of new engines. The majority of this loan has not yet been repaid, which could be an indication either of the unprofitability of the activity or of the lack of coercive measures on the part of the Government to secure repayment of the loan.

Another factor that contributed to the development of commercial fisheries was the explosive growth of the major cities in the region during the 1970s and 1980s, which increased urban demand for fish, especially among the poorer sectors of the population. The increased production made possible by technological innovation was in turn spurred by the growth in human population and, particularly in Brazil, the growth of export markets and the spread of refrigeration plants. The fact that ice (for storage) and markets were concentrated in major urban areas made these the natural base of operations for commercial fishermen. Thus, a new type of urban-based professional itinerant fishermen was created (McGrath *et al* 1993).

1.4 Hydrology and biological factors

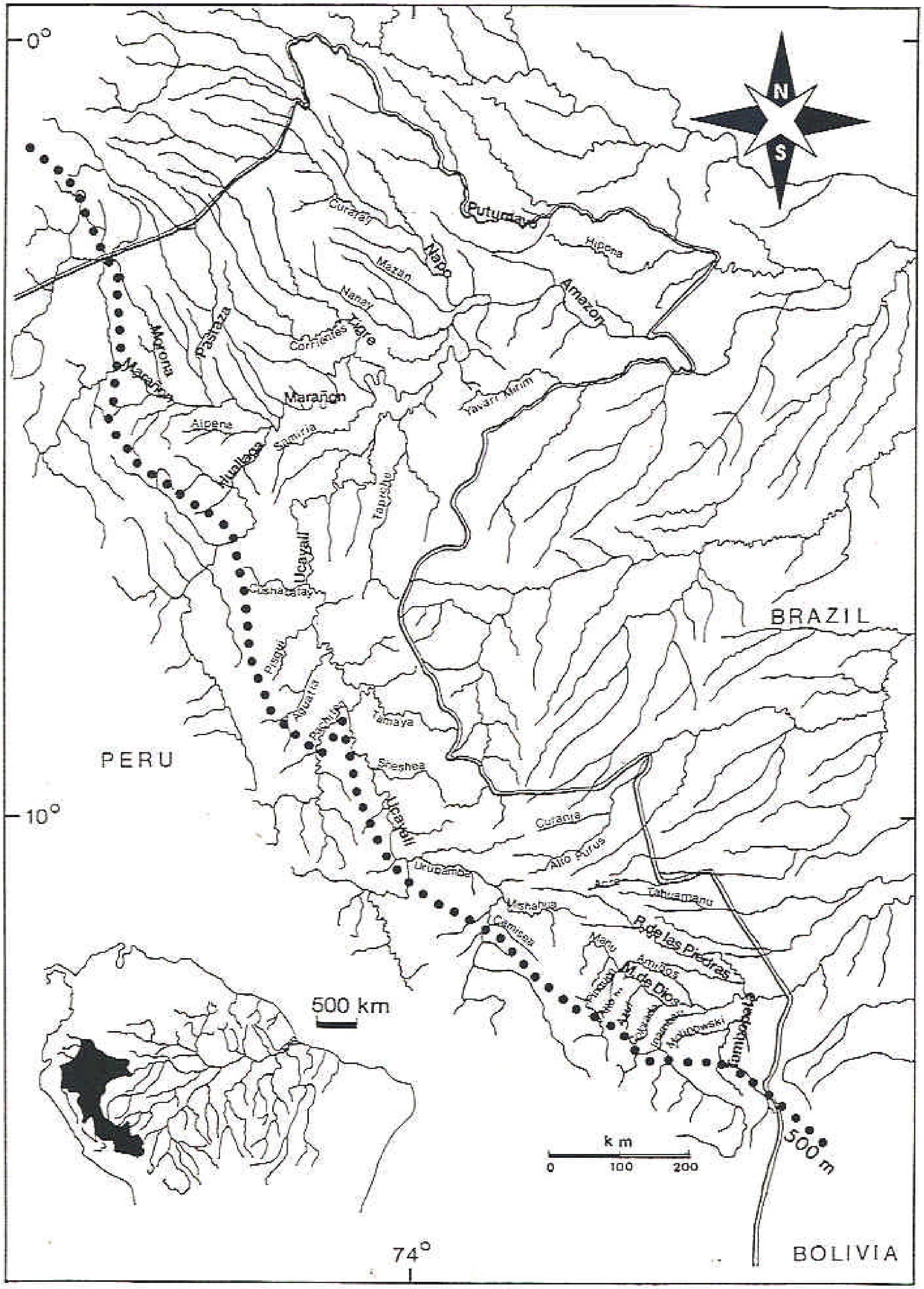
The Amazon basin is the largest watershed in the world, covering an area of more than 5,800,000 km^2 and is drained by many rivers and lakes of different sizes (Figure 2a). The active inundation area is around 41,600 km^2 (Bayley 1981; cited by TCA, 1994). The volume of water discharged by the Amazon system is four times that of the Congo, and eight times that of the Mississippi (Lowe-McConnell 1975).

Figure 2a: The Amazon Basin *(Source: Kalliola et al 1993)*



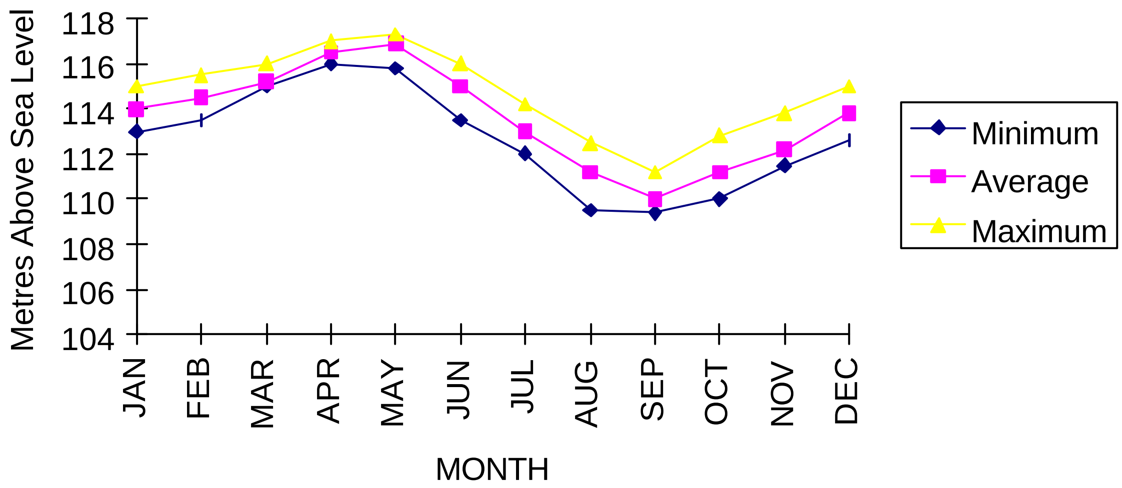
The main channel, the Amazon river, has its origin in the Andes. On the Peruvian side, the Amazon has two main effluents, the Marañón river from the West, and the Apurimac river from the South. The latter turns into the Ene, Tambo and Ucayali rivers as it progresses downstream until it joins the Marañón and forms the Upper Amazon (Figure 2b). Many other tributary rivers join the main stream of the Amazon, including innumerable channels, creeks and streams, sidearms and mouthlakes, lagoons in the floodplain, flooded forests, water courses, swampy valleys and periodically flooded grasslands (Lowe-McConnel 1975).

Figure 2b: The river system in the Peruvian Amazon *(Source: Kalliola et al 1993)*



Two seasons can be distinguished in the hydrological cycle of the Amazon river system: high water season, which in Peru lasts from November to May; and low water season, from June to October (Figure 3). These fluctuations in water level are a direct consequence of the precipitation pattern in the region. The magnitude of these fluctuations decreases as the river reaches its outlet in the Atlantic Ocean. In Pucallpa, the average fluctuation for the period 1981-1985 was 9.3m, while downstream, in Iquitos and Manaus, the range of fluctuation was 8.0m and 7.8m respectively. In addition, the point in time at which the maximum and minimum water levels occur is delayed in the downstream direction. The changing water level is significant for fisheries, as will be seen in the following sections.

Figure 3: Amazon Basin's hydrological cycle (*Source: Montreuil et al 1991)*



The water bodies in the Amazon basin have been classified into three types: white water, clear water and black water. White waters, which originate in the Andes, are usually muddy and turbid, which gives them their characteristic brown colour. They are highly productive and provide the best conditions for aquatic life. Clear waters, on the other hand, are of a yellowish colour and are of medium productivity, while black waters are the least productive and originate from the humid forest (Lowe-McConnel 1975; TCA 1994). The Ucayali in Peru is a white water river and has one of the highest fishery potentials in the Amazon (Guerra *et al* 1990).

The productivity of the fisheries strongly depends on the hydrology of the basin. During the high water season, extensive areas of forest surrounding the rivers and lakes are flooded. Many fish species rely on these flooded forests for feeding, spawning and refuge from predators, especially during the most vulnerable stages of their life cycles. Goulding (1985; cited by Chapman, 1984) estimates that about 75% of the commercialised fish species in Manaus originate from such flooded forests.

If these extensive floodings did not occur or if there were no forests near the river banks, the system would not be able to support such a large fish population as it now does (Goulding 1980; cited by Chapman, 1989). Therefore, extensive deforestation in flood-prone areas may affect fisheries significantly, as not only breeding and spawning grounds are lost, but food sources as well.

Migration, which plays an important part in the reproductive behaviour of many fish species in the Amazon, is also strongly dependent upon the hydrological cycle of the basin. As water levels change, fish respond differently in terms of their migrating behaviour, and accordingly, can be classified into three categories: (1) fish that migrate through the main river channel; (2) fish that do not migrate; and (3) fish that migrate between the flooded area and the main channel (Welcomme 1990; cited by TCA, 1994). Fish migration in part reflects the availability of different food sources and the search for protected areas within the flooded forest which the higher water levels make possible.

1.5 Composition of catch

The Amazon basin has one of the most diverse aquatic fauna in the world. Estimates range from 2,500 to 3,000 species (Smith 1979 and Goulding 1980; cited by Guerra *et al* 1990). Many species have yet to be named, while in some cases different species are grouped under the same denomination, giving a false impression of the real number of distinct species.

For Peru estimates range between 723 and 736 species of inland fish, of which 85% are found in the Peruvian area of the Amazon region (Fowler 1945, and Ortega and Vari 1986; cited by Guerra, 1990). However, it is expected that more species will be added to this list.

In Peru, commercial fisheries exploit about 35 species. In a strict taxonomical sense, the figure may be even higher, since in many cases more than one biological species may be grouped under a single common name. However, two species alone, *Prochidolus nigricans* and *Potamorhina altamazonica* accounted for over 40% of total landings registered for the city of Pucallpa between the years 1980 and 1991, while 17 species accounted for 90% of the fish landings during the same period (Table 1). Most of these are bottom-feeding species characterised by fast growth rates and short life spans. As fishing activity becomes more intensive, these fast-growing species tend to replace the larger piscivorous species with slower growth rates and longer life spans (Guerra 1990; Montreuil *et al* 1989). However, due to the lack of historical records, it is not possible to prove whether the composition of species has changed. It may be the case that the relative importance of each species in the capture fisheries has been stable over time and that the composition of landings simply reflects the preferences of the Amazonian population for medium-sized fish with scales (bottom-feeders) rather than larger species which usually have thick skin[2] (TCA 1994). Bayley and Petrere (1989) indicate that a decline in the yields of large species is a predictable result as effort increases, and this may already be occurring near certain cities, where the intensity of fishing has increased over the years.

It has been reported in the past that mono-specific fishing of highly valued species such as *Colossoma macropomum* and *Arapaima gigas* has resulted in a marked diminution of their yields. This was the case between the years 1971 and 1976, when the State imposed a ban on the fishing of *Arapaima gigas* ("paiche") after a dramatic decline in numbers. This in turn was a consequence of previous policies which had promoted its exploitation and where, ironically, the State was primarily responsible through a government-owned fishing company (TCA 1994).

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[2] One reason for this preference is the widespread belief that eating fish with thick skin produces skin diseases!

Table 1: Species composition of fish landings near the city of Pucallpa, Peru (based on total landings from 1980 to 1991) *(Source: TCA 1994)*

Scientific name	Common name (Peru)	% of landings
Prochidolus nigricans	Boquichico	32.2
Potamorhina altamazonica	Yahuarachi	9.2
Brachyplatistoma flavicans	Dorado	9.1
Mylossoma duriventris	Palometa	4.7
Pseudoplatystoma fasciatus	Doncella	4.6
Hypophtalamus edentaus	Maparate	3.8
Arapaima gigas	Paiche	3.5
Pimelodus spp.	Bagre	2.8
Colossoma macropomum	Gamitana	2.8
Plagioscion squamosissimus	Corvina	2.6
Curimata rutiloides	Ractacara	2.5
Triportheus spp.	Sardina	2.1
Brachyplatystoma filamentosum	Salton	2.1
Pterygoplichthys multiradiatus	Carachama	2.0
Anodus elongatus	Yulilla	1.8
Schizodon fasciatus	Lisa	1.7
Paulicea lutkeni	Cunchi mama	1.6
Others		10.9
Total		100.0

1.6 Yields and factors that affect them

Yields in the Amazonian fisheries in Peru have shown a modest upward tendency throughout the period 1980-1992, as Figures 4 and 5 show. In Pucallpa, however, there was a sharp decrease in captures between the years 1988 and 1990 (Figure 5), but it is uncertain whether this was due to environmental factors or to changes taking place in the economy at that time. These included the removal of a subsidy on the price of fuel, which greatly increased fishing costs.

Figure 4: Total fish landings near the city of Iquitos *(Source: TCA 1994)*

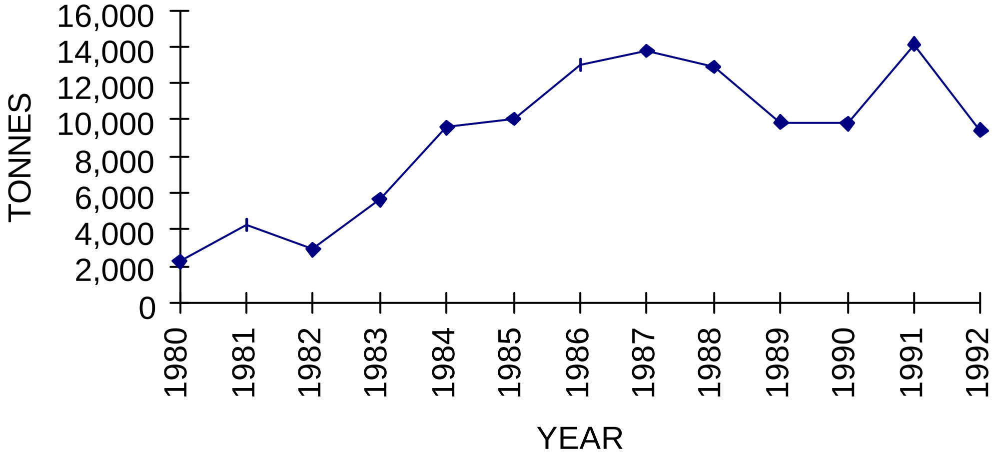
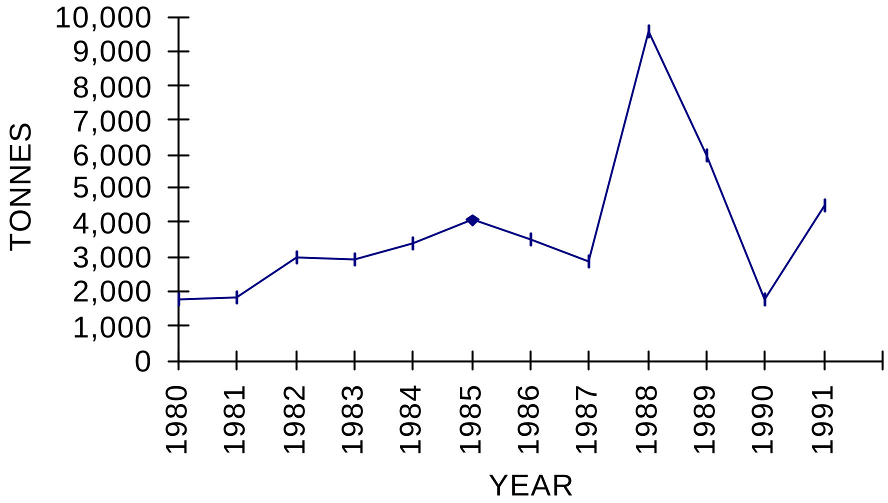
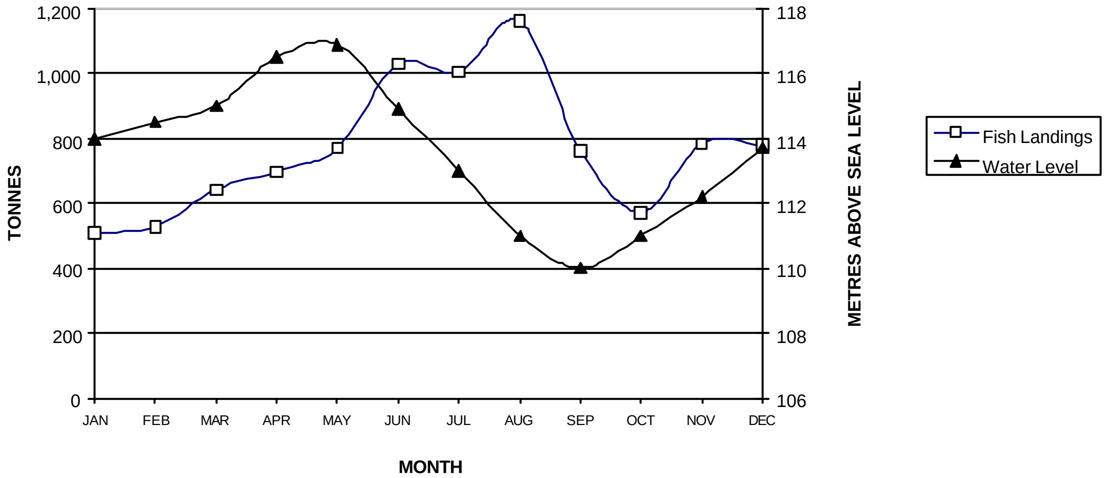


Figure 5: Total fish landings near the city of Pucallpa (*Source: TCA 1994*)



Fish yield in the Amazon varies according to water level (Figure 6). The highest yields are observed during the season of low water level, when fish tend to concentrate in smaller bodies of water, making them easier to catch. During the high water season, fish tend to disperse into the flooded forests, which are areas that fishermen avoid because of their inaccessibility and the propensity for nets to become entangled and broken by submerged vegetation (Chapman 1989; McGrath *et al* 1993). Thus, the hydrological period affects fishing activity in two important ways: on the one hand, the flooding that occurs during the rainy season allows fish to expand their area of resource extraction, which results in a high population, while on the other hand, flooding also allows fish to be relatively undisturbed during their reproduction, remaining protected from predators, humans included. The forest and flood thus play an important part in making possible a natural closed-season, which prevents year-round exploitation and gives time for fish populations to recover (Chapman 1989).

Figure 6: Fish landings near Iquitos 1993 compared to average water level.
(Source TCA 1994)

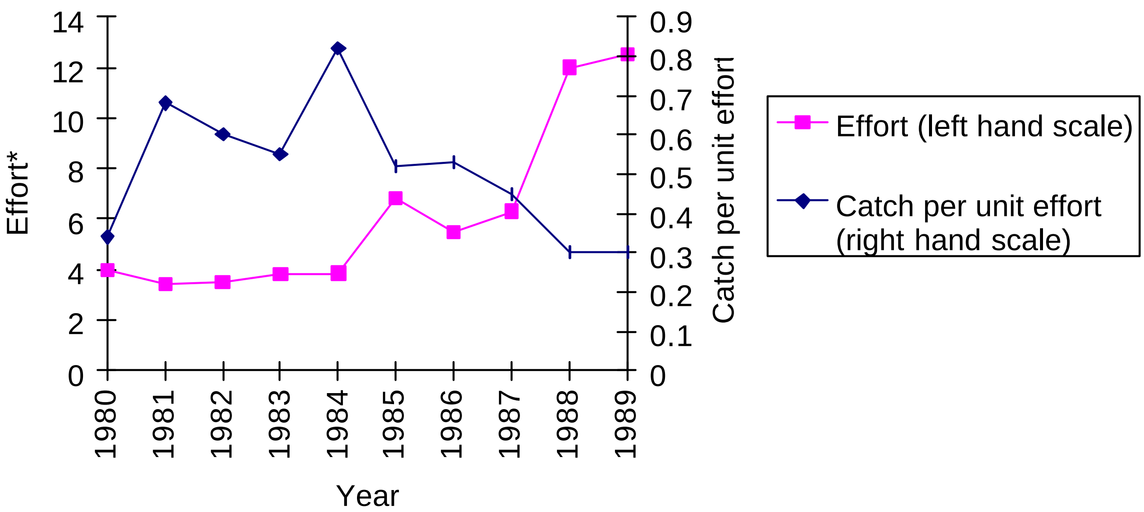


The size of the area subject to flooding is also important in determining fish yield. Welcomme (1976; cited by Bayley, 1981b) found that catch levels in 'extensive' floodplains covering over 1% of the total drainage area were 3.3 times greater than yields obtained in rivers with 'normal' floodplain development. The Amazon river, with floodplains covering 2.6% of the basin area, falls within the extensive floodplain category. Wellcome also found that 98% of the variance of catches in rivers with extensive floodplains could be explained by the basin area, while 88% of the variance was explained by the main channel length of the river.

Changes in fishing effort in relation to yield have been used to assess the status of the fisheries in the Amazon. Fishing effort has been measured either by the total number of fishing trips (Montreuil *et al* 1989) or the storage capacity of the vessels multiplied by the number of trips (Guerra *et al* 1990). The latter is said to be more accurate, given the variable size of the vessels. The evolution of catch per unit effort[3] (cpue) during the 1980's is shown in Figure 7, where the total effort is also shown, using Guerra *et al's* measure of effort. From 1987 to 1989 there was a considerable increase in the amount of effort and a drop in cpue (Guerra *et al* 1990). However, environmental factors rather than increases in fishing effort may have been more responsible for the apparent decline in productivity.

[3] Catch per unit effort (cpue) measures the efficiency of effort for any level of harvest. As fishing intensity increases the biomass of the stock changes, which is reflected in the amount that is harvested at each level of effort (see Panayotou 1982).

Figure 7: Effort and catch per unit effort of commercial fisheries
(Source: TCA 1994)



*Note: Effort is defined as storage capacity (in thousands of tonnes) multiplied by number of trips, following Guerra *et al* 1990.

The models commonly used to evaluate the state of tropical fisheries assume that fish mortality, measured by fishing effort, is the only cause of biomass variations, implicitly assuming a constant environment. But this assumption is not valid for tropical floodplain environments according to Merona (1990), who has shown that fishing effort does not explain cpue variations between years. The author points out that there are natural variations in populations due to environmental factors. As discussed above, the flood event could be the most important environmental factor affecting production and thus explaining inter-annual variations in yield.

Traditional models therefore appear unsuitable for adequately explaining and predicting fish populations in the Amazon, since they tend to overlook the environmental dimension of the fishery. In addition, the complexity of the system, with a variety of life histories, interactions and vulnerabilities among many different species, is beyond the predictive capabilities of existing models. The use of different types of gear further complicates the picture (Bayley and Petrere 1989).

1.7 Is there overfishing?

A widely held view is that the Amazonian fisheries are close to being overexploited. One empirical study that supports this view is by Montreuil *et al*. (1989) who, using data from five years (1980-1985), estimate a maximum sustainable yield of 5,000 tonnes/year for the commercial fisheries supplying the city of Iquitos. The yield in 1988 was close to this figure, which led the authors to conclude that fishing effort should not increase if overfishing was to be avoided.

On the other hand, Bayley and Petrere (1989) consider that fisheries in the Amazon remain largely under-exploited. Their conclusion stems from comparative studies with tropical floodplains in Africa and from models which relate fish yield to the area of floodplains. In a previous report, Bayley (1988) estimated maximum sustainable yields of 110-160 kg/ha for tropical floodplains, using methods that account for both effort and the total area of floodplain. With current technology a yield in this range would correspond to about 13 full and part-time fishermen per km^2 of flooded area. In Peru the fishing intensity is considerably lower than this figure, as it is estimated that there are only about two fishermen per km^2 of floodplain (Bayley and Petrere, 1989).

In another study, Bayley *et al* (1992) use the total fish yield for 1981 to project future fish yields, based on the assumption of increased demand for fish resulting from population growth and the current per capita consumption of fish. By comparing the predicted yield for the year 2001 with actual yields obtained in other tropical fisheries that had a much higher density of fishermen than the Amazon, they found that catches in the Amazon per unit area were still much less than those extracted from river systems with high fishing intensities. This explains why in the Amazon basin the market is still relatively selective, which is no longer possible in African fisheries with much higher effort levels. This led the authors to conclude that fisheries in the Peruvian Amazon were, on the whole, under-exploited and capable of providing animal protein for many years to come.

However, Merona (1990) has argued that there may be some areas which are already overexploited. In fisheries that target larger species with slower growth rates, such as *Arapaimas gigas* (Paiche) and *Colossoma macropomum* (Gamitana), yields have declined in some areas despite increased effort. It should be noted that increases in fishing effort may not be the main cause of changes in fish populations. In tropical freshwater fisheries, year to year fluctuations are the result of recruitment and responses to changing external conditions (FAO 1995). Even when it has been observed that stocks are declining in a permanent fashion in certain parts of the world, in almost every case this has been shown to be mainly due to changes in the hydrological system, resulting from human activities other than fishing. Such activities include the introduction of exotic species, engineering projects, alteration of water quality due to pollution or the effects of agricultural activity in the watershed (see Box 2). In very few cases has it been possible to prove that fishing activities brought any permanent changes of a significant nature (FAO, 1995). In this respect, Bayley (1995) indicates that there is no evidence that higher fishing intensities have caused the biological extinction of fish species in any system which has not been altered by human activity[4].

It is not well understood how changes in the environment may be affecting fisheries in the Peruvian Amazon. There are on-going changes in the watershed which may already have had an effect on the fisheries of the region (Box 2). However, at present there seems to be no conclusive evidence that such environmental changes are affecting the fisheries in a significant way, although it could well be the case that some effects may already be taking place at a local level. But if the aforementioned environmental changes continue to occur, then it would only be a matter of time before their effect on fisheries became widespread.

[4] Although from the point of view of the market there may be an economical extinction which occurs when a species has such a low population that the amount of effort required to catch it makes the operation unprofitable.

To conclude, while there is still fear among fisheries managers in the region that the intensification of commercial fisheries is leading to the depletion of the Amazonian fish population, the problem seems not to be the status of the fishery as a whole, but the heavy reliance on a few species and the pressure around major urban centres (McGrath *et al* 1993).

Box 2. Possible effects of environmental degradation on fisheries in the Peruvian Amazon.

For the Peruvian sector of the Amazon basin little is known about how patterns of land-use may have affected fisheries. There has been extensive deforestation in the uplands (Selva Alta) mostly as a result of clearing for planting illegal crops. Deforestation and erosion in this region may already be causing alterations in the hydrology of the basin, although there is no evidence to confirm this (Bayley, personal communication). Agriculture in the lowlands still operates mainly on a low input basis, so there may not be a problem of chemicals discharged to the river, although deforestation for agriculture in the fertile floodplains may be affecting the availability of natural refuges and breeding grounds. This effect is likely to intensify as more land is converted for agriculture.

The exploitation of the vast oil reserves in the Amazon is another potential source of environmental damage. For many years large quantities of connate water (a by-product of oil extraction) have been discharged into the rivers of the northern Peruvian Amazon, although the extent of the damage to local fisheries caused by this is as yet unknown. On the other hand, accidental spillage from the pipelines that transport oil to the processing centres on the coast could have devastating consequences for the fisheries. While difficult to predict, due to the complexity of the ecosystem, the potential environmental impacts of oil spills and of connate water discharge should be the subject of further research, considering that oil extraction in the Amazon is likely to intensify in the near future.

1.8 Conflicts between subsistence and commercial fishing

When commercial vessels begin to fish in areas that have previously been used only by subsistence fishermen, such areas become subject to higher fishing intensities due to the larger scale of operations and more advanced technology brought by commercial fisheries. Higher fishing intensities may lead to changes in species composition and to lower fish densities. Local fishermen operating at the subsistence level are thus forced either to spend more time fishing or to look for less desirable species. Since most subsistence fishermen are also farmers, spending additional time on fishing may have a high opportunity cost. Increasing fishing efficiency through better technology may also be difficult for subsistence fishermen, who often lack access to formal credit with which to finance such investment. In addition, commercial fishermen have the advantage of being able to move to other areas if the harvest falls too low, while subsistence fishermen may be unable to do this[5] (Bayley and Petrere 1989).

[5] As Panayotou (1982) indicates, under normal conditions the displacement of less efficient producers by more efficient producers would be a desirable process. However, Panayotou gives the following reasons why this outcome may not be efficient or equitable: market distortions and imperfections; sociably unacceptable

In Brazil, conflicts between subsistence and commercial fishermen have mostly occurred in lakes rather than rivers (McGrath *et al* 1993). In enclosed bodies of water, subsistence fishermen are able to see a direct relationship between dwindling fish stocks and the increase in commercial exploitation, which may be less evident in the case of rivers. The problem is also seasonal, since commercial exploitation of lake fisheries is most intense during the low water season, when fish populations are trapped in the smaller volume of water, and risk being decimated if fishing intensity is high.

In Ucayali, the Fisheries Regional Authority has reported conflicts between commercial fishermen and the 41 native communities in the region whose territories enclose the lakes that are also used by commercial fishermen. The communities have argued that these lakes form part of the communal territory, and that they therefore have exclusive rights over them. The Ministry of Agriculture has recently begun a process of allocating property titles to native communities. However, according to the Law of Native Communities, territories defined as communal do not normally include lakes within their boundaries[6].

1.9 Conclusions

The Amazon fisheries are influenced by a complex set of environmental and socio-economic factors. Experience in other parts of the world suggests that environmental factors may be more important than total effort in determining fluctuations in yields of freshwater fisheries, although it is not known if this is also the case for the Amazon. Increased fishing intensities, on the other hand, are more likely to be responsible for changes in the composition of catch.

The hydrological cycle of high and low waters is a major environmental factor in determining the presence of large fish populations. Annual flood events provide large areas for breeding and feeding, creating a natural process of replenishment where the migration of fish from the main channels to the flooded forests limits fishing intensity during the high water season. The total area of the basin that is flooded is thus a very important factor in determining the yield, and models have been developed to account for this.

Some studies suggest that Amazonian fisheries are largely under-exploited. If correct, they imply that these fisheries will be able to support the rapid growth in urban population that is expected in the Amazon region. However, an increase in effort to meet the growth in demand will inevitably change the species composition of the catch. Managing a multispecies fishery in order to maintain a desired species composition would be an extremely complex task, given the largely unknown interactions between species and their response to increased fishing intensity. Furthermore, each

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distribution of income; lack of alternative employment opportunities for displaced fishermen; and the need to slow migration to cities. Most of these circumstances apply to the Amazon fisheries.

6 Peru's General Law of Waters states that the waters, without exception, are common property, with no private property of the waters nor acquired rights over them. It is up to the State to manage them through planning strategies which respond to policies of sustainability, in conjunction with the preservation of the Amazonian ecosystem (TCA 1994). Unfortunately, the State is often unable to fulfill its legal obligations.

species has a different yield and effort curve, which means that their maximum sustainable yields will be reached at different fishing intensities (see Annex 2).

Conflicts between commercial and subsistence fishermen stem from changes in the composition of catch and fish population densities, brought about by the higher fishing intensities at which commercial vessels operate. Such changes disadvantage subsistence fishermen, who find themselves investing more time in fishing. Unlike full-time commercial fishermen, they often have to "juggle" fishing with other occupations such as farming. This situation is further aggravated by differences in technology between the two fisheries. In order to remedy their unfavourable situation, many communities of subsistence fishermen have claimed exclusive fishing rights over lakes, thus denying commercial fishermen access to these fishing grounds.

The gradual appearance of lake reserves throughout the Amazon basin raises the question of whether the establishment of exclusive rights over water bodies, and the use of community-based management to regulate the use of these resources, are effective means of achieving equity and sustainability in the fisheries of the region. These aspects are discussed in the following section.

2 Management systems: definitions and case studies

2.1 Introduction

Experience with different fisheries management systems around the world offers valuable lessons for the design of policies for the Amazon. Many of these systems have been developed in response to problems that the Amazonian fisheries are only now beginning to face, such as a high number of resource users and the resulting conflicts between them. Hence, it is worthwhile to consider the solutions that different societies have found for such problems.

This section begins with a classification and description of different management systems that are currently applied to fisheries around the world. This classification is then followed by some specific examples of community-based management and co-operative management systems applied in different areas.

2.2 Approaches to Fisheries Management

Approaches to fisheries management can be classified according to the degree of control that the state or the resource users have on their design and implementation. State management and community-based management are two extreme approaches, where the resource is either managed completely by the government or management is devolved totally to the fishermen. Situated in the middle of the two extremes, co-management involves the participation of both government and fishermen in the regulation of the resource (Sarch 1994). Each of the three basic approaches will be briefly discussed in the following pages.

2.2.1 State management

Objectives

The main objective of state management is to optimise yields through efficient use of the factors of production. State management also tries to secure an equitable distribution of the resource among its users. The philosophy behind state management is that fish resources should be conserved for the benefit of the society as a whole (Sarch 1994).

Instruments

There are several instruments through which the state may try to regulate fishing effort in order to reach its management objectives. Instruments may include the imposition of catch limits or quotas (total allowable catch), restrictions on the use of certain types of gear (either to reduce total catch or the catch of certain species), the setting of minimum size limits (to avoid impacts on recruitment and growth), imposition of closed seasons (to protect the stock during vital periods of their life cycle), restricting fishing in certain areas (usually to protect juvenile or spawning fish), taxing resources, and granting licences in order to limit entry and effort in a fishery (for more details on these instruments see, for example, Bland 1991).

Applicability

There are several reasons why state management can be seen as necessary (Jentoft 1988). First, it is the state's function to prevent common property resource depletion and rent dissipation by imposing limits on effort. Second, the state may assume the responsibility of securing equal fishing opportunities and incomes among fishermen. In such cases government intervention to secure the survival of small-scale fisheries would be seen as desirable. Third, the state is usually the only entity with the authority to implement management regulations and with the means to enforce regulations.

On the negative side, with state management it may be difficult to reconcile efficiency and equity objectives, since these may be contradictory. Moreover, state regulations often lack "legitimacy" from the point of view of the fishermen, if they have not taken part in their design and implementation (Jentoft 1988). Finally, it is very unlikely that in developing countries the state will have sufficient resources to enforce management regulations effectively. The information requirements needed to apply certain regulations (ie species size restrictions) are often costly; in some cases prohibitive, even for developed economies.

2.2.2 Co-management

Objectives

The objective of co-management is to achieve more efficient and equitable management, by reducing conflicts among fishermen. The concept behind co-management is that fishermen's objectives should be taken into account, and that they should participate fully in planning and management, so that regulations reflect actual experience. Within the objectives of management, allocation and distributional issues are often given special significance (Sarch 1994).

Instruments

In co-management users are allowed to regulate themselves within broad limits established by the government through the use of targeted incentives. Co-management involves the active participation of fishermen in the design, implementation and enforcement of fisheries regulations. Government agencies and fishermen, through their cooperative organisations, share responsibility for management of the resource (Jentoft 1989). Co-management may commence when government formally recognises the traditional rules used by fishermen themselves, or when regulatory power is transferred from the government to the fishermen's organisations.

Applicability

Co-management may be an appropriate response to the question of "legitimacy", which determines to what extent fishermen will accept regulation. Jentoft (1989) lists the factors on which the legitimacy of a regulatory scheme will depend:

1) Satisfaction: the more that regulations coincide with the way fishermen themselves define their problems, the greater their legitimacy and the likelihood of compliance;

2) Distributional effects: the more equitable the restrictions imposed, the more legitimate they will be;

3) Formulation: the more that fishermen are involved in the decision-making process, the more legitimate the regulatory process will be perceived to be;

4) Implementation: the more that fishermen are directly involved in installing and enforcing regulations, the more the regulations will be accepted as legitimate.

Co-management can greatly reduce enforcement and regulating costs to governments, but there is always the risk that the objectives of resource users may conflict with the objectives of those of the state (Sarch 1994).

2.2.3 Community-based management and territorial use rights

Objectives

Sometimes called traditional management, this approach is developed within the community to regulate the use of common property resources. Community-based management gives priority to achieving the economic and social well-being of fishing communities and to maintaining the fishery (Sarch 1994).

Instruments

Although traditional management strategies are usually seen as a set of rules established by the community to regulate the use of a common resource, communities may have certain socio-cultural characteristics which inadvertently act as mechanisms to prevent over-exploitation. Such characteristics are termed ‘passive regulations’. According to McGoodwin (1983), the single most important passive regulation in unmanaged fisheries is the simple inability of a community to over-harvest the resource, due to a low human population pressure or the use of low intensity fishing technology. The existence of alternative occupations to fishing is also a very important factor in preventing overfishing, since it reduces fishing pressure during certain times of the year. This is particularly the case with small-scale fishermen, who usually alternate between fishing and other activities such as agriculture. Other passive regulators may include low demand for fish, negative attitudes towards fishing, and fishing areas which are closed due to ritual prohibitions (Bland 1991; McGoodwin 1983).

Active or intentional regulations in traditional fisheries management may include restrictions on the type of gear, or the use of closed seasons. Based on a review of management systems among 32 different societies, Wilson *et al* (1994) found that all of the rules practised in traditional management sought to regulate 'how' fishing was carried out, rather than limiting the quantity of each species caught. Many of the rules listed by these authors suggest that regulations found in community-based management may not have been devised with the primary intention of conserving species, but rather to ensure equitable access to the resource.

One of the most common strategies used in community-based management has been the regulation of access to fishing areas (McCay 1978; cited by McGoodwin 1983). Only by limiting access to the resource can the owners (be they individuals or communities) determine the objectives to be sought from the resource and the mechanisms used to achieve these objectives (Christy 1982). In the case of fisheries, rights of access to the resource are limited by the establishment of territorial use rights, as discussed below.

Limiting access to fishing resources in traditional management regimes has often been achieved through what are called territorial use rights in fisheries (TURFs). TURFs have evolved where a group of people have found that the benefits of excluding outsiders and regulating the allocation of resources within the group is worth more than the costs of imposing such limited access (Bland 1991). TURFs can belong to a private individual, private enterprise, a cooperative, association or community, a town or province, a government or even a multinational agency (Christy 1982).

Applicability

One of the main advantages of community-based management is that it takes into account the physical and socio-economic variability within communities. In contrast, state management tends to impose uniform regulations on different communities, even if their physical environment and capability are completely different (Pomeroy 1991).

With private or communal ownership, owners are interested in maintaining the productivity of the resource now and in the future. The creation of TURFs in fisheries has the objective of delegating management to the owners, who have an interest in controlling fishing effort, not only in order to maximise their benefits, but also to ensure sustainability (Panayotou 1982).

Several factors determine the effectiveness of TURFs for managing fish resources (Christy 1982). For example, if the fish species in question is sedentary or can be raised in closed pens or cages, then establishing territorial user rights will be easy. The degree to which boundaries can be defined and defended will also be important in determining the success of TURFs. In this case the natural attributes of the adjacent land can be useful for setting boundaries. Fishing techniques and the type of gear used also determine the potential success of TURFs. Gear that is fixed to one place is best suited for establishing territorial rights. On the other hand, gear or fishing techniques which need to cover large areas of water are not well suited to the creation of TURFs. Dahl (1988) also mentions group/territorial identification and resource scarcity as factors that determine the effectiveness of TURFs. The cohesion of a group by means of a common identification with a particular territory is bound to reduce internal conflicts. On the other hand, when a resource is scarce, more care will be taken in how rights are defined and how much effort will be devoted to defending the territory.

A possible problem with territorial use rights is that control over fisheries can be difficult to define, because most fish resources are highly mobile (Christy 1982). As Berkes (1986, p.70) notes, "divisibility poses both a theoretical and practical problem". Being highly mobile, the fish stock becomes effectively indivisible, which makes it difficult to allocate among several private owners.

2.3 Case studies

The following case studies provide examples of self-regulation with differing degrees of state involvement. With one exception, all of the cases apply to marine fisheries since this environment has received more attention in the literature. However, many of the experiences state fundamental principles of common property management, which are applicable to both inland and marine fisheries. The examples range from co-management to community-based management, as state intervention in some is clearly apparent, while in others it is almost totally absent.

2.3.1 Systems with state participation

Norway

The Lofoten fishery in Norway is an example of the successful application of co-management. The basic elements of the scheme were introduced in the late 1890s, in response to conflicts related to the use of different kinds of gear. Special legislation enacted by the Norwegian Government for the Lofoten fishery delegated responsibility for the regulation of the fishery to the fishermen themselves. Special district committees of fishermen representing different gear groups were set up to establish rules for the fishery. These rules included restrictions on allowable fishing times, allowable gears for different fishing grounds, and area reserved for different types of gear. A public enforcement agency was established to ensure that rules instituted by the fishermen's committees were obeyed. The system prevails today in the Lofoten fishery and, although some minor changes have taken place, the basic principles of co-management remain intact (Jentoft 1989).

Sri Lanka

Managing fisheries by restricting access to lagoons, estuaries or certain areas of the sea has been common practice for centuries in Sri Lanka. Traditional fisheries management, in the form of unwritten by-laws promulgated by fishing communities themselves, seems to have worked well. However, recent increases in fishing pressure have created a need for government intervention (Atapattu 1987).

Exclusive rights were originally exercised by individuals or families that owned beach seines. These rights gave them control over access to the coastal waters where their gear was in operation. Such access rights could be inherited, in which case each child would inherit a fraction of the right to fish off a particular beach. With population growth, the rights of access became so diffuse that the possession of a single net would be sufficient grounds for claiming a right of access. Thus, in spite of its success in limiting outsiders' access, the system was unable to limit the effort employed by members of an expanding community. To prevent overfishing, the Government limited the number of nets to those existing in the 1930s (no information is given on when these new regulations were imposed). New entrants were allowed to participate in the fishery by purchasing shares in the nets. Over time these shares were concentrated in the hands of a small elite with access to capital, transforming an activity that mainly operated at a subsistence level into a profitable enterprise. The impact of this measure on the distribution of wealth is unknown.

Property rights are also exercised by fishing villages. In Sri Lanka, villages tend to be closed communities which do not allow access to their fishing grounds to outsiders. Even the hiring of labour from outside the village is restricted. This appears to be one of the factors that explain why the revenue generated by Sri Lankan coastal fishermen is much higher than the opportunity cost of their labour, a situation not normally encountered in Southeast Asian fisheries. However, the barrier to entry which has worked so well for centuries has been jeopardised recently, since outsiders have begun to be employed as crewmen due to local labour shortages. These outsiders are soon incorporated into the community, breaking the closed-community tradition. As a result, an eventual increase in pressure on the fishery may arise (Panayotou 1982).

Japan

Japanese fishery rights are based on a traditional management system in existence since feudal times, when rights of access were controlled by feudal lords. Fishermen had to pay taxes to the lords or share part of their profits with them for the right to fish in their territory. After the Second World War, the ancient feudal territorial rights were transferred to village associations (Yamamoto 1983). In this way the community was given exclusive property rights over coastal fishing grounds. All households seeking the right to fish were obliged to join a fisheries cooperative association (FCA), through which they automatically acquired a 'title' to the coastal fishing areas and the right to fish in communal waters. Fisheries management thus became a combination of both communal and private fishing rights, with the FCAs wholly responsible for the administration of the fishery (Ruddle 1989). The role of the FCA was not to engage in fishing directly, but rather to regulate how fishing was carried out (Panayotou 1982).

Japan's fisheries law makes no distinction between land tenure and water tenure. The right of every household to use the coastal fishery is recognised by law, provided that they first join an FCA. Common fishing rights are granted only to the FCAs, on the condition that fishery resources are used in a co-ordinated manner by all members of the co-operative. Each FCA establishes its own regulations for managing various types of fishery and is responsible for ensuring the sustained development of the marine territory over which the community has tenure (Ruddle 1989).

By law, the coastal strips are reserved for small-scale operations, where the territorial rights of access are distributed among FCAs. A second strip further offshore is reserved for medium-scale trawlers. Thus, conflicts between small and large scale operations are prevented and the survival of labour-intensive small-scale fisheries is guaranteed.

The fishing rights system in Japan has been preserved up to the present and seems to be successful. It provides an interesting example of how traditional community institutions can be adapted to modern conditions, resulting in successful management regimes that have been able to withstand and adapt to rapid technological change and population growth (Ruddle 1989).

2.3.2 Systems in which the state does not participate

Nigeria

Many inland fisheries in Africa have been managed to some degree under traditional systems which evolved within local communities and were based on indigenous knowledge. Neiland *et al* (1994) describe some aspects of these traditional management systems in the case of Nigeria's inland fisheries.

Open access predominates in Lake Chad and the larger rivers, while in the smaller rivers, lakes, dry-season pools and floodplains, restricted-access common property fisheries exist. Most restricted-access fishing grounds belong to communities of nearby villages, who collectively manage the water bodies as common property resources. In many cases the authority responsible for allowing fishing in these waters is a senior member of the community, often the village head.

In some cases, traditional private tenure over water bodies is claimed by an individual, family or clan. These rights are normally inherited within the kin group. In other cases, access is restricted to people belonging to the same village or ethnic group, who at the same time are the controlling authority. Outsiders must seek permission to enter the fishing grounds.

Traditional control systems are the primary means of assigning fishing rights, even though government licensing schemes exist. Nevertheless, traditional regulations often require fishermen to show their Government permits when applying for a right of access.

As in other parts of the developing world, traditional systems in Africa are disappearing as market forces change local economies and as traditional local governments become less influential in relation to central governments.

Pacific Islands

Before the first contact with European civilisation, there was already a strong tradition of community-based fisheries management in the Pacific Islands, which still prevails today in some areas. The reef and lagoon communal tenure system was the most common conservation method in traditional management. Rights of access belonged to individual villages, which controlled access to nearby fishing grounds. The controlled-access fishing territory was usually defined as the area between the beach and the seaward side of the outer reef. Individuals were usually allowed to fish in the waters of adjacent villages only if they paid a fee. The local village chief enforced the rules relating to fishing rights (Dahl 1988; Wilson *et al* 1994).

There was a strong conservation ethic with respect to the exploitation of the fishery, and taking more fish than one could eat was frowned upon. In each island group, certain species were protected by special regulations governing when and how often they could be caught. For instance, certain species were restricted for emergency supply only and were not fished in good weather when other species were available. Fishing in inland lagoons was only permitted in periods of bad weather; at other times they were left as a reserve (Wilson *et al* 1994).

Brazil

In the coastal fisheries of Bahia there is an elaborate system of fishing rights which operates independently of national regulations and laws. These informal regulations conflict with the prevailing national fishing laws, which specify that the waters belong to the State and are therefore public property. On the contrary, Bahia's rural fishermen operate under an informal tenure system whereby territorial rights over coastal waters are claimed. In general, rural fishermen in Bahia do not comply with the national law, which is a sign of the institutional weakness of the Fisheries Department. For instance, fishermen avoid purchasing licences for their boats or gear and they surreptitiously market their product to avoid paying docking and municipal fisheries tariffs (Cordell and McKean 1986).

Sea tenure has existed for at least a century in Bahia. The nature of the tenure ranges from sequential net-casting claims on migratory species, lasting hours or a few days, to long-term private claims over brackish water spawning grounds, reefs, and net-fishing spots defined by the lunar-tide cycle. Rights to fish may be transmitted through apprenticeships, kinships and other relationships from the same working environment. The people or entities that hold the rights of access to fishing grounds may be groups of fish captains, families, informal partnerships, extended ritual kin groupings or individual canoe fishing captains who monopolise clusters of net-casting spots (Cordell and McKean 1986).

The success of tenure systems in Bahia largely depends on mutual trust, built upon the exchange of favours which eventually result in interdependencies that are extended to the fishing activity. In this way a fisherman is unlikely to violate the territorial rights of another, for fear of losing respect and undermining cooperative relations with others. When a violation of fishing rights does occur, the other fishermen may use retaliatory measures such as denying territorial use rights to the transgressor or withdrawing their cooperation onshore. In other instances, mediators are used to resolve conflicts between fishermen.

Although the tenure system in Bahia has worked very well over many years, it is in danger of disappearing as a result of the modernisation of fishing technology and the expansion of markets. The influx of affluent non-resident fishermen to the area since the early 1970s has disrupted the system of territorial rights, through the introduction of more effective gear. Technological innovation has increased the degree of exploitation of the fishery, creating unfair competition between newcomers and local inhabitants. The dwindling stocks of native estuarine and reef species has also fuelled competition among local inhabitants, resulting in a breakdown of the traditional fishing codes. The sea tenure system in Bahia is, thus, an example of how technological innovation can disrupt traditional management systems.

2.4 Conclusions

Both co-management and community-based management can be powerful instruments for achieving the sustainable use of fisheries resources, provided that mechanisms exist which allow them to adapt to changing social and environmental conditions. In many cases traditional management systems which have worked well for centuries have failed when confronted with new challenges, such as rapid population growth and technological developments. The state's recognition of community-based management systems is important to guarantee their survival and also for ensuring that such systems not only meet the needs of local communities, but the rest of society as well. The Japanese fishery rights system is a good example of how the legal recognition of traditional management systems can help to achieve social justice and meet demand for fish by the wider society. The resulting co-management system has reduced the very large burden of regulation enforcement on the state, freeing resources which can be used more productively elsewhere.

One of the most important lessons from the successful cases of co-management, is that the state should take advantage of local knowledge of the environment and of the rules that have been developed in response to the particular needs and culture of local communities. Although it is not usually desirable to change the fundamental structure of these management systems, it will sometimes be necessary to modify them to a certain degree in order to meet the interests of other sectors of society, and to accommodate changing technology and market relations.

3. Management Implications

3.1 Introduction

Most of the recommendations and proposals made for fisheries management in the Amazon assume that the resource is already overexploited (Montreuil *et al* 1991; TCA 1994). Such proposals usually include mesh-size controls, closed seasons and the gathering of more biological data. Although the potential of community-based management is sometimes acknowledged, policy recommendations usually focus on the biological objectives of fisheries management rather than on resolving social or economic conflicts.

A more comprehensive evaluation of management alternatives for the Amazon fisheries requires consideration of the various factors that characterise the dynamics of this resource. This final section analyses the key characteristics of Amazon fisheries identified in Section 1, in terms of how well the different management systems presented in Section 2 can cope with them.
The specific characteristics discussed here are: composition of catch; co-existence of commercial and subsistence fisheries; variability of the environment; the unpredictable nature of the system; limited state capacity for management; breeding grounds/mobility of the resource; demand characteristics, and fisheries regulatory traditions among communities in the area. Based on this analysis, some important information gaps that limit management are identified, suggesting areas for further research.

3.2 Key features of Amazonian fisheries and implications for management

3.2.1 Composition of the catch

The interactions between the numerous species that compose the fish stocks of the Amazon make it very difficult to predict the overall consequences of increases in fishing intensity. Since each species has its particular growth curve, at any given level of effort certain species will be overexploited while others will remain under-exploited (see Annex 2). Biological interactions between species can be very complicated in terms of predator/prey relationships, or in terms of competition for the same food resource. Therefore, changes in the population density of one species will generally have effects on the population of other species.

For most fish species in the Amazon basin, the nature of these interactions is far from understood. Consequently, there is insufficient information to develop models that accurately describe the behaviour of fisheries in the rain forest ecosystem. Unfortunately, state management still relies on over-simplified models to determine catch quotas and other limits on effort.

Generally speaking, all three alternatives - state management, co-management and community-based management - will be affected by the uncertainties inherent in multispecies fisheries. However, state management may tend to treat the whole basin as a uniform entity, and therefore fail to account for the particular characteristics of demand and the environment at any given location, which will determine the relative priority of different species in a management system. In this sense, co-management and community-based management may be more responsive to local environmental and market conditions.

3.2.2 Co-existence of commercial and subsistence fisheries

Subsistence fishermen perceive themselves to be at a disadvantage when commercial vessels with more efficient gear and higher productivity per unit effort begin to fish a resource where user-rights are not well defined.

However, given the vast area that fisheries cover in the Amazon and the relatively low human population that makes use of the resource, the problem of over-fishing and resulting conflicts between commercial and subsistence fishermen tend to be confined to specific locations. Underlying these conflicts is the problem of defining fishing rights. State management typically grants free access to the fisheries resource in any area (provided there is no seasonal closure) and therefore no exclusive fishing rights exist. Experience in other fisheries of the world, however, suggests that the allocation of fishing rights may help to resolve conflicts where there is high demand for the resource, and can result in better management of the resource.

The problem is how to allocate fishing rights equitably. In the case of the Amazon fisheries, certain areas where boundaries can easily be defined (ie, lakes) could be appropriate for granting exclusive fishing rights to populations who rely on those areas for their subsistence.

Granting exclusive fishing rights to local communities could be compatible with a state objective of preserving fish stocks of high-valued species in remote areas. Achieving such an objective would also be in the best interests of local communities, who would therefore have the incentive to co-operate with the management scheme. If exclusive use-rights were granted to local communities, provision could still be made to allow commercial fishermen to use the fisheries of these areas. Such provisions could involve the limited sale of access rights by local communities to commercial fishermen.

Traditional community-based fisheries management in the Amazon basin remains poorly documented. It may be that native communities had no need to manage fish resources before European colonisation, since until then the population of the region was low relative to the resource endowment. It should also be borne in mind that rapid population growth in the Amazon only began in the second half of this century. Thus, community-based management could be a relatively recent social phenomenon in the Amazon basin. Community management is a spontaneous process which requires a degree of cohesion between the social groups involved, as well as certain physical characteristics of the fishing environment which make it possible to define the community's jurisdiction over the fishing grounds. Hence, it would be difficult to introduce community management suddenly in areas where local populations had not previously been organised in any way.

The appearance of village and inter-village reserves in the Peruvian Amazon to protect both forest and fish resources from outside interests has been reported by Pinedo-Vasquez *et al,* (1992). In the Iquitos region there are at least 44 reserves of this kind, 34 of which are lake or lake/forest reserves. These reserves lack legal status and come under the jurisdiction of the Ministry of Agriculture. The communities that have created them are either natives or *ribereños*, who are descendants of immigrants or indigenous people who have lost their tribal identities. The delimitation of the reserves and the regulations to control the extraction of resources have been agreed upon through village or inter-village meetings. An example of rules governing fishing activity in an inter-village reserve in Ucayali is given by Pinedo-Vasquez *et al* (1992). These rules include the following:

1. Villagers are allowed to fish only for their own consumption and for selling in any of the three villages that control the reserve. No fish can be sold to middlemen or to commercial fleets;

2. People from other villages require a special permit from the village authorities to fish in the reserve, and in such cases fishing can only be carried out for their own consumption;

3. Large fishing nets, poison and dynamite are banned;

4. People who infringe the rules will have their catch confiscated as well as their equipment, and in extreme cases may be expelled from the village;

5. In order to reduce the pressure on the lake, people are encouraged to fish elsewhere during the dry season;

6. Residents of the three villages have the right to denounce anyone who violates the rules to the competent authorities.

No mention is made of how long these reserves have existed, or if fish stocks in these reserves are substantially more plentiful than in open-access lakes. The success of any regulatory scheme depends on several factors, as Dahl (1988) points out. For example, the more closely individuals identify themselves with their group and territory, the greater the chance of success for self-regulation. In this respect it would be interesting to compare the success of reserves belonging to tribal communities versus those belonging to *ribereños*.

The transition from state management to community-based management in localised areas should be carried out by delegating responsibilities to local communities in a progressive manner. However, state management should also be reinforced in those areas where there is insufficient social cohesion to guarantee the success of community-based management. The presence of the state in one way or another will be always be necessary to harmonise the interests of local communities, commercial fishermen and the rest of society.

An altogether different alternative would be to grant priority to commercial fisheries and keeping the resource in its current open access status. The overall fishing efficiency in the region could be improved if commercial fleets with better fishing technology gradually displaced less efficient fishermen. In an ideal situation, the additional economic rents generated by greater efficiency would be sufficient to compensate subsistence fishermen for the decline in their catch and their eventual displacement from the activity. However, this would require mechanisms for compensatory transfers, which do not exist in the Amazon at present. An example of such mechanisms would be the imposition of taxes on the total catch; with revenues used for development projects that offer alternatives to fishing for the local population. Alternatively, if local communities were granted property rights over the fishing grounds, efficiency could also be achieved through the creation of a fishing rights market where local fishermen would sell or lease their fishing rights to more efficient fishermen.

3.2.3 Environmental dynamics

Most fisheries models used for management implicitly assume a stable natural environment, in which changes in the total biomass of the stock result only from changes in effort. In tropical fisheries, however, the environment is far from constant, and may even have a stronger influence on the total biomass and species composition of the stock than fishing intensity. For example, annual flood events have a significant role in spawning and future recruitment. If a year has been particularly dry and the extension of the flooded areas is smaller than normal, this will be reflected in lower recruitment in following years.

Another fundamental problem in the predictive power of models is that fisheries, like many other natural systems, tend to behave in a chaotic manner. According to Wilson *et al* (1994), in chaotic systems it is practically impossible to use numerical approaches for long-term predictions, since even small changes in any of the parameters of the system may result in large variations in the future state of the system. The chain of events that lead to these variations are in many cases unknown or practically impossible to monitor. This means that the outcome of management actions such as the establishment of quotas cannot be predicted with models that assume fishing effort to be the main factor for controlling stock sizes. How quotas will change future fish populations depends on numerous interactions and events which we are not able to predict or fully incorporate into existing models.

In order to cope with environmental variability and the chaotic nature of fisheries, Wilson *et al*. (1994) propose management strategies which regulate "how", "when" and "where" fish are caught rather than the volume of catch. Although the authors refer to marine fisheries in particular, the principles on which they base their work could well apply to the case of Amazon fisheries. According to their recommendations, fisheries management should focus on maintaining the system's parameters in order to maintain the fishery within its normal bounds of variation. Such parameters include the ecological characteristics that determine growth, reproduction, migration and predation, among others. The relative stability of the system depends on how constant these parameters are kept; if they remain undisturbed, the system will remain within its normal range of variation. This assumes, of course, that fisheries managers can accurately identify all relevant parameters and the factors which influence them.

Management systems developed as part of a community's set of traditions are often based on the principle of allowing biological processes such as spawning and migration to proceed without interruption. In these cases some form of territoriality is usually involved (see Section 2). State management may also apply these principles through seasonal closures of certain areas, in order to ensure reproduction. However, enforcement in such a vast area as the Amazon floodplain is unlikely to be effective if local communities are not involved in the process.

3.2.4 Limited state capacity for management

According to the General Law of Waters, the hydro-biological resources of the Peruvian Amazon are defined as "state common property" (see Annex 1), whereby the resource is owned by the state, but can be used by individuals. Other forms of property are not acknowledged under current legislation. The state is also the only entity responsible for the management of continental fisheries in Peru.

Although regulations governing fishing activity exist under Peruvian legislation, fisheries in the Peruvian Amazon have in practice remained largely unmanaged by the state. The few cases of enforcement have usually occurred near urban areas, while in remote areas state management has been almost entirely absent. Where state regulations have been enforced, the management instruments mainly consisted of minimum mesh-size restrictions, seasonal prohibitions for the catch of certain fish species such as *Arapaima gigas*, and the banning of explosives and poison. However, given the chronic lack of resources that the state has at its disposal, such rules have been difficult to enforce even near major urban areas.

As noted in Section 1, local communities have been claiming exclusive rights of access to fishing grounds and creating their own institutions to manage their self-allocated portion of the fisheries resource. Although not legally recognised, such grass-roots initiatives could offer an opportunity for the state to delegate its management responsibilities to resource users. Such delegation would be especially attractive for a state which currently lacks capacity to effectively manage the fishery over such a vast area.

Another way for the state to delegate management responsibilities would be to establish co-management in areas where commercial fisheries predominate. Co-management would have the advantage of involving fishermen's organisations in the design and enforcement of rules, reducing the state's enforcement and regulation costs, and improving the legitimacy of the regulatory scheme (see Section 2). Delegating management responsibilities would release resources that could be used in other critical areas, such as monitoring and baseline data collection. However, co-management could also be a potential source of additional conflict between different groups of fishermen in the event that certain groups were given more power in decision-making than others.

3.2.5 Natural refuges, breeding grounds and the mobility of the resource

In Section 1 we observed that the productivity of the Amazon fisheries largely depends on the availability of natural refuges for reproduction. Migration also plays an important part in the reproductive behaviour of many fish species and is strongly dependent on the hydrological cycle of the basin, where annual flooding events open large areas in which migrating species find room to spawn, feed and protect themselves from predators.

Since management's key objective is to ensure the sustainable exploitation of the resource, it is essential to maintain both these breeding grounds and the migration patterns of fish stocks. Although community-based management in some instances may seem a promising alternative to achieve a sustainable fishery in localised areas (such as lakes), a higher level of management will always be needed to avoid potential problems which may arise when territorial rights are allocated to local communities.

For instance, if natural refuges and breeding grounds are under private or communal property, the owners could find that it is in their best interest to modify the natural refuge, clearing the forest that is subject to periodical flooding or draining these areas and incorporating them into their agricultural land. Since fish stocks are highly mobile, such actions would be likely to affect fisheries elsewhere. This reflects the fact that, while it may be relatively easy to grant property rights over fishing areas, it is very difficult to grant property rights over the fish stocks, especially in the case of fish that spawn in different places from where they are caught or fish that migrate. Modifying one of their temporary habitats is more than likely to have adverse effects elsewhere. Thus, special rules would be needed to protect areas that are crucial in the development of fish stocks, and the enforcement of these rules would necessarily have to be at a regional level.

3.2.6 Demand characteristics

The supply of cheap sources of protein to urban areas is an important consideration for any fisheries management system. However, the Amazon basin is also a source of highly valued species which are usually the most sensitive to increases in fishing pressure. In this respect, an effective management system would be one that meets the growing demand for protein in urban areas and at the same time allows for the profitable and sustainable exploitation of highly valued species in areas that are distant from the main markets.

Bayley (1995) and Bayley and Petrere (1989) have proposed a management system that accommodates, to some extent, the interests of all groups of consumers, and fishermen as well. This management system, denominated 'Progressive Pulse Fishing' by the authors, works under the assumption that the present level of extraction of the resource in the Amazon is still far below the maximum sustainable yield. Progressive Pulse Fishing aims to achieve a balance between different objectives for different areas. Near the cities, the objective would be to maximise total yield, maintaining effort levels which produce relatively high yields per unit area. At increasing distances from the market the total yield per unit area would be progressively reduced, optimising instead the exploitation of larger and more valuable species. More extensive periodic area closures would allow the conservation of a higher biomass of these species along with the rest of the fish population. Thus, optimum exploitation rates and species composition would be defined for each area according to their specific ecological and socio-economic realities (Bayley 1995).

A management system of this nature would probably require a mixture of both community-based management for remote areas, and co-management for fishing areas that supply urban populations.

3.3 Information gaps

There are several biological and social considerations on which further information is required in order to assess the viability of any proposed management system. The following is a list of some of the topics on which further research is needed:

a) The state of exploitation of the Amazon fisheries. Although some studies provide evidence that, in general, the Amazon fisheries may be currently under-exploited (Bayley and Petrere 1989, and Bayley 1988), the particular situation of different areas may vary considerably. For instance, in areas near cities where fishing intensity has remained relatively high, it has been observed that the average size of harvested fish has decreased over the years and that large species have become less common (Ortega 1996, personal communication). However, there is insufficient information to confirm such observations, given that no data exists on changes in species composition which might have occurred since the commercial fishing activity started to flourish in the region and fishing pressure increased as a result. On the other hand, incomplete knowledge of the spatial distribution, dynamics, interactions, sustainability and other ecological aspects of fish stocks creates uncertainty about the consequences of allowing the pressure on fisheries to increase near major urban areas.

b) Effects of an increase in fishing intensity on stocks. It is not known if an intensified multispecies fishery will produce irreversible changes such as the biological extinction of certain species. The available data on yield, effort, species composition and environmental variables is insufficient to determine the relation between fishing effort, environmental change, fish yields and species composition. Another limitation is the fact that the official statistics only consider the yield that originates from commercial fisheries, but exclude yields in subsistence fisheries. Hence, estimates of the maximum sustainable yield will be inaccurate if based upon these statistics.

c) The relationship between fish stocks and environmental change. With a better understanding of the environment, key ecological characteristics that keep the system relatively stable could be determined, as well as the degree to which these parameters should remain constant in order to preserve (or enhance) the fishery.

d) Baseline data. Any management system must rely on continuous monitoring of the state of the fishery in order to assess its effectiveness and make the necessary changes in time. Therefore, data collection should be given a high priority in the allocation of management resources. Although the yield and composition of all commercial fish stocks should be followed, it would be desirable to give additional attention to species with high market value, especially in areas where the management objective is to preserve and enhance their stocks.

e) By-catch composition. It would be important to determine the proportion of the total catch that is discarded as by-catch by commercial fisheries, and whether such by-catch is composed of species that would otherwise be used by subsistence fisheries. With this information, rules aimed at reducing by-catch in commercial vessels could be assessed as mechanisms for mitigating conflicts between subsistence and commercial fishermen.

f) Use of new species. It is important to study the utilisation of species which are not yet commercially exploited and develop markets for them. If a change in species composition occurs in areas where fishing intensity is allowed to remain high, then such a change will probably result in the predominance of smaller and lower-valued species, as well as species which at present do not have well established markets. The great biodiversity that characterises the fish population in the Amazon is indicative of the potential for finding new species which can be profitably exploited provided that a demand for them is created.

g) Effectiveness of existing community-based management systems in the Amazon. In previous sections we noted that several community-based management systems have emerged spontaneously throughout the basin, especially in the form of lake reserves. However, no information could be found concerning differences in the specific regulatory schemes that may exist between different communities. Furthermore, it is not known whether the implementation of community-based management has been effective in improving the catch composition or increasing the yield per unit effort, compared to the situation that existed before such management systems were implemented.

3.4 Final considerations

It is difficult to offer any conclusive policy recommendations based only on the secondary information gathered in the present study. We can only go so far as to say that there is no comprehensive strategy for the management of fisheries, at least in the Peruvian Amazon, and that few really imaginative management schemes that consider both the biological and socio-economic dimensions of fisheries have been proposed for the region.

When considering policy options for the fisheries in the Amazon there has usually been a bias towards the biological aspects of the activity, giving more weight to the prevention of biological extinction than to social objectives such as providing cheap sources of protein to low-income groups or assuring a fair share of the resource for the different groups of fishermen involved in the activity. Thus, state management has been unable to address either efficiency or equity issues. One of the reasons for this bias towards biological objectives in the existing management scheme for the continental fisheries in Peru (which is also the case with marine fisheries) could be the fact that fisheries management has traditionally been the preserve of biologists with little or no training in the social sciences.

Management schemes developed for the Amazon fisheries need to be flexible in nature, reflecting an awareness that the Amazonian aquatic systems are still insufficiently understood, and that any current regulation is likely to change as more information becomes available through monitoring of the key factors that determine yields and species composition. Any fisheries management scheme implemented in the Amazon should also be seen as an experiment, with care being taken to follow the effects it has on fish populations and the aquatic ecosystem in general. Flexibility in the management scheme should also be seen in terms of adapting to different socio-economic and environmental realities that are found throughout the basin.

Community-based management seems to be a promising tool for decentralising management and increasing its effectiveness in remote areas. Given that the state is unlikely to acquire quickly the capacity to regulate the fisheries effectively in areas far removed from the main markets, delegating management responsibilities to local communities would be an efficient way of regulating the fishing activity in these areas.

More information on the relationship between changes in land use and fisheries is required through research and monitoring. Fisheries management should not only account for the characteristics of the aquatic medium, but also the potential effects of changes in terrestrial ecosystems. Co-ordination between the Fisheries Department and other state agencies dealing with such ecosystems (e.g. Forestry and Agriculture Departments) is, therefore, very important.

Urban populations will inevitably continue to grow for years to come, as will the demand for cheap sources of protein. This protein will either have to come from the terrestrial or aquatic ecosystems. The production of alternative protein sources in the Amazon such as beef or milk has for long been regarded as one of the main causes of the Amazon's environmental degradation, in terms of deforestation, soil compaction and erosion. Hence, fish production in the Amazon may be regarded by the international community as more environmentally-friendly than alternative protein-supplying activities in the region. However, international funding has not reflected this perspective, since more funds have been allocated to the development of terrestrial resources in the Amazon - such as timber and agriculture - than to the sustainable development of fisheries.

The relatively low human pressure on the resource in the Amazon basin compared to other freshwater tropical fisheries in the world (e.g. Africa and South East Asia) and the relatively undisturbed nature of the floodplain system, mean that it is still feasible to develop a strategy by which social benefit is obtained from the resource while preserving the environment and its natural processes to a considerable extent.

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ANNEX 1. Principles of common property resource management

Definition of public goods and common property

The terms 'common good' and 'common property' are often confused and sometimes - mistakenly - used interchangeably. The first term refers to the nature of the good itself, while the second specifies a type of ownership. There are common goods which are not subject to ownership, while others are. We may define 'common goods' by contrasting them with other types of goods.

According to the economic definition, a common good is located between a 'pure private good' and 'pure public good'. The difference resides in the concepts of jointness and exclusion (Moorehead 1991). A pure private good is a good with the property of exclusivity, which means that the consumption of the good in question by one individual will prevent another from consuming it as well. The owner of such a good can dispose of it as desired and can deny other people access to the good. On the other hand, a public good can be jointly consumed with others and is therefore non-exclusive. Any individual can freely consume it without denying others the ability to benefit from it. In other words, the rate of consumption is independent of the number of consumers and how the good is utilised (Oakerson 1986). The air and sunlight are examples of this type of good (Moorehead 1991).

A common good has characteristics of both private and public goods since it contains a certain degree of subtractability and excludability. The consumption of a common good by one individual will reduce another individual's ability to consume the same good. That is, the rate of consumption varies according to the number of users and the type of use (Moorehead 1991; Oakerson 1986). Nevertheless, it is possible for many consumers to jointly benefit from the resource, as long as there are mechanisms to exclude others from its use (Moorehead 1991). Examples of common goods include water resources, rangelands, forests, wildlife, fisheries and, in some instances, arable land.[1]

When talking about property, we are referring to the degree of excludability which applies to a resource. Public resources are entirely joint and non-exclusive, they are 'free' and therefore do not have property rights at all. Such goods are then said to be 'open access'. At the other extreme, private goods are completely exclusive and subtractive, and the owner has the right to exclude others and regulate the use of the resource. This is what constitutes private property. Common resources are partly joint and partly exclusive, which means that a type of property regime has to apply to exclude certain parts of society from its use. Communal or common property tries to achieve this by making the resource accessible only to an identifiable group or community of users, who can then regulate its use (Berkes 1993; Moorehead 1991).

Common property occurs at different scales, from global or international to local. Global property regimes include those resources which are owned internationally, such as Antarctica, where entry is only for those states that have treaty rights (Moorehead 1991). On the other hand, in state common property the government controls access and regulates the use of a resource which is found within

[1] Some of these natural resources may have aspects that also make them public goods, such as the carbon sink function of forests or the biodiversity contained in wildlife.

the national boundaries. Examples of this type of property right are found in national parks, reserves and river systems. Finally, in communal property the resource is owned and managed by a local community which has exclusive access to the resource. A distinguishing feature of communal property is that individuals have the right to make use of the resource but not to dispose of it, which means that the resource cannot be sold or given away (Moorehead 1991).

Management of common property

Hardin (1968) saw over-exploitation as an inevitable outcome of the use of common goods, even when the individuals sharing the benefits of such resources acted in an economically rational way. He called this phenomenon the 'tragedy of the commons'. To illustrate this concept, Hardin described the hypothetical example of a pastoralist society where each individual wants to increase the number of his herd in a given rangeland as long as his personal gain from adding one animal exceeds his personal loss from doing so. Since all herdsmen are assumed to behave in the same way, the carrying capacity of the land will eventually be exceeded, resulting in degradation and a loss for all.

When there are no rules to regulate the use of a common good, then its disappearance is inevitable. The same would happen if rules existed, but nobody observed them. According to Gibbs and Bromley (1989), 'free riding' is the basis of the tragedy of the commons, that is, individuals failing to contribute to the management of a collective good because they expect that others will do so.

While the tragedy of the commons seems to be unavoidable in the case of open access resources, Berkes (1993) argues that private property, state property and common property can, under some circumstances, lead to sustainable resource use. Management of common property requires a specific set of rules with which all members of the community comply. However, as Gibbs and Bromley (1989) point out, the sustainable management of a resource cannot be dependent upon the altruistic behaviour of individuals, as free riding always seems to prevail. There need to be mechanisms to ensure compliance.

All common property faces a common problem: how to coordinate individual users to attain an optimal rate of production or consumption for the whole community (Oakerson 1986). Gibbs and Bromley (1989) distinguish the success of common property regimes through the following indicators:

1. efficiency: a minimum (or absence) of disputes and limited effort necessary to maintain compliance;

2. stability: a capacity to cope with progressive changes through adaptation, such as the arrival of new production techniques;

3. resilience: a capacity to accommodate surprise or sudden shocks; and

4. equity: a shared perception of fairness among the members with respect to inputs and outcomes.

The case of fisheries

Fisheries are usually either open access or common property resources. As such, fisheries are also subject to the tragedy of the commons if no effective mechanisms exist to regulate access to the resource and its use. The profitability of the first fisherman fishing a body of water will attract other fishermen to enter the fishery. New boats will be introduced in the fishery, which brings the owners both a gain and a loss. Initially, for each fishermen his loss will be much smaller than his gain, since the loss is shared by other fishermen. Each fisherman will thus have an incentive to expand his share of the resource, until the fishery becomes overexploited. To prevent this situation from occurring, fisheries management is introduced (Bland 1992).

The purpose of fisheries management is to achieve certain objectives through direct or indirect control of fishing effort. The general objective of management is to avoid the over-exploitation of the resource (Panayotou 1982).

There are several subsidiary policy objectives, according to which the optimum level of exploitation of a fishery may be defined. If the objective is to prevent biological over-exploitation (which may ultimately lead to extinction), the maximum sustainable yield (MSY) will be defined as the optimum level of exploitation. The MSY is the maximum catch that can be obtained on a sustainable basis. If the MSY is known then it is possible to determine if the fishery is overexploited or not (Panayotou 1982).

If the objective is to maximise the net economic benefit from the fishery, then the maximum economic yield (MEY) is taken as the optimum level of exploitation. The MEY is a modification of the MSY taking into account the value of the fish caught and the cost of catching it. If there is insufficient effort and the level of extraction is below the MEY, then the fishery is not generating as much economic benefit to society as it could, and thus is in need of development. On the other hand, if the level of extraction is above the MEY, then the economic returns again will be below the optimum due to over-exploitation of the resource, and hence management is required (Panayotou 1982).

Alternatively, social considerations can be taken as the main objectives, which may include improvement of the socio-economic conditions of fishermen, generation of employment opportunities and the improvement of income distribution. In such cases the maximum social yield (MScY) is taken as the optimum level of exploitation. MScY is mostly applicable to small-scale fisheries, where social considerations are given more weight than biological or economic objectives (Panayotou 1982). A review of the economic principles underlying the definitions of optimum levels of exploitation can be found in Annex 2.

There are several mechanisms by which management systems may attempt to reach the optimum exploitation levels described above. These include fishing quotas or total allowable catch, restrictions of gear type, restrictions of gear selectivity, species size restriction, closed season, closed areas, licensing and the allocation of property rights over fishing grounds. These regulatory mechanisms are explained in detail by Anderson (1977) and Panayotou (1982).

ANNEX 2. A review of fisheries economics

The bio-economic fisheries model

The Schaefer-Gordon model is the most widely used and the simplest of the many models that have been developed for fisheries. The model postulates that the growth of a stock depends on its size (Panayotou 1982). When the stock size is small the growth is small, but as the stock becomes larger, the growth increases until a point of maximum growth. Beyond this level food and space become limited and growth declines with further increases in stock size.

Figure A1 shows the relationship between the stock size and growth which describes an inverted U-shaped curve. Growth is equal to recruitment (young fish entering the stock) plus individual growth of existing fish minus natural mortality (Panayotou 1982). The growth is positive between zero and the maximum potential stock size, which corresponds to the environmental carrying capacity (EEC). Growth is normally greatest when the stock is at half of its maximum potential size. When EEC is reached, recruitment and growth are matched by mortality and the corresponding stock size is maintained.

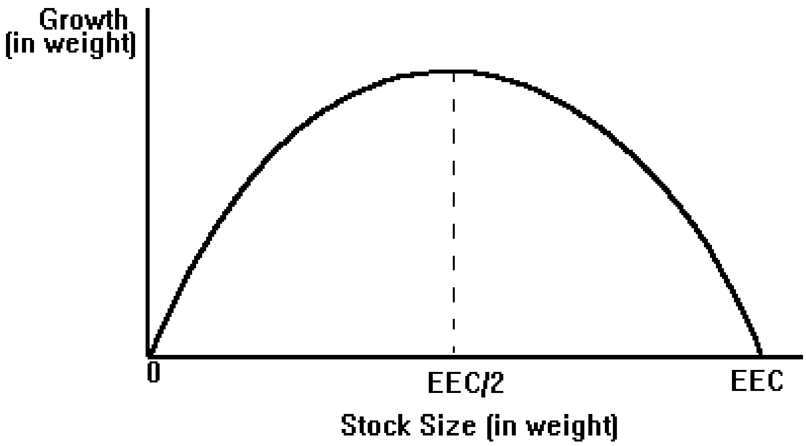

Figure A1. Growth-stock relationship (Source: Cunningham & Whitmarsh, 1981)

When the stock size is at EEC and fishing begins, the stock size is reduced by an amount equal to the catch (Cunningham and Whitmarsh 1981). Fishing effort[2] then enters into the model as another form of fish mortality. The part of the stock that is removed by fishing is balanced by the biological productivity of the stock, and no further change in the stock size occurs if fishing effort remains

[2] Fishing effort is an expression of the effect that fishing has on fish stocks which in turn depends on the inputs that are employed. Fishing effort is most often expressed in nominal terms by quantifying factor inputs such as boats, men or gear. Fishing effort is the main parameter which man controls in the fisheries production function, since he has little or no control over the biological and environmental factors which may have a stronger effect on yield.

constant. Therefore, the catch can be maintained indefinitely at this level and a sustainable yield is achieved. A sustainable yield exists for every stock size, which is equivalent to the growth at that level (Cunningham and Whitmarsh 1981).

Figure A2 shows the sustainable yield curve where yield is a response to fishing effort. It is similar to the productivity curve (Figure A1) but with the difference that the origin corresponds to EEC. In the sustainable yield curve a move to the right of the origin will mean a reduction in the stock size. The highest yield will be obtained at half the EEC, which is known as the maximum sustainable yield (MSY).

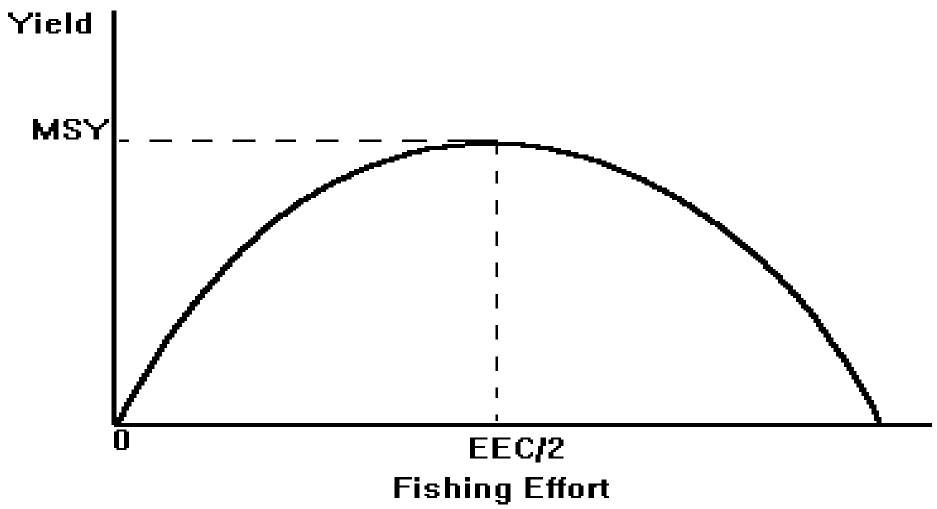

Figure A2. Sustainable yield curve

[Source: Cunningham & Whitmarsh 1981]

Figure A3 shows the bio-economic model, which is based on the sustainable yield curve. Here the Y-axis represents revenue (yield times price) and fishing costs. The total cost curve (TC) is a linear function of the fishing effort, where an increase in total cost will be directly proportional to an increase in fishing effort.

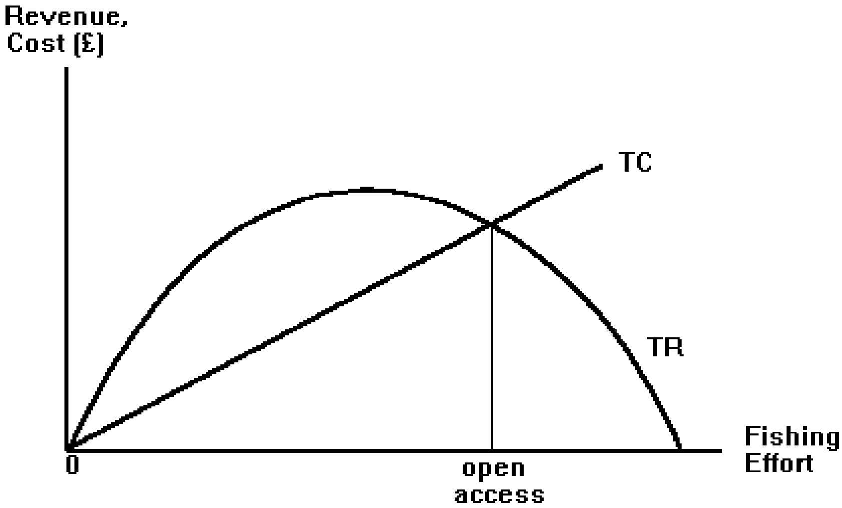

Figure A3. Fisheries bio-economic model (Source: Cunningham & Whitmarsh, 1981)

Three important assumptions are made in the bio-economic model. The first one is that the fishery represents only a small fraction of the total world market for a species. The unit price for any particular fishery is thus assumed to be constant over a particular time and independent of the level of output. The second assumption is that fishermen derive only monetary benefits from fishing; non-monetary benefits are not considered. Third, it is assumed that changes in fishing effort are the result of boats entering or leaving the fishery and not of the expansion of effort by existing boats, which makes total cost a linear function of fishing effort (Cunningham and Whitmarsh 1981)

What constitutes overfishing?

As biologists are primarily concerned with the biological productivity of fish stocks, they define overfishing as fishing at levels of effort that are above the one corresponding to MSY. At effort levels below MSY, a reduction in the biomass might increase the stock's ability to reproduce due to compensatory mechanisms within the fish population. Thus there is still room for increasing yield with additional effort. However, as fishing intensity expands beyond MSY, additional effort reduces the sustainable catch and creates the danger of overexploiting young fish and parent stock. When the parental stock is reduced by heavy fishing, the average recruitment into the stock (new fishes) tends to decline. A continuous drop in recruitment may eventually lead to the extinction of certain species.

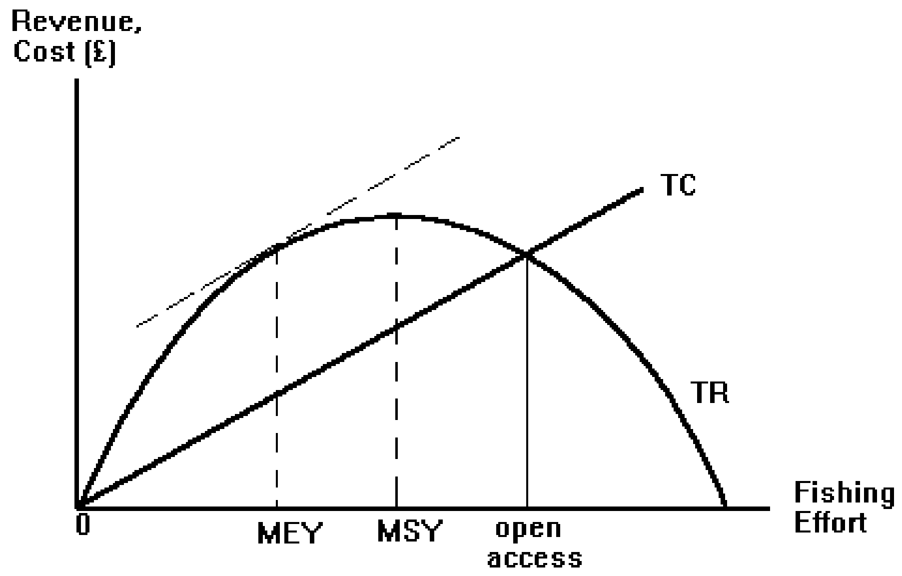

Figure A4. Maximum economic yield, maximum Sustainable yield and open access in the bio-economic model.

[Source: Cunningham & Whitmarsh 1981]

From the economic point of view, the value of the fish caught and the cost of catching them must be taken into account to define overfishing. Maximum economic yield (MEY) is the level of effort at which sustainable net benefit (or rent) is maximised. This optimum is reached when the marginal revenue (MR) equals the marginal cost (MC), that is, where the slopes of the total revenue (TR) and total cost curves are equal, as shown in Figure A4. At effort levels below MEY, MR exceeds MC and it is thus worthwhile to expand effort in order to obtain additional revenue. At effort levels above MEY each additional unit of effort will cost more than the revenue it produces, which results in what is defined as economic overfishing.

Open-access equilibrium

In open-access fisheries the equilibrium occurs when the total revenue (TR) equals total cost (TC) (Figure A3). Depending on the costs of fishing, this equilibrium point may be biologically unstable if it is beyond MSY. Effort levels below the point of open-access equilibrium will generate profits and encourage the entry of more fishermen into the activity even when MR becomes negative. As long as the average revenue (ERR) remains greater than marginal cost (MC), new fishermen will enter the activity attracted by the possibility of obtaining profits.

From an economic point of view, the problem with open-access fisheries is that society at large gets no benefits from the fisheries, as the activity generates little or no surplus to invest in economic and social development (Panayotou 1988). On the other hand, fishermen may find themselves earning very low incomes under open-access. However, low opportunity incomes may prevent fishermen from leaving the activity. Copes (1988; cited by Cunningham 1993) gives several explanations for why small-scale fisheries usually face low opportunity incomes. Among these are the difficulty in liquidating capital assets, lifestyle preferences, and the isolation of some fishing communities which result in poor education and lack of alternative employment. It is important to point out that, in addition to income, there is a psychic return to fishing, which is termed "worker satisfaction bonus". This type of benefit is likely to be higher in fishing than in most other activities and may be a decisive factor in preventing many fishermen from abandoning the activity even when more profitable activities are available (Cunningham 1993).

Time preference considered

The bio-economic fisheries model so far presented is a static one and does not take into account time preference. Here society is assumed to be indifferent between consumption now or later (Cunningham and Whitmarsh 1981). When time preference is introduced, the short-term loss of reducing effort from the open-access level to the MEY level is given more weight than the long-term benefits of doing so. Future gains are discounted and compared to the current loss. The more distant the future gains are in time, the more heavily they will be discounted. When accounting for time preference, a new economic optimum is defined where the difference between total discounted benefits and current costs is maximised, which is known as the dynamic MEY. There are two extremes within which the dynamic MEY may be located. On the one hand, if society shows no time preference then the dynamic MEY will be the same as the static MEY. On the other hand, if society shows infinite time preference, then the dynamic MEY will be the same as the open-access equilibrium, since future gains from reducing effort will not be considered (Cunningham and Whitmarsh 1981). The degree to which individuals discount future benefits depends on various factors. For example, fishermen who depend on a particular fishing area may give more weight to the future incomes the resource may generate than itinerant fishermen who can move to other areas. On the other hand, commercial fishermen may discount the future benefits of a particular area according to the probability of obtaining lower benefits in the future due to stock depletion. In other words, they may prefer to exploit a fishing area now while the fish stock is still plentiful (Tucker and McKellar 1993).

Multispecies fisheries

One of the fundamental characteristics of tropical fisheries is the multispecies composition of the fish stocks. This characteristic brings along technological and biological interactions within the fishery that complicate its modelling. A technological interaction occurs when, due to the use of non-discriminatory gear, it is not possible to concentrate fishing effort on any single species that makes up the stock. On the other hand, a biological interaction occurs when there is competition between species for the same food or when there is a predator/prey relationship (Panayotou 1982).

In multispecies fisheries different species have varying likelihoods of being captured when subjected to the same overall fishing effort. If fishing effort is maintained constant for a sufficiently long time, a certain species composition, age structure and total biomass will become characteristic. In this way the abundance of some species will increase relative to others which in turn may decrease to very low levels in the catch, resulting in the sequential collapse of some species and the emergence of others (Panayotou 1982).

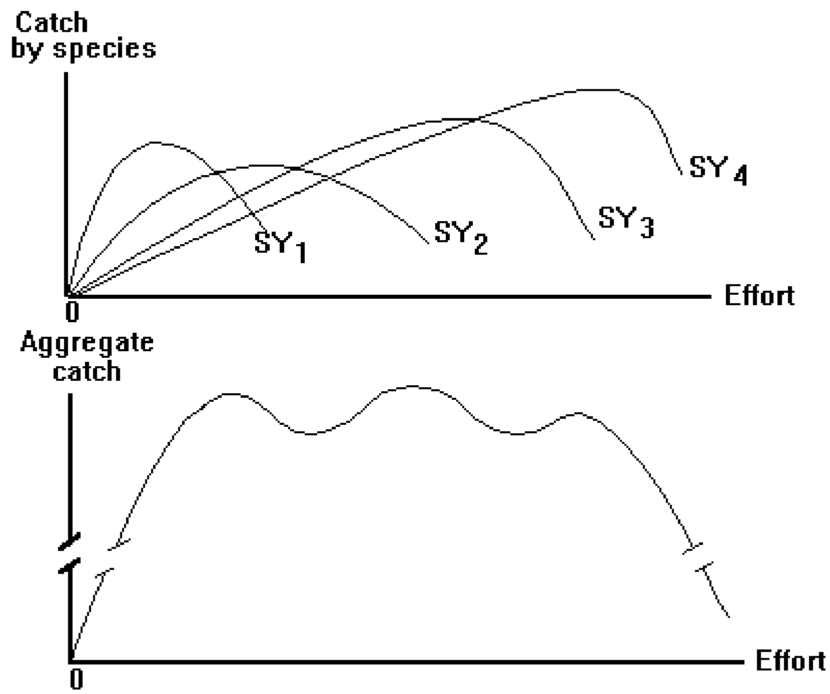

Figure A5. Derivation of a multispecies yield curve through vertical sumation of individual yield curves (Source: Panayotou 1982)

A multispecies yield curve resembles the single species model curve in that catches increase with additional effort up to a certain point and then decline. However, a multispecies yield curve is the sum of the individual yield curves of the component species (Figure A5) and therefore movements along the curve will not only change the total catch and age structure, but also the species composition.

Another difference with single species models is that fishing effort changes qualitatively at higher fishing intensities. Changes in gear and reductions in mesh size are necessary for catching smaller species. The decrease in multispecies yield at high levels of effort thus reflects both the over-exploitation of some species and the technical limitations of harvesting smaller but more productive species (Bayley 1995).