Fisheries management in the Brazilian Amazon

by

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A thesis submitted for the degree of Doctor of Philosophy and the Diploma of Imperial College in the Faculty of Science of the University of London

2004

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The miracle

Luke 5:1-11

One day as Jesus was standing by the Lake of Gennesaret, with the people crowding around him and listening to the word of God, he saw at the water's edge two boats, left there by the fishers, who were washing their nets. He got into one of the boats, the one belonging to Simon, and asked him to put out a little from shore. Then he sat down and taught the people from the boat.

When he had finished speaking, he said to Simon, "Put out into deep water, and let down the nets for a catch."

Simon answered, "Master, we've worked hard all night and haven't caught anything. But because you say so, I will let down the nets."

When they had done so, they caught such a large number of fish that their nets began to break. So they signaled their partners in the other boat to come and help them, and they came and filled both boats so full that they began to sink.

Abstract

The purpose of this work is to analyse the prospects of co-management for small-scale and commercial fisheries of the Amazon, evaluation of effects of co-management agreements and the likely impact of alternative management scenarios. Specifically, the study analysed the importance of the fishing sector for the Amazon region, the production function of the commercial fishing sector, the role of fisheries in the livelihoods of small-scale rural fishers; and interactions between the commercial and small-scale rural-based fishing sectors. The methodology combined interviews with a range of different stakeholders, analysis of a long-term landings database, and use of a bio-economic model to integrate information and explore likely outcomes of alternative management measures. The fisheries sector in the Brazilian Amazon generates a total income of R$389 million and employs 168 thousand people. Ninety-five percent of those employed are fishers, but their contribution is much undervalued in official statistics. Fish processing plants account for the largest share of income generated, while small-scale rural fishers account for most of the employment. Despite the regional differences found within the commercial fleet study on social and technical aspects of the fleet, there is no difference in efficiency between small and large boats. Community management of floodplain lake fisheries increased their productivity, probably as a result of reduced commercial fishing. Analysis of the bio-economic model shows that the commercial and small-scale fishing sectors, and lake and river fisheries are likely to interact strongly, and that benefits from the expansion of the community management systems in lakes will be at least partially offset by increases in fishing pressures in the river.

Acknowledgements

This research involved extensive field work. About 1,680 interviews were conducted to provide data for studies of three aspects of the economic life of the population living on the banks of the Amazon River: the fishing sector as a whole, the commercial fishing fleet, and the small-scale fishing sector. As a result the list of acknowledgements is a long one. There are, however, three people I have to acknowledge first. Kai Lorenzen, for the three years he spent by my side throughout the analysis of this data set. I sincerely thank him for his patience, creativity, and objectivity. David McGrath, for always supporting me in whichever direction I decided to take this work, and the many others we worked with over the last 8 years at IPAM. Finally, I want to thank Sandra Charity for her generosity. During her four years as the Program Officer of IPAM's Várzea Program, she not only facilitated my work in a professional manner, but also went beyond her obligations in order to support it.

Throughout my fieldwork many people helped me, and I am forever grateful for the support they provided. In particular I thank Alzenilson de Aquino, Nadson Oliveira, Waldemir Oliveira, Manoel Silva, and Pedro Afrâneo for helping to collect the data from 3,000 fishing trips in the ports of Belém, Santarém, Manaus, and Tefé.

In 2000 I collected data in 18 communities in the lower Amazon in order to compare communities with and without management agreements. I have to thank Lucilene Silva, Luciene Campos Sales, Rosandra Santos, Leusabeth Silva, and Kemerson Silva for their help in collecting that data. I also have to thank Lucimar Lima for helping to test the questionnaire early in January that year in the community of Tapará, and Lucilene and Ivoneide for going back to the field to collect a second set of data in the following year.

In 2001 we picked a random sample from 51 cities on the Amazon/Solimões River for the sectoral analysis. We chose 15 cities to visit in order to estimate the importance of the fishing sector. Lucilene was a key person in the development of this task. She helped by testing the questionnaire with me in Santarém, training an assistant, and visiting the cities to interview all businesses related to fishing activity. I owe her special gratitude for this work. I also thank my brother Horácio Almeida, who knows each municipality in state of Amazonas, for giving us many contacts in each selected city of that state. These contacts facilitated our work in many ways, both in conducting preliminary phone interviews as well as in support while visiting the city.

I want to thank Nalinda de Coutinho, Tatiane Santos, Elisabeth Silva, Vanda Silva, and Ivoneide Moreira for entering the data collected into a database, calculating the costs of the 3,000 fishing trips analysed, and giving support with the office work. Over the last 3 or 4 years they worked with patience and dedication on this project.

As we carried out the interviews for this research I promised the fishers who responded to the 16 page questionnaire that I would send a report when the data was analysed. To fulfil my promise, I prepared two booklets to present the material in a more didactic way. I want to thank Edi Lopes, from IPAM, for illustrating these two wonderful booklets, one on household economics and the other on the analysis of the Santarém fleet.

I want to thank the Fishers' Union, Z-20, for providing information, opinions and advice about specific topics. They helped me with many different things throughout this project. Additionally, I would like to thank many community leaders, the Ituqui Island families, Jose Vicente and Paulo Taketomi from the fishing industry, other fishers' unions, representatives of NGOs, and all the interviewees for taking their time to help me gather additional information necessary to complete this work.

I would like to thank Socorro Pena not only for being a great friend but also for helping me organize two workshops on fishery policies with leaders of the fishing sector. Socorro chose and invited the participants, organized the logistics of the events, and defined the workshop dynamics. I would never have been able to do this from London, and could not have found a better person to organise these workshops. Her ability to organise events, her knowledge of the political network, and her connections with the popular movements in the state of Pará were essential for the success of these events.

Many people helped me to review this work. I would like to thank Trond Bjorndal for taking the time to read and criticize the fleet analysis presented in chapter 4 and the bio-economic model presented in chapter 6. I am also most indebted to Iago Mosqueira who corrected the English of my earlier manuscripts. I also want to thank Ulrike Killguss, my sister Veronica Ribeiro, and John Viar for reviewing some parts of this dissertation and Christopher Scott and James Welsh who did the final review of this work.

Some friends did not help me directly with this work, but have made my stay in London very pleasant. I would not be able to thank all of them. Through the Brazilian Work Party Centre in London, ABEP, and Imperial College I had the opportunity to meet more than 200 Brazilians, many of whom became great friends. I would like to specially thank Larissa Chermont, Renee Assayag, Jeff

Almeida, Lilian Costa, and Lidia Smoleanschi for their friendship; my very dear flat mate Saifon who taught me to cook Thai food and who took me to visit the rubber tree plantations of smallholders in NakonSiThammarat in southern Thailand. I would also like to thank Wilson Cabral, my flat mate, as he made the last year of my stay in London very pleasant; From RRAG, at Imperial College, I have to thank my office mates Carlos Vazquez, Monica Poggioli, and Sophie Nguyen Khoa with whom I had lunch at Imperial College almost every day during these three years. Finally I could not fail to thank my mother Ruth Almeida and my sisters Olivia Leite, Veronica Ribeiro, and Fernanda Caballero who called me so many times just to chat while I was working during the weekends at Imperial College.

Funding

Many agencies supported this work financially. The major source of direct support for this three-year project came from The Darwin Initiative, WWF UK, DFID, WWF Brazil and the Gordon and Betty Moore Foundation. I would also like to thank ProVárzea/IBAMA and the Iara Project for the data used in chapter 6 which were essential for the construction of the model. This database comprises more than 70,000 interviews collected by these institutions over the last ten years. I am also thankful to PPD/Finep for publishing the two booklets which allowed the data on household economics and fleet analysis to be passed back to the communities and fishers, and for financing two workshops on policies to help with the model construction.

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Chapter 1

Introduction

1.1. Management issues in Amazon fisheries

While there has been little concern with fisheries in the context of Amazon development policy, Amazon fisheries have been profoundly affected by the changes taking place in the regional economy. Over the last forty years, a series of developments have contributed to the expansion and intensification of the commercial fisheries, resulting in the transformation of fishing and processing technology, types of fish products, and in the characteristics of the commercial fisher. These changes have placed great pressure on regional fisheries and led to ever more intense competition between local and outside fishers for access to floodplain lakes. In response to the perception of increasing scarcity, floodplain communities throughout the region have sought to take control of surrounding lakes and impose rules to control local fishing effort. Though at first rejecting community management, IBAMA, the federal institute responsible for managing fisheries, has now come to recognize the legitimacy of this approach. Over the last decade, IBAMA, fishers' unions, floodplain communities, church related organizations and local NGO's have worked together to develop a co-management system that incorporates community fishing agreements into the formal structure of fisheries management. The purpose of this thesis is to examine the commercial and small-scale fisheries of the Amazon River, especially in relation to developing co-management systems, and to evaluate the possible impacts of alternative policies and market conditions on the status and management of regional fisheries.

Fishing in the Amazon has been, and is at present, an important activity in the region. In the past, fishing has been important mostly as a subsistence activity. While subsistence fishing predominated, commercial activity was also important for regional urban markets and was concentrated on the commercialization of dried salted fish sold in the regional markets.

Recently, in the last forty years, the Brazilian government implemented major policies and infrastructural projects designed to develop the Amazon region and integrate it into the Brazilian economy. The fisheries sector was also transformed with the introduction of new technologies such as diesel engines, nets of synthetic fibers, ice-making and storage technology. With these innovations, boats could travel longer distances, catch larger amounts of fish, and store them to market fresh in the main urban markets.

Regional development policies sought to encourage migration to the Amazon and contributed to the growth of urban markets for fresh fish. At the same time, the government provided incentives for the construction of large fish processing plants to export Amazon fish products to other cities in Brazil and the exterior. These changes transformed the commercial fishery from a seasonal activity concentrating on the production of dried-salted fish during the low-water season to supply rubber tappers, to a year round activity producing fresh and frozen fish for regional, urban, and export markets in other states of Brazil and abroad. During the 1970's and 80's the commercial fisheries expanded to cover virtually the entire basin. Today commercial fishers travel thousands of kilometers between urban centres and fishing grounds up the major tributaries.

Yet the consequences of these intense changes spanning the last 40 years have not been studied to generate an integrated vision of the fishing sector. Studies of the ecology of key species have been carried out (see for example, Petrere 1978a & b, Batista 1998, Barthem 1999, Isaac *et al.* 1996) and studies on the social relationships of small-scale rural fishers were also undertaken by anthropologists (e.g., Smith 1981). Studies of the industrial fleet were also frequent (Isaac 1998, IBAMA 1994, IBAMA 1999). However, these studies concentrated on one specific aspect of the sector, such as the study of one species or on one type of fishing (subsistence or commercial). A complete view of the sector was not forthcoming.

For the fishing sector as a whole, an estimate of the economic and social impacts of the sector was attempted in a very simplified way. These estimates just multiplied total landed fish in a city, a region, or the whole Amazon by the price of the fish at first sale. This methodology underestimated the economic activity in the sector by a large amount. Firstly, it did not consider income or employment of the supporting sector such as commerce, shipyards or gas stations. Also it did not account for income or employment of other sectors such as fish markets and fish processing plants. Most importantly, very few attempts were made to estimate the total number of fishers in the subsistence and commercial sectors, or even the size of the commercial sector. This lack of information in the statistics made any comprehensive assessment impossible.

The fleet in the Amazon was not studied as a whole. Usually, studies of individual fleets were carried out for each region, creating a fragmented view of separate independent fleets. However, as the result of different habitats and capital availability between large and small cities, very different fleets have developed along the Amazon-Solimoes River. Independent studies of the fleets have shown that larger boats concentrate in large cities with capacity to fish far away from these markets, while small boats concentrated in small cities supply fish to local markets near their base. However, with the recent development and change in these fisheries, and the large area occupied by the Amazon floodplains, it is fundamental to understand the similarities and differences between the fleet through a comparative analysis.

The change and expansion of the commercial fleet has had major impacts on the subsistence fisher. With the invasion of the lakes by large commercial boats, the residents of the floodplain that used to fish with canoes near their communities, had a strong reaction to the increasing presence of the commercial boats with higher production capacity. As the number of boats increased, communities started to block their entrance into their lakes, initiating conflicts between the two types of fishers. These conflicts arose because the subsistence fisher could not legally close access to their lakes which the commercial fishers continued to enter.

As a result, during the 1990s local organizations and fishers' unions pressured the government for new legislation (McGrath *et al*. 2003) which would give the communities the right to regulate access to their resources. As a result in 1998 the federal government issued a law that allowed subsistence fishers to implement fishing agreements (this was initially a provisional measure which was later converted to Administrative Law in 2003). Through this legislation, the fishing resources in the Amazon started to be controlled by the communities.

With this law, the system moved from being an informal non-legal form of community management, not recognized by outsider fishers, to a system organized by the community and supported by a federal government law. These changes initiated, for the first time in Brazil, a community based co-management system, where the government and the community shared the responsibility of managing the resources.

The pace with which the communities have moved to co-management has varied among different communities and regions. This initiative has become most consolidated in the lower Amazon, but it has emerged in other regions of the Amazon also, both within Brazil and in neighboring countries having different characteristics. With the ability to manage their resources, small-scale rural fishers have become key agents in the design of management policies in the Amazon.

The degree to which each community applies the regulations in the agreement is not known because it is not certain that the regulations are enforced by the communities. Increases in productivity in the lakes may occur if the communities implement the rules and enforce them. To some extent this success will depend on fish migratory patterns.

In this case community co-management affects the lives of subsistence and commercial fishers. The degree to which one type of fisher affects the other is not understood but it is fundamental for fisheries management. Much has been done to study different aspect of the fisheries, but no attempt has been made to integrate different segments and evaluate the entire management system.

1.2. Purpose and research approach

The purpose of this dissertation is to analyze the changing nature and role of the commercial and small-scale rural-based fisheries of the Amazon floodplain, in order to better understand the prospects for co-management of Amazon fisheries, and to evaluate the impact of alternative management scenarios for lower Amazonian fisheries.

In particular this study aims to:

- Estimate the importance of the fisheries sector in the Amazon regional economy in terms of employment and income generation including subsistence and commercial fishers.

- Characterise similarities and differences within the commercial fishing fleet operating in the four major regional fisheries of the Amazon-Solimões river, to evaluate the impact of community management on commercial fishing activity and efficiency.

- Evaluate the impact of the community fishing agreements on household fishing and on lake fisheries to analyse the effectiveness of agreements on fishing productivity and characterise the economic strategies of floodplain fishers.

- Undertake an integrated analysis of the effects of alternative management scenarios on subsistence and commercial fisheries, that incorporates interactions between the two sectors.

Several different research approaches were employed to achieve these aims. Surveys of the fisheries, support and processing industries were carried out to quantify the overall contribution of the fisheries sector to regional economy. A survey of subsistence-oriented, managed and non-managed floodplain lake fisheries was conducted to evaluate the role of fishing in the livelihoods of floodplain residents, and the impacts of management agreements. A bio-economic model was used to integrate this information, analyse interactions between sectors, and evaluate the likely effects of alternative management actions.

1.3. Outline of the thesis

Because of the large amount of data analysed, and the different methodologies employed, initial explanations of methodologies are also provided. However, more detailed explanations of the methodologies are provided in each chapter. The project research team conducted 1680 interviews for this study. The research also analysed approximately 70,000 landings interviews with commercial fishers carried out over the last 10 years by the IBAMA/IARA/Pró-várzea projects. A summary of the number of interviews by region and by chapter is given in Table 1.1. This table also specifies whether the data used were collected by the government or for this research.

The thesis is divided into 7 chapters. The first chapter is the introduction which defines the research problem and outlines objectives and organization of the book. The second chapter reviews the literature on Amazon fisheries and provides a brief overview of the biogeographical characteristics of the Amazon basin. It also provides a socio-economic characterisation of commercial and subsistence fishers and reviews the literature on the status of regional fisheries.

Table 1.1 Objective, number of interviews, and region for each chapter in this dissertation.

Chapter	Objective	Number of interviews	Region or cities.
Chapter 3	Relevance of Fishing Sector	421 interviews with different segments of fishing sector	15 cities along the Amazon/Solimões river
Chapter 4	Characterisation of Commercial Fleet	997 interviews of different boat operators	Commercial fleet of Belém, Santarém, Manaus and Tefé
Chapter 5	Floodplain Fishers and lake management	259 household interviews	18 communities from the lower Amazon
Chapter 6	Bio-economic model simulations	Interviews (Chapters 4 and 5). Analysis of 70,000 fish landings interviews (IBAMA-1991 to 2001)	Santarém Region

The third chapter evaluates the importance of the fisheries sector within the regional economy, estimating the direct employment and income generated by fishers, fish processing plants, stores that sell fishing equipment, fish markets, and ice factories, and comparing these estimates with those for other sectors of the regional economy along the Amazon and Solimões rivers. The objective is to quantify the economic benefits generated by Amazon fisheries and compare these with the benefits generated by the logging sector under comparable conditions. To assess the importance of the fisheries sector along the Amazon-Solimões river, businesses and Municipal Fishers' Union leaders were interviewed in a sample of 15 of a total of 51 cities along the Amazon-Solimões rivers. In each city we sought to interview all businesses with the exception of fish markets where a sampling strategy was employed. Interviews were short and included questions on the number of employees, production or volume of product sold, selling prices of products, and seasonal variation in economic activity. The number of fishers and fishing boats in each city was obtained from the Municipal Fishers' Union and Coast Guard district office, respectively. The importance of the fishing sector and related activities was estimated in terms of employment, gross income and added value.

The fourth chapter presents a regional characterisation of the commercial fishing fleets of the four main regional fish markets of the Brazilian Amazon (Belém, Santarém, Manaus and Tefé). Regional fleets are compared in terms of fishing technology and the socio-economics of fishers and fishing. A model is presented to explain regional differences in catch. I also analyse returns to scale for the fleet to identify the relative economic efficiencies of larger and smaller fishing boats. Finally, based on this information, the possible responses of the commercial fleet to community management are evaluated. For this study field interviews were conducted in the four main ports along the Amazon-Solimões river, Belém, Santarém, Manaus and Tefé. Daily interviews were conducted at the main landing sites for each port, during the peak hours. Interviews followed the same model in all ports and included questions on the characteristics of the fishing vessel, and on operational aspects of fishing activities (number of fishers and canoes, ice use and fuel consumption, seasonality, etc.), as well as on the skipper's life history.

In the fifth and sixth chapters the study moves from the Amazon-Solimões corridor to a case study of the lower Amazon region fishery, site of the major experiment in formal co-management under way in the Brazilian Amazon. In the fifth chapter I investigate the impact of fishing activity and fishing agreements on floodplain households. The study consisted of two main components: First, I analyse the floodplain household economy to identify the main economic activities, and the interactions between them within the household economy. Second, differences between the fisheries of managed and unmanaged lakes are investigated in terms of catch, effort, CPUE (catch per unit of effort) and income. The sample consisted of nine pairs of communities, one that managed its lakes and another that did not, but with otherwise similar social and environmental characteristics. Detailed interviews were carried out with 259 families in the 18 communities in the 2000 low water season and the 2001 high water season. Questions covered social and economic aspects of the household and detailed information on fishing activities including fishing trips taken over the previous week. Additional interviews were carried out with community leaders in 2001 in order to determine the community's motives in establishing agreements, and to identify and name lakes surrounding each community on satellite images.

In Chapter 6 a bio-economic model, constructed by Kai Lorenzen, that integrates the socio-economic and biological dimensions of lower Amazon fisheries, was used to analyse interactions between the biological and socio-economic dimensions of the fishery. This model was used to show how changes in management and market conditions affect both fishers and fish stocks. Four specific situations were studied: 1) The proliferation of co-management agreements, leading to the exclusion of commercial fishers from floodplain lakes; 2) Charging commercial fishers for access; 3) Allowing the use of more efficient gear; and 4) Increase in prices due to market expansion after road improvements. These simulations use the data collected for analyses described in previous chapters including the ten years series of landing data, which made it possible to identify long term trends in the Santarém regional fishery. In the seventh chapter the major findings of this study are summarized with regard to each of the major issues that have been investigated here: the role of the fisheries sector in the regional economy, regional differences in the Amazon commercial fishing fleet, the role of fishing in the floodplain household economy, the efficacy of lake management, and the impact of changing management policies and market conditions for regional fisheries and subsistence and commercial fishers. I conclude with a discussion of fruitful directions for future research on Amazon fisheries and management identified in this study.

Chapter 2

Amazon Fisheries

2.1. The Amazon basin

The Amazon basin with an area of 6,869,000 km^2 is the largest drainage basin in the world. A large portion (68%) of the area is in Brazil (Barthem, Guerra & Valderrama 1995). The discharge, which constitutes twenty percent of the world's fresh water, is estimated to be five times greater than the discharge of the Zaire River, the second largest in the world.

The Amazon River originates in the Andes at an altitude of five thousand meters. The best estimate of the river length varies from 6,500 to 6,800 km if the mouth is taken to be near Balique when it reaches the Atlantic Ocean (Goulding *et al.* 2003). The Amazon originates as the Purimac River in the Peruvian Andes. It is referred to as the 'Amazon' in Peru when the Ucayaly meets the Maranon. When the river enters Brazil it is called the Solimões until its confluence with the Negro, when it is again called the Amazon river.

The Amazon basin drains the eastern and central aspect of the Andes. The average annual precipitation of 2,127 in the region results in high rates of erosion and leaching of heavy minerals that form the sediment in the Amazon. The quantity of sediment is estimated to be 0.82 to 0.93 x 10^3 tonnes/year, the third highest rate of sedimentation in the world (Barthem *et al.* 1995).

The geological structure of the Amazon basin has a large influence on the quality of the water in the rivers of the Amazon basin. Based on the underlying geological formation, the waters of the Amazon can be classified as white, black, or clear. White-water rivers have a large quantity of sediment derived from the recent geological formation in the Andes and thus have low visibility. This sediment is the source of rich nutrients for the Amazon River as well as for its 13 largest tributaries. The rich sediment also enriches the generally poor soils of the lowland Amazon. Clear-water rivers originate in the crystalline shields of Guiana and central Brazil and compared with the white water the clear water has minimal suspended sediment loads. Chemically these clear-water rivers range from acidic to nearly alkaline and are relatively nutrient-poor as little sediment is carried due to past erosion of soils from the basin. In these rivers sediments are drastically lower than in the Amazon. For example, the Tapajos River sometimes only has 1% of the average sediment concentration of the Amazon. The largest clear water rivers are Rio Tapajós, Rio Xingu, and Rio Tocantins. Black-water rivers are free of sediment but dark in colour due to the organic chemicals carried into the streams and river. The waters of these rivers have low densities of micro-organisms that are required to decompose such organic matter (Goulding *et al.* 1996). Black-water rivers such as the Negro and the Urubu have low pH (4 to 5.5) due to the high concentrations of organic compounds (Goulding *et al.* 2003, Goulding *et al.* 1996, Barthem *et al.* 1995).

2.2. The flood pulse

For a long time, the floodplain was studied either as a river, based on the river continuum concept, or as a lake. The river continuum concept suggests that a river has a continuous gradient of physical conditions from the headwaters to the mouth. Producer and consumer communities are considered to be in harmony and adapted to the physical conditions of the river and the downstream biotic communities survive on the inefficiency of upstream communities (Vannote *et al.* 1980)

The concept of the river continuum was developed for small, temperate streams but was later generalized for all types of rivers. Lakes, on the other hand, are regarded as closed systems with internal hydrological processes (Welcomme 2001).

Lakes in the Amazon floodplain were thus classified by most limnologists as closed, lentic systems with accumulating characteristics, while the main river channels were classified as open, lotic systems with discharging characteristics such as streams and rivers (Junk, Bayley & Sparks 1989).

However, floodplains neither function as lakes nor rivers. A smooth and predictable flood curve with one pronounced peak per year inundates the Amazon floodplain (Junk *et al.* 1989). The average river-level fluctuation ranges from 4 to 15 m along the Amazon. Small basins in the Andean headwaters can fluctuate even on a daily basis because of heavy rainfall. Within the Amazon Basin annual river-level fluctuations are most extreme from the middle Madeira in the East to the middle Juruá in the West. Downstream along the Madeira, average decreases progressively to as low as 2 m in the estuary. In a calendar year the peak floods are reached first in May in the Amazon near Iquitos, Peru, and in the Central Amazon, near Manaus, in June and July. Due to the low-lying terrain (mostly under 200 meters in elevation, Goulding *et al.* 1996) a huge area of Amazonia is inundated seasonally. The total area subject to seasonal flooding is estimaged at 400,000 km^2, 87% of which is flooded by the Amazon and its major tributaries. The area that is inundated varies along the length of the main channel. Near the estuary the width along the main channel can be as large as 200 km, about 50 km in the lower Amazon, and about 80 km near the Ucayali River (Barthem *et al*. 1995).

Junk *et al*. (1989) developed the concept of the flood pulse to study the floodplain. Junk *et al*. (1989) defined the floodplain as an area periodically inundated by the lateral overflows of rivers. Therefore, the floodplain comprises permanent lotic habitats (main channels), permanent lentic habitats (the perennial lakes) and floodplain (ATTZ: aquatic terrestrial transition zones). While hydrologists consider the river and floodplain to be one unit, Junk *et al.* (1989) emphasized the differences among these three habitats in the river-floodplain system as key to understanding the concept of pulse and its effects on the biotic and abiotic components.

The flood pulse influences biota in the river floodplain as it periodically connects the main channel and the permanent lakes. During flooding, nutrient cycling and the lateral exchange between river and floodplain have a larger impact on the biota than the nutrients transported from upstream. The inundated floodplain forest plays a key role in the maintenance of the diversity and productivity of fish species (Goulding *et al.* 1996). Due to the flood pulse, floodplains contain the most productive habitats of the Amazonian inland waters. The combination of flooded forest, grasslands, and algal communities sustains a diverse and abundant fish species community (Goulding *et al.* 1996).

2.3. Natural History of Amazon Fish species

About 1,700 species of fish have already been described in the Amazon but it is estimated that the number might be about 2,500 to 3,000 species (Goulding *et al.* 1996). 150 of these species are edible and about 40 are found in the markets (Soares and Junk 2000). The diversity and migratory behaviour of fish in the main channel, lakes, and floodplain are key elements in fisheries management strategies.

Species migrate because the best breeding areas do not coincide with the best feeding areas. Migration can be longitudinal, when fish migrate along the main channel, or lateral, when fish migrate from the main channel to the floodplains (Welcomme 1985).

Based on the migratory behaviour of the species, Welcomme (1990) divided the freshwater fish of South America and Africa into three categories: 1) species that migrate long distances to and within river channels; 2) species that spend most of their lives in the floodplain and are adapted to the temperature and low dissolved oxygen conditions; and 3) species that undertake short distance migration between the channel and the floodplain.

Bayley and Petrere (1989) used similar criteria to classify fish species of the Amazon into two categories: migratory and sedentary. The principal migratory fishes of the Amazon are characins (*Colossoma, Brycon, Mylossoma, Triportheus, Leporinus, Schizodon, Rhytiodus, Prochilodus, Semaprochilodus, Prochilodus nigrican)* and catfishes (*Brachyplatystoma flavicans, Brachyplatystoma vaillantii, Brachyplatystoma filamentosum, Pseudoplatystoma tigrinum, Paulicea Lutkeni*, etc.).

In most rivers fish tend to migrate once a year to spawn (Goulding *et al.* 1996), but in the Amazon most characin species migrate upstream and downstream at least twice a year. The first migration starts when the rising water inundates the floodplain. The sediment-rich water (white water) is preferred for spawning, and is thus the main nursery habitat of the migratory characins. The second migration commences when the water recedes, and continues until the lowest water levels are reached. During this period, fish move from the floodplain back to the main river channel (Goulding *et al*. 1996).

Sedentary species confined to floodplain lakes include the osteoglossids, *Arapaima gigas* and *Osteoglossum bicirrhosum*, and the cichlids such as *Cichla ocellaris*, *Cichlasoma severum* and *Geophagus surinamensis*.

2.4. Characterisation of fishing activity in the Amazon

Fishing activity in the past has been commonly classified as both subsistence and commercial. Today even the smallest artisanal fishery sells their fish surplus (Berkes *et al.* 2001) and it is very rare to find fisher groups that fish only for consumption. Berkes *et al.* (2001) divided fishery operations into two categories: small-scale fisheries, which include commercial, artisanal and subsistence fisheries, and large-scale fisheries which include commercial and industrial fisheries. Small-scale fishers usually operate in a context where management is poorly enforced and they often represent a larger proportion of the fleet in comparison to the industrial fleet. The large-scale commercial fishers or industrial fishers are characterised by having mechanized gear and sophisticated equipment. Their fleet however represents a smaller number of vessels when compared to the artisanal fleet (Berkes *et al.* 2001).

In the Amazon a more simplified version of this classification has been used. A fisher can be classified as someone who partakes in industrial, commercial, or subsistence fishing. Although the industrial fisher is also commercial, here the term commercial is used to qualify the commercial artesanal fisher. The commercial fisher has been characterised as a fisher that operates a traditional wooden motorized boat that uses a storage container to conserve fish and hires a fisher crew to carry out the active fishing activities. The industrial fisher only operates in the estuary and on the north coast of the estuary with an iron vessel and mechanized gear mainly to supply fish to the fish processing industry. A subsistence fisher carries out small-scale fishing which involves the use of a canoe and short daily trips to sustain their families (Smith 1981). Nowadays, the pure subsistence fisher is very rare; many fishers sell most of their catch. Although they maintain most of their basic fishing characteristics, these fishers have intensified their activity and started to sell their surplus which nowadays has become larger then their consumption volume (Berkes *et al.* 2001, Soares & Junk 2000).

2.4.1. Commercial fishers

Studies of commercial fisheries in the Amazon have been restricted to large-city markets, with the result that commercial fisheries have come to be strongly associated with the use of motorized boats. Isaac *et al*. (1996) define commercial fishers as those that own a boat and hire crews to do the actual fishing. Cerdeira *et al.* (2000) suggests that commercial fishers focus mainly on the capture of migratory species in the main river during the dry season and fish in the lake during the rainy season, but this is not necessarly so. Barthem (1999) includes in the commercial fisheries category the fishers of the middle Solimões who fish with small canoes equipped with outboard motors, as they supply 10 to 22% of the total catch in the urban market. Isaac and Barthem (1995) divide commercial fishers into artisanal and industrial, as they study fishing in the estuary where there is an industrial fleet. In this case they describe the artisanal as the fishers who use boats for storage and transportation of fish, while hired fishers use canoes to catch fish and only operate during certain seasons. The industrial fishers use large metal trawlers to fish in the estuary and in the ocean and usually target a single species of fish.

The characterisation of fishers changes according to country and region. Even among the regions of the Amazon, commercial fishing fleets show differences between cities. Some fleets, such as those in Tefé, use motorized canoes that supply markets of smaller cities, while others, such as those in Manaus, use large motorized boats that have more storage capacity compared to the industrial boats operating in estuaries.

In the Amazon most of the research to characterise commercial fishers in each city has been conducted by biologists interested in analysing the impact of commercial fishing on resource stocks. The first landing statistics was first collected by Petrere (1978a, 1978b) in the main market in Manaus in 1977. Based on this survey Petrere characterised fishing trips in relation to species caught, number of fishers, gears used and fishing places. Searching for parameters to explain catch, he showed that the number of fishers and fishing days explained 95-98% of the variance in catch.

Petrere's approach was later adopted by researchers in the markets of Belém (1993-96, Barthem manuscript), Tefé (1991-94, Barthem 1999), Santarém (1991, Isaac *et al.* 1996), Manaus (1994-96, Batista 1998), Manacapuru, Itacoatiara and Parintins (1995-6, Batista 1998) (Figure 2.1).

As a result, the fishing activity in each one of these cities has been characterised in terms of species of fish caught, fishing gear used, length of fishing trips, number of fishers and area of operation. Belém differs from other regions due to its location near the mouth of the Amazon and is therefore highly influenced by the estuary and marine fisheries. The flat clean bottom of the estuary and offshore allows the use of trawlers that cannot be used elsewhere in the Amazon. In upriver sites, fishery operations vary largely in the size of the fleet and type of fishing gear. All fleets however consist of a wooden boat used for storage and transport, and canoes from which the actual fishing is done.

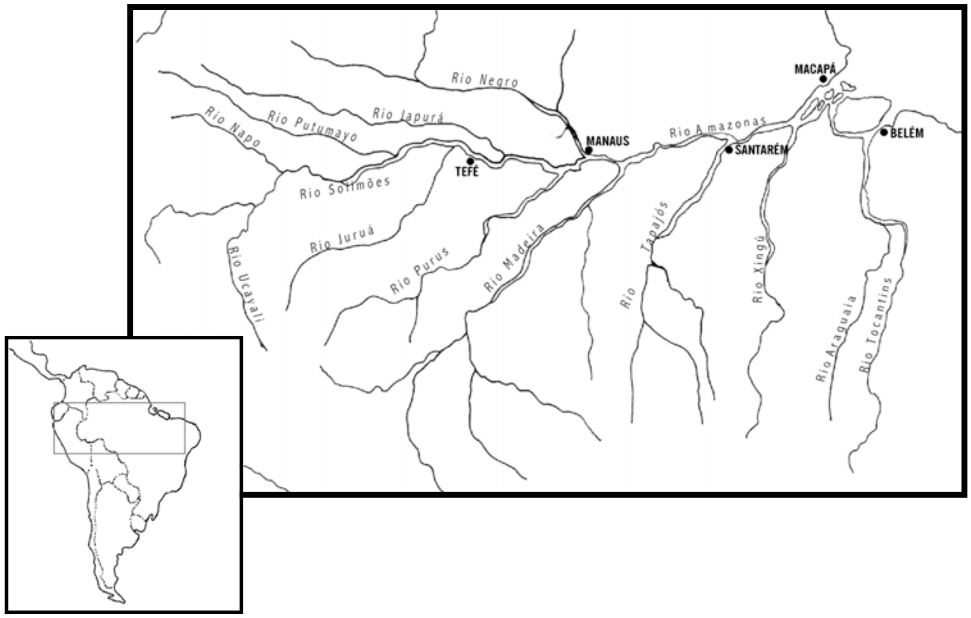


Figure 2.1 Main fishing ports in the Brazilian Amazon

2.4.2. Belém

Belém, the capital of Pará state, is a city of 1.8 million inhabitants. It is located in the estuary formed by the confluence of the Amazon River, the Tocantins River and the ocean. The location ensures the occurrence of a variety of habitats, such as river, lake, ocean, and estuary. Although estuarine areas are affected by tides, the discharge of fresh water from the Amazon River is so great that the estuarine region is largely fresh water for most of the year. However, due to their proximity to the sea, fishers harvest both fresh water and saline species. Fish, shrimp, and crab are also important in the estuary. Shrimp occur in brackish water and in the marine zone, breeding in mangrove areas and migrating to the marine waters east of Marajó Island (Goulding *et al.* 1996).

Barthem (1995) has divided the estuarine area into four distinct fishing regions: Salgado, Bay of Marajó, Mouth of the Amazon, and the North. In the Salgado region, fishing is mainly by traditional fishers in the state of Pará. Fishing is conducted largely in the winter for freshwater species, as the huge discharge of fresh water from the Amazon pushes the salt water towards the east of Pará state. Fishers in this region mainly use dragnets, trawl lines and fish traps.

The bay of Marajó is formed by the confluence of the Tocantins, Pará and Amazon rivers. The fish species assemblage changes dramatically when the water changes from fresh in the winter to saline in the summer. In this region fishers mainly use dragnet, followed by trawl line and cast net.

In the mouth of the Amazon such fresh water fish species as *Brachyplatystoma vaillantii, Brachyplatystoma flavicans* and *Brachyplatystoma filamentosum* are caught during the winter, and species such as *Carcharinus acoupa*, C. *porosus*, C. *leucas* are caught during the summer. Commercial fishers concentrate on these high value species as this region is far from the urban market (Barthem 1995).

In the Northern region, from the estuary to north of the equator, traditional, commercial and industrial fishers operate. Close to the coast, commercial fleets use large nets (2-3 km) to exploit marine and estuarine species. During the winter, when the Amazon water is high, fresh water fish, especially *Brachyplatystoma flavicans* are caught. Farther from the coast, to the north of the equator, there is an industrial fleet that exploits prawn, specifically *Penaeus subtili, P. brasiliensis and Brachyplatystoma vaillantii*. This fleet uses double dragnets on the high sea at depths of 10 to 100 m (Barthem 1995, Isaac 1998, IBAMA 1994).

Nearly 1,400 artisanal fleet vessels in the region of Belém have supplied fish to the Ver-o-Peso market. Fishing boats supplied 40% and ‘buying’ boats (boat that buy fish in the rural areas to sell in the city) supplied 33%. A large amount of the fish is supplied directly by trucks (21%) that bring marine fish from other regions of Pará State to the market. Small boats, such as canoes, supplied only 5%

of the total landings. The industrial fleet that operates in the region supplies fish directly to the fish industry in Belém, and none of it goes to the Ver-o-Peso market.

The total fish supplied to the Ver-o-Peso market varied between 8.8 to 9.5 thousands tonnes in the 1990s (Ruffino 2002). The estimated total fish supplied to fish processing plants is estimated at about 36 thousands tonnes per year (Almeida & Cabral 2004) indicating that a total of 46 thousands tonnes per year is landed in Belém. Most of the fish supplied are marine and fresh water species, such as *Brachyplatystoma flavican, Brachyplatystoma vaillantii, Plagioscion spp., Cynoscion acoupa, Arius luniscutis* and *Hoplosternum spp.* (see Table 2.1). *Brachyplatystoma vaillantii* is the most important species exploited in the estuary, and is caught intensively by both the artisanal and industrial fleet (Barthem manuscript, Goulding *et al.* 1996, Soares & Junk 2000).

2.4.3. Santarém

Santarém, located at the confluence of the Tapajós and Amazon rivers, has 150,000 inhabitants, and is one of the largest fishing ports in the Brazilian Amazon (Isaac, Milstein & Ruffino 1996). It is the principal fish market of the lower Amazon, a region that extends from the mouth of the Xingu River to the border of Amazonas State (Figure 2.1.). The annual fish catch in this region has fluctuated between 3 and 4 thousands tonnes over the last five years with half of it being landed in fish processing plants (Ruffino 1996). About 60 species are sold in the market; however ten species represent 86% of the total yield. Two catfish species (*Brachyplatystoma flavicans* and *Hypophthalmus* spp.) are the most abundant.

Fish are landed in Santarém mainly by fishing boats. While there is considerable diversity of fishing gear, ranging from gillnets to bow and arrow, gillnets of various types account for a major share of the regional catch. There is very little difference among boats in the kind of gear used and in the way it is employed. The principal unit of capture is the canoe operated by two fishers.

The great majority of fishing boats are designed for general use so very few boats have storage compartments built into the hull. Smaller boats use one or more styrofoam ice chests while larger boats use removable styrofoam lined wooden boxes. The average storage capacity of fishing boats is 1,613 kg (Isaac & Ruffino 1996)

2.4.4. Manaus

Manaus is located 700 km upriver from Santarém, near the confluence of the Rio Negro and Solimões. Like Belém, it is a city with over 1 million inhabitants. The fish yield was estimated at thirty thousand tonnes per year in 1996, but has subsequently fallen to 24 thousand tonnes annually in recent years (Soares & Junk 2000, Batista 1998). The commercial fleet of Manaus uses traditional boats similar to the ones used in Santarém but gear use varies. In Manaus most of the catch (60 to 80%) is with purse seine, while in Santarém boats that use purse seines are either from Manaus or from Óbidos. The rest of the fishing in Manaus is carried out with gear similar to that in Santarém. Up to 40% of the fish is caught with gillnet, and a smaller proportion by fishing pole (Batista 1998).

The species most important to commercial fishing are *Semaprochilodus theraponura*, *Prochilodus Nigricans*, *Mylossoma* spp., *Colossoma macropomun* and *Brycon cephalus* (Batista 1998). More than 70% of the catch comes from the Purus, the middle Solimões, the Madeira, and the lower Solimões.

Most of the fishing trips (94%) are within 600 km of Manaus, while some boats, mainly in the Juruá River, travel as much as 1,100 kilometres. In Manaus the size of the fleet is larger than in Santarém. While the mean length of boats in Santarém was about 10.2 metres (Isaac & Ruffino manuscript), in Manaus it was about 14 meters in 1996 (Batista 1998).

2.4.5. Tefé

Tefé, located 600 kilometres west of Manaus, is a city of approximately 30,000 inhabitants, and is the main market in the middle Solimões River, a region located around the confluence of Solimões-Japurá and Solimões-Juruá River. The annual fish catch in this region has fluctuated between 1,400 and 1,700 thousand kilos (Barthem 1999).

Between 59-74% of the catch is brought in by fishing boats, about 15-19% by boats without a proper wood storage container and the rest is brought by motorized canoe. Seventy percent of the fishing occurs in the lake system of Mamirauá and Jaruá (Barthem 1999).

Five species of fish constituted more then 50% of the total fish yield. The most important species caught were: *Prochilodus nigricans* (22%), followed by *Osteoglossum bicirrhosum* (14%), *Semaprochilodus theraponura* and *S. taenieurus* (11% and 7% respectively), and *Mylossoma* spp. (6.5%).

Eighty-one percent of the total fish yield was obtained by boats that used only one kind of fishing gear. Of the fish caught by boats using only one gear type, 51% percent were caught with purse seines, 32% percent were caught with gillnets, and the remainder were caught with such gears as beach nets, harpoons, cast nets, and hooks (Barthem 1999).

As in Santarém and Manaus, fishing is done by canoes. If purse seines are used 3 auxiliary canoes are used. For gillnet fishing a pair of canoes is used to fish away from the boat, returning to the boat to store the fish in ice.

In summary, Belém is the only region in the Amazon that has an industrial fleet operating in the mouth of the Amazon and offshore. There is also however a traditional artisanal fleet operating in the region and supplying fish to local markets in Belém. In Santarém, commercial fishing is carried out by boats that are used in association with auxiliary canoes and the main gear used is gillnets. Finally, Tefé and Manaus are similar with respect to species of fish caught and fishing gear (purse seine) used. However, the average size of the boat of the commercial fishing fleet in Manaus is larger than the fleet in Tefé.

2.4.6. Small-scale rural fishers

Characterising subsistence fisheries in the Amazon is more complicated than characterising commercial fisheries, as these types of fishers in the floodplain sometimes catch fish for their own consumption but also sell the surplus, and at other times sell most of the catch. Cerdeira *et al.* (2000) define subsistence fishing as that which is conducted by one or two fishers using a canoe and simple gear with the objective to catch fish for consumption. Isaac and Barthem (1995) describe subsistence fishing as being carried out with a canoe and simple gear mainly for consumption and by fishers who augment their income with other economic activities.

McGrath *et al.* (1998) divides subsistence fishers in the amazon into two groups based on the proportion of the catch that is sold. While some subsistence fishers occasionally sell surplus catch, others for whom fishing is the main economic activity sell a large portion of their catch. To characterise these two groups of fishers in the lower Amazon, McGrath *et al.* (1998) studied fishing activities in two communities, one in which fishers consume a large part of their catch and the other where fishers sold most of fish obtained. In the first community, fishing trips were short (4.2 hours) and more frequent (20 times per month) with an average catch of 7 kg trip^{-1}. These households consumed about 600 kg year^{-1} and sold the surplus (about a 1,000 kg year^{-1}). The commercial small-scale rural fishers fished more intensively than subsistence fishers. They spent an average of eight hours fishing with a canoe and obtained about 18 kg trip^{-1}. In one year fishers obtained 3,542 kg of fish, consuming about 600 kg year^{-1} and selling the rest (about 3,000 kg year^{-1}).

The gear used by subsistence fishers is similar to that of the commercial fishers. Most of the fishing is with gillnets (51%) during the high water from January to September but a significant amount (thirty percent) also use fishing rods in the floodplain. During the low water period, fishers switch to cast net and this becomes the most important gear used. However, McGrath *et al.* (1998) did not determine the thresholds in order to separate commercial from subsistence fisheries. They classified fisher communities as tending towards subsistence or towards commercial. Using these categories, they estimated that subsistence fishers sold 65% of the total catch while commercial fishers sold 85 percent.

There are differences in quantities consumed and proportions sold depending on the region. In the Mamirauá reserve, for example, the average consumption of fish is over 1,000 kg year^{-1} per household which is higher than in the lower Amazon. On the other hand, the average quantity of fish sold in Mamirauá is lower than in the lower Amazon, at about 561 kg year^{-1} (Queiroz, 1999).

The separation between subsistence and commercial fisheries when dealing with small-scale fishers is not simple and researchers have therefore classified fishers into more categories (Batista *el al.* 2000). Often there might be no noticeable difference in fishing intensity between fishers who claim to be subsistence and those that claim to be commercial fishers. Cerdeira *et al.* (1997) studied fishing communities in the Lago Grande de Monte Alegre, in the lower Amazon, and did not find significant differences in catch between families that claimed to fish to trade, and those that claimed to fish only for consumption. The lack of difference can be based on subjective individual evaluation as to whether the fishers consider themselves as one category or the other, or it can be a result of large variability in average catches per family.

For the purpose of this study however, fishers are classified as either commercial or small-scale rural fishers. The latter live in the floodplain and fish with canoes. They sometimes use specialised gear to fish in the main channel, such as the case of commercial fishers who own expensive nets that can be 5 or 10 times the value of the canoe. Commercial fishers own a boat and undertake fishing trips with a hired crew for several days. As both of them fish in rivers and lakes they compete for the same resources. They fish in the lakes during the low water season and in the river during the migration of the catfish. They also sell fish to the same market: commercial fishers sell a larger proportion and subsistence a smaller proportion of their catch.

The total fish sold by each category of fishers does not imply that the number of subsistence fishers is trivial. The population of subsistence fishers is actually much larger that that of commercial fishers. Based on an average of 2 fishers/km^2 in Peru, Bayley and Petrere (1989) estimated the number of commercial and subsistence fishers in the 1980s to be 227,600. They estimated that there are 215,000 subsistence fishers and 13,600 commercial fishers landing fish in the main markets of the Amazon. Thus 94% are subsistence fishers and 6% are commercial fishers.

The joint influence of commercial and subsistence fishers on fish stocks has not yet been studied, although this is crucial for management decisions especially due to the large impact that fisheries have experienced in recent years. The increasing number of commercial fishers, the introduction of new technology such as ice, nets, motor boats, and the increasing population of the floodplain make a study of this nature extremely important.

2.5. Stock assessment

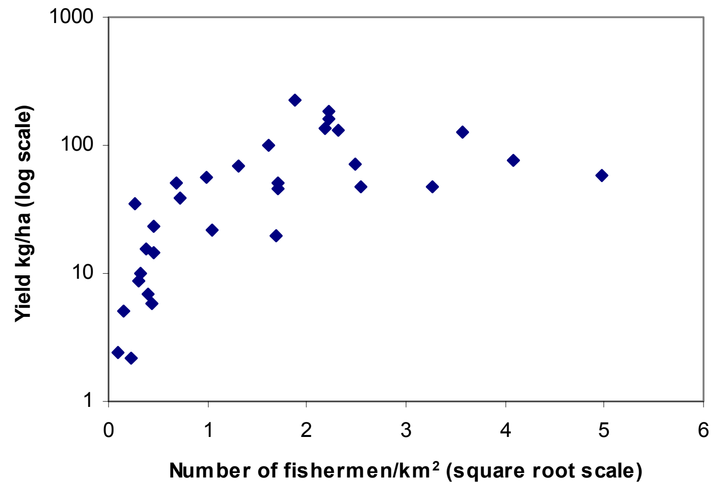
With the increase in demand of urban markets and with new technology, several researchers have evaluated the status of fish stocks in the Amazon. Using statistical and mathematical tools they have attempted to predict the effect of management strategies on fish populations. In the Amazon, assessment of stocks is difficult due to multi-species fisheries, large areas of operations, and high costs of data collection.

There are primarily three ways to assess stock. The first is an empirical method where data from similar regions can be used to estimate the potential stock of other regions. The second is based on a dynamic pool model to evaluate yield using recruitment model and stock-recruitment model. The former shows whether there is over fishing (degree of maturity of the species been caught); the latter shows whether there is recruitment overfishing (when recruitment rate is lower than mortality rate). The third method is based on production models. This method requires long-term data on catch and effort in a given region.

Due to the general difficulty of using standard models relating catch and effort in large rivers, some alternative methods have been developed. Welcomme (1985) has shown that because of the poor quality and scarcity of catch, two approaches can be adopted with the available data. First, data from individual rivers can be used to study relationships in temporal fishing patterns or the data from a set of rivers can be grouped. Analysing two data sets from the Mississippi and the Nile resulted in an inverse power linear curve relating catch and number of fishers. Since such a set of data for one river is rare, Welcomme (1985) grouped data from 16 rivers which also resulted in an inverse power curve between these two variables.

Using the same approach Bayley (1988) used data from 59 tropical fisheries to understand the relationship between effort and catch. By testing all possible combinations of untransformed, log-transformed and square-root-transformed variables, he fit a unimodal curve in the form of a second-order polynomial that conforms to a Scheafer-type relationship curve (See figure 2.2).

Using data from 6 lagoons in Africa Laë (1997) applied an asymptotic exponential model to log-transformed yield data from lagoon fisheries, introducing an inflexion point in the rising section. In this case the asymptotic level is reached without the declining yield section inherent in the Schaefer model (Figure 2.2).



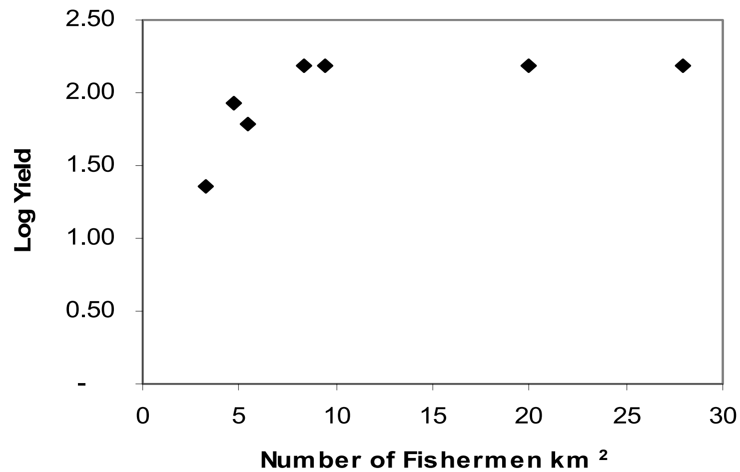


Figure 2.2 Yield (log scale) vs. effort (square-root scale for African lakes, river-floodplains and lagoons), Bayley (1988) (Top). Yield (log scale) vs. effort for 6 African lagoons (Botton), Laë (1997).

Not as much data exists for South American rivers as for African rivers so some researchers have used the empirical method to estimate potential fish yields in the Amazon, using data from other regions and comparing it with the potential total catch from the river. This was used to evaluate overall exploitation level in the Amazon.

Using regression analysis of catch, length of the river, and area of the catchment, Welcomme (1985) derived an equation to estimate the yield of tropical rivers in Africa and South America.

Based on his analysis, he estimated the yield for Latin American rivers to be 24.8 kg/ha (s=14.47) and the estimated yield for African rivers was 50.1 kg/ha (s=42.8). Since these figures are based on the catch, the lower estimate reported for Latin American Rivers probably represents a low level of exploitation relative to African rivers, rather than lower productivity (Welcome 1990).

Using Welcomme's equation, Bayley (1981) estimated the potential fish yields for five regions of the Amazon using catchments areas and length of rivers. The equation uses two criteria: one considering that less than 1% of basin area is flooded and the other using an extensive model that assumes that between 1.8 and 2.3% of the area is flooded. This author thus estimated the potential yield for the entire Amazon to be 900,000 tonnes yr^{-1}. Given that 198,650 tonnes yr^{-1}, or 20% of the estimated potential, is exploited**,** the Amazon is considered to be under-exploited.

While these results might be valid for the fisheries as a whole, they might not hold for some species. There is intensive exploitation of high economic value species such as *Arapaima gigas*, *Colossoma macropomun*, *Brachyplatystoma vaillantii*, *Brachyplatystoma flavican*, *Cichla ocellaris* and Pseudoplaystoma tigrinum. The level of exploitation of species such *as Colossoma macropomun and* Pseudoplaystoma tigrinum has been assessed using dynamic pool models. Isaac and Ruffino (1999) used the yield per recruit method in the lower Amazon and their results showed excessive fishing of *Colossoma macropomun* and a reduction in the average length of fish captured. In Tefé, Costa *et al.* (1999) also showed excessive fishing of smaller sized *Colossoma macropomun*, though the rate of exploitation was not as high as in Santarém (F=0.94/year vs. F=0.72/year).

Ruffino and Isaac (1999) used the catch per recruit model for *Pseudoplatystoma tigrinum* in the lower Amazon. They found a level of catch very near the maximum sustainable yield (MSY). Although *Arapaima gigas* is an important species, not enough studies have been conducted on this species. However, recent data from the Tefé region, a lightly exploited area, shows that the *Arapaima gigas* catch is at, or above, the MSY (Queiroz & Sardinha 1999).

Only one production model has been applied in the Amazon fisheries. They are hard to use mainly because Amazonian fisheries are multi-species. The production model was used in the estuary of the Amazon where *Brachyplatystoma vaillantii* is intensely fished by artisanal and industrial fleets to supply fish processing plants. The catch peaked in the late 1970's when large quantities of *Brachyplatystoma vaillantii* were caught (up to 29,000 tonnes) in the estuary. Data of catch and effort from 1972 to 1984 was fitted to a Schaeffer model and MSY was estimated at 19,400 t/year (Bayley & Petrere 1989). These results suggest that *Brachyplatystoma vaillantii* was overexploited from 1975 to 1979 as catches were higher than this 19,400 t/year value. Since the peak catch of *Brachyplatystoma vaillantii* in 1977, the amount is steadily falling, and from 1988 to 1990 it was below 16,000 tones (13 tones by the industrial fleet). Although at present it is believed that *Brachyplatystoma vaillantii* is not being overfished (Barthem & Goulding 1997), in 1997, the Permanent Group for the study of *Brachyplatystoma vaillantii* evaluated that the species was suffering growth overfishing in the estuary. This group recommended the increase in mesh size to 125 mm and restricting the number of industrial boats to 44.

As the production model is developed to relate catch and effort for one species, in regions where multi-species fisheries occurs it can only be used in special situations such as the fishing of *Brachyplatystoma vaillantii* in the Amazon estuary where fishing occurs in a very specialized way. The model could be used as a general indicator of the status of multi-species fisheries, but the results might not be definitive because the species is also heavily fished during its migration up river.

In Manaus the fish catch in the main market varied from 9,538 t to 14,746 between 1970 and 1974 and up to 22,322 in 1995 and 23,589 t in 1996 (Petrere 1978a & b, Batista 1998, Junk *et al*. 2000). Although the data is incomplete due to discontinuation of data collection, this suggests that Manaus fisheries have kept the total catch around 20,000 t in the last few years.

Although the evaluation of the fisheries potential of the Amazon shows that the Amazon is largely underexploited (Bayley & Petere 1989) data from the Manaus market, the Schaefer model for *Brachyplatystoma vaillantii*, and the dynamic pool models for several species show signs of overfishing of specific stocks (Soares & Junk 2000).

Table 2.1 Landing data for Manaus

Year	Tonnes	Source
1976	30,243	Soares & Junk (2000)
1977	21,652	Soares & Junk (2000)
1978	22,432	Petrere (1989)
1994	25,084	Batista (1998)
1995	22,322	Batista (1998)
1996	23,589	Batista (1998)

2.6. Fisheries Management

2.6.1. Scientific management, community management and co-management

Fisheries are difficult to manage, due to their common pool nature, the high mobility of the resource, and the often strong influence of variability in the physical system. Acheson (1989) has classified the management system in open access, government management, local level management, and co-management. When the resource is used with little management by the government or by the community, the resource is called an open-access resource. In this case the free availability of the resource generates a race between the users that can lead to depletion. This is due to the lack of property rights as each unit retrieved from the resource is an individual gain for the person that exploits while the cost is disseminated among all other users. This well known process leads to what Hardin has called, “the tragedy of the commons.”

The situation of total open access is actually very rare and the resource is usually regulated by users or government. The division of responsibilities of the management of the resource between government and fishers can be achieved through a wide spectrum of arrangements between pure state property and pure communal property regimes. State management is based on the idea that fish species management has to be managed by a central government (Pinkerton 1989). Management by the state is usually conducted by formally trained professionals based on well-received theories of human behaviour (Ostrom 1999).

This view ignores the contributions and success from community based management initiatives as an alternative to top-down centralised management (Jentoft 2000, Acheson 1989). Community management is defined as the situation when the community has the power to make decisions (Pomeroy 1995). Local management is common and exists in different variations especially in remote areas of developing countries where the government is usually absent (Acheson 1989). Recent studies have shown that over the last 20 years there have been numerous cases of community managed initiatives (Pomeroy & Berkes 1997, Sen & Nielsen 1996).

There are several arguments posed by researchers to defend community management: First it is argued that the people who depend on the resource have a great stake in protecting it. Second, the system seems more efficient and economic than management by the national government as local users can enforce rules (Ruttan 1998).

This is not to say, as many authors have suggested, that indigenous people are, or are not, in harmony with nature. This view of harmony comes from the fact that the term community is often confused with a unified and organic whole with similar ethics, religion, and language. Communities are complex entities that might not be in harmony with nature. More often than not they are heterogeneous entities and its actors have multiple interests that influence differently the decision-making process (Agrawal and Clark 2001). This is not to say that communities are completely independent from central government. All communities are in one way or another influenced by the state since they are inside the political system, but in the developing countries they tend to have more power since in many regions of these countries the presence of the government is rarely felt (Acheson 1989).

Even considering internal heterogeneity and diversity within the community, many researchers worldwide have shown that when left to their responsibilities, communities of fishers can regulate access and enforce rules of resource use in a sustainable way (Pomeroy 1995). This tendency to obtain better results with local management is because community-based resource management includes several elements such as a group of people with common interest, mechanisms for effective and equitable management of conflict, community control and management of productive resources, local systems and mechanisms for resource use (Pomeroy 1998).

While self regulation has been positive in many situations, self regulation works better when there is only one user group using the resource because groups tend to be more homogeneous. In this case they can regulate the use of the resource based on common value and rules. However, when there are other user groups that compete for the resource this mechanism can not solve the problem (Berkes 1985).

Co-management occurs through the co-operation and shared decision making among fishers, government, and other stakeholders (Pinkerton 1989). Community management system is considered to be a more appropriate, efficient and equitable system than state management as it is a decentralised system.

Co-management has arisen out of crises between government and fishers interests. In a state centralised management system, the government usually views fishers as a group that will completely exploit the fish resource unless it is strictly regulated by the government. At the same time, fishers view the government with distrust carrying on management plans based on inadequate data. Co-management has been defined by Pomeroy & Berkes (1997) "as the sharing of responsibility and authority between the government and the community of local fishers to manage a fishery". Decentralisation seems to reduce conflicts and increases participation of all stakeholders and is said to be more appropriate because it brings benefits such as decentralised decision-making and conflict reduction through a process of participatory democracy (Pinkerton 1989).

Although many works have classified or characterised these 4 system types (open access, government management, local level management, and co-management), quite often many cases will not be completely in accordance with any one definition. Also it is very common that some of these systems are evolving and not yet in a definite format. This is so because for many regions, communities or even countries, the intensification of resource use is recent and only now are users feeling the impact of open access to resources and looking for ways to regulate use.

Fisheries management in the Brazilian Amazon is a good example of such an evolving system. Generally, fisheries management has been characterised by regulation from the central government with the purpose of protecting stocks. In the past few decades of intensifying resource use, communities have started to regulate the use of the fishery resources in their lakes.

Currently there are state regulations that regulates gear, limits the size of fish caught, defines closed areas and seasons with which communities and fishers must comply; and there is regulation based on community agreements supported by the government.

2.6.2. State controlled Fisheries Management

State-controlled fisheries management with defined laws has been the traditional form of regulation in Brazil. The system has used the most common management measures used to manage fish stocks in the Amazon such as gear regulation, size limits, closed areas and closed seasons (Charles 2001).

The regulation of fishing gear is mainly aimed at size of mesh, type of gear, and the use of gear. The regulation (Decree 466/72) limits the mesh size of gillnets and cast-nets to a minimum size of of 70 and 50 mm, respectively. These rules are aimed at reducing the catch of juvenile fish to enable them to reach reproductive age.

The legislation has also limited the size of gear relative to the body of water being fished. Nets larger then one third of the width of the river are prohibited and in some rivers the use of gillnets longer than 150 m is not allowed. The law also does not allow the use of hazardous gear such as explosives and electricity.

There are also several regulations on the minimum size of fish to be caught. Legislation specifies the minimum capture size for 18 species of fish (Table 2.2). These are the largest species such as *Arapaima gigas*, *Brachyplatystoma filamentosum*, or *Pseudoplaystoma fasciatum* in the Amazon or intensively caught smaller species such as *Astronotus ocelatus*, *Mylossoma spp*, *Hoplosternum littorale*. This regulation can either be for the whole basin or for some states.

Table 2.2 Minimum size of fish that can be harvested in the Brazilian Amazon.

Common name	Scientific name	Minimum size (cm)	Region
Acará-açu	*Astronotus ocelatus*	20	Amazon basin
Aruanã branca	*Osteoglossum bicirrhosum*	44	Amazon basin
Aruanã preta	*Osteoglossum ferreiral*	44	Amazon basin
Dourada	*Brachyplatystoma flavicans*	60	PA, AP
Jaraqui (fina)	*Semaprochilodus taenirus*	20/25	Amazon basin, PA, AP
Jaraqui (grossa)	*Semaprochilodus insignis*	20/25	Amazon basin, PA, AP
Jatuarana	*Hemiodus notatus*	18	PA, AP
Mapará	*Hypophthalmus spp*	29	PA, AP
Matrichã	*Brycon melanopterus*	22	Amazon basin
Pacu	*Mylossoma spp*	30	PA, AP
Piraíba	*Brachyplatystoma filamentosum*	100	PA, AP
Pirarara	*Phractocephalus hemioliopterus*	50	PA, AP
Pirarucu	*Arapaimas gigas*	150	Amazon basin
Surubim lenha	*Pseudoplaystoma fasciatum*	80/50	Amazon basin, PA, AP
Surubim tigre	*Pseudoplaystoma tigrinum*	60	PA, AP
Tambaqui	*Colossoma macropomum*	55/65	Amazon basin, PA, AP
Tamuatá	*Hoplosternum littorale*	15	PA, AP
Tucunaré	*Cichla spp*	25	Amazon basin

There are also some closed areas defined by law. Regulation has been drafted specifically for the estuary where certain areas have been closed specifically in order to protect spawning areas. In this case the industrial fishing fleet is prohibited from fishing in the estuary between the parallels of 00 05' N and west of meridian 48 00 W and the coast line (Decree 009/83 from SUDEPE, IBAMA 1999, Ruffino & Barthem 1996). To enforce these measures concrete and iron structures that impede the use of trawl nets have been dropped in the area.

The creation of protected areas for the conservation of fauna and flora has also resulted in the closing of these areas to fishing and the subsequent protection of fishery resources. Recently many protected floodplain areas have been created, some with areas as larger as 2.3 million hectares.

A closed fishing season was established to protect species that are showing signs of overfishing. The state prohibits fishing during the spawning period of 18 species for a period that varied from 3 to 5 months depending on the species (*Colossoma macropomun*, *Arapaima gigas*, *Hypophthalmus spp*, etc). Fishing for *Arapaima gigas* has been closed from December 1 to May 31 since 1991 (Administrative Decree nº 480, 04/03/91). For species such as *Hypophthalmus spp*, *Brycon cephalus, Prochilodus nigricans, (Myleus spp, Mylossoma spp), Colossoma macropomun*, *Schizodon spp, Leporinus spp***,** etc., the closed season was from November 1 to February 28. As these regulations need to be issued each year they can be easily changed or even discontinued (Table 2.3).

Fishing effort has been widely used as an indicator of fishing intensity and has therefore been used to regulate fisheries (Charles 2001). Although it is not the sole measure for determining capture, it has been the main variable used for predicting catch. Fishing effort can be determined by number of vessels, intensity of operation or average fishing time. Therefore fishing effort could be limited by controlling the entry of boats, the capacity of the vessel, the intensity of operation and the time spent fishing. In the Amazon these measures have been adopted to regulate only the industrial fleet fishing for *Brachyplatystoma vaillantii* in the estuary. Since 1983 the number of industrial boats has been limited to 45 boats (Administrative Law 9, IBAMA 1999). This measure was adopted in the late 1970s when the number of boats was unregulated and the fishing of *Brachyplatystoma vaillantii* exceeded the estimated maximum sustainable yield.

Table 2.3 Closed season for specific species and region.

Species	Period	Region
Pirarucu (*Arapaima gigas)*	01/12 to 31/05	Amazon Basin
aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***tambaqui*** *(Colossoma macropomum)* ***curimatã*** *(Prochilodus negricans),* ***pirapitinga*** *(Colossoma brachypomum),* ***matrinchã*** *(Brycon cephalus),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica)*	01/12/1997 to 28/12/1998	Pará, Amazonas and Amapá State
jaraqui *(Semaprochilodus brama),* ***pacu*** *(Myleus spp, mylossoma spp),* ***piau*** *(Leporinus spp, anostomoides Laticeps, Laemolyta petiti, Schizodon vittatum)* ***curimatã*** *(Prochilodus nigricans),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica)*	01/12/1997 to 28/02/1998	Tocantins River and tributaries
jeju *(Joplerythrinus unitaeniatus, Erythrinus erytrinus),* ***traíra*** *(Hoplias malabaricus),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***curimata*** *(Prochilodus negricans),* ***aracu*** *(Schizodon spp, Leporinus spp),* ***aparari*** *(Astronotus ocellatus),* ***tamuatá*** *(Hiplosternum litorale),* ***cachorro de padre*** *(Anuja trachycoristes galeatus)*	01/01/1998 to 31/03/1998	Marajó Island, Amazon Basin (Pará e Amapá)
Aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(myleus spp, mylossoma spp),* ***tambaqui*** *(Colossoma macropomum)* ***curimatã*** *(Prochilodus negricans),* ***pirapitinga*** *(Colossoma brachypomum),* ***matrinchã*** *(Brycon cephalus),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica)*	01/12/1998 to 28/02/1999	Jari River (Pará e Amapá). Only Tambaqui on Amazonas State
aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***tambaqui*** *(Colossoma macropomum)* ***curimatã*** *(Prochilodus negricans),* ***pirapitinga*** *(Colossoma brachypomum),* ***matrinchã*** *(Brycon cephalus),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica),* ***mapará*** *(Hipophthalmus sp)*	01/11/2001 to 28/02/2001	Amazonas Basin (Pará, Amapá and Amazonas)
aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***tambaqui*** *(Colossoma macropomum)* ***curimatã*** *(Prochilodus negricans),* ***pirapitinga*** *(Colossoma brachypomum),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica),* ***mapará*** *(Hipophthalmus sp)*	01/11/2001 to 28/02/2002	Amazon Basin
aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***tambaqui*** *(Colossoma macropomum)* ***curimatã*** *(Prochilodus negricans),* ***pirapitinga*** *(Colossoma brachypomum),* ***matrinchã*** *(Brycon cephalus),* ***branquinha*** *(Curimata amazonica, C. inorata, Potamorhina latior, P. altamazonica),* ***mapará*** *(Hipophthalmus sp)*	04/11/2002 to 28/02/2003	Amazon Basin (Rivers from Pará, Amapá, Mato Grosso and Amazonas)
aracu *(Schizodon spp, Leporinus spp),* ***pacu*** *(Myleus spp, Mylossoma spp),* ***curimatã*** *(Prochilodus negricans),* ***jeju*** *(Hoplerythrinus unitaeniatus e Erythrinus erythrinus),* ***traíra*** *(Hoplias malabaricus),* ***tamoatá*** *(Hoplosternum spp),* ***apaiarí*** *(Astronotus ocellatus)*	01/11/2002 to 31/01/2003	Amazon Basin (Marajó Island)
pirapitinga (*Colossoma brachypomum*), **surubim** (Pseudoplatystoma fasciatum), **tambaqui** (Colossoma macropomum), **matrinchã** (Brycon spp)	01/11/2002 to 31/01/2003	Amazon Basin (Rondônia and Mato Grosso State Rivers)
tambaqui *(Colossoma macropomum)*	01/11/2002 to 31/01/2003	Acre State
tambaqui *(Colossoma macropomum),* ***matrinchã*** *(Brycon cephalus),* ***curimatã*** *(Prochilodus nigricans),* ***mapará*** *(Hypophthalmus spp)*	01/11/2002 to 31/01/2003	Rivers from Acre e Amazonas States

In general, the regulation by government has addressed one of the most critical problems of the Amazon which is the fishing pressure on specific species. However, the monitoring by the federal government to implement these laws has been weak and it is not known to what extent fishers follow the legislation.

2.7. Co-management in the Amazon

Co-management evolved from community management initiatives that were not supported by the government and was in constant conflict with commercial fishers. This initiative was started in the Brazilian Amazon as well as in some surrounding countries (Fernandez-Baca 1998, Smith 2000). Subsistence fishers have begun to take control of their lakes and define rules for resource use through what is known as community agreements, fishing agreements or fishing accords. These informal agreements generated conflicts with other subsistence fishers as well as with commercial fishers. These conflicts occurred because commercial fishers did not recognize the authority of the communities to close their lakes or define the regulation to fish in them. Based on the federal fishing regulation and on the Federal Water Code, commercial fishers argued that they had free access to lakes and river and, as long as they were complying with federal law, they were allowed to fish anywhere in the Amazon floodplains.

Local communities associated with NGOs pressured government to legalize Fishing Agreements and in 1998, the central government granted management rights to local fishers (Normative instruction in the official press, 2003). This law allowed subsistence fishers to regulate fisheries by a co-management agreement in lakes near their communities. Armed with this legislation, communities now had the power to define their fishing regulations.

According to this new law, the agreement to be made within the community must be in accordance with higher legislation and be established through a participatory process within the community. Once the agreement is approved, the community is entitled to government training to monitor the agreement, and has the power to register and report any case of infraction to the federal environmental agency.

Communities gained much power. The agreements can restrict the use of certain gear, limit the size and power of fishing boats, limit the catch by species, define fishing seasons, and other relevant measures for their lakes (De Castro 1999). With this law, the central management regulations were integrated with community management initiatives thereby initiating a co-management system in the Amazon.

The history and the intensity of co-management agreements in the Amazon have varied depending on the region or the state in which communities are located. Studies of co-management systems in the Amazon have been carried out intensively in the lower Amazon. Around Santarém where 69 community accords involving 137 communities and 100 lakes have been recorded. Half of the accords involved only one community and 32% involved two communities. These agreements regulate the use of fishing gear, season, areas of operation and type of fishing (commercial versus subsistence). Since 1992, the number of accords that regulated other activities besides fishing such as hunting, the use of grassland for cattle, and logging increased to about 35%. The most frequent rules in the agreement were seasonal restrictions (75%), gillnet bans (59%), and commercial fishing bans (56%) (De Castro 1999). Although the fishers cannot close their lakes to outsiders, the banning of gillnet makes it economically impossible for commercial boats to fish in the lakes.

In the region of Tefé, community management has evolved as a result of the creation of the Mamirauá Reserve in 1990 and the GDP (Preservation and Development Group) initiatives in 1992. The Mamirauá reserve covers an area of

11,240 km^2 near the city of Tefé and the restrictions over the use of fish resources were put in place as part of the management plan for the reserve since 1996. As a result of the restrictions, several conflicts between resident and outside fishers occurred. Queiroz (1999) reported that in less than two years there were 661 incursions by outside fishers into the focal area of the reserve (20% of the reserve area). The community-based management system in the reserve is different because the reserve legislation can be much more restrictive than the fishing-accord legislation. Community reserve management is allowed to exclude outsiders from fishing whereas this is not possible under community based co-management. In this latter case fishing regulations can be restrictive but may not exclude outsiders.

The communities linked to the GDP situated outside the Mamirauá Reserve also had the power to exclude commercial fishers from their lakes just as in Mamirauá Reserve (Oliveira & Cunha 2000). Besides this difference, there are other major differences between the lower Amazon and Tefé region management. In the Lower Amazon the fishing activity in each lake is regulated, while in the Tefé region the management system classifies the lakes as reproductive, maintenance or free lakes and manages them accordingly. Reproductive lakes are lakes designated for conservation and no one is allowed to fish there; subsistence fishing is allowed in maintenance lakes; and free lakes are unregulated. With the support of the Catholic Church these communities were able to receive approval from the branch of the federal agency for the environment (IBAMA) in the state of Amazonas.

This was done before the legislation that supported community management was adopted as a national law. Due to several fishing restrictions forbidding commercial fishers from entering lakes, there has been an increase in the number of conflicts between fishers from the community and urban commercial fishers. The expansion of community management in this region would severely impact

Tefé's fleet as they already face serious restrictions in the Mamirauá reserve and the GDP legislation.

While in the Amazon river bank the expansion of agreements is large, this is not true for the estuary. The occurrence of estuarine, marine and riverine habitats in the region gives the Belém fleet a wide range of fishing areas and habitats. Most fleets however focus their efforts in the estuary on fresh water species such as *Brachyplatystoma flavican* and *Brachyplatystoma vaillantii*. Given that few boats migrate from the estuary to fish in the lower Amazon and that community management up to now has not attempted to establish rules for the various ecosystems of the Belém Region (rivers and large bays), this fleet might not be much affected by the adoption of community co-management arrangements in the floodplain (Barthem *et al.* 1995).

There have been few studies so far on community management initiatives in the area around Manaus. Pereira (2000) studied 62 communities in the Itaquatiara area (120 km down river from Manaus) which represented management systems similar to that in Santarém. As there are no sustainable reserves near Manaus such as the one near Tefé, communities near Manaus might not find it as difficult to implement community management as in Tefé. The Tefé region experiences a higher level of conflict due to several restrictions imposed by reserve legislation, the primary cause for tensions between commercial and subsistence fishers.

The impact of government regulation on fisheries is not currently known. Community regulation has made the evaluation of management an even more difficult exercise, especially as communities can have different management systems. However, it is important to assess the impact of state legislation and community co-management on fish stocks, on local economies and on the interactions between subsistence and commercial fishers to assess the prospect of community management.

2.8. Summary

The Amazon basin is the largest river basin in the world. Nutrients eroded from the eastern side of the Andes contribute to the rich sediment water in the Amazon-Solimões Rivers. Due to the rise of the water once a year large areas of the Amazon are inundated, flooding the lower areas near the river and connecting the main river and lakes to form a single body of water. The period of inundation is known as the flood pulse. The flood pulse is the source of nutrients generated in the system which is responsible for the recycling of nutrients in the system which sustains the large fish fauna in the Amazon. Fish in the Amazon have been classified into three types according to behaviour: migratory, these are mostly catfish that migrate long distances from the estuary to the head of the Amazon system and often use the main channel; semi-migratory, that migrate short distances to spawn; and sedentary which remain mostly in the lakes. Although many researchers have suggested that fish are under-exploited in the Amazon, species with high economic value are now experiencing population declines due to over fishing.

Two types of fishers have been characterised in this region: subsistence and commercial. Based on Bayley and Petrere (1989) about 215,000 subsistence fishers and 13,600 commercial fishers in the Brazilian Amazon depend on fish. But as rural and urban populations grow, the pressure on fish resources has steadily increased.

In order to reduce the pressure on fish stocks the government has implemented such measures as defining a minimum size of catch for several species and protection of fish during spawning. In an attempt to protect fish stocks, traditional communities have excluded outsider fishers from their lakes. This initiative by communities was recently legalised by the government. The impact of community management on fish stocks and on the local economy has not yet been studied. In order to resolve the often trenchant management issues and to evaluate the prospects of community co-management in the Amazon it is critical to understand the socio-economic impact of management strategies.

Chapter 3

The fishing sector in the regional economy

3.1. Introduction

Fisheries have long played an important role in both the subsistence and trading aspects of the regional economy but this fact has rarely been recognized by the government or acknowledge by the general public because the activity does not appear as strongly as it should in the official statistics. The reason for this is probably because both subsistence and commercial fishers are scattered throughout the floodplain and since they practise other activities, such as agriculture and ranching, in conjunction with fishing they are generally registered as farmers rather than as fishers.

Nevertheless, both commercial and subsistence fishing are fundamental to the regional economy of the Amazon. Subsistence fishing is in fact the main activity in the floodplain. Most of the population residing in the floodplain fish either part time or full time. Fish have therefore become a major source of either income or protein. The commercial fisher is the other major actor in the fishing sector. Most of what is taken to the urban markets is supplied by the commercial fishers while the rest is supplied by subsistence fishers.

In the urban centres the fish are sent to two main destinations: to fish markets to sell to consumers and to fish processing plants. A significant part of what is taken to urban centres goes to the fish processing plants. In some cities, the amount of fish taken to the fish processing plant can be up to three quarters of the total. The other portion is landed in the main local landing market and distributed to the local open markets.

The subsistence and commercial fishers form the core of the fishing sector. Around these two actors there is a large network of businesses which supply ice, gas, fishing equipment, and boats.

Although important economically and socially, an estimation of the economic dimension of the sector has been given by estimating the total revenue obtained by multiplying the total landing of fish in the cities by the first price of commercialization. This estimate grossly underestimates the magnitude and importance of the sector which effectively turns the fishing sector into an invisible sector, with a size and importance in the regional economy which is largely unknown.

In this chapter the objective is to determine the true magnitude of the fisheries sector along the Amazon-Solimões river. The total income and employment for the fisheries sector will be estimated for the main activities of the sector, including fish processing plants, stores selling fishing equipment, gas stations, restaurants, ice factories, and boatyards. In addition, the total number of fishers, boats and the total catch along the Amazon/Solimões River will also be estimated.

3.2. Methodology

3.2.1. Data collection

To assess the importance of the fisheries sector along the Amazon-Solimões river, businessmen, Municipal Fishers' Union leaders and Coast Guard members were interviewed in 15 of a total of 52 cities along the Amazon-Solimões river. Cities were chosen from a stratified sample. All three cities larger than 250,000 inhabitants were selected and a random sample of 12 cities was chosen from the remaining 49 cities (Figure 3.1). In each city the aim was to interview representatives of all fish processing plants, stores selling fishing gear, gas stations, fish restaurants, ice factories, and boatyards. A slightly different sampling strategy was employed for fish markets due to the large number of individual vendors. In the two largest cities, Belém and Manaus, a random sample of markets was chosen. In the remaining cities all public fish markets were visited. In each fish market, a sample of the individual vendors was interviewed. Businesses involved in the fishing sector were identified through interviews with key informants such as presidents of Fishers' Unions, government officials, researchers, and businessmen. For activities such as boatyards and gas stations, owners were asked to estimate the proportion of their business that was attributed to the fishing sector.

Fieldwork was conducted from April to June 2001 and 436 interviews were undertaken. About 17% (n=238) of market vendors and 76% of other businesses were interviewed. Interviews were short and included questions on the number of employees, production or volume of product sold, selling prices of products and seasonal variation in economic activity. The number of fishers and fishing boats were obtained from the local Fishers' Union and Coast Guard in all cities in which they had an office.

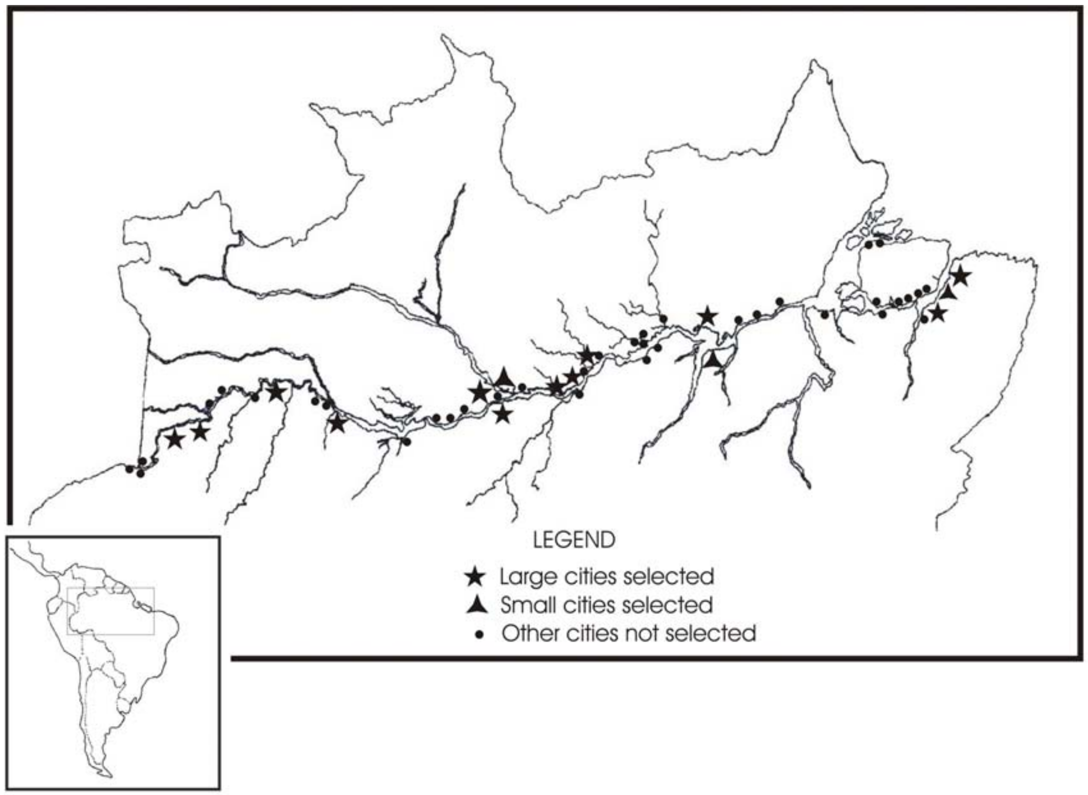


Figure 3.1 Map of cities located on the banks of the Amazon River, indicating those selected for survey.

3.2.2. Analysis

The economic performance of the fishing sector was estimated in terms of employment, gross income and added value. Gross income is the value of the goods and services in the market and is used to compare the segments in the sector (Samuelson & Nordhaus 1998).

Estimates were calculated separately for the small cities (49) and for the larger cities (3) and then added together to avoid overestimating total values, since the larger cities were not randomly sampled. Average income for each business was calculated by multiplying sales volume by price. To estimate total income, employment and number of boats per city along the Amazon-Solimões river, average income and employment were calculated for each type of business and then this value was multiplied by the average number of businesses of cities in the sample. To avoid double counting the fish several times in the marketing chain, the value of the fish sold by the commercial fleet to the fish market and to the fish processing plant, was deducted from the total income of these two segments (Table 3.1). Small-scale catch is also valued, including the value of the fish consumed, using the price of fish in the community to enhance the importance of this segment in relation to other segments of the sector (Cowx 2003, Hanley *et al.* 1997).

Table 3.1 Total interviews per type of business, average income and total estimation of annual income (in R$1) in the Amazon/Solimões River, 2001. (R$3 equivalent to US$1; Gas station and restaurant: only take into consideration the proportion linked to the fishing sector).

	Number of business (1)		Average income		Number business per city		Total Annual income of 3 large cities	Total Annual Income of 49 small cities	Total Annual income All cities
	Interviewed	Existing	Large	Small	Large cities	Small cities			
Fish Markets	238	1,366	24,241	13,803	367.67	21.92	26,737,773	14,825,394	41,563,167
Business	48	51	80,786	19,761	10.33	1.67	2,504,369	1,613,813	4,118,183
Ship Yard	7	10	150,000	119,300	1.00	0.58	450,000	3,390,506	3,840,506
Ice factory	24	26	463,987	128,570	4.00	1.17	5,567,843	7,370,918	12,938,761
Fish processing plant (2)	12	14	10,896,806	8,462,500					193,593,060
Gas station	32	36	310,905	217,441	6.00	1.50	5,596,283	15,981,883	21,578,166
Restaurant	18	22	232,574	23,628	5.33	0.56	3,718,853	648,352	4,367,205
Total	379	1,525							281,999,048

(1) Number of business interviews (Does not include interviews with the Union, Coast Guard, and Fish market managers).

(2) Of the 14 fish processing plants in the cities visited a total of 12 were interviewed. As official statistics provide the total number of fish processing plants for the two states (20) there is no need estimate using the cities sampled.

Data on fish landings in 7 cities was obtained from the literature. This data did not include landings at fishing processing plants. A linear relationship was found between the total catch landed and the population of each city. This relationship was used to estimate the total catch landed in the cities (Figure 3.2).

3.3. The fishing sector in the regional economy

3.3.1. The numbers of fishers and boats

Based on the number of fishing boats registered with the Coast Guard in each city, it was estimated that 7,531 fishing boats operate on the Amazon-Solimões river. The number of fishers in the commercial fleet can be estimated from the average number of fishers per boat. Assuming that there are 6.4 fishers per boat (based on data from Chapter 4) and 7,531 fishing boats, it is estimated that there are 48,198 fishers in the commercial fleet.

The number of subsistence fishers is important for the estimation of the total catch and total employment in the Amazon. To estimate the total number of rural families along the Amazon/Solimões River, data from the Santarém and Tefé regions were used. In Santarém there were about 198 communities and 9,876 families (De Castro 1999) on 2,683 km^2 (Pro-Várzea/PPG7) of floodplain. This gives a population density of 3.68 families/km^2. If this density is multiplied by the floodplain area along the Amazon river in the State of Pará, which is estimated at 21,720 km^2 (Bayley & Petrere 1989), we get a total of 79,930 families. For the Tefé region, it is estimated that the population of the Mamirauá Ecological Station on the Solimões river is of 672 families in an area of 2,420 km^2, giving a population density of 0.28 families/km^2 (Queiroz 1999). Multiplying that by the area of floodplain along the Solimões River, it is estimated that the total number of rural families on the Solimões floodplain is 18,166. The total for the states of Pará and

Amazonas, then, is 98,096 families. Assuming 1.14 (IARA database) fishers per household, the number of subsistence fishers on the Solimões-Amazonas floodplain is estimated to be 111,829. This added with the commercial estimate gives 160,027 total fishers.

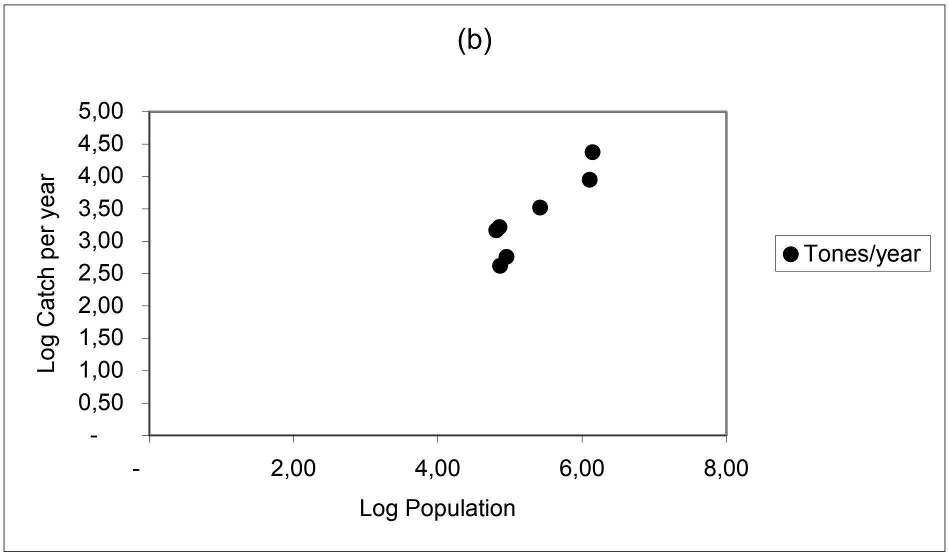


Figure 3.2 Total metric tonnage landed in relation to County Population (in log values).

Source (b): Manaus, Itacoatiara, Manacapuru and Parintins based on Batista (1998); Santarém, from Chapter 6; Tefé, from Barthem (1999); Belém, from Barthem (manuscript), Population data: IBGE several years.

Using a higher density of fishers per km^2, Bayley and Petrere (1989) arrived at a figure of 228,600 subsistence and commercial fishers in the Amazon basin in 1980. If only the Amazon-Solimões River is considered, the estimated number of fishers would be 102,870 (45% of the total). When this number is corrected for population growth during the last 20 years (IBGE various years) the present number of fishers is estimated at 146,742. Deducting the commercial fishers (48,198) from the total, we are left with an estimated 98,544 subsistence fishers, which is near the number estimated above.

Finally, based on landing data available for the regional markets of seven Amazon cities (Figure 3.2), the total volume of fish landed in urban markets along the Amazon-Solimões rivers is estimated at 46,269 tonnes (based on regression of logged catch and population of a= -1.72 and b=0.959). When the value of the catch landed at processing plants is included (37,578 tones; Almeida & Cabral 2003) the total commercial landings along the Amazon-Solimões River is estimated at 83,847 tones.

3.4. Income and employment generated

The total income of the fisheries sector is estimated at R$389 million. The main activities generating this income are fish processing plants, fishing fleets, fish markets, boatyards, ice factories, commercial establishments, gas stations and fish restaurants. However, there are significant differences in the size of each activity's contribution to total sector income and employment. Fish restaurants, businesses specialized in selling fishing equipment, and boatyards specialized in building fishing boats each contribute 1% of the total income generated by the sector. Ice factories and gas stations specialized in selling to fishing boats contribute about 3% and 6%, respectively. The activities that contribute most to the total sector income are fish processing plants, subsistence fishers, and the commercial fleet, generating 36%, 33%, and 16% respectively (Table 3.2).

The importance of fish processing plants, despite the small number operating in the Amazon, is due to their large size and high income per plant (averaging R$10 million in sales). Fish processing plants represent a large part of income generated by the fisheries sector. In 1995, for example, 20 fish processing plants landed approximately 38,000 tonnes of fish. Most of these plants (70%) are located in Belém, Manaus (and surrounding counties), and Santarém. The main species processed included the *Brachyplatystoma vaillantii* and *Brachyplatystoma flavican*.

Table 3.2 Annual income and employment along the Amazon and Solimões rivers bank, Brazil, 2001. (US$1 equal R$3 in 2004)

	Annual Income (R$)		Annual Employment		
	Total for riverbank	**%**	**Average per Business per year**	**Total for riverbank**	**%**
Subsistence fishers (a)	127,485,060	33%		111,829	66%
Commercial fishing fleet (b)	62,000,460	16%		48,198	29%
Fish Markets (c)	12,468,950	3%	1.3	2,839	2%
Commerce	4,120,027	1%	2.8	324	0%
Ship yard	3,859,594	1%	4.63	124	0%
Ice factory	12,918,190	3%	9.61	397	0%
Fish processing plant (d)	139,993,060	36%	147.47	4,044	2%
Gas station	21,578,166	6%	4.29	301	0%
Fish restaurant	4,364,332	1%	6.93	259	0%
Total	388,787,839	100%		168,315	100%

a) 111,829 families * 1,583 kg per family (based on Queiroz 1999 and McGrath *et al*. 1998) multiplied by R$ 0.72 per kilo (Almeida & McGrath 2000).
b) Consider total landing on cities (46,269 tones, see text) multiplied by the average price of Santarém, Manaus, and Belém (R$1.34; Ruffino 2002).
c) Consider 30% of the total income of fish market from Table 3.1.
d) Total income of fish processing plants estimated in Table 3.1 minus the value paid to commercial fishers (40,000 tones times the price R$1.34; Ruffino 2002 and Almeida & Cabral 2003).
e) Increase of 44% based on Bayley and Petrere (1989) - not including Bolivia and Peru.

Employment was generated mainly by subsistence (66%) and commercial fishing (29%). These categories together generated 95% of the total employment in the sector. The remaining 5% was divided between fish processing plants and all other activities.

3.5. Discussion

The results of this chapter show that total income generated by the sector, R$389 million, is almost four times greater than earlier estimates based on fish landings data and the average price at first sale (Mitlewski 1997; recalculated based on present dollar exchange rate and only for the Amazon-Solimões corridor). Fish processing plants are the major contributor to total sector income (36%), while the subsistence and commercial fishing fleets are the major contributors to sector employment (95%). The other major activity in terms of employment and income generation is marketing. Other activities, such as establishments selling fishing gear, gas stations, ice factories and restaurants, make a comparatively limited contribution to total sector income and employment, together generating only about R$60 million annually, about 15% of the total. It is likely that because of the sampling methodology employed and because some sectors such as the informal sector and supermarkets were not considered, this figure underestimates the contribution of these activities. Because it was only sampled in cities along the main river, the employment and income generated by boatyards, many of which are located on tributaries with better access to wood, are also underestimated.

The results of this analysis also confirm observations made in an earlier study; that the last twenty-five years of fisheries development have led to growth, but only partial transformation of the sector. Employment has grown with the expansion of the commercial fisheries, but is still overwhelmingly concentrated in the capture of larger fish. The low level of capitalization of the fleet is reflected in the limited employment and income generated by the activities that support the fishing fleet and by the rest of the sector. Each commercial fisher, for example, generates only 0.17 jobs in the rest of the sector (not considering subsistence fishers). While processing activities are the second largest source of employment, they are still a small fraction of the total for the sector.

The importance of subsistence fishing often goes unrecognised in terms of both its contribution to total catch, as well as to the overall floodplain economy. Employment generation by subsistence fishing is far larger than that of any other segment of the sector (66%). The total catch is also larger, with subsistence fishing accounting for roughly 57% of the total catch in the Brazilian Amazon. The relative importance of this segment as a source of employment in the regional economy is a significant factor that policy makers must be aware of when designing development policies for the floodplain (Cowx 2003, Hanley *et al*. 1997).

Subsistence fishing is also fundamental for counties along the Amazon rivers as a source of food and as a source of cash for daily household expenses. The protein obtained from fishing is by far the most important source for floodplain populations (Murrieta 1998). In the Santarém region, for example, it is estimated that the total catch of subsistence fishing is roughly two times that landed in Santarém by commercial fishing. In the floodplain, about 84% of floodplain households fish for subsistence and occasional sale (Chapter 5). In these households, fishing provides food and cash that enable these households to devote more effort to other activities, especially farming, small animal husbandry and raising cattle. The income of families that practise several activities is greater because subsistence fishers also earn income from agricultural production and from raising cattle. In the household economy fish represents 37% of total income (based on the value of the fish consumed), agriculture represents 18% and cattle represents 3%. (A large proportion also originates from retirement pensions, but those are earned mainly by older people). Subsistence fishing, then, often constitutes a critical factor in the overall viability of the smallholder economy of the floodplain.

The analysis in this Chapter also reveals the deficiencies in official statistics for the fisheries sector. Table 3.3, for example, shows employment per activity in the primary sector. According to this table there are 1.2 million people employed in the primary sector in the states of Amazonas and Pará and only 17,742 employed in fishing. However, comparison of these government employment statistics with the number of fishers calculated in this study (160,027) shows that the official figure grossly underestimates employment in the activity. See also estimates by Bayley and Petrere (1989). The difference between official estimates and reality is actually even larger because the data in Table 3.3 covers two entire states while the estimate used here is only for the Amazon-Solimões river corridor.

Table 3.3 Official statistics on occupation in primary sector activities, 1996, Pará and Amazonas State, Brazil.

	Amazon as State	%	Pará State	%	Total	%
Annual crops	203,842	58%	371,794	42%	575,636	47%
Horticulture	8,458	2%	7,323	1%	15,781	1%
Perennial crops	67,953	19%	91,743	10%	159,696	13%
Ranching	30,858	9%	175,900	20%	206,758	17%
Agriculture and ranching	7,762	2%	95,465	11%	103,227	8%
Silviculture and Forest exploitation	20,444	6%	128,766	15%	149,210	12%
Fishing and aquaculture	10,525	3%	7,217	1%	17,742	1%
Production of vegetable coal.	597	0%	5,717	1%	6,314	1%
Total	**350,439**		**883,925**		**1,234,364**	**100%**

Source: IBGE (1997)

In this regard, this study provides a basis for comparing the relative contributions that the fisheries and forestry sectors make. This comparison hinges on the relative sustainability and long-term productivity of the two sectors in municipalities where a substantial part of their total area consists of floodplain and upland forest, as in the municipality of Santarém.

To compare the forestry sector with the fishing sector, some assumptions have to be made. The total floodplain area of Santarém region is estimated at 268,300 ha (Data from Pro-Várzea/PPG7). Half of the commercial catch of 3,500 tons is landed in local markets and the other half at fish processing plants. The catch landed at local markets and consumed by the local population is equivalent to roundwood production by the timber industry as both are in the primary sector. Likewise, the catch landed at the processing industry is equivalent to sawnwood production for the region. If the catch processed by the processing industry in taken into consideration, then the total area would be 134,150 ha (consider half of the area for half of the catch). Based on present patterns of exploitation, this same area of forest would provide roundwood for 6 sawmills (134,150 ha / 242 ha / 90 year rotation cycle system; Almeida & Uhl 1995, Veríssimo *et al.* 1992) and generate an annual income of US$4 million. By comparison, the main fish processing factory in Santarém generates an annual income of R$10.5 million, almost twice that of the forestry sector for an equivalent area. Although this comparison is not quite accurate because of the existence of migratory species, it shows the enormous potential of fishery resources to generate and aggregate income. The total forested area of the Amazon basin dwarfs that of the floodplain; however, for municipalities located along the Amazon-Solimões corridor the area of floodplain can be a significant proportion of their total area, providing an income equivalent to that provided by the forestry sector.

3.6. Conclusion

The contribution of the Amazon fisheries sector to the regional economy is grossly underestimated, and consequently insufficiently appreciated by government policy makers, due to the lack of detailed data. This chapter has presented the results of a first attempt to estimate the actual magnitude of the sector in terms of employment and income generation for the Amazon-Solimões river corridor. The results of this analysis show that the income generation capacity of the sector is four times larger than those of previous estimates (Mitlewski, 1997), while direct employment is eight times that stated in published government statistics. The present study also reveals that the major contributors to sector employment are the subsistence and commercial fisheries. Fish processing plants are major contributors to sector income. The forth most important component in terms of employment and income is marketing, while the contribution of other activities, both upstream and downstream, is negligible. As these results suggest, total job creation in the sector per commercial fisher is estimated to be very low, 0.17 (subsistence fishing is not included), underscoring the manual nature of fishing activities. While the magnitude of the subsistence fishing is captured in this study, the sector's contribution to overall floodplain income and employment has not been adequately assessed, due to the absence of data on floodplain agriculture and ranching. However, data from the Santarém region indicate that it can be considerable. Finally, while at the basin level fisheries' income and employment are dwarfed by those of the forestry sector, for municipalities along the Amazon-Solimões river corridor the relative importance of local fisheries can be significantly greater than that of the forestry sector, at least for the municipalities along the Amazon River.

In conclusion, data from this Chapter shows the relevance of the fishing sector, thereby allowing policy makers to have a greater appreciation of the sector's contribution to regional income and employment in order to stimulate them to adopt policies that enhance the sector's contribution to regional livelihoods and development.

Data from this chapter also shows that commercial and subsistence fishers are the key agents in the fishing sector. In the following chapters these two actors will be characterised in more detailed.

Chapter 4

The commercial fishing fleet in the Amazon, and co-management in the lower Amazon

4.1. Introduction

In the previous chapter subsistence and commercial fishers were described as the key actors in the fishing sector of the Amazon. Based on the number of boats registered with the Coast Guard, it was estimated that there are approximately 7,531 boats on the Amazon/Solimões River. This number is actually larger because this estimate does not take into consideration the boats in the remaining 40% of the basin, although a large share of the fleet should operate in the Amazon-Solimoes river. This fleet operates in the floodplain area that comprises 2.6% of the total Amazon basin (Bayley & Petrere 1989).

Commercial fishing is carried out mainly by mobile and often urban-based professional fishers that exploit stocks in both the main river channel as well as in floodplain lakes. The commercial fishing fleets in the Amazon expanded rapidly in the 1970s and 1980s. During this period the commercial fishers increasingly targeted the same resources as the subsistence fishing communities in the Amazon and the resulting pressure on fishing resources led to widespread attempts by rural communities to restrict commercial fishing in local floodplain lakes (McGrath *et al*. 1993, McGrath *et al*. 2003).

Regulations defined in co-management agreements are legally binding for mobile commercial fishers, and are enforced by local environmental agents working in association with the Federal Environment Agency. The regulations put severe restrictions on commercial fishing in floodplain lakes through boat size and gear restrictions, and total catch limits. Despite the federal law, the commercial fishers have remained largely outside the management and decision-making processes which produce the co-management agreements. They have no formal representation in the agreements and little power to influence regulations (except where rural-based commercial fishers participate in their capacity as local residents). The further proliferation of co-management agreements will have major implications for the commercial fishing sector, and the ability of commercial fishers to respond to and engage with the co-management process will be important to the institutional sustainability of co-management as well as the future of the sector.

While the federal fisheries law applies to the whole of the Brazilian Amazon, regional differences are apparent in the institutional sustainability of agreements. This is exemplified by the levels of conflict associated with them in both the upper and lower Amazon, as described in Chapter 2. In the upper Amazon region of Tefé, co-management agreements do not involve even informal consultation with commercial fishers, and are the subject of intense conflict and frequent transgressions (Queiroz 1999). In the lower Amazon region of Santarém, on the other hand, the Fishers' Unions have become informally involved in the co-management process, and conflict and transgression are rare (De Castro 1999).

Within this context it is fundamental to analyse regional differences in the Amazon commercial fishing fleet, with particular reference to characteristics that may have a bearing on the sector's capacity to adapt to and engage with the co-management agreements. Although commercial fishing has been extensively studied in individual regions of the Amazon, as summarized in Chapter 2 (Petrere 1978a, 1978b; Isaac *et al.* 1996; Batista 1998, Barthem 1999), there has been no systematic study of regional differences. There have also been very few attempts to characterise the social aspects of the fishers (Parente 1996).

In this chapter the basic characteristics of the boats and skippers are analysed for the four main urban markets of the Amazon (Belém, Santarém, Manaus and Tefé). Then a production function is estimated and used to evaluate regional differences in efficiency and the total elasticity of scale between the regions. Results are discussed with respect to the institutional sustainability of co-management agreements and their possible effects on the efficiency of commercial fishing.

4.2. Methodology

4.2.1. Study area

Field studies were conducted in the main ports of four regions: Belém in the Estuary, Santarém in the lower Amazon, Manaus in the central Amazon and Tefé in the middle Solimões (Figure 2.1). Belém is a city with over a million inhabitants located in the Amazon estuary, formed by the Amazon and Tocantins Rivers. Santarém is located on the Amazon River, 600 kilometres upstream from Belém. Santarém is a city of 150,000 inhabitants and is considered the main commercial centre of the lower Amazon. Manaus is a city with over a million inhabitants, located on the Rio Negro, a few kilometres upriver from the confluence of the Negro and Solimões Rivers (the point where the

Amazon River originates). Finally, Tefé is a relatively small town with about 70,000 inhabitants, located on the Solimões River about 600 kilometres upstream from Manaus. Estimated volumes landed in the cities and fish processing plants by the commercial artisanal fleet are approximately 30,000 t in Belém, 40,000 t in Manaus, 4,000 t in Santarém, and 2000 t in Tefé (Isaac *et al.* 1996; Batista 1998; Barthem 1999, Ruffino 2002, Almeida & Cabral 2003).

The fishing areas associated with these ports are largely, but not completely, isolated. A small proportion of the catch is obtained from overlapping areas, and boats also may occasionally land catches in ports other than their home port.

4.2.2. Data collection

Interviews were conducted at the main landing sites for each port on a daily basis, during the peak hours of fish landing (in the morning in Belém and Santarém, at night in Manaus and both morning and afternoon in Tefé). There was one collector in each port so the boats were interviewed as they arrived to sell the fish. Interviews essentially followed the same model in all ports and included questions on the characteristics of the fishing vessel, the number of fishers and canoes, ice use and fuel consumption, the trip itinerary and duration of the voyage, catch size and composition, and the final sale price of the fish. Skippers were also asked about the number of trips undertaken in the previous month, and this information was used to scale up the catch, ice use and fuel consumption data to monthly totals. Interviews also included questions on the life history of the skippers (birth place, age, level of education, involvement in activities other than fishing), and their fishing activities (where and when fishing activities occurred, conflicts with other fishers, bank loans). Data collection covered two full years (1998 and 1999) in Belém, one year in Manaus (June 1999 to June 2000), one month each in January and June 1998 in Santarém, and October 1998 to January1999, and May to July 1999 in Tefé.

4.2.3. Description of fleet characteristics

Multiple comparisons of means with confidence limits were used to describe regional differences in fleet and skipper characteristics. A correlation matrix was used to explore relationships between variables.

4.2.4. Regional and scale effects on efficiency

Exploratory analyses were carried out to test for seasonality in input-output relationships in the fleets for which at least one full year of data was available (Belém and Manaus). No significant seasonal effects were detected and therefore all data was pooled by port regardless of season.

Production functions show the relationships between inputs and outputs given the current state of technology. In fisheries, output is the harvest and inputs are the fish stocks, capital (boat and gear), labour (quantity and quality), and consumables such as fuel and ice. In the present study, the inputs were quantified as follows: The fish stock abundance could not be measured directly in each region, hence dummy variables for fishing ports were introduced to account for possible regional differences in stock abundance. Capital inputs were described by several different measures of boat size (length, ice storage capacity, and engine power), and the type of gear used (gillnets or purse seine). Labour inputs were measured by the number of fishers employed on the boat, and skipper characteristics (age, years of schooling, and dummy variables for owner-operator or hired skipper, and for affiliation with the fishers' union). Fuel and ice inputs were measured directly.

A Cobb-Douglas production function was estimated to determine output elasticities for the different inputs, and test for regional differentiation in stock levels (Bairam 1994):

$$\ln c = \ln \alpha_0 + \sum \alpha_i \ln x_i + \sum \beta_j D_j$$

where c is the catch, x_i are the factors of production, α_i are the output elasticities of these factors, D_i are dummy variables and β_i are the corresponding coefficients. The total scale elasticity ε is the sum of the output elasticities, and the variance of ε is the sum of the variances of the factor elasticities. The production function was estimated by stepwise multiple regression.

4.3. Regional differentiation in fleet characteristics and efficiency

4.3.1. Regional differentiation in fleet and skipper characteristics

Physical boat characteristics are summarized in Table 4.1. Of the four ports, Tefé is the only one that has a significant number of canoes in the fleet. The Tefé-based fleet comprises both covered boats with inboard engines and smaller open canoes with outboard engines. Because these two boats are very different they are presented separately in the table. The Manaus-based fleet has the largest boats in terms of length, motor power, and especially ice storage capacity, while the overall boat sizes in the other fleets are similar. Fishing was carried out in all ports almost exclusively with gillnets and purse seines. Purse seines are banned in the lower Amazon state of Pará (ports of Belém and Santarém), but are frequently used in the upper Amazon. The fishing is basically modular as the main fishing boats serve to store and transport the catch, while active fishing is carried out from canoes.

Table 4.1 Key boat characteristics. Means with 95% confidence intervals. Means followed by the same letters are not significantly different.

Port	Belém	Santarém	Manaus	Tefé (Boats)	Tefé (Canoes)
Length (m)	10.0 [9.5, 10.5] A	12.1 [11.4, 12.8] B	14.4 [14.0, 14.8] C	11.8 [11.2, 12.4] B	7.9 [7.7, 8.0] D
Ice storage capacity(t)	4.8 [4.4, 5.2] A	4.3 [2.5, 6.1] B	11.1 [9.8, 12.4] C	3.6 [2.7, 4.4] B	0.5 [0.4, 0.6] D
Engine power (hp)	30 [27, 33]A	26 [21, 30]A	36 [33, 40]B	23 [18, 28]A	8.1 [7.3, 8.8] D
Number of fishers	5.2 [4.9, 5.5] A	8.6 [7.2, 10.0] B	8.2 [7.8, 8.6] B	5.7 [5.0 6.4] A	3.1 [2.7, 3.4] C
Proportion using purse seines (%)	0A	0A	49[44, 54]B	36 [22,50]C	11[4, 19]D
Catch (t per month)	2.8 [2.6, 3.1] A	5.1 [3.1, 7.1] BD	7.1 [5.8, 8.5]B	3.8 [2.1, 5.5]AD	1.6 [1.2, 1.9]C

Skippers from the four fleets showed a number of common characteristics (Table 4.2). In all regions the majority of the skippers are dependent on fishing as their main source of income, and with the exception of Belém, the majority have always worked in the sector. The level of affiliation with the Fishers' Union is also high in all fleets, with more than 50% of the skippers being affiliated. In spite of these similarities, there was a clear regional differentiation in the characteristics of skippers and crew. Some general trends are evident between small and large cities. Boats based in smaller cities (Santarém, Tefé) tend to be operated by the owner and have a permanent crew while hired skippers and temporary crew were the case for larger cities (Belém, Manaus).

Operators from smaller towns also showed the highest levels of affiliation with the Fishers' Union. The majority of fishers in the lower Amazon (53% in Belém and 89% in Santarém) are based in rural areas, while the fishers in the upper Amazon/Solimões are predominantly urban-based. Fishing is the main source of income for the majority of operators in all ports, but a far higher proportion (40%) of skippers in the Santarém region have other sources of income than elsewhere (less than 20%). Labour mobility in the fisheries in Belém port is also high.

Table 4.2 Socio-economic characteristics of fishing boat operators landing in the major ports of the Brazilian Amazon basin. Means with 95% confidence intervals. Means followed by the same letters are not significantly different.

	Belém	Santarém	Manaus	Tefé
Operator is owner (%)	33 [29, 37] A	60 [41, 79] B	34 [29, 39] A	78 [70, 86] B
Affiliated with Fishers' Union (%)	68 [63, 73] A	86 [78, 94] B	52 [46, 58] C	77 [69, 85] A,B
Uses permanent crew (%)	37 [32, 42] A	90 [82, 98] B	39 [34, 44] A	94 [83, 100] B
Fishing only source of income (%)	96 [94, 98] A	60 [49, 71] B	86 [82, 90] C	82 [75, 89] B,C
Fisher based in rural area (%)	53 [48, 58] A	89 [79, 99] B	39 [34, 44] C	25 [17, 33] D
Age (years)	37 [36, 38] A	40 [37, 42] A	40 [38, 41] A	39 [37, 41] A
School education (years)	3.1 [2.9, 3.3] A	3.0 [2.6, 3.4] A,B	3.2 [2.9, 3.5] A	2.4 [2.0, 2.8] B
Always worked as fisher (%)	32 [28, 36] A	51 [40, 62] B	78 [74, 82] C	57 [48, 66] B

In Belém, boats tend to be operated by young, professional skippers who depend on fishing for their income, but have had other previous occupations, and non-permanent crews. Interestingly, Manaus has the highest proportion of skippers who have always worked as fishers, but only a minority use permanent crew.

The correlation matrix (Table 4.3) shows the overall relationships between the various boat and skipper characteristics and catch. Overall, boat characteristics (ice storage capacity, boat length, and engine power) are highly correlated with each other, with the number of fishers employed, and with the resulting catch. As a rule, the larger a boat, the more fishers will be taken on a trip and the larger the catch which is landed. Social characteristics are less strongly correlated with each other or with physical trip characteristics, but some patterns are evident. Compared with smaller boats, larger boats are more likely to be skippered by a person other than the owner, use a non-permanent crew and be urban-based.

Table 4.3 Correlation matrix of boat characteristics and catch (log transformed). Significant correlations (p<0.01) in bold.

	Catch (t)	Fishers	Ice storage (t)	Boat length (m)	Engine power (hp)	Owner-operated	Age (years)	Education (years)	Colonia member ship	Gear	Ice	Fuel
Catch (t)	1.00	**0.56**	**0.53**	**0.46**	**0.47**	**-0.17**	0.03	0.06	0.00	**0.27**	**0.58**	**0.57**
Fishers		1.00	**0.61**	**0.74**	**0.63**	**-0.24**	**0.09**	-0.04	-0.03	**0.32**	**0.55**	**0.65**
Ice storage (t)			1.00	**0.66**	**0.64**	**-0.20**	**0.16**	0.00	-0.04	**0.30**	**0.67**	**0.64**
Boat length (m)				1.00	**0.64**	**-0.19**	**0.16**	-0.03	-0.05	**0.43**	**0.54**	**0.64**
Engine power (hp)					1.00	**-0.24**	**0.11**	0.04	0.02	**0.20**	**0.58**	**0.70**
Owner-operated						1.00	**0.29**	-0.03	**0.23**	-0.04	**-0.24**	**-0.26**
Age (years)							1.00	**-0.26**	**0.32**	0.05	**0.10**	**0.13**
Education (years)								1.00	0.00	0.00	-0.02	-0.06
Colonia membership									1.00	**-0.10**	0.03	-0.01
Gear										1.00	**0.23**	**0.21**
Ice											1.00	**0.66**
Fuel												1.00

4.3.2. Regional and scale effects on efficiency

Of the various input measures with significant correlation considered (in Table 4.3), only boat length, gear type, number of fishers, education level of the skipper, and fuel and ice quantities, were retained in the final multiple regression model (Table 4.4). The multicollinearity of the input variables (see Table 4.3) implies that the role of individual inputs cannot be clearly established, and the negative elasticity estimated for boat size must therefore be interpreted with caution. When this variable is taken out, the other coefficients do not change much. Total scale elasticity was estimated as 0.67, not significantly different from one given a standard error of 0.20. None of the regional coefficients were significant; hence there is no evidence for regional differentiation in stock levels. Boats using purse seines achieve significantly higher catches (by 28%), for the same level of other inputs, than those using gillnets.

Table 4.4 Production function parameters estimated for the Amazon commercial fleet.

Economic production function	
Coefficients	Parameter (SE)
Capital equipment	
Boat length	-0.51 (0.17)
Boat ice capacity	NS
Boat engine power	NS
Labour	
Number of fishers	0.53 (0.09)
Age of skipper	NS
Education level of skipper	0.10 (0.05)
Skipper affiliation	NS
Consumables	
Fuel	0.20 (0.05)
Ice	0.35 (0.04)
Total elasticity	0.67 (0.20)
Dummy variables	
Santarém stock level	NS
Manaus stock level	NS
Tefé stock level	NS
Gear type	0.28 (0.09)
R^2	0.43

4.4. Discussion

4.4.1. Regional differentiation in fleet characteristics

Overall the commercial fisheries sector throughout the Brazilian Amazon is characterised by a high degree of professionalism. In all regional fleets, the majority of operators are dependent on fishing as their main source of income. With the exception of the Belém fleet, the majority of boat operators have always worked in the sector. However, apart from these common characteristics the study identified substantial regional differentiation in the characteristics of skippers and crew. Boats landing in smaller cities tend to be operated by the owner and use permanent crew while in larger cities they are operated by hired skippers and temporary crew. Overall, this suggests a high degree of specialisation and a relatively low mobility of operators in the sector as a whole. Hence any changes in management are unlikely to lead to rapid entry into or exit from the sector. Labour mobility in the fisheries sector is highest in Belém, where boats tend to be operated by non-permanent crews under the command of relatively young skippers who, although presently dependent on fishing for their income, have had previous occupations outside the sector.

The majority of fishers in the lower Amazon are based in rural areas, while the fishers in the upper Amazon/Solimões are predominantly urban-based. Consequently benefits from the commercial exploitation of fishery resources accrue in the rural areas of the lower Amazon, but are effectively transferred to urban areas in the upper Amazon/Solimões.

Levels of affiliation with the Fishers' Unions are generally high, and highest in the fleets landing in smaller towns. This suggests that the Fishers' Unions can effectively represent the majority of commercial fishers throughout the Brazilian Amazon, and perhaps can act as a means of resolving conflicts in the fish agreement process.

4.4.2. Regional and scale effects on efficiency

The production function analysis indicates that there are no regional effects on efficiency that could indicate differences in stock levels. This suggests that stock levels are similar in different regions of the Amazon basin, and that observed differences in fleet characteristics are unlikely to reflect adaptations to differences in resource availability. Although the analysis uses regionally aggregated data, no relation was found between higher productivity and lengh of the trips. Data from the literature shows that in the long run the fishing up process seems to take place when effort increases too much. This process seems to start with the larger species disappearing or with reduction of fishing productivity. This has been the case for the Orinoco River where smaller species started to substitute for the larger species as effort increased. In the Oueme River, large species have completely disappeared and others have diminished in abundance to be replaced by small catfish (Welcomme 1985).

While there is no regional effect linked to stock levels, an indirect regional effect is introduced by the legislation banning the use of purse seines in the lower Amazon state of Pará, which includes the ports of Santarém and Belém. Given that the use of purse seines results in 28% higher catches for the same level of other inputs, boats operating in the lower Amazon effectively do so at lower levels of efficiency than those operating in the middle and upper Amazon. It is possible that this increase in efficiency can include also an increase in regional fish abundance since density of small-scale fishers in Santarém is much higher than the density in Tefé (3 vs 0.25 fisher per km^2).

No significant scale effects on efficiency were detected. This may be expected given the technology used and the modular nature of the fishing. Larger fishing boats carry more fishers and canoes, but otherwise use the same technology as the smaller boats. On the other hand, larger boats tend to operate over larger areas and may be better placed to respond to spatio-temporal variations in resource availability. Overall, the current results indicate that there is no efficiency advantage for larger boats; but this conclusion must be interpreted with caution as the standard error of the elasticity estimate is fairly large.

4.5. Implications for co-management

Many of the fleet characteristics and their regional differences reported above have implications for the ability of the commercial fishers to respond to and engage with the co-management agreements. Overall the commercial fishing sector is characterised by some labour mobility as 32% to 51% of the fishers have worked in other activities in Belém and Santarém. At the same time most boat owners depend on fishing as their only source of income. However, it can be expected that most commercial fishers will remain in the sector even though their activities will be increasingly restricted by the proliferation of co-management agreements. The constructive engagement of commercial fishers in the co-management process is therefore important to minimise negative impacts on their livelihoods that could exacerbate conflicts and threaten the institutional sustainability of co-management. The high level of affiliation of commercial fishers with the Fishers' Unions suggests that these institutions would be well placed to help with conflict resolution.

The commercial fleet could have many responses to community co-management. As many agreements restrict the size of boats allowed to operate on floodplain lakes, a possible response would be for commercial operators to switch towards smaller boats. Constant elasticity suggests that such a change would be neutral with respect to the economic efficiency of fishing.

As mentioned in the introduction of this chapter, there appear to be regional differences in the levels of conflict associated with the agreements, and therefore with their institutional sustainability. Given the lack of regional differentiation in resource availability, the higher levels of conflict observed in the upper Amazon cannot be explained by greater resource scarcity. However, substantial differentiation in certain fleet characteristics may, at least in part, explain the different levels of conflict. Conditions in the lower Amazon region of Santarém are in many ways the most favourable for the institutional sustainability of co-management systems. The majority of commercial fishers are rural based, i.e. part of communities that may instigate co-management agreements or have already done so. By virtue of their place of residence, these commercial fishers have a say in local agreements and may reap benefits from increases in local resource abundance that may partially compensate for access restrictions elsewhere. Moreover, commercial fishers in the Santarém region have a high level of affiliation with the Fishers' Union, which is informally involved in many local agreements. A comparatively high proportion of operators have sources of income other than fishing and may therefore be more able and willing to change their fishing effort and practises than the more strongly fisheries-dependent operators elsewhere.

Conversely, commercial fishing in the upper Amazon has remained the preserve of urban-based fishers who stand to gain little from co-management agreements that serve primarily to restrict their access to floodplain lakes. Hence opposition to the agreements and transgression by commercial fishers may continue to threaten the institutional sustainability of co-management in the upper Amazon (Oliveira & Cunha 2000, Queiroz 1999). However, both sides may stand to gain from constructive engagement. The dominant contribution of urban fishers to commercial landings also implies a low level of rural participation in fishing as an income-generating activity. Consequently, rural fishers may not realize the full economic benefits which may be obtainable from increased control over fishery resources. The inclusion of commercial fishers in management agreements, possibly with some form of access to the resource and profit sharing between commercial fishers and local communities, may generate benefits for both groups. The Fishers' Unions could play a key role in the further development of co-management agreements, but this would require a more flexible and less confrontational approach by both local communities and the Unions.

Evaluation of the positive and negative aspects should take place, and should be fed back into the co-management system. From the point of view of the communities, they are better off if no commercial fishers enter their lakes. If community management expands, however, and the lakes are closed to commercial fishing then commercial fishers would have three possible choices: leave the fishing business; move the location of their fishing to the rivers; or initiate some kind conflict over the issue. At present, the co-management agreement in the Amazon is an ongoing experiment that has to have its impact on the fish stock, and on the commercial and subsistence fishers, evaluated, to determine its effectiveness as a management system. This change in resource access would centainly also cause an impact on the structure of commercialization in urban centres with a possible reduction in fish supplied by the commercial fisher and an increase in fish supplied by the small-scale fisher. Presently the small-scale fishers take fish to the urban market either using a passenger boat or by selling their fish to the buying boats that travel to rural areas.

Chapter 5

Small-scale rural fishers and co-management in the lower Amazon

5.1. Introduction

In this chapter a detailed analysis of subsistence fishing will be developed for the lower Amazon. Fishing is generally considered as a sectoral activity and this is adequate when dealing with groups such as commercial fishers who have fishing as their main activity. However, small-scale rural fishers usually practise a diversified livelihood strategy which involves several activities such as agriculture, ranching, and small animal husbandry, among others. They do this to reduce risk and to adjust to the seasonal availability of resources and the cyclical fluctuation of stocks (Allison & Ellis 2001). In the Amazon, these activities are concentrated during the low water period. In this dry season they practise agriculture on the levees, which is labour intensive, and release their cattle on the emerging grasslands near the lake, which is somewhat labour extensive. This is also the period in which the fishing is most productive, so most of the activities need to be carried out at this time. Before the decline in the price of jute, small holders would plant this crop at the beginning of the rainy season so that it would be ready to harvest at the time when the waters are rising, a period with low activity and therefore suitable for harvesting other crops.

With the decline in the production of jute, the high water period became very unproductive (McGrath *et al.* 1993) and subsistence-oriented fishing became the main activity. At the same time the commercial fishing fleet increased because of the expansion of urban markets. As a result of the increasing pressure on fish resources community-based management initiatives aimed to reduce pressure on the fish stocks and raise the productivity of lake fisheries by limiting exploitation by larger commercial boats, often from outside the area, as well as by local fishers (McGrath *et al.* 1993, De Castro 1999, Oliveira & Cunha 2000, Pereira 2000, Smith 2000). Community based management expanded as an initiative of communities to regulate fishery resources. As one of the main initiatives was to close lakes to outsiders, community management conflicted with the federal water code and, therefore, was not accepted by commercial fishers. As a result, a law was passed that transformed the regulation by the community based management to a co-management system partially supported by the government (see Chapter 2 for a definition).

Despite the widespread support for co-management agreements among local communities, and governmental as well as non-governmental conservation organizations, the effectiveness of the agreements in raising productivity and conserving resources has not been rigorously evaluated. A number of recent studies have focused on the socio-economic context and on institutional aspects of the fishing agreements (McGrath *et al.* 1993, De Castro 1999, Oliveira & Cunha 2000, Pereira 2000, Smith 2000) but no quantitative study has been carried out on this subject. Among the factors that may limit the effectiveness of the system are the difficulties of setting and enforcing appropriate exploitation limits, and the migration of stocks between managed and non-managed areas.

The present analysis aims to provide a rigorous evaluation of the productivity and conservation benefits of co-management agreements in the lower Amazon, based on a replicated field survey. First, a descriptive data analysis of household livelihood is made to evaluate the importance of fishing activities in the household economy. Then, the comparison of catch, effort and productivity, between communities with and without co-management systems will be used to see if there is any difference in the outcomes between these two types of communities. Finally, an empirical yield model is derived to assess the relationship between local fishing effort and yield, and the impact of exploitation by external commercial boats on non-managed lake fisheries.

5.2. Methodology

5.2.1. Data Collection

This study was designed as a replicated, paired comparison of fishing effort and catch between communities with established and successful co-management agreements, and communities without such agreements. At first, nine communities with established, successful co-management agreements were selected from a list of registered agreements. Successful communities were chosen considering only communities where co-management was perceived by community leaders, by the the commercial fishers' union, the federal environmental agency (IBAMA), and NGOs alike, to be successful – typically on account of a defined set of regulation that was generally respected by the community and because they had a monitoring system that worked. For each such community with a co-management agreement, a similar local community without a functioning management agreement was selected for the paired comparison. Pairing was based on similarity in terms of geographical proximity, dominant land type (upland or floodplain), and the size of lakes in the vicinity of the community (Figure 5.1).

Detailed interviews were carried out with 259 families in 18 communities during the period of October to December 2000 (low water season), and again during July 2001 (high water season). Questions covered general household, social, and economic aspects, detailed information on fishing activities carried out and catches obtained during the previous week. Additional interviews were carried out with community leaders in most of the communities with co-management agreements in order to establish their motivation for setting up the agreements.

5.2.2. Analysis

Descriptive statistics were used to provide an overview of community characteristics and perceptions of management success. Fishing effort expended with different gear types was standardized to units of gillnet soak time, based on within-lake comparisons of catch per unit of effort (CPUE). Gillnets were more productive than other types of gear and the fishing effort of each fishing trip with rod and line and castnet was multiplied by 1.2. Household effort and catch samples were averaged for the two periods, scaled up to a full year and adjusted for the number of families in each community. Paired t-tests were used to compare fishing effort, catches and CPUE between households in communities with and without co-management agreements. Total fishing effort and yield per unit area were determined for a subset of lakes (both managed and non-managed) where the lake area could be clearly defined and fishing was carried out predominantly by communities covered in the survey (i.e., excluding lakes shared by communities for which no data was available).

An asymptotic yield model, similar to that proposed by Lae (1997), was fit to the data collected (22 lakes) to evaluate the relationship between yield, local fishing effort and management status:

$$\mathrm{Log}_{10}(y_i) = \mathrm{Log}_{10}(y_{max})\,(1-\exp(-a\,f_i)) + b\,m_i$$

Where

y_i is the yield of lake i

f_i is the fishing effort in lake i

m_i is the management status of lake i (managed =0; non-managed =1)

y_{max} is the maximum (asymptotic) yield

a describes the steepness of the yield curve

b is the coefficient of management status

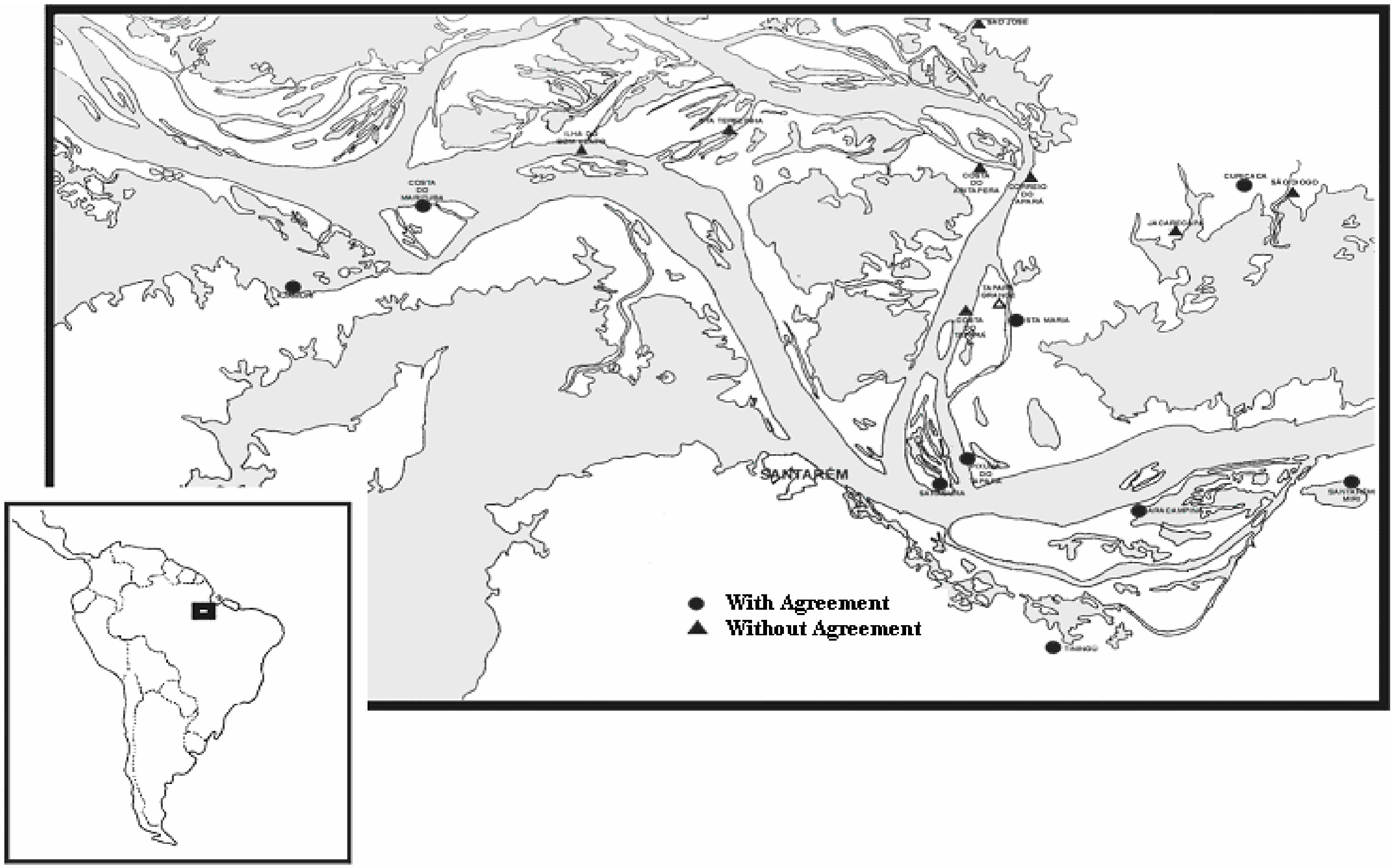


Figure 5.1 Map showing selected communities with and without agreements in part of the lower Amazon.

5.3. Co-Management in the lower Amazon

5.3.1. Description of communities and households

The families in the survey were quite well along in their life-cycle. The average ages of the heads of households were high, 48 for men and 44 for women, possibly because children migrate to urban centres to attend high school. The families were predominantly Catholic with only 12% belonging to a Protestant evangelical faith. Women had an average of 3.5 years of schooling and men 3 years. They had an average of six children with an average age of 18. The great majority of families (76%) had one property, with another 22% having two properties, and only five families having three properties (2%). Of the 24% of families with two or more properties about two thirds were floodplain families that also owned land upland areas and the remaining third were families from upland areas that owned land on the floodplain.

The main economic activity of the families interviewed can be grouped into six categories: fishing, farming, government benefits, cattle ranching and salaried employment (Table 5.1). Of these, the most important as a source of income was fishing, followed by government benefits, farming, cattle ranching and salaries. Small animal husbandry is widely practised but on a small scale and almost exclusively to complement family subsistence.

Table 5.1 Frequency of activities practised by the sample households

Income Source	Frequency
Fishing	84%
Farming	81%
Government benefits	60%
Cattle ranching	45%
Salaries	16%

5.3.2. Fishing

Fishing was the most widely cited source of income and was practised by 84% of the families in the sample. Most fishers fish from dugout canoes, either singly or in pairs, and use a wide variety of gear types of which gillnets, cast nets and fishing poles are the most important. On average, families fish three times a week. Fishing effort varies relatively little between dry and flooded seasons. Fishing trips average four to five hours, and the catch per trip is 6-7 kg which gives an average CPUE per hour of fishing of 2.4kg/hr in the dry season and 2.3kg/hr in the flood season. On an annual basis a family catches an average of 1,178 kg. Assuming a family consumes 600 kg of fish per year (McGrath *et al*. 1998), the total weight of fish available for sale is estimated at 578 kg/year. Most families sell their catch in the community. Using the average price paid by community fish buyers (R$0.75 per kg.), the cash income from fishing is R$434/year. If subsistence catch is included, then the value of the total catch is R$884 (Table 5.2).

Table 5.2 Catch, CPUE and income from small-scale fishing in lower Amazonian communities.

Calculation	Value
Number of families which fish	216
Number of fishing trips per week	2.9
Hours fishing (dry and flooded season)	4.31-4.98
Kilos per trip (dry and flooded season)	6.85-7.37
CPUE (dry and flooded season)	2.42-2.33
Total catch year per family (kilos)	1,178
Average price paid by fish buyer	R$0.75
Total value of catch per family	R$884

A small proportion of families own motorized boats which enable them to travel farther and store larger catches. Boat owners employ other fishers and pay them in proportion to how much they catch. They represent only 7% of the families sampled.

5.3.3. Farming

Farming is the second most frequently cited economic activity. The main crops planted on the floodplain are beans, corn, watermelon and manioc (cassava). Beans are planted by 56% of families, corn by 40%, watermelon by 39%, and cassava by 29%. The remaining crops, squash, tomato, cabbage and green pepper, which with the exception of squash are fairly new to the floodplain, were planted by only 7% of families (Table 5.3).

Table 5.3 Area planted per type of crop per family, lower Amazon, 2001.

Crops	% Planted plots (Sample)	% of the families	Average Area (Ha)	SD ha
Beans	33%	56%	0.30	0.43
Corn	23%	40%	0.20	0.23
Watermelon	23%	39%	0.42	0.41
Cassava	17%	29%	0.22	0.29
Squash	1%	2%	0.11	0.07
Others	3%	5%	-	-
Total	**443 plots**	**259**		

The total area per smallholder was surprisingly large by Amazon smallholder standards, averaging 0.75 hectares for farmers living on the floodplain and 0.38 hectares for farmers living on the adjacent upland areas. The area per crop varied according to the crop, ranging from 0.43 hectares for watermelon to 0.11 hectares for squash.

While the area planted is large, crop diversity is quite low. Most families (73%) specialize in one or two crops with another 22% planting three crops. Only a tiny fraction of farmers (4%) plant more than three crops (Table 5.4). Farmers market much of their harvest, with the proportion sold ranging from 93% for beans to 63% for cassava, and the same proportion for corn.

Table 5.4 Number of crops planted per family, lower Amazon, 2001.

Number of Crops	Number of families	%
1	79	37%
2	77	36%
3	46	22%
4	6	3%
5	3	1%
Total	**211**	**100%**

While beans are the main commercial crop, in terms of the number of farmers who plant beans and the proportion of the crop which is sold (Table 5.4 & 5.5), watermelon provided the most important income per family, accounting for 43% of total agricultural income in the year of the survey (Table 5.6). The next two most important crops from a commercial standpoint are cassava and beans, contributing 23-21%, respectively. Finally, corn is the fourth most planted crop in the sampled communities. Other crops, such as green peppers, cabbage and squash, account for only 5% of the value of crop sales (Table 5.6).

Table 5.5 Average agricultural production and sales by crop per household, lower Amazon, 2001.

Crop	Number	Production (a)	Quantity Sold	% Sell / production
Beans	74	478	444	93%
Watermelon	51	1,653	1,390	84%
Cassava	34	2,681	1,699	63%
Corn	24	932	590	63%

(a) All production is in kilos with the exception of watermelon which is in numbers of fruit.

When the value of the total production per crop rather than total number of families is considered, beans fall slightly in importance in relation to cassava. This is due to the fact that a larger area of cassava is planted by families either to sell or to consume. Farinha (flour made from cassava) is, along with fish, the main staple of the local diet. In the same way a significant proportion of the corn crop is fed to farm animals.

Table 5.6 Total agricultural production and income of sampled families, lower Amazon, 2001.

Crop	Total Hectares	Value of Production	%	Value of Sales	%	% Expected Production
Watermelon	22.7	56,608	39%	49,623	43%	63%
Cassava	13.7	41,375	29%	26,704	23%	73%
Beans	26	26,137	18%	24,665	21%	49%
Corn	10.0	13,006	9%	8,099	7%	74%
Cabbage	0.4	2,508	2%	2,508	2%	
G. Pepper	0.2	1,800	1%	1,800	2%	
Squash	0.6	1,560	1%	880	1%	
Rice	0.2	1,197	1%	363	0%	
Tomato	0.3	305	0%	305	0%	
Total		**144,496**	**100%**	**114,947**	**100%**	

It is important to note that the total value of production presented here is underestimated because of the excessive rain in the year of the survey. The rain had a large impact on the production of beans and watermelon, the harvests of which were 49% and 63%, respectively, from the expected (Table 5.6).

5.3.4. Cattle ranching

Cattle ranching has long been practised on the floodplain and in recent decades it has become increasingly prevalent, especially among small-scale ranchers. Almost half (45%) the families in the sample raised cattle. Herds are small and while the average owner has 20 animals (Table 5.7), this figure is skewed upwards by the small number of farmers (8%) with more than 100. Half of those with cattle have fewer than 17 animals and these ranchers account for only 17% of the total herd.

Table 5.7 Small-scale cattle ranching, lower Amazon, 2001.

Calculation	Value
Families with cattle	116
Number of head owned by family	20
Number of head owned & shared	36
% of sample	45%
Value of sales (2000)	R$613
Percent families sold cattle in 2000	10%
Percent of families sold cattle in 1999	12%

Partnerships are an important institution among Amazon cattle owners and 63% were involved in a partnership. Of those in partnerships, 70% had only one partner, 15% two partners and 14% three or more (Table 5.8). The average herd size for partnerships involved 16 animals per family. Almost half the partnerships involve friends and the other half involved relatives. The conditions of partnerships are fairly uniform. Partnerships include the owner of the cattle and the partner who raises them. The partner raising the cattle usually covers most of the maintenance expenses of the herd and divides any calves equally with the owner of the shared animals. Partnerships usually have a fixed duration at the end of which the partner returns the original animals to the owner and the two divide any calves produced during the period.

Table 5.8 Number of partners and animals per partnership, lower Amazon.

Number Partners	Total	%	Average Number Head
1 Partners	51	70%	25.67
2 Partners	11	15%	7.67
3 Partners	5	7%	15.00
4 Partners	4	5%	19.00
5 Partners	1	1%	2.00
6 Partners	1	1%	36.00
Total	**73**	**100%**	

As one would expect given the small size of cattle herds, the total income from cattle sales is low. Only about 10% of families with cattle sold animals in 2000 and roughly the same proportion (12%) in 1999. With the exception of one owner who sold 50 animals, the number sold by those who did sell cattle was small, ranging from one to six. The average value of sales for these families was R$613 per year. The income from this activity was usually used for larger expenses such as purchasing of land, boat, or house, but many times for families' regular expenses or maintenance of the herd.

5.3.5. Small animal husbandry

Small animal husbandry is widely practised by floodplain farmers. While it is negligible as an income source, it can be an important source of animal protein, especially during periods when fish are scarce. Most of the families (88%) raise chickens with an average of 25 head per family. Families consume about 4.2 chickens per month in the flooded season and 2.4 per month in the dry season. Considerably fewer families (27%) raise ducks, which are raised in smaller numbers, and less than 10% of the sample raise pigs. These are consumed much less frequently, averaging one pig every three or four months. While about two thirds of the sample raises just one type, another third raises two types of animals (Table 5.9).

Table 5.9 Number of families raising small animals (the same family can raise more than one type), lower Amazon, 2001.

Animals	Number Families	Average Head	Consume per Month - Flood	Consume per Month - Dry
Chicken	227	25	4.2	2.4
Duck	69	12	3	3
Pig	31	9	0.31	0.4
Others	4			
Total	**331**			

5.3.6. Food exchange

The exchange of food between families is also an important practise. Around 69% of the families interviewed said they had given some kind of food, while 41% said they had received food. The main food item exchanged was fish, followed by farinha (cassava flour). Most exchanges are between neighbours and close relatives. Food exchange between families, especially of perishable items such as fish, is a way of dealing with temporary excess when people do not have refrigerators. In the process excess food is turned into credit while at the same time strengthening relations with friends and relatives.

5.3.7. Government benefits and salaries

Government benefits were received by about 60% of the sample. Five different types of benefits were identified. The most important were retirement benefits received by 44% of families, followed by unemployment benefits (8%) and health benefits (6%). Another 3% received either pensions or maternity leave. In terms of income, retirement benefits were the highest at R$1,937/year. Unemployment insurance was received by some fishers who were affiliated with the Fishers' Union, as compensation for the three month closed season, and was equivalent to three minimum salaries or a total of R$444 (see Table 5.10).

Salaried employment was held by members of 21% of the families in the sample. The three main types of salaried employment available in floodplain communities are teachers, health agents for the municipal government, and cowboys on neighbouring ranches. Salaries ranged from one to two minimum salaries per month and averaged R$2,111/year, the largest average income source received by floodplain households (Table 5.10).

About a third of families received more than one kind of government benefit or salary and another 5% had three or more sources of income. The average income of families that received two incomes was R$3,692 per year, or double that of one-income families.

Table 5.10 Types of government benefits and salary, in lower Amazonian communities, 2001.

Type of Income	Total	%	Total Annual Income per family
Retirement	114	44%	1,937
Salary	41	16%	2,111
Unemployment	22	8%	444
Health Benefits	15	6%	1,393
Pension	3	1%	1,812
Maternity Leave	2	1%	-
Total Interviewed	**259**		

5.3.8. Household and regional income

The average annual income for households is estimated at R$2,577 or R$215 per month, about 1.4 minimum salaries for one year. This estimate uses the value of farm production and fish catch rather than that of sales, and considers subsistence consumption to be part of income. If the volumes of fish and farm products consumed were subtracted the total would be somewhat less. Of this total the largest income source is that of fishing, which contributes 31%, about the same as government benefits, followed by agriculture (18%) and salaried employment (10%). Average income from cattle was only 3% of the total, but increases in the capital value of the herd were not accounted for. Fishing, farming and cattle ranching are considered the productive activities and account for 52% of household income, with government benefits responsible for about one third.

Scaling up to the community level, the average community in the sample has 71 households. In total there are 170 communities or 8,759 families on the floodplain in the Santarém area. Total income for the floodplain population is estimated at R$25 million, of which productive activities account for around R$13 million. The total regional fish catch for these families is estimated at 10,321 tons for a total value of R$7.7 million (Table 5.11).

Table 5.11 Total annual income by type of activity, lower Amazon, 2001.

	Region	%
Government Benefits	8,577,304	31%
Fishing	7,740,679	31%
Agriculture	4,804,805	18%
Salaries (Gov & Non-gov)	2,877,357	10%
Cattle	889,423	3%
Total	**24,889,568**	**100%**
Primary Activities	**13,434,907**	**54%**
Population (families)	**8,759**	

5.3.9. Interaction among activities

Some studies have argued that there is a clear relationship among activities with agriculture increasing when fish productivity increases, but in this region activities are not necessarily interrelated. Using only the variables that show significant correlation with fishing, a linear regression of log of income and social variables showed that there is a significant relation between fishing and agriculture and number of children but no relation with cattle, number of boats, income from salary and retirement and age of husband (all log transformed). Nor was significance found between these variables and the families that lived in upland or flooded areas (Table 5.12). Probably a more instensive study focused on these aspects is necessary to understand how the various activities are practised to maximize benefits.

Table 5.12 Regression of fishing with income and social variables (log transformed; total fish income as dependent variable; R^2=0,290).

	Coefficients	SE	Sig.
(Constant)	6,376	2,347	0,007
Agriculture Value (LN)	0,148	0,058	0,011
Number Children (LN)	0,817	0,358	0,023
Salary (LN)	-4,83E-02	0,058	0,405
Retirement (LN)	-3,26E-02	0,058	0,572
Cattle sell (LN)	-7,41E-02	0,064	0,247
Age Husband (LN)	-0,842	0,686	0,221
Location in Floodplain	-0,482	0,34	0,158
Own a boat	0,394	0,598	0,511

5.3.10. Income per family

Although there is no strong correlation among activities, most of the families practise several activities together, while a small percentage practise only one activity at a time. Families that practise only one activity make up 25% of the families and have a lower overall income, varying from R$63 to R$1,888. In this type of family (families with only one income) agriculture and retirement provide an income around R$750-900, while fishing and salaries bring incomes of R$1,200 and R$1,888, respectively (Table 5.13).

Families with more than one source of income have higher total incomes. About 30% of the families practise agriculture, cattle ranching and fishing together. These families have an average income of R$3,797, a value much higher than the families that have only one source of income. The second biggest group are the families that practise fishing and agriculture. They represent 27% of the families, and have an average income of R$2,361. Families that practise cattle ranching with either agriculture or fishing have a similar income (varying from R$2,900-3,200) but represent only 12% of the families. Finally only 1% of the families practises all the three activities and receives wages and retirement pensions. This group has the highest total income of R$5,783 (Table 5.13). Using percentage of income from fishing to explain total income of household resulted in a negative significant relationship (R^2 = 0.58). Given the great variance in the data the precise relevance of fishing in the family income needs further study.

Table 5.13 Number of families that practise an activity or a mix of activities and income per year.

Activity	Count	%	% (of 259)	Value Income	SD
Only Fishing	21	32%	8%	1,201.57	
Only Agriculture	13	20%	5%	767.71	
Only Retirement	7	11%	3%	884.17	
Only Wage	5	8%	2%	1,888.15	
Only Cattle	3	5%	1%	63.35	
Total	66	100%	25%		
Activity	**Count**	**%**		**Value Income**	**SD**
Fishing and Agriculture, No Cattle	70	27%		2,361.33	3,785.21
Agriculture and Cattle, No Fishing	12	5%		2,853.69	4,005.95
Fishing and Cattle, No Agriculture	18	7%		3,172.03	5,403.18
Fishing, Agriculture and Cattle	78	30%		3,796.70	6,874.93
Fishing, Agriculture, Cattle and Retirement Wage	3	1%		5,782.73	1,574.85

5.3.11. Fishing agreements: rules and perceived compliance

Interviews with leaders of communities operating successful management or co-management agreements indicated that most agreements had been established with the objective of safeguarding the fish supply for the subsistence needs of the community, while restricting commercial fishing.

Agreements were initiated from 1995 to 2001, but mostly in 1999, and they are currently at different stages in the legalisation process. Of the 9 communities with management agreements 5 already have their accord regulated by the federal environmental agency, while the rest implement the agreement although it is not yet approved by law. All those that are legalised also have environmental agents since the government trains the volunteers only after the agreement is approved (Table 5.14)

Table 5.14 Management rules in communities in the lower Amazon.

Pair	Community	Families	Location - Floodplain or Upland & Water body system	Date of agreement	Legalised	Environ. Agent	Monitoring	Community comply	# Month gillnet ban	Ban commercialization	Catch per trip (Kg)	Motor Boat Ban
1	Aracampina	67	Flood &	1999	Yes	Yes	Regular	Yes	4	Yes	50	Yes
1	Costa do Aritapera	28	River/Lake									
2	Santa Maria do	52	Flood &	1999	No	No	Good	Yes	5	Yes	30	Yes
2	Tapará Grande	87	River/Lake									
3	Pixuna do Tapará	50		1997	No	No	Good	Yes	6	Yes	30	Yes
3	Santa Terezinha	96	Flood & Lakes									
4	Saracura	65		1999	Yes	Yes	Regular	Yes	4	Yes	No	No
4	Costa do Tapará	43	Flood & Lakes									
5	Costa do Marituba	18	Flood &	2001	No	No	No	Yes	6	No	No	No
5	Ilha do Bom Vento	28	River/Lake									
6	Tiningu	43		1999	Yes	Yes	Good	Yes	6	Yes	50	Yes
6	São José	90	Upland & Lakes									
7	Curicaca	67	Upland & Large	1995	No	No	Good	Yes	6	Yes	No	Yes
7	São Diogo	130	Lakes									
8	Santarém Miri	156		1999	Yes	Yes	Regular	Yes	4	Yes	15	Yes
8	Correio do Tapará	43	Upland & Lakes									
9	Ajamuri	110	Upland & Large	1999	Yes	Yes	Yes	Yes	No	No	100	No
9	Jacarecapá	111	Lakes									

All fishing agreements but one ban gillnet and dragnet use for about 6 months during the low water period. Many agreements also set daily catch limits or limits on the size of boats which are allowed to enter the lakes. Most agreements explicitly restrict the commercialisation of the catch.

The families in the communities are knowledgeable about the local agreement. In the household survey, most interviewees (85%) correctly reported the main rules set out in the local agreement. Other details of the agreements, such as the year the agreement was officially approved, were less commonly known (36% of the respondents).

The majority (80%) of interviewees in communities with co-managed fisheries considered the agreements successful. When asked about the proportion of community members complying with the rules, 70% thought that more than 50% of the families in the community complied with them (Table 5.15)

Table 5.15 Percentage of families that interviewees believe comply with the agreement.

Interviewees (%)	Perceived percentage of residents complying with the agreement
24%	> 90%
46%	Between 50 and 90%
30%	< 50%
100%	

5.3.12. Impact of co-management on exploitation by local households

The impact of the rules on managed lakes, as compared with unmanaged lakes, was evaluated by comparing total effort, catch and CPUE. The result showed that there was no noticeable difference in standardized household fishing effort between communities with and without co-management agreements. Although the average total effort is larger in non-managed lakes, this value is not significantly larger when the confidence interval is taken into consideration (Figure 5.2).

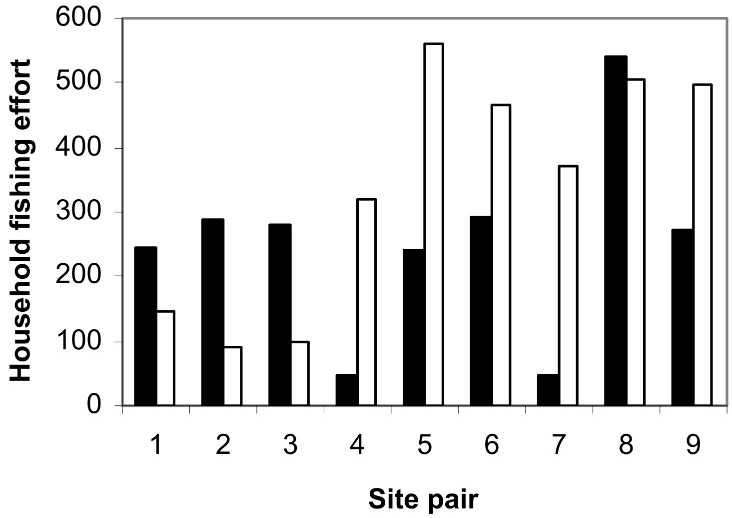


Figure 5.2 Comparison of standardised household fishing effort per year (hours) in communities with co-management agreements (solid bars) and without such agreements (open bars).

As one of the key rules to control effort in the agreement is the ban on the use of gillnets during the low season. During the low water period only 1% used fishing rods while in the high water, when the water floods the forest, 17% uses this gear. Gillnets are only used by 10% of the families on managed lakes, while half of the families on unmanaged lakes use gillnets. At this time fishing on managed lakes is mostly done with cast nets.

The proportion of fishing effort expended using gillnets was significantly lower in communities with co-management agreements considering both season (38% on average) than in those without (76%), as can be seen in the pair comparison in Figure 5.3. This indicates a reasonable degree of compliance with the restrictions on the use of gillnets. However, the reduction in gillnet effort appears to be compensated to a large extent by an increase in effort expended with other gear since there is no difference in effort (see figure 5.2). This may explain the lack of an overall reduction in fishing effort within community operating agreements.

Another reason to think that the regulation actually worked to reduce the effort from outside the community is that the regulations actually permit these residents in the community to practise fishing very much in the same way they do without agreement. For example, the limit of catch per trip is 15, 30 or 50 kg in some of the agreements, while the average catch per trip in the communities without management in low or high water varies from 5 to 9 kg (Table 5.16). Only 2% of the catch exceeded a catch of 50 kg per trip in managed lakes and only 1% in unmanaged lakes.

Table 5.16 Catch per trip in the communities in the lower and high water period in managed and unmanaged lakes.

	Period	N	Average Kg	SD	Lower Bound	Upper Bound
No Management	Low Water	263	9.35	15.34	7.49	11.20
No Management	High Water	192	5.01	5.38	4.25	5.77
Management	Low Water	255	11.32	36.95	6.78	15.85
Management	High Water	218	8.65	14.30	6.75	10.55

It can be seen that regulation does not modify drastically the fishing behaviour of the fishers resident in the community. All the regulation does not have a great effect on the fishing activity when comparing communities with and without management except for the gear used. Even when the difference is related to gear, it is possible that the restriction to gillnet has the objective of restricting the entrance of fishing boats that are operated basically with the use of gillnet and not to regulate the fishing activity by the residents themselves. So fishing management restrains mainly the fishing activity of the commercial fishers in the lakes.

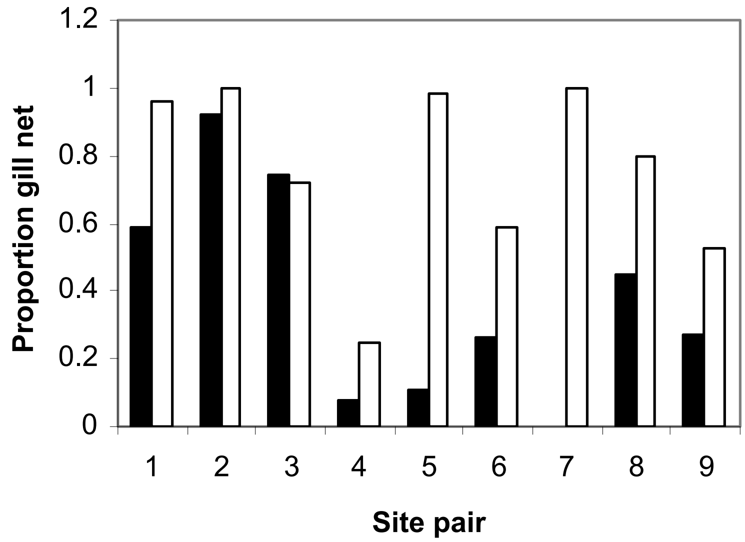


Figure 5.3 Comparison of the proportion of fishing effort expended with gillnets in communities with co-management agreements (solid bars) and without such agreements (open bars).

5.3.13. Impact of co-management on fisheries productivity

To evaluate the difference in productivity between managed and unmanaged lakes the two situations were compared using catch per unit of effort (CPUE). The pair comparison in Figure 5.4 shows that productivity was significantly and consistently higher in communities with co-management agreements than in those without. On average, CPUE was 60% higher in managed fisheries.

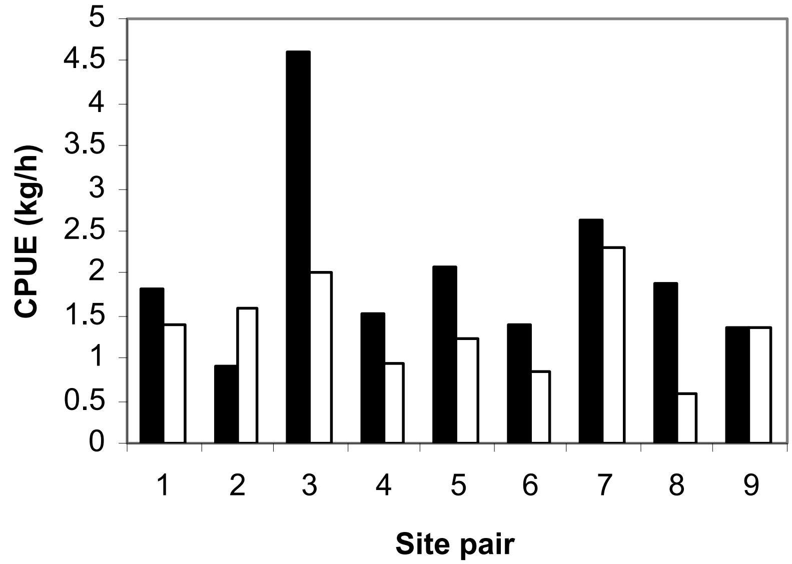


Figure 5.4 Comparison of fisheries productivity (in catch per unit of effort, CPUE) in communities with co-management agreements (solid bars) and without such agreements (open bars).

The asymptotic yield model provided an excellent fit to the data, with parameter estimates of y_{max} = 106 kg/ha, a= 0.069 and b=-0.241. The management coefficient b was significantly different from 0, indicating that for a given level of local fishing effort, yield and CPUE are significantly lower in unmanaged fisheries than in co-managed ones. This difference between managed and unmanaged fisheries is likely to reflect the impact of additional fishing by external commercial boats in unmanaged fisheries which could not be quantified directly in the present work. The relationship between local fishing effort and yield is shown in Figure 5.5, differentiating between managed and non-managed lakes. Note that the relationship between CPUE and effort in these multi-species fisheries is complex and non-linear, as opposed to the continuous reduction in CPUE with effort predicted by single-species production models.

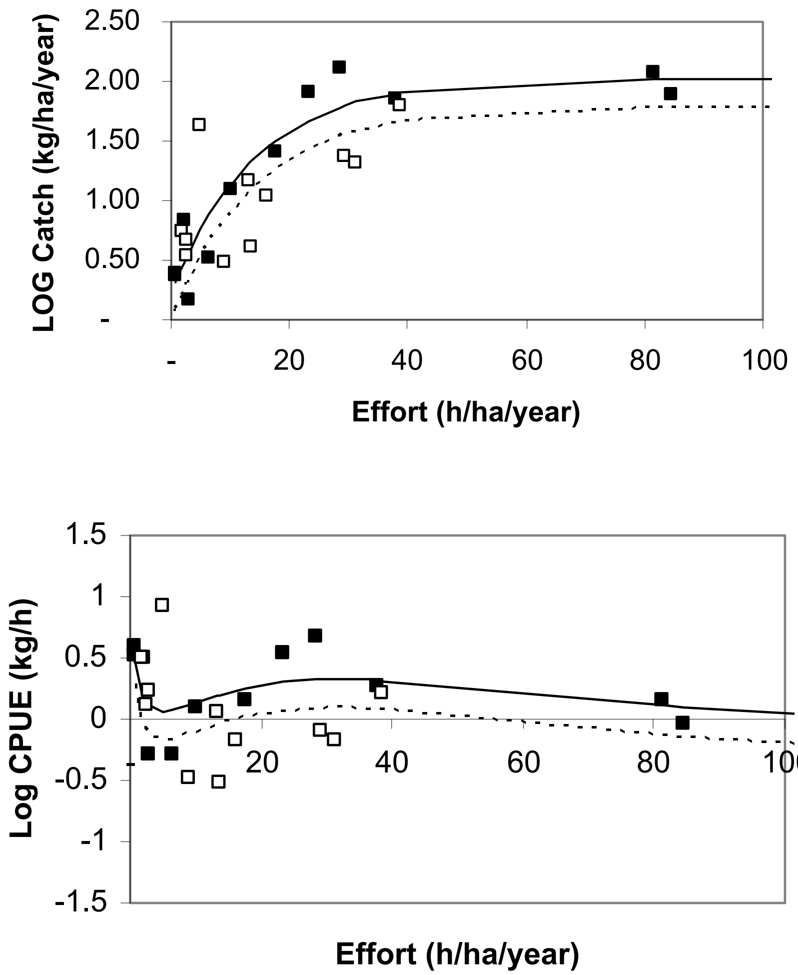


Figure 5.5 Relationship of yield (top) and CPUE (bottom) to fishing effort in managed (closed symbols and solid line) and non-managed (open symbols and dotted line) floodplain lake fisheries.

5.4. Discussion

Fishing is of major importance to the livelihoods of rural households in the lower Amazon, contributing an average of 31% to total household income (and higher if the rural fleet would be considered). Participation in fishing is almost universal at 84%. Hence it is not surprising that many community and co-management initiatives for natural resource management in the Amazon have evolved around fisheries (McGrath *et al.* 1993, De Castro 1999). Under the new Brazilian federal fisheries law, rules devised by local communities may be formalized and enforced by government agencies, thereby effectively creating one of the most far-reaching co-management systems for aquatic resources.

The present analysis provides the first rigorous evaluation of the productivity and conservation benefits of the co-management regimes. Results show that co-management of floodplain fisheries does indeed provide real and significant benefits to local communities. The estimated average increase in productivity (CPUE) of 60-70% in managed lakes, over unmanaged lakes, provides very substantial benefits to local households. Underlying this increase in CPUE is a proportional increase in standing stock, and therefore an equally substantial conservation benefit.

Results suggest that the productivity and conservation benefits of co-management schemes are achieved primarily by excluding outside commercial fishers from the managed lakes. The exclusion of outside commercial fishers was the most frequently cited reason for entering into co-management agreements in the first place. Although explicit discrimination against outsiders is illegal under the federal fisheries law, rules tend to be designed so that they restrict fishing activities by external commercial boats more than those by local households. The communities co-operate for gain more than restraint, and achieve an effective conservation benefit through rules that exclude outsiders (Ruttan 1998).

Where communities have gained effective control over their local aquatic resources, more active and outcome-oriented management of exploitation within the community may be expected to develop. Nonetheless some constraints on the success of co-management do exist, especially with respect to the monitoring system which is carried out at the cost of the community and without the support from the environmental agency (McGrath *et al.* 2003).

Chapter 6

Interactions between commercial and small-scale rural fisheries in the lower Amazon: using a bio-economic model

6.1. Introduction

The goal of this research is to understand the prospects for co-management in the Amazon, and to evaluate the impact of possible alternative management scenarios for the lower Amazon. To achieve this, the approach chosen has been to understand the overall importance of the fishing sector in the Amazon, the differences in the regional fishing fleets, and the impact of community management on household economies. Finally a bio-economic model based on this data was used to understand the dynamics and changes resulting from the adoption of community management in the region of Santarém.

The fishing sector analysis showed the importance of the sector for the generation of income and employment for both subsistence and commercial fishers. The result of this study highlighted the importance of small-scale rural fishers, who represent about 70% of all fishers, while the rest are commercial fishers. The regional fleet study showed that the use of purse seine nets in Manaus and Tefé results in a productivity 30% higher than that achieved with other types of gear. It also showed that boats in Santarém are mostly based in rural areas, while the fleets from other regions are mostly urban based. The context of each region and the rural origin of the commercial fishers indicate that in Santarém there is a smaller likelihood of conflict between commercial and small-scale rural fishers as a result of the introduction of community agreements than in other regions.

In the fifth chapter the household livelihood of the small-scale rural fishers was addressed and the results showed that in managed lakes the productivity was 60% higher than in non-managed lakes. Based on this lake data an empirical yield model was estimated to assess the relationship between local fishing effort and yield.

This chapter has the objective of integrating information on small-scale and commercial fisheries and analysing their interactions and likely responses to alternative management options. To do this it uses a simple bio-economic model. The model was elaborated based on the start-up scenario of the lower Amazon that integrates the small-scale rural-based and commercial fishers.

This model is then used to evaluate five policy and change scenarios: 1) the proliferation of co-management agreements leading to the exclusion of commercial fishers from lakes; 2) a change in effort between commercial and small-scale rural fishers; 3) charging commercial fishers for access; 4) allowing the use of more efficient gear; and 5) the expansion of markets due to improved transport access to inland areas.

6.2. Methodology

6.2.1. Study area

The focal area of the study is the Santarém region of the lower Amazon in Brazil (Figure 6.1). The area is rich in water resources, with a floodplain area of about 268,300 ha and a river area of about 50,000 ha. The total population in the area numbers about 200,000, of whom 150,000 live in the urban centre of Santarém, and 50,000 are resident in the regional floodplains.

6.2.2. Exploratory analysis

An exploratory analysis of catch and effort data for the commercial and small-scale fisheries was carried out in order to establish a baseline scenario for modelling, and to explore the behaviour of stocks (catch responses to variation in effort) and fishers (effort responses to changes in economic returns).

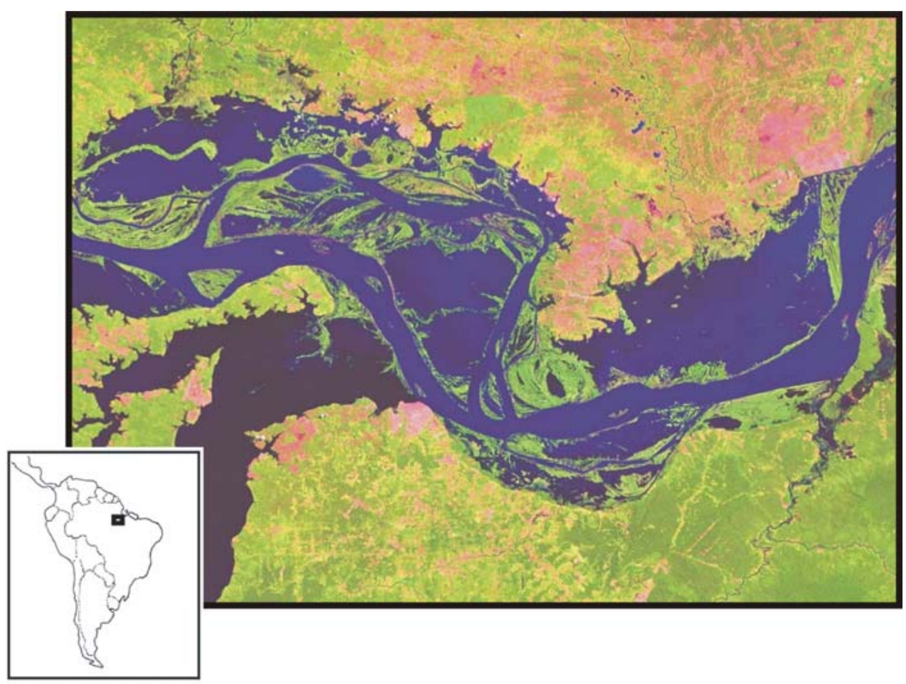


Figure 6.1 The lower Amazon region of Santarém.

The landing data used were collected daily by the IARA Project between 1992 and 1998 and by PRO-VARZEA between 1999 and 2001. Interviews were carried out by four people located at the main landing sites along the waterfront (markets and processing plants) during the peak hours of fish landings. Interviews included information on the characteristics of the fishing vessel, trip itinerary, catch size and composition, number of fishers and canoes, duration of the voyage, ice and fuel consumption, and the sale price of fish. This data set consists of 73,578 interviews with boat operators.

The data were analysed for trends for effort, catch per unit of effort in fisher-hours, and revenue from commercial fishing. Responses in commercial fishing effort to short-term variations in catch per unit of effort (CPUE) (i.e. returns to effort) were investigated through a regression of first differences in effort against CPUE.

Household level catch and effort data for the small-scale fishery were obtained from Chapter 5. Small-scale effort (originally in units of hours) was converted to units of commercial fisher days based on a comparison of regional average catch per unit of effort. Household level catch and effort were scaled up to regional small-scale catch and effort using the total number of floodplain households estimated in a previous survey by the IARA/IBAMA Project.

6.2.3. The relationship between catch and effort

Estimates of total fishing effort and catch from the commercial landings database and household surveys in the Santarém region have been summarized (Table 6.1) to provide a baseline scenario for modelling. Based on table 6.1 about 66% of the fish were caught in lakes while the rest were caught in rivers. Note also that small-scale fishing accounts for over two-thirds of the regional catch.

Table 6.1 Baseline scenario of the bio-economic model

		Fishing Effort (days per year)	**Catch (t per year)**
Commercial fisher	River	63000	1165
	Lakes	98000	1610
Small-scale rural fisher	River	115000	2130
	Lakes	250000	4110

On an annual basis fishing activity is extremely seasonal. Fishers will switch from fishing in the lakes to the river in accordance with the scale of their operation and the migration of the species. Over the past 10 years, however, the total catch and effort of the commercial fishery in the Santarém region have been remarkably stable. Fishers usually fish in the lakes and the river in almost the same proportion. The same analyses were carried out for the 10 major fish species, but again most did not show any trend in catch or CPUE.

The data was also separated by river and lakes for the same 10-year period and this too failed to show any trend, as can be seen in Figures 6.2 and 6.3. The data aggregated by year also does not show any trend and gives no clue about the current level of exploitation of stocks. Overall the commercial fishery in the Santarém region is in a very static condition.

While the uninformative nature of the effort and catch data makes it difficult to assess the exploitation status of the fishery directly, comparative information provides an indication of the exploitation status. The total catch by commercial fishers, and the estimated catch of all small-scale rural fisher families in the lower Amazon, is estimated to be around 9,015 t/year from a water area of 268,300 ha. In this case, the present catch per area is about 34 kg/ha/year. This is about 37% of the maximum multi-species yield (91 kg/ha/year) estimated for Amazon lake fisheries in a comparative empirical study (see Lorenzen *et al*. 2004 in Appendix I). Hence, overall, the fishery appears to be only moderately exploited (Welcomme 1999).

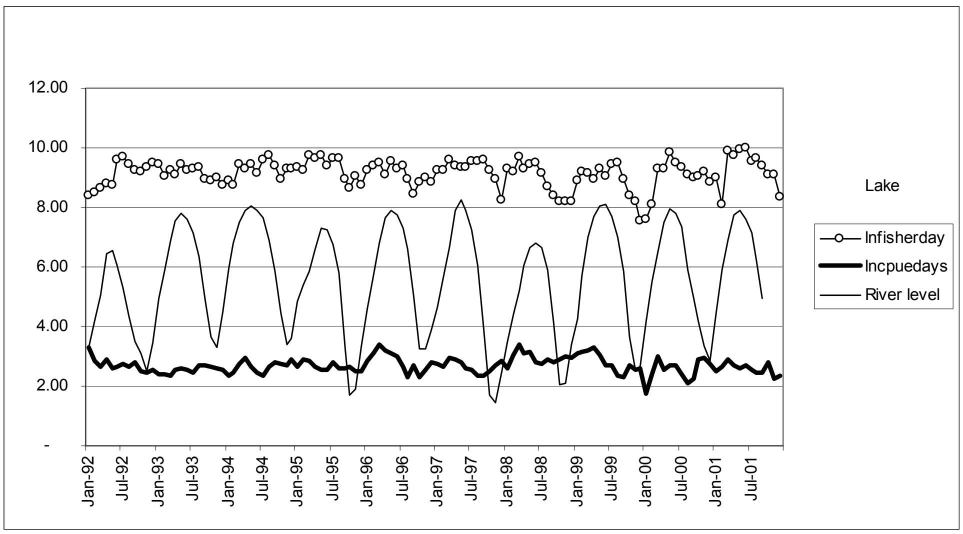


Figure 6.2 Long-term trends in the Santarém commercial fishery per month in lakes: fishing effort (open circles), catch per unit of effort (solid bold line) and river level (solid thin line).

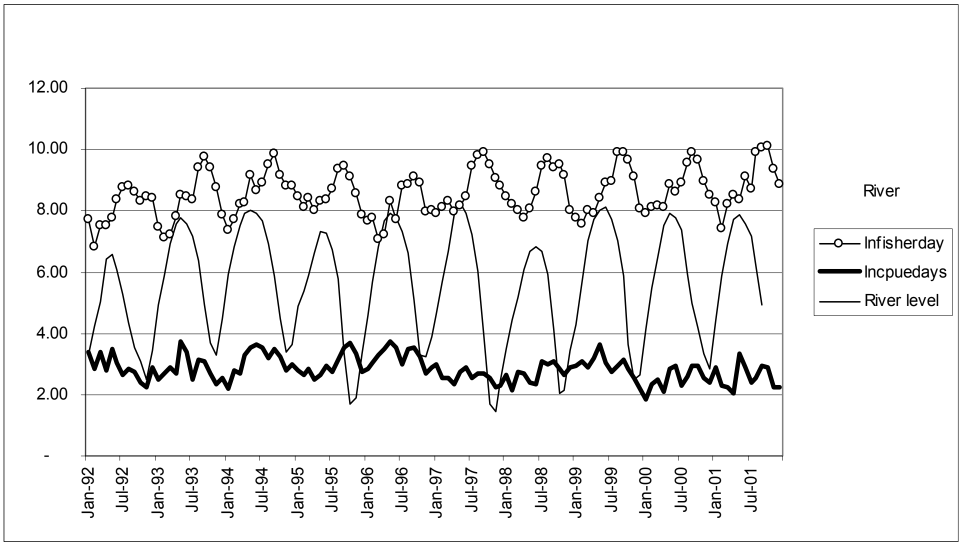


Figure 6.3 Long-term trends in the Santarém commercial fishery per month in river: fishing effort (open circles), catch per unit of effort (solid bold line) and river level (solid thin line).

6.2.4. Bio-economic model

Based on the data from this work and the long term analysis on commercial landing data, a simple bio-economic model was formulated by Kai Lorenzen. This model was used here to analyse the fisheries, and the interaction between small-scale rural fisher**s** and commercial fishers.

To build the model the fishery was divided into four components based on the sector (commercial or small-scale) and the physical habitat (river or lake). The harvest, revenue and cost functions were specified as follows:

Two alternative functional forms of the relationship between the aggregated multi-species catch and fishing effort were used throughout the analysis: a sigmoid and an asymptotic model. The sigmoid model has the form:

$$Y(E) = \frac{Y_{\max}}{1 + \exp(a(b - E))}$$

where Y_{max} is the asymptotic yield, a determines the steepness of the relationship, b is the effort level at which yield equals 50% of the asymptotic yield.

The asymptotic model with monotonically declining slope has the form:

$$Y(E) = Y_{max}(1 - \exp(-a(E - b)))$$

where Y_{max} is the asymptotic yield, a determines the steepness of the curve, and b its position relative to the origin.

The model was chosen as a result of a study of the work of Lorenzen *et al.* (manuscript; Appendix I) that tested three models with data from Laos and the Amazon. The analysis of several multi-species artisanal fisheries suggests that the sigmoid model provides the best description of the aggregated catch-effort relationships. The asymptotic model was also used as a plausible alternative model that conforms more readily to the tenet that catch per unit of effort declines continuously with increasing effort. The alternative forms of the catch-effort relationship are illustrated in Figure 6.4.

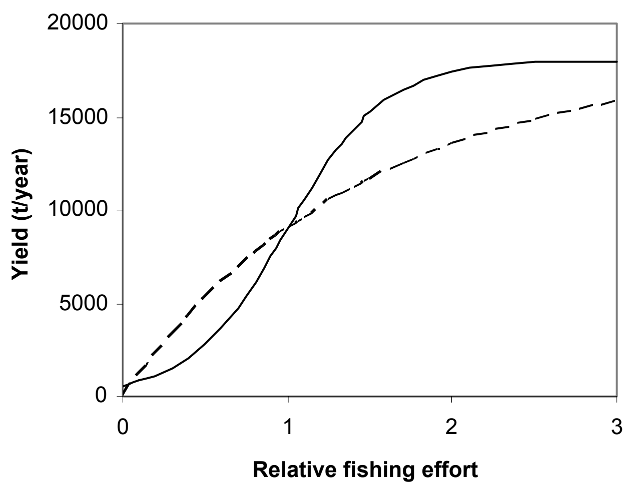


Figure 6.4 Examples of the sigmoid (solid line) and asymptotic (dashed line) harvest models for the lower Amazon fishery. In this case, it is assumed that all fisheries act on the same stock and that the baseline level of exploitation is at 50% of the asymptotic yield.

Fishing effort and habitat was defined for the four components as $E_{c,r}$, $E_{c,l}$, $E_{s,r}$ and $E_{s,l}$ where the subscripts denote the sector (c, commercial and s, small-scale rural fisher) and the habitat (r, river and l, lake). Because the extent to which the river and lake fisheries interact biologically is uncertain, alternative models were set up based on the contrasting assumptions that the fisheries act on entirely separate stocks, or on the same stocks. In the case of separate stocks, the harvest functions for the commercial and small-scale fisheries are:

$$Y_c = \frac{E_{c,r}}{E_{c,r} + E_{s,r}} Y_r(E_{c,r} + E_{s,r}) + \frac{E_{c,l}}{E_{c,l} + E_{s,l}} Y_l(E_{c,l} + E_{s,l})$$

and:

$$Y_s = \frac{E_{s,r}}{E_{c,r} + E_{s,r}} Y_r(E_{c,r} + E_{s,r}) + \frac{E_{s,l}}{E_{c,l} + E_{s,l}} Y_l(E_{c,l} + E_{s,l})$$

where the river and lake yield models Y_r and Y_l are defined by the (sigmoid or asymptotic) relationships introduced above. In the alternative case of the river and lake fisheries exploiting the same stock, the harvest functions are:

$$Y_c = \frac{E_c}{E_c + E_s} Y(E_c + E_s)$$

and

$$Y_s = \frac{E_s}{E_c + E_s} Y(E_c + E_s)$$

where Y is the (sigmoid or asymptotic) yield model of the combined stock.

Because the true exploitation status of the fishery is unknown due to the lack of trends in the landing data, three different model parameter sets were defined considering that the current exploitation level was 30%, 50% or 70% of the potential maximum yield of the fishery. All analyses were thus carried out for a total of 12 harvest model configurations which are summarized in Table 6.2.

The revenue function for the commercial fishery was specified as:

$$R_c = Y_c \, \alpha \left(\frac{Y_c}{Y_r} \right)^{\beta_Y} \left(\frac{\sum E}{\sum E_c} \right)^{\beta_E}$$

Table 6.2 Alternative harvest functions used in the bio-economic analysis

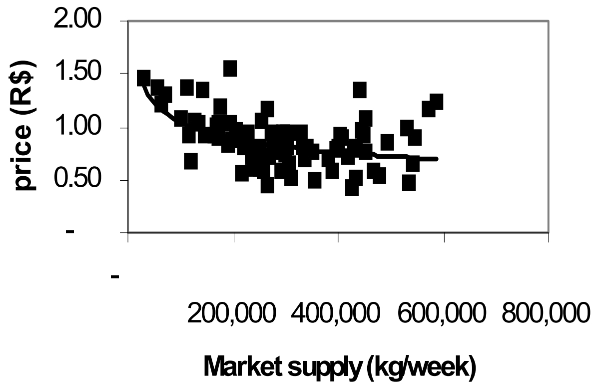
<table>
<tr><th>Model</th><th>Function</th><th>River exploitation</th><th>Lake exploitation</th></tr>
<tr><td>A1</td><td>Sigmoid</td><td>30%</td><td>30%</td></tr>
<tr><td>B1</td><td>Sigmoid</td><td>50%</td><td>50%</td></tr>
<tr><td>C1</td><td>Sigmoid</td><td>70%</td><td>70%</td></tr>
<tr><td>D1</td><td>Sigmoid</td><td colspan="2">30%</td></tr>
<tr><td>E1</td><td>Sigmoid</td><td colspan="2">50%</td></tr>
<tr><td>F1</td><td>Sigmoid</td><td colspan="2">70%</td></tr>
<tr><td>A1</td><td>Asymptotic</td><td>30%</td><td>30%</td></tr>
<tr><td>B1</td><td>Asymptotic</td><td>50%</td><td>50%</td></tr>
<tr><td>C1</td><td>Asymptotic</td><td>70%</td><td>70%</td></tr>
<tr><td>D1</td><td>Asymptotic</td><td colspan="2">30%</td></tr>
<tr><td>E1</td><td>Asymptotic</td><td colspan="2">50%</td></tr>
<tr><td>F1</td><td>Asymptotic</td><td colspan="2">70%</td></tr>
</table>

where R_c is the revenue obtained for a commercial yield of Y_c, α is the price per unit of yield at the baseline yield Y_r, and β_Y is the price elasticity of supply. A price elasticity of effort β_E has been introduced to account for the fact that in the multi-species fishery increasing effort leads to the substitution of high value by lower value species. This elasticity is dependent on the total effort ΣE relative to the total baseline reference effort ΣE_r. The price elasticity of supply in the Santarém market was estimated at –0.23 from landing records based on changes in price when landings vary through the year. The price elasticity of effort was set at –0.4, implying that average prices would reach those of the highest value species at a relative total effort level of 0.1 ΣE_r. Both components of the revenue function are illustrated in Figure 6.5.

The long-term cost function of the commercial fishery was specified as a linear function of effort with zero intercept:

$$C_c = E_c(l + v + d)$$

where C_c is the cost of commercial effort E_c, and l, v and d are, respectively, the labour cost, other variable costs, and depreciation associated with one unit of fishing effort. Cost was estimated based on survey data from Chapter 4 for the lower Amazon. The average labour cost was estimated at 5 R$/fisherday, other variable costs at 5.7 R$/ fisherday, and depreciation of boat and gear as 2 R$/fisherday.



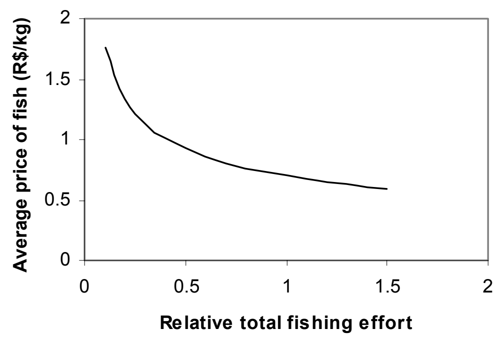


Figure 6.5 Components of the revenue function. Empirical relationship between average ex-vessel price and supply in Santarém (top), and assumed relationship between total fishing effort and the average price of fish.

Appropriate revenue and cost functions for the small-scale fishery are more difficult to define mainly because fishing is mostly for subsistence. Only when the dynamics of fish commercialization and the interaction between activities are understood will it be possible to model revenue and cost functions. As a result of this restriction the small-scale rural-based fishery is analysed in terms of physical effort and yield.

6.2.5. Bio-economic analysis

The bio-economic status of the fishery is explored in Figures 6.6 and 6.7, which show the responses of the commercial and small-scale fisheries to changes in commercial (Figure 6.6) and small-scale (Figure 6.7) effort. Results are shown separately for the sigmoid (top) and asymptotic (bottom) functional forms of the harvest model. Within these different functional forms, each line of the revenue or yield predictions corresponds to an alternative assumption about the exploitation status (considering that the current total catch is 30, 50, or 70% of the maximum), and the degree of biological interaction between lake and river fisheries (separate stocks or one single stock) as detailed in Table 6.2.

Two important results emerge immediately from the predictions presented in Figures 6.6 and 6.7. Figure 6.6 shows that when commercial effort increases there is a mild decline in the catch of the small-scale fishers (Figure 6.6, top, right) according to the sigmoid form, while in the asymptotic form the total catch of small-scale rural fishers suffers a decrease.

Figure 6.7 (top, left) shows the variation in catch according to the sigmoid model, when the effort of small-scale rural fishers is changed. In this case, as small-scale effort increases, the variation in the commercial fishers total catch is also mild. In the asymptotic model (bottom) there is a large decrease in total catch as the effort of small-scale rural fishers increases. The use of these two models to analyse the impact of changes in effort shows that the alternative forms of the harvest function seems to have a greater influence on the results than the assumptions about the current exploitation level or the degree to which river and lake fisheries interact biologically.

However, even taking into account the uncertainties highlighted by the alternative models, consistent results emerge in many areas. It is notable that, in all cases, a change in the commercial fishing effort has a smaller overall effect than a change in the small-scale effort of the same magnitude. This reflects the fact that the commercial effort only accounts for about 30% of the total effort expended in the fishery.

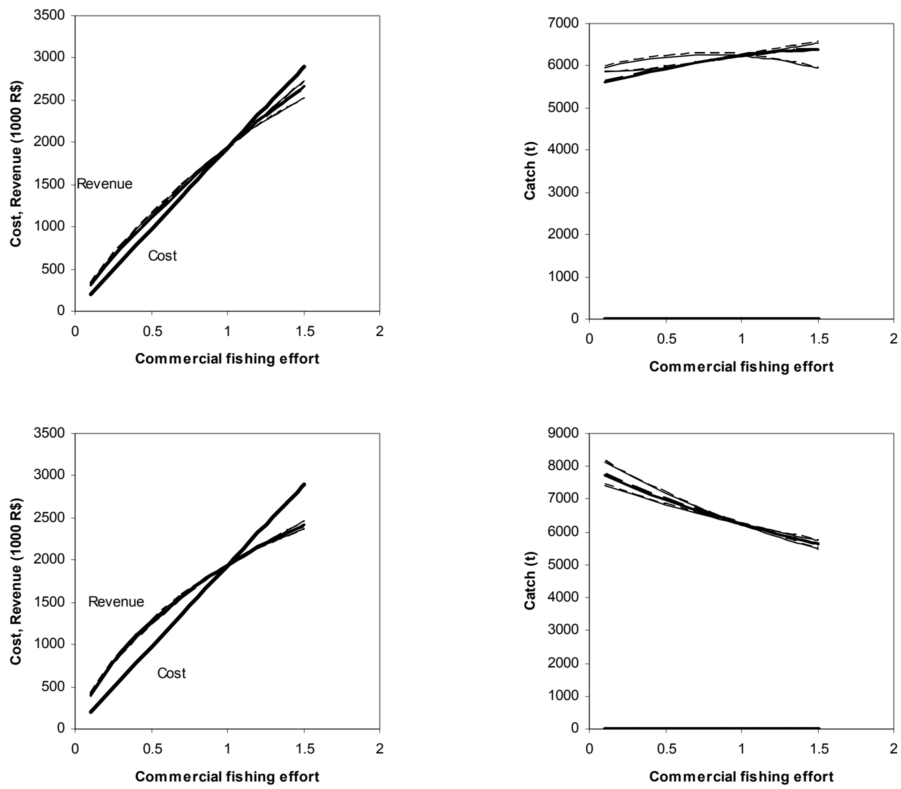


Figure 6.6 Effect of changes in commercial fishing effort on revenue and costs in the commercial fishery (left), and on yields in the small-scale fishery (right), predicted using the sigmoid (top) and asymptotic (bottom) harvest functions. (Effort equal 1 is the base line).

As can be seen in Figure 6.6, the commercial fishery operates, in economic terms, at the open access equilibrium, i.e., revenue just equals costs. There is no room for further expansion, unless either fish prices increase or costs are reduced. Both alternative models give similar predictions of commercial revenue responses to changes in commercial fishing effort, although the sigmoid model predicts lower gains from effort reduction. A reduction in small-scale effort is predicted to have only a marginal (sigmoid model), or a moderately positive (asymptotic model) impact on commercial fishery revenue or small-scale CPUE. Overall the sigmoid model suggests that, given the likely current level of exploitation, yield changes roughly in proportion with effort and hence productivity is insensitive to changes in effort (Figure 6.7).

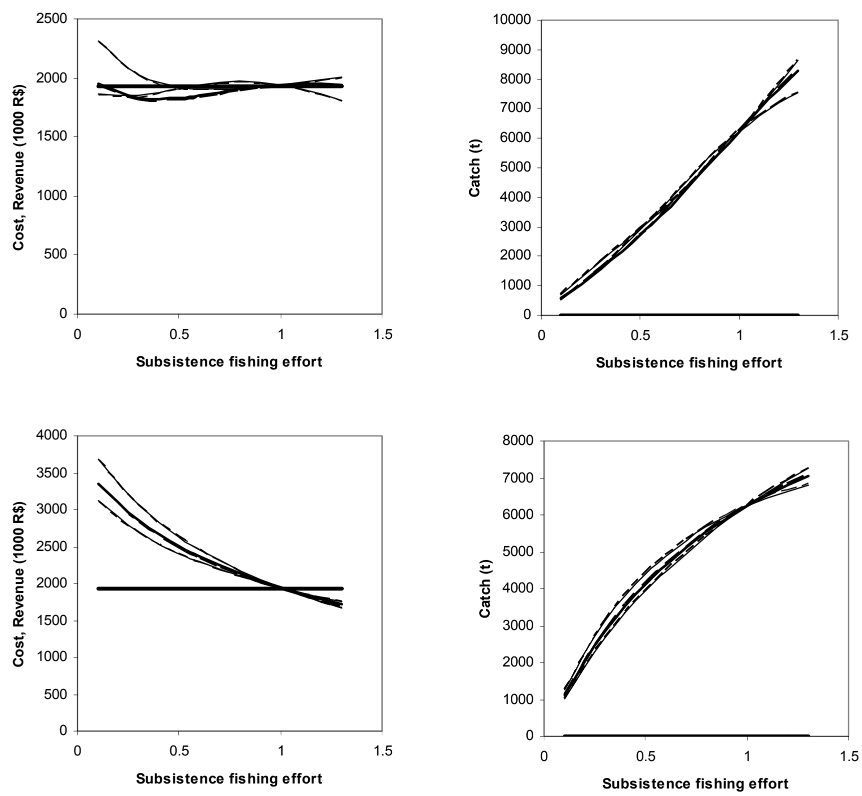


Figure 6.7 Effect of changes in small-scale fishing effort on revenue in the commercial fishery (left), and on yield in the small-scale fishery (right), predicted using the sigmoid (top) and asymptotic (bottom) harvest functions. (Effort equal to 1 is the base line).

6.2.6. Separate and joint stocks

The model was also used to see what the differences are when the stocks are considered to be separate or joined. In Figure 6.8 the three models (considering that the current total catch is 30, 50 and 70% of the maximum) were plotted, with each graph showing the income and catch of both commercial and small-scale rural fishers. As the graphs show, the separation of the stocks does not result in relevant differences as the lines of both models are superimposed on each other in such a way that no difference can be seen. In the same figure it is possible to see the effect of price elasticity by comparing the income curve with the catch curve. As can be seen, there is a slight reduction in income as total catch increases (Figure 6.8).

6.2.7. Prediction

The two models (Figures 6.6 and 6.7) may also be used to evaluate the likely impacts of other changes such as price increases due to the expansion of markets, the charging of commercial fishers for access to lakes, and allowing the use of more efficient gear.

In the lower Amazon, one limitation for market expansion is the access to good roads which would allow fish to be sold in the national market. Presently fish have to be taken by barge to Belém and then go by road to Sâo Paulo. The asphalting of federal highway BR-163, the road that connects Santarém to central and southern Brazil, foreseen for 2004, will provide a direct link between the lower Amazon and the centre-west of Brazil. If this project is actually carried out the price of fish will probably rise due to the expansion of the market. In Belém, for example, where the market is larger, the average price for fish in 2001 was 30% higher than the average price in Santarém.

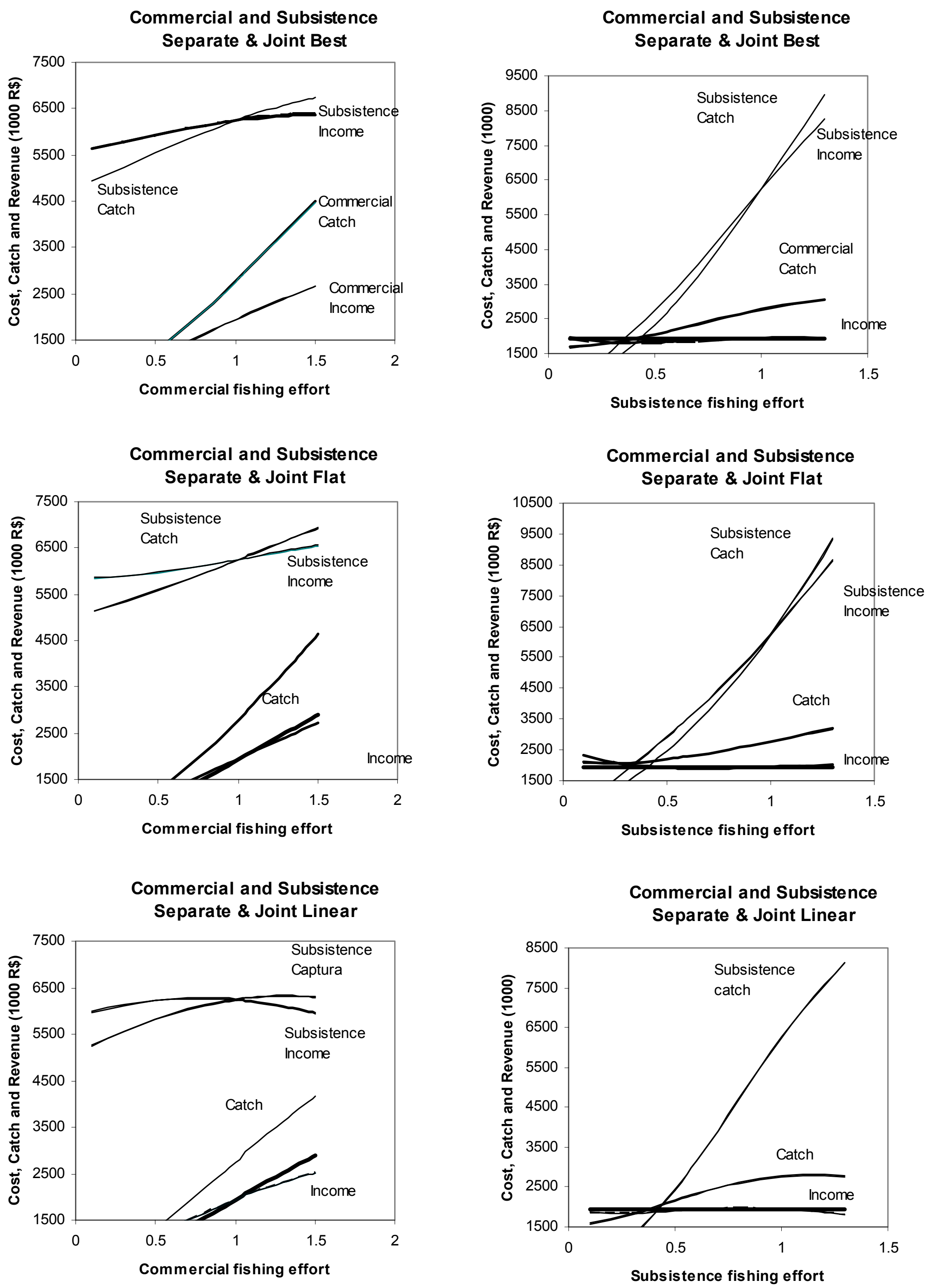


Figure 6.8 Result of commercial and small-scale catch and income in six different models. (Effort equal to 1 is the base line).

Using the sigmoid model it can be seen in Figure 6.9 that with an increase in price of 30% the commercial fishers will double their effort and catch to reach a new open access equilibrium point. The increase in effort also shows that as effort increases the assumption of each model has a different impact on income. If present exploitation is considered to be at 70% of the maximum, the revenue reaches the open equilibrium access when effort doubles (first curve to touch the cost curve), but if the current catch is assumed to be 30% of the maximum then the open access equilibrium will be reached when effort reaches a value three times larger than the current level. In any case, if price increases the total catch per hectare would increase from 34 kg/ha to 42-53 kg/ha (depending which model is considered).

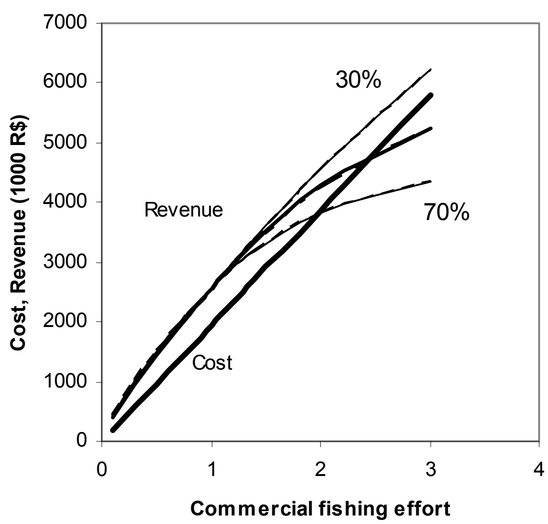


Figure 6.9 Impact on commercial revenue when the price increases 30% (from 0.70 to 0.92). (Effort equal to 1 is the base line).

In the model, effort elasticity was provided by an arbitrary value, but using the model it is possible to evaluate the changes in outputs when effort elasticity varies. When effort is larger than the baseline scenario the income is reduced as elasticity is reduced. By changing effort elasticity from -0.4 to -0.2, the change in income varies from 3% positive to 3% negative when the effort reduces 50% or increases 50%, respectively. This is a very small variation, but when elasticity is changed to -0.4, profit is generally larger for situations where the effort is below the baseline effort (Figure 6.10).

Up to now the legislation does not allow fees to be charged for fishers to fish in the lakes. Although this would be an extra management tool for the communities, they have not yet attempted to implement this practise formally. In interviews with the skippers of fishing boats in Manaus several fishers report having to pay fees to communities, but this is still informal and it is not legal. Charging would have the effect of increasing the cost of fishing, and commercial fishers would respond by reducing effort until a new equilibrium is reached.

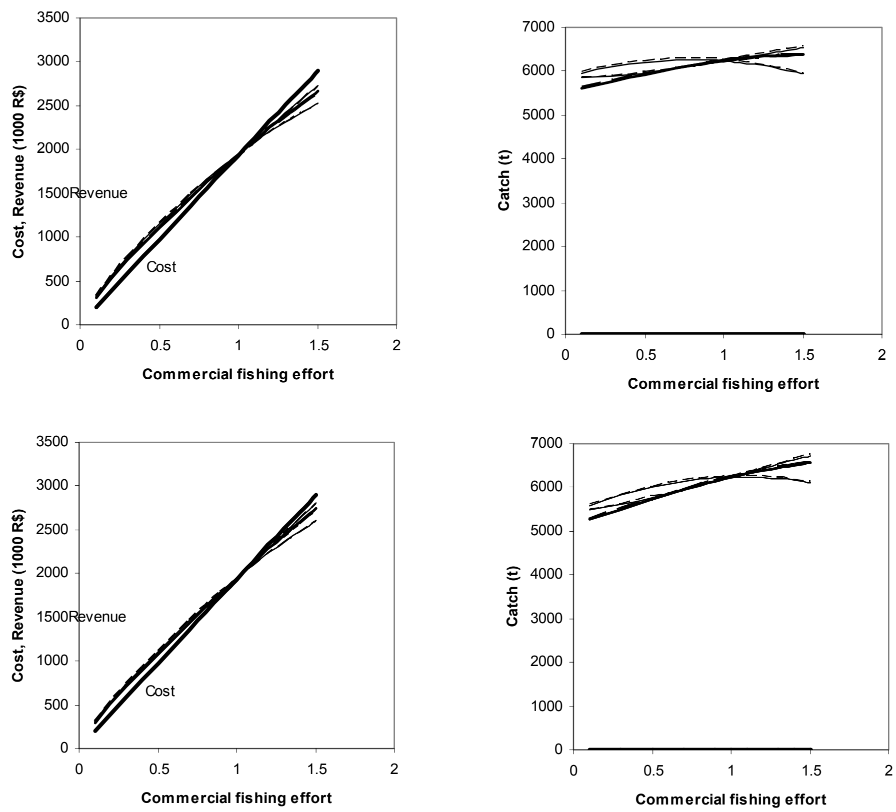


Figure 6.10 Change in income of commercial fishers when the effort elasticity is changed from -0.4 (top) to -0.2 (bottom).

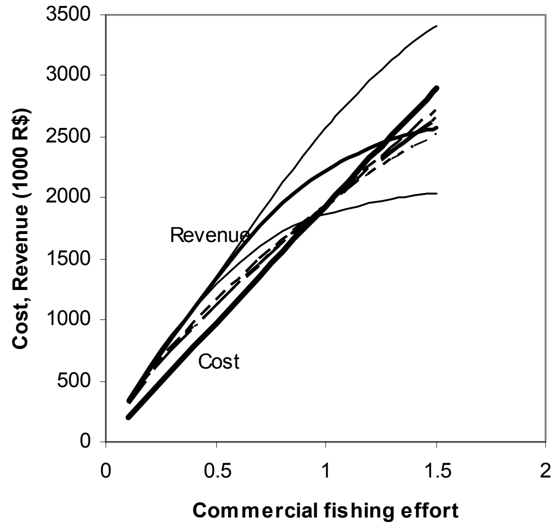
A reduction in costs would also increase profit and create new possibilities for expansion just as an increase in price does. Allowing the use of more efficient gear, such as purse seine nets, would effectively reduce the cost of fishing by about 30% (see Chapter 4, Table 4.4).

In this case, the reduction of costs, or the increase of price, will determine an increase in effort and would need to be monitored. When higher prices or smaller costs are foreseen it is important to regulate the fishery effectively so as not to put excessive pressure on the resources.

If co-management agreements were to proliferate and effectively close all lakes to commercial fishers, the sigmoid model predicts a slight increase in commercial fishers catch of no more than 10%. The overall small-scale catch is unlikely to be affected strongly in either case, because the effect on lake fisheries of removing commercial effort, will be largely compensated by the opposite effect on river fisheries, where commercial effort will be concentrated. This assumption has, however, a higher impact when the current level of exploitation is considered to be 70% of the maximum, as it reaches the open access equilibrium sooner than when the current level is considered to be 30% (6.11, top).

6.2.8. Asymptotic functions

Given the non-monotonic nature of the sigmoid function it is important to explore the differences in results in comparison with the asymptotic function. The asymptotic model function is more in accordance with the general view that when fishing effort increases there is a reduction in CPUE. Therefore, in the asymptotic model when small-scale effort increases there is a strong decrease in revenue for the commercial fishers (see Figure 6.7, left, bottom).



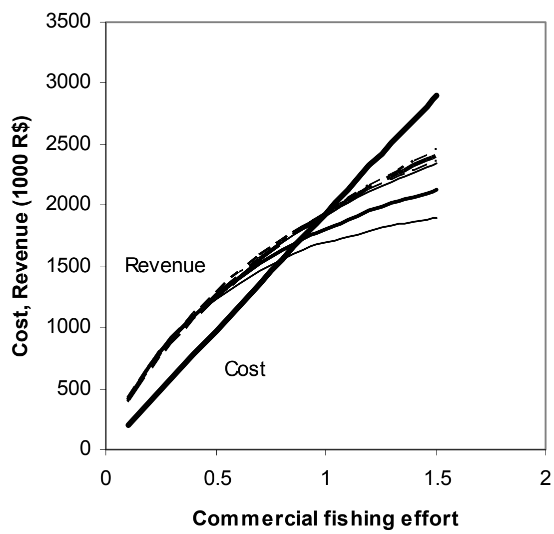


Figure 6.11 Effect of removing commercial fishing effort from the lakes to the river fishery on revenues and costs in the commercial fishery. Sigmoid harvest function (top) and asymptotic harvest function (bottom).

If, with the expansion of the agreements, the effort of commercial fishers shifts from the lakes to the river, then the open access equilibrium stays more or less at the same level of effort because the total effort will not change. However, the assumption of the present level of exploitation (30, 50 or 70% of the maximum) will result in a difference in output. In this case, the open access equilibrium will be reached at a lower level of effort for the model that considers that the present level is 70% of the maximum and later for that which considers it is 30% (Figure 6.11).

In the sigmoid model the CPUE for commercial fishing also varies differently from that predicted by the asymptotic model. In the asymptotic model, when the relative commercial or small-scale fishing effort increases, there is a reduction of CPUE. When the effort of commercial fishers rises to 30% above the present level of effort, the CPUE suffers a reduction of up to 17%, while when the effort of the small-scale fishers rises the same amount, the reduction in CPUE can be as high as 34%. This is explained by the fact that because small-scale effort represents 75% of total effort it has a larger impact on the CPUE. When all the effort from commercial fishers is shifted from the lakes to the river then the CPUE will fall slightly.

6.3. Discussion

6.3.1. Status of fisheries

Biologically, the fishery of the lower Amazon appears to be exploited at about 37% of the multi-species maximum yield (dividing total catch in the region by the respective area and comparing with the Ymax from Figure 5.5). This level of exploitation of the multi-species system suggests that some of the large and slow-growing species may be overexploited, while smaller species may not yet be fully exploited.

Economically, however, the commercial fishery is at the open access equilibrium and no further expansion is possible unless prices increase or costs can be reduced. An increase of 30% in the price would at least double the effort of commercial fishers to reach the new open access equilibrium. Although this estimate considers an effort elasticity of -0.4 it is also necessary to take in consideration if markets actually will accept smaller species.

Allowing the operation of more efficient gear such as purse seines would reduce the cost of fishing. Doing this would permit a higher rent to be extracted in a regulated fishery. Allowing the use of purse seines (currently banned in the lower Amazon, but used upstream), while at the same time charging for access, could increase the resource rent by about 30%.

Just as with reduced costs, the expansion of the market for fisheries products and the resulting increase in ex-vessel prices, will increase profits and will also lead to a very considerable expansion of the fishery.

6.3.2. Likely impacts of proliferation of co-management agreements

If co-management agreements were to proliferate, and effectively close all lakes to commercial fishers, the models predict a slight increase (sigmoid model) or decrease (asymptotic model) in commercial effort of no more than 10%.

Closing all lakes will probably not significantly affect the overall small-scale catch, provided that commercial fishers removed from the lakes shift the same effort to the river. Locally, the impact of lake management will depend on specific circumstances (e.g. the level of commercial lake effort, or access to the river by small-scale rural fishers). Nonetheless, each community's entering into a co-management agreement will gain from reducing commercial effort in their lake, but the displaced effort will be redirected to the remaining unregulated waters (the river and non-managed lakes), i.e., the costs will be shared by all. Therefore, the benefit to the individual community becomes smaller as more lakes are managed, and at a regional level the effect is simply one of redistributing effort. Effective effort management must adopt a regional perspective. With respect to which model should be used, a precautionary approach is recommended when using either the sigmoid or asymptotic model, since they show some different results.

The Amazon fishery is unusual in that, due to market limitations, the bio-economic open access equilibrium has been reached at a relatively low level of biological exploitation. Measures aimed at restricting effort to current levels carry no immediate social cost, but would prove highly beneficial in the case of market expansion.

As has been shown in this analysis, a large change in the level of activity of commercial fishers has little effect on the overall fisheries, while a small change in the level of activity of small-scale rural fishers will have a large effect on the fisheries as a whole. It is fundamental to understand this when one is considering schemes for managing the livelihood of families in the floodplain. For example, it has sometimes been suggested that fishing could be developed as a substitute for agriculture in the varzea, thus reducing pressure on terrestrial habitat. The analysis here shows that if small-scale rural fishers were to replace their income from agriculture by fishing, total effort would have to increase by 38%. In this case, the income of commercial fishers would fall and the returns to effort for small-scale rural fishers themselves would decline.

For this reason one of the main strategies in support of the adoption of fisheries management agreements is to encourage small-scale rural fishers to diversify their economic activities. McGrath *et al* (1993) has showed that management permits high productivity for fishers that will invest the extra time in agriculture. This in turn encourages the formation of diversified household economies which generate surplus cash for consumption. This multi-activity strategy has also been used for the reduction of poverty in low-income countries and is known as the livelihood approach. Allison & Ellis (2001) argue that conventional fisheries management can result in inappropriate policy as it focuses on an increase in productivity in one activity. At the same time a diversified approach may be beneficial to resource conservation. This livelihood approach is even more important in the Amazon where the impact of the small-scale rural fishers is very large. As the model shows, a large change in the activities of the commercial fishers has little impact on the overall fisheries, while a small change in those of small-scale rural fishers has a large impact on the fisheries.

The present study shows that even simple bio-economic models constructed in conditions of very limited biological knowledge can provide important insights to inform policy decisions.

Chapter 7

Conclusions

7.1. Contributions of this study

In thirty years, the fisheries in the Amazon developed from a sector basically characterised by small-scale fishing to a more complex system where small-scale fisheries, industrial fleet with large fishing capacity, and many small-scale artisanal commercial fleets, operate together along the river bank of the Amazon and its tributaries competing for the same resource.

Although of great importance to the fishing sector, research in the Amazon has not provided a holistic view of the sector or the interaction among actors to create a framework from which the management system can be evaluated. The purpose of this work was to analyze the prospect for co-management in the Amazon for the commercial and small-scale fisheries, as well as to evaluate the impact of possible alternative management scenarios by analysing different segments of the fisheries sector in the Amazon and understand the relationship between these segments. This objective has been achieved and this thesis has made the following distinct contributions to the understanding of Amazon fisheries and their management:

1. An estimate of the importance of the fishing sector considering income and employment generation of each segment;

2. Characterisation of the regional differentiation of the commercial fleet in the Amazon;

3. Analysis of the following factors: the role of fisheries in the life of floodplain residents in terms of the rules, enforcement and effects of community management;

4. Integrated analysis of alternative management scenarios and their implications for small-scale and commercial fisheries.

Results and their implications are briefly reviewed in the next section.

7.2. Key results and management implications

The study of the sector showed that total fishing sector employed 168,315 workers, with most of them being small-scale rural and commercial fishers and that the sector generated an income of almost R$400 million per year, with the fish processing plants being responsible for most of it. Using market value to estimate the value of fish caught by the small-scale rural fishers, this work also showed that this category, usually ignored by government policy, catches about 33% of total fish value. Supporting activities for the fisheries such as commerce, shipyard, gas station, etc., although fundamental to the existence of the sector, contribute very little in terms of income and employment. This part of the study showed that commercial and small-scale fishing activities are keyto generating employment in the sector representing 95% of total jobs created.

Commercial fishers have emerged with a higher fishing capacity, equipped with a boat, motor engine and with a crew of fishers, fishing in the main channel of the river or in lakes near which the small-scale rural fishers resided. This fleet supplied fish to the local regional markets and to the industry along river bank and its tributaries. The expansion of these commercial fishers into the lakes where the traditional population reside led to closure of the lakes by the small-scale rural fishers to restrict resource access to outside fishers. This action resulted in conflicts for the control of the resource. Commercial fishers did not accept this measure because legislation did not allow fishing to be regulated by communities, increasing conflicts even further. To reconcile these groups, government created a law that allowed local residents to regulate the fishing activity using what is called a Fishing Agreement or Fishing Accord. This new system also established support for a communal monitoring system supported by IBAMA (the Brazilian Federal Environmental Agency) moving from an official top-down management system and an informal community management to a system where the management responsibilities began to be shared between the government and the fishers.

With the new law for lake fisheries management, the second contribution of this study was to understand how commercial fishers would be impacted by lake regulation, which could range from a ban on boats or on inputs such as ice or gillnets, which ended up functioning as a barrier to the entrance of boats into the lake, as they could not operate without this technology. Some agreements reduced the size of the boats and in this sense the agreement could result in a reduction of the size of the fleet. Based on the results of the fleet study the reduction of the fleet would result in no economic loss since the efficiency is the same for all sizes of boats. Also by understanding the origin of the fleet this study showed that when the fishers are based in rural areas, such as in the lower Amazon, conflicts between commercial and small-scale rural fishers seem to be less probable, while in regions such as Tefé, where most of the fishers are urban based the conflicts are a constant threat. Either way, it is worrisome to foresee the possible / probable development of the relationship between commercial and small-scale rural fishers once the system is disseminated and more community lakes are closed to the commercial fishers.

The third contribution made by this work was the evaluation of the impact of agreements on community fishing activity and on stocks. Based on these agreements communities regulate the level of effort in the lake through rules. The result showed that communities do comply with the main agreement rules, as fewer fishers use gillnets in the managed lakes. The productivity in managed lakes was also higher than in the unmanaged ones. The regulation does not seem to make a difference in the catch or effort per family suggesting that the increase in productivity was the result of eliminating the extra effort that comes from outside boats.

Another reason to think that the regulation actually worked in reducing the effort from outside the community is that the regulations allow the residents of the community to practise fishing very much in the way that they practise without an agreement. For example, the limit of catch per trip is 15, 30 or 50 kg in some of the agreements, while the average catch per trip in the communities without management is generally low, from 5 to 9 kg, in low or high water, respectively. Only 2% of the catch exceeded a catch of 50 kg per trip in managed lakes and only 1% in unmanaged lakes. The higher productivity obtained in the lakes was not used for commercial ends and possibily the tendency was for communities to fish less as productivity increased.

The regulation, therefore, does not modify drastically the fishing behaviour of the community's fishers. The regulation does not have a great effect on the fishing activity when comparing communities with and without management except for the type of gear used. Even when the difference is related to the gear it is possible that the restriction on gillnets has the objective of restricting the entrance of fishing boats that are operated basically with the use of gillnets and not to regulate the fishing activity by the residents themselves. So fishing management restrains mainly the fishing activity of the commercial fishers in the lakes.

The result of management is, however, positive for the community since the reduction of effort does increase productivity. The fact that the regulation increases productivity indicates that there is a potential for longevity of the co-management systems. If the co-management were simply a means to exclude outsider fishers without a real return to the community, then the prospect in the long term for community management in the Amazon would be dim because communities have a high cost of monitoring associated with fishing-agreement systems. If, on the other hand, the investment in community management brings true benefits for the community, then there is a real incentive and a good prospect for community management in the long run.

The results of this study also showed that there is little indication that households substitute fishing with other activities even when returns are high. Hence it is unlikely that fisheries management initiatives will reduce reliance on other activities that may be more damaging to the várzea environment. At the same time, an increase in fish productivity would not lead also to excessive fishing since they do not increase the effort. This means that the fishers are organizing themselves to avoid reduction in productivity, to maintain both their current household livelihood and the same level of returns.

Another very important result was the relationship between local fishing effort and yield. This model implies a strongly non-linear relationship between effort and catch per unit of effort (CPUE) from the observed data which is different from relationships found in previous studies. Data of yield per hectare is scarce in the Amazon and this work adds a new set of data to the literature to help evaluate resource pressure.

The data and analysis described in this study served as a basis to develop a bio economic model to be used in the evaluation of fishery trends as well as alternative management options. The non linear relationship found between catch and effort in the communities' lakes and the long-term trends from the commercial fisheries in the lower Amazon, was used to develop the bio-economic model in Chapter 6. The bio-economic model was developed to evaluate interactions between the small-scale rural and commercial fishers and effects of various policy measures on each other. The model showed that the current state of exploitation or the degree to which river and lake fisheries interact biologically does not have a great impact on the fisheries. Overall results show that the lower Amazon is under-exploited when compared to its potential and that the limits to expansion are determined by economic reasons.

The estimate of total yield in lakes studied in this work shows that the level of exploitation is low in the lower Amazon (37% of total maximum yield - dividing total catch in the region by the respective area and comparing with the Ymax from Figure 5.5) and that the open access equilibrium is reached with a low level of exploitation.

Overall fisheries in the Amazon are broadly underexploited when yield is compared with other similar system. Comparing the African and Amazon productivity, Bayley (1981) estimated that the theoretical yield in the Amazon could be two and half times higher than the yield for the time period he analized. Ten years later, Merona (1990), in a study in the Lago do Rei on the Central Amazon, near Manaus, estimated that a yield of 70 to 100 kg / ha were obtained in the Lago do Rei. This value was much higher then the average yield for Latin American rivers (24.8 kg/ha) or for the African rivers (50.1 kg/ha) (Welcomme 1990) and indicated a high yield possibily because the lake is near large urban areas. As should be expected the yield in the Amazon is not homogeneous for the whole basin and some white-water fisheries near large urban centres, such as Lago do Rei, are more exploited then white-water fisheries further upriver. The average yield for the Amazon, however, seems to be much lower than the values found by Merona (1990).

In African Rivers, where larger amount of data for rivers, floodplains, and lakes is available, Bayley (1988) found values that ranged from 1.17 to 226.42 kg / ha with average of 58.42 kg / ha (s=57.80) for 31 lakes. Based on data for five rivers, Lae (1997) had a higher variability, with yield ranging from 1.22 to 1,500.00 kg / ha which result in a average of 155.30 kg /ha (s=609.83). Considering the similarities between African and Amazon river environments (Bayley 1981), the higher yield of African rivers are thought to be a consequence of the higher population density in the rivers.

In multispecies fisheries, the overall catch rate is not greatly affected by the fishing process directly because the species that became over-exploited are substituted with other less exploited species. Generally the larger species are caught first and, as they become depleted, smaller ones started to be exploited. Thus heavy fishing will affect the species being caught but not the total amount caught (Hoggarth *et al.* 1999). Because of this substitution of one species for another, when the yield reaches the maximum, it remains at that level while effort increases. Only in few cases has the total catch dropped.

One case of fishing up process with decline in total catch has been reported in rivers (Wecomme 1985) with an extremely high level of effort, such as the Oueme River. The Oueme River catch fell from 10,400 to 6,484 t from the period 1955-57 to 1968-69. In this case some large species disappeared completely and were replaced by smaller ones, resulting in a decrease of productivity.

Welcomme (1999) defined several stages of exploitation for multi-species fisheries to guide managers about the level of exploitation of the fisheries. Welcomme (1999) shows that when the fisheries are exploited at yields below 60 or 70 kg/ha, the fisheries are in the initial level of exploitation. When yield reaches around 65 kg/ha then CPUE starts to decline although the fisheries reach a plateau during which overall levels of yield do not change with increasing effort. Eventually further increases of effort should push the fishery to un-sustainable exploitation levels (Welcomme 1999). Comparing these figures to the data from this dissertation, the yield range from 1.45 kg/ ha to 131.08 kg / ha, with about 21% of the lakes above initial phase of exploitation

The development of models for multi-species fisheries is still in early stages. In the case of the Amazon, there are many limitations to developing a model for fisheries management. Most bio-economic models have been used to integrate biological and economic data for management strategies for a single species stock (Hannesson 1993, Charles 1989, Dayaratne & Sivakumaran 1994, Trinidad *et al*. 1993). The conventional stock-assessment methods have been inadequate to analyze the multi-species fisheries (Welcomme 1999, Wakeford, 2000).

The model used in this dissertation was used to evaluate the interaction between the small-scale and commercial fisher and also to explore effects of effort, price and costs change on yield. It is very unlikely that the effort will increase because the commercial fisheries are already in the open-access equilibrium. Any boat that enters the activity will sustain losses. Thus, an increase in effort would only be possible after an increase in price or reduction of costs. An increase of 30% in price (or proportional reduction in costs), for example, would cause the effort to increase two or three times. In this case, yield would increase to 42-53 kg/ha (depending on the assumptions of the model) and still be considered lighly exploited. A price increase of 30% might seem large, but prices in Belém are twice as high as prices in Santarém (Ruffino 2002). With the paving of the Cuiabá-Santarém road and the expansion of markets to Brazil's centre-west, there is a possibility that prices might rise and cause changes in the present equilibrium leading to an increase in effort. The magnitude of the increase in price will determine the increase in effort.

With an increase of effort, there will be changes in the composition of species being caught. Studies using a dynamic pool model, as described in Chapter 2, have shown that many species are overfished or have growth overfishing. Therefore, any policies to intensify the level of exploitation have to come as strong measures to control the exploitation of large species currently under pressure. If exploitation level is still in the initial stage (although many species are decreasing in size), there is a relevant number of larger species that are being intensively caught now (Welcomme 1999).

While large species can be substituted in the total volume with smaller species as effort increase, the small one are not used for export or for urban markets. As a result, the loss of larger species might be associated with loss of international fish export markets and reduction of regional urban markets. As showed in Chapter 3, export is very important within the fishing sector - representing 36% of total income generated - so the depletion of larger species would be a great loss to the industry. In this way a fishing management system that maintains the present species composition could be the best way to maintain income and conserve the resource at the same time.

7.3. Further research

This work has shown that some communities implemented successful management leading to higher fisheries productivity. However this work did not involve a comprehensive evaluation of the monitoring system. Presently, the monitoring system is only based on voluntary work from the communities that act as “environmental agents.” The government does take action in training these agents. However, other then training, the rest of the monitoring costs falls on the community. Monitoring systems based on voluntary work face two problems: one of a financial nature, because the volunteer has an opportunity cost to work as a volunteer; and the other is that the agent needs materials and equipment to monitor the lake. To raise money, the community relies on fundraising activities such as parties or other non fishing activities leaving the management system much too dependent on activities that take up even more of the fishers' time. To support long term fishing activity and community management, the fishers have to depend on funds that are sporadic and not related with the fishing activity.

A second problem is that the community needs support from the government to enforce and carry out sanctions once infraction occurs. Some years ago, communities apprehended gillnets from intruders and sometimes burned them. This generated many problems for the communities, often with the involvement of the police. Now, with training from the government, communities are educated and learn that they cannot punish any violator and that they have to leave punishment to be implemented by IBAMA. Generally, however, when the communities register an infraction the government does not take action against the infractor weakening the management system and the formal support to community based management (McGrath *et al.* 2003).

In the long run, there is a need to evaluate the cost effectiveness of co-management in communities comparing the benefits from the management and the additional cost to the community. Other more subtle aspects, such as the one suggested by Pereira (2000) that interpersonal relationships within a small social group make punishment a threat to the group also need to be addressed but they do not seem as determinative and urgent as the monitoring support from the government.

In parallel with the economic analysis of a monitoring system for the communities, it is important to search for other market incentives besides increasing productivity to promote sustainable use of the floodplain. This could be seen as the other side of the monitoring cost evaluation since an increase in fish price would bring a higher return that could counterbalance the cost of the monitoring system. Certification is one initiative that tries to create a market which pays better prices for managed products. This type of market incentives to promote environmental protection has been much more developed in the Amazon for the wood sector (Sobral *et al*. 2002, Smeraldi & Verissimo 1999). Certification that generates better market prices has been a dim alternative for the Amazon fisheries. Researchers and organizations that want to promote sustainable resource use in the Amazon have looked into ways to certify fisheries in the Amazon (Blake 1999) but have not succeeded yet because of the technical difficult in evaluating sustainability in tropical fisheries and the conservative views of fisheries management displayed by the Marine Stewardship Council (MSC).

Barnes (2001) showed that community managed fisheries in the Amazon would not meet the standards to pass an MSC certification procedure, mainly due to the lack of sufficient information. However, he recommended a more holistic approach and suggested that community management organization should be compensated with certification since they contribute to overall stock preservation. Parallel attempts have been made locally to pay higher price for managed fish through the construction of a fish processing plant to process managed fish; but this type of measure has not been possible yet (David McGrath, personal communication).

Another creative system to pay for good environmental quality in the forestry sector in Brazilian Amazon is the program called Pro-Ambiente, which was created recently as an investment fund that integrates a financial system for agro-forestry activities with an environmental fund that pays the owner of the property for environmental services such as carbon sequestration, deforestation avoidance and reduction of soil degradation, among other things (Mattos *et al*. 2001, Mattos 2002). This system created by two NGOs, IPAM and Fetagri, has been implemented by small-scale farmers in the Amazon and is now becoming an environmental policy adopted by the Ministry of Environment. Pro-Ambiente can also be introduced in the floodplain as another alternative source of income. A recent experience of reforestation in a degraded area in the lower Amazon has shown a positive result in recuperating lost habitats and as a means of providing a carbon sink (IPAM). Just as with the upland small holders, the system now is been expanded for the small holders in the floodplain but only in communities with management. This could be one of the ways that communities could be stimulated to do management and have some economic compensation for their voluntary work in the monitoring system.

If communities could receive compensation for their management, then management would not be an expensive initiative for poor communities, which invest a lot of energy and money implementing fishing agreements. The economic evaluation of fishing agreements needs to be addressed urgently to guarantee that there are no major constrains to community management.

Another aspect that needs to be addressed in community management in the Amazon is the impact of fluctuation in size of flooding. Since many authors have shown the relevance of water variation to the stock, it is important to deepen the studies on management taking into consideration the flooding season to see what impact it might have on fish stock and what role it may play in community management and fishing productivity (Welcomme 1990).

By providing a transparent and rigorous analysis of management issues, researchers can foster a constructive dialogue for development of Amazon fisheries, and their role in the conservation of floodplain habitats.

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Appendix I Paper from Lorenzen, K., Almeida, O.T., Garaway, C.J. & Nguyen Khoa, S. (2004). The relationship between aggregated catch and effort in multi-species artisanal fisheries. Manuscript.

Relationship between aggregated yield and fishing effort in multi-species fisheries

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Abstract

Many tropical fisheries are inherently of a multi-species nature, with any given type of fishing gear harvesting a wide range of species, can be managed only on a species-aggregated level. We studied species-aggregated yield-effort relationships in multi-species inland fisheries, where spatial replication combined with relative temporal stability of fishing patterns allowed us to analyze yield-effort relationships corresponding approximately to equilibrium conditions. Of three functional forms considered, a sigmoid model provided a better fit to aggregated yield-effort data than either an asymptotic exponential or a quadratic (Schaefer) model. Catch per unit of effort (CPUE) was high and declined steeply with increasing effort at very low overall effort levels, but responded only weakly and in a non-monotonous over w wide range of higher effort levels. This suggests that reductions in effort do not necessarily lead to long-term increases in aggregated multispecies CPUE. Substantial increases in CPUE can be expected if fishing effort is reduced to extremely low levels, but these CPUE increases are unlikely to reflect proportional underlying increases in community biomass. We discuss these findings in the light of other empirical and theoretical studies and their implications for fisheries management.

Introduction

Many tropical fisheries are inherently of a multispecies nature, with any given gear type exploiting a wide range of species (Pauly 1979, Welcomme 1985). This is particularly true of subsistence-oriented inland fisheries where a wide range of fishing gear is used to harvest a diversity of species to meet household consumption needs. In general such fisheries can only be analysed and managed on an aggregated production basis, due to inevitable technical interactions in multispecies harvesting as well as limited data availability for disaggregated analyses. The relationship between aggregated yield and effort in multispecies fisheries is thus of great interest to practical management of tropical small-scale fisheries. The relationship is also of wider ecological interest, as it provides insights into the aggregated response of communities to exploitation. Analyzing such relationships using comparative data from spatially replicated small-scale fisheries may provide information on such responses under quasi-equilibrium conditions, given that effort is determined largely by human population density relative to the extent of water resources and thus is relatively stable over time.

This leads to the question whether there is a general relationship between aggregated yield and effort that applies to a brad range of fisheries. Single species yield and effort data are often interpreted within the framework of the Schaefer surplus production model: assuming a quadratic (dome-shaped) relationship between yield and effort, and continuously declining CPUE (Hilborn & Walters 1992). The Schaefer model has also been applied to multispecies fisheries (e.g. Pauly 1979), but disaggregation into ecologically defined species groups (Ralston & Polovina 1982) or transformation of variables (Bayley 1988) are usually required for species-aggregated data to conform to a Scheafer-type relationship. Theoretical studies suggest that aggregated yield-effort relationships are unlikely to follow the shape of Schaefer or similar surplus production models unless very restrictive conditions apply, but have not identified any general alternative models (Pope 1979; Kirkwood 1982). Systematic differences between multispecies and single species yield-effort relationships have been noted in empirical studies (Pauly 1979; Marten & Polovina 1982; Ralston & Polovina 1982). In particular, it has been noted that aggregated multispecies yield does not tend to decline even at very high levels of fishing effort (Pauly 1979; Marten & Polovina 1982). Welcomme (1985, 1999) developed a three-stage conceptual model of the response of multi-species stocks to exploitation, consisting of an initial linear increase in yield with effort, followed by a plateau of constant yield and eventual decline at very high effort. In more quantitative terms, Bayley (1988) showed that comparative yield and effort data from a wide range of water bodies can fitted to a Schaefer curve provided that yield is transformed to a logarithmic scale. The logarithmic transformation has the effect of making the data approximately normally distributed, but it also introduces an inflexion point within the rising section of the linear (back-transforned) yield curve. Laë (1997) applied an asymptotic exponential model to log-transformed yield data from lagoon fisheries, again introducing an inflexion point in the rising section, but also dispensing with the declining yield section immanent in the Schaefer model.

The above studies indicate that aggregated multispecies yield-effort relationships depart from the Schaefer model at both low and high effort levels. However, no systematic confrontation of alternative functional relationships with empirical data has been reported. Bayley (1988) provides the most extensive quantitative analysis of multispecies yield-effort relationships, but does not explicitly test alternative functional forms. Use of transformed variables to meet conditions of regression analysis also obscures the underlying form of the functional relationship. Bayley (1988) also acknowledged the limitations immanent in assembling data from ecologically and technologically very heterogeneous systems, and called for systematic comparative studies within more homogeneous systems. Our study aims to further the empirical study of aggregated yield-effort relationships by collecting primary data from ecologically and technologically homogeneous systems exploited at different levels of intensity, confronting alternative functional relationships with these data, and using maximum likelihood estimation to account for log-normal error structure without constraining the functional form of the yield-effort relationship. We also re-analyze the comparative data assembled for more heterogeneous systems by Bayley (1988).

Materials and Methods

Primary data collection

Catch and effort surveys were carried out in lake fisheries in the Brazilian Amazon, non-stocked and stocked lake fisheries in Lao PDR, and floodplain fisheries also in Lao PDR. The Amazon floodplain lakes ranged in size from 10 to 1200 ha. Their fisheries were exploited by local communities predominantly with gill nets, cats nets and hook and line. Lakes in Lao PDR were smaller, between 1 and 20 ha in area. Non-stocked lakes were exploited by local households on an individual basis, using mostly gill and cats nets. Other lakes were stocked with Nile tilapia (*Oreochromis niloticus*) and Indian and Chinese carp species. Stocked lakes were exploited on a communal basis, usually by fishing teams using gill nets and cast nets but often cooperating to drive fish into confined areas. Yield estimates for wild fish from stocked lakes were included in the current analysis, because previous and concurrent studies showed no impact of stocking on wild fish population abundance (Lorenzen et al 1998; Arthur 2004). Lao floodplain fisheries are based to a large extend on natural fish production in rainfed rice paddies. These fisheries are exploited by a plethora of different gears used throughout the local wetland area. For the purpose of this study, wetland areas were delineated on a village basis and catch and effort expressed per unit of village wetland area.

Effort and yield data were collected by means of household surveys covering two one week periods in the dry and wet seasons respectively in the case of Amazon lake and Lao floodplain fisheries, twelve one-week periods (one per month) in the case of Lao non-stocked lake fisheries, and continuous village records in Lao stocked lake fisheries. For each one-week recall period, respondents were asked to list all fishing activities by household members including details on location, gear, time spent fishing, and catch weight. In Laos a visualisation method was used to facilitate recall through the use of sticks and bowls of different size in order to estimate individual weight of larger, and combined weight of small fish (Garaway 1999). In the Amazon catch weight was estimated without such aids to recall. Catch and effort data were scaled up to the full village and year, but separated by water body in the case of lake fisheries. Only lakes not shared with other villages were included in the comparative analysis.

In the case of lake fisheries, which were exploited by relatively few different gear types (gill nets, cast nets and rod and line), total effort was standardized in units of gill net hours. In the floodplain fisheries, which were exploited by a wider range of gears including a plethora of different traps, effort was measured as hours fished without reference to gear type. Both yield and fishing effort were calculated per unit lake area, or per maximum flooded area in the case of the floodplain study. Gear composition was unrelated to total fishing effort per unit area within systems. However the gears used differed between systems with the Amazon lake fisheries used larger mesh nets and targeted larger species than Lao lake or floodplain fisheries which targeted virtually the full size range of fish present. Hence effort measures are not comparable across systems.

Surveys were carried out during 2001 in the Amazon lakes, 1996-97 in Lao lakes, and 1999-2000 in Lao floodplains.

Analysis

Three alternative models were fitted to describe the aggregated yield-effort relationships: a sigmoid model, an asymptotic exponential model and a quadratic (Schaefer) model. All models had three parameters and did not force the relationship through the origin, and were written with maximum or asymptotic yield Y_{max} as an explicit parameter.

The sigmoid model with an inflexion point in the rising section is of the form

$$Y(E) = \frac{Y_{\max}}{1 + \exp(a(b - E))} + \varepsilon$$

where Y(E) is the aggregated yield at aggregated effort level E, Y_{max} is the maximum yield, a determines the steepness of the curve, b is the effort level at which yield equals 50% of the asymptotic yield, and ε is a log-normally distributed random error. The asymptotic exponential model with monotonically declining slope is of the form

$$Y(E) = Y_{\max}(1 - \exp(-a(\ E - b)) + \varepsilon$$

where a determines the steepness of the curve and b is the effort at the origin of the yield curve. The quadratic (Schaefer) model is of the form

$$Y(E) = Y_{\max}\left(1 - \left(1 - (a(E - b)\right)^{2}\right) + \varepsilon$$

where a is the inverse of effort at maximum yield, and b is the effort at the origin of the yield curve. This model is asymptotic with Y(E)-> 0 for E->-∞ and Y(E)-> Y_{max} for E-> ∞, hence Y(0) > 0. The form of the alternative yield-effort models and the corresponding CPUE-effort relationships are illustrated in Fig. 1. Note that all models in Fig. 1 are set to give a slight positive yield at zero effort, and hence show a steep increase in CPUE as effort approaches zero. At higher effort levels, the sigmoid model implies that CPUE increases and then declines with effort, reaching a maximum at intermediate levels of effort. The asymptotic and quadratic models with b<0 (i.e., Y(0) >0) imply a continuous decline in CPUE with increasing effort, and at high effort levels this decline is steepest in the quadratic model.

The models were fitted using the method of maximum likelihood. Omitting constant terms, the negative log likelihood L for each of the candidate models j is given by:

$$L_j = \frac{n}{2}\ln\left(\frac{1}{n}\sum_{i=1}^{n}(\ln(Y_{obs,i}) - \ln(Y_{pred,i,j}))^2\right)$$

where n is the number of observations and Y_{obs} and Y_{pred} are the observed and predicted yield in replicate i (Hilborn & Mangel 1997; Johnson & Omland 2004). Because only the differences between L_j values (i.e. the ratio between likelihoods) of the data given alternative models are of interest, we report likelihoods as

$$\Delta L_j = L_j - L_{\min}$$

where $L_{\min}$ is the minimum L_j among the candidate set of models. The relative weight of evidence for each model can be expressed by the normalized likelihood

$$W_j = \frac{\exp(-\Delta L_j)}{\sum_{k=1}^{3}\exp(-\Delta L_k)}$$

which may be interpreted as the probability that model j is the best model for the given data given the candidate set of models. The expression given here is the Akaike weight (Johnson & Omland 2004) when all alternative models have the same number of free parameters. Because the same set of alternative models is compared on several independent data sets, the likelihood of the combined data for a given model may be calculated as the sum of the negative log likelihoods associated with the model in ach of the independent analyses.

Results

The sigmoid model provided the best fit to the observed yield-effort relationship in Amazon lakes, stocked Lao lakes, Bayley's (1988) data sets for African lakes and river floodplains (Tables 1, 2). The asymptotic model performed best for non-stocked Lao lakes and Bayley's lagoon data, and the Schaefer model peformed best for the Lao floodplain system. Evidence in favour of the asymptotic or Schaefer models is, however, not strong in any of the cases where they perform best. (kai, you test for bayleys data too? Should it go in the methodology?)

When analysis results are combined between studies (Table 3), the sigmoid model emerges as most likely to be the best model for the observed data among the candidate set. This applies to the analysis of our primary data sets as well as to that of Bayley's data. Both sets of studies also show similar qualitative patterns of yield and CPUE. If likelihoods from all studies are combined, Akaike weights strongly favour the sigmoid model as the best description of the data.

Three regularities in the relationship between aggregated CPUE and effort emerge from the analysis (Tables 1 to 3, Figures 2 and 3). First, there is no evidence of aggregated yield declining with effort throughout the effort range represented in the studies. Second, observed and predicted CPUE are very high near the origin of the effort scale and decline steeply to much lower values at moderate effort levels. This pattern is evident in all data sets except for the African lakes. Third, after the initial steep decline, aggregated CPUE changes only very gradually with increasing effort. The change in CPUE may involve a maximum, which is predicted by the sigmoid model and evident in several of the data sets, or a very gradual monotonous decline.

Discussion

Overall, a sigmoid functional form provides the best description of the relationship between aggregated yield and fishing effort in the multi-species fisheries. This implies certain regularities in the relationship between aggregated yield, CPUE and effort, which warrant interpretation and discussion. When interpreting these patterns, it must be born in mind that catch rates (CPUE) reflect both the abundance of the stock and a host of factors that influence catchability (the effectiveness of fishing), and that it usually very difficult to separate these factors (Hilborn & Walters 1992).

Observed and predicted CPUE are very high near the origin of the effort scale and decline steeply to much lower values at moderate effort levels. This pattern is evident in all data sets except for the African lakes. Mathematically, this pattern arises because the fitted models predict a small positive yield even at zero effort. While it may reasonably be argued that the yield-effort relationship must pass through the origin as no yield can be achieved without fishing effort, the model fits reflect the fact that very high CPUE values are indeed being measured at very low levels of exploitation. Forcing the model to comply with the conceptual imperative of passing through the origin (which is of no fisheries management interest) would thus result in a poor representation of CPUE dynamics at very low effort levels (which may be of management interest). Why do CPUE values increase so steeply as effort approaches zero? It is worth noting that the CPUE dynamcis at low effort detected here are consistent with the rapid temporal declines in multispecies CPUE described for early stages of developing fisheries (Myers & Worm 2003). In both cases, the rapid decline in CPUE occurs while overall levels of harvest are extremely small. This makes it unlikely that the change in CPUE can be interpreted in terms of community level, or even species level biomass abundance. Rather, it is likely to reflect changes in catchability due to changes in the spatial distribution of fishing, size structure of stocks, or fish behaviour (Hilborn & Walters 1992; Walters 2003). We are unable to resolve this question, but note that the pattern of steep decline in aggregated CPUE with effort at very low levels of effort and harvest holds some generality.

After the initial steep decline, aggregated CPUE changes only very gradually with increasing effort. The change in CPUE may involve a maximum, which is predicted by the sigmoid model and evident in several of the data sets, or a very gradual monotonous decline. Again it is difficult to changes in biomass from changes in catchability that may underlie this pattern. However, overall harvests in this effort range are certainly large enough to have measurable effects on biomass and production of species and communities. Maintenance or increase in multispecies CPUE with increasing exploitation may be consistent with community change as forage fish populations are relieved of predation pressure (May et al. 1979; Christensen 1995; Pauly 1998). The corresponding structural changes, i.e. the replacement of large, slow growing predators by small, fast growing forage fish are well documented for many fisheries (Laë 1997; Pauly et al. 1998, Welcomme 1999). Investigating the conditions under which such structural changes lead to the aggregated yield and CPUE responses identified here may provide further insights into the ecosystem effects of fishing (see also Mangel & Levin 2004).

The result that equilibrium catch per unit of effort is relatively inert or changes in a non-monotonous way over a wide range of effort levels is intriguing for its ecological and management implications. It suggests that reducing fishing effort will not necessarily increase aggregated CPUE and economic returns to effort in multispecies fisheris. This implication is seemingly at odds with the results of studies that have shown much increased community or species abundance in areas were fishing has been restricted, as compared to exploited control areas (Lorenzen et al. 1998; Mosquera et al. 2000). There are several possible explanations for this apparent contradiction, which we briefly discuss in turn. (1) Fishers may systematically change gear use with increasing effort is a way that compensates for declining CPUE. However, no systematic change in gear use with overall effort was evident in the primary data collected for this study. Also, several of the comparative reserve studies also rely on fisheries CPUE data to show increases in abundance. (2) Reserves are created in inherently more productive areas, thus confounding the effect of fishing restrictions measured in cross-sectional comparisons. This possibility is difficult to refute unless reserves have been placed at random of innate productivity can be measured independently. There are, however, some before-after comparisons that also show a positive effect of reserves on fish abundance (Roberts 1995). (3) Large responses measured after establishment of restricted fishing areas are transient, and total biomass will decline again as community structure matures. Transient responses are to be expected theoretically (Mangel & Levin 2004), even though for logistic reasons they have not been well documented empirically. Transient responses appear likely to contribute to the discrepancy identified here but require further study. (4) positive responses occur mostly in target species of commercial interest and are not reflected at the community level. Responses are indeed positive mostly for target species, and frequently negative for non-target species (Mosquera et al 2000).

In management studies where data are limited to comparative aggregated yield and effort data, a sigmoid functional relationship is most likely to provide a good description of long-term effects of fishing. Transient responses to management measures may depart from this relationship.

Acknowledgements

This study was supported by the Darwin Initiative and the Department for International Development of the United Kingdom. We thank Geoff Kirkwood and Robin Welcomme for commenting on an earlier draft of the manuscript.

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Tables

Table 1 Parameter estimates of the yield-effort models. Y_{max}, a and b are the model parameters (see text for explanation), n is the number of observations, and L is the negative log likelihood.

System	Model	Y_{max} ($kg\ ha^{-1} year^{-1}$)	a (h^{-1} ha year)	b ($h\ ha^{-1} year^{-1}$)	n	ΔL
Amazon lakes	Sigmoid	92	0.11	30	23	0.00
	Asymptotic	2993	0.0004	-1.4	23	1.25
	Quadratic	5220	0.0001	-1.6	23	1.24
Lao lakes	Sigmoid	199	0.002	1967	11	0.05
	Asymptotic	1878	0.00002	-15	11	0.00
	Quadratic	609	0.00005	-13	11	0.01
Lao lakes	Sigmoid	547	0.0023	1630	41	0.00
	Asymptotic	1087	0.0001	-63	41	1.10
	Quadratic	1012	0.00005	-64	41	1.03
Lao floodplain	Sigmoid	129	0.018	184	18	0.08
	Asymptotic	321	0.0011	-8.1	18	0.16
	Quadratic	157	0.0011	-7.6	18	0.00

Table 2 Parameter estimates of the yield-effort models. Y_{max}, a and b are the model parameters (see text for explanation), n is the number of observations, and L is the negative log likelihood.

System	Model	Y_{max} (kg $ha^{-1}year^{-1}$)	a (fisher^{-1} km^2 year)	b (fishers km^{-2} year^{-1})	n	ΔL
African lakes	Sigmoid	76	5.30	0.74	31	0.00
	Asymptotic	153	0.29	0.07	31	0.70
	Quadratic	155	0.11	0.07	31	1.52
River-floodplains	Sigmoid	99	1.04	1.97	14	0.00
	Asymptotic	97	0.32	-0.22	14	0.76
	Quadratic	186	0.06	-0.22	14	0.60
Lagoons	Sigmoid	106	0.51	2.88	13	0.29
	Asymptotic	120	0.18	-0.52	13	0.00
	Quadratic	132	0.05	-1.32	13	0.19

Table 3. Combined likelihood and Akaike weights associated with the alternative models.

Model	Our studies		Bayley (1988)		All studies combined	
	ΔL	W	ΔL	W	ΔL	W
Sigmoid	0.00	0.86	0.00	0.69	0.00	0.96
Asymptotic	1.95	0.12	1.17	0.22	3.12	0.04
Quadratic	3.75	0.02	2.02	0.09	5.77	0.00

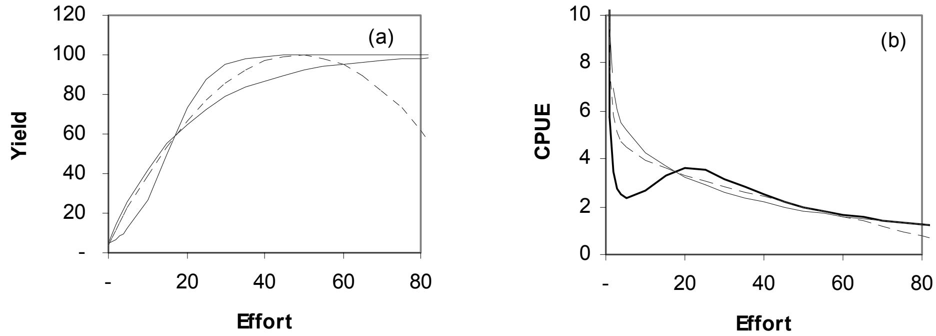

Figure 1 Overview of the alternative relationships between fishing effort and yield (a) and CPUE (b): sigmoid (solid line), asymptotic (dashed line) and quadratic (dotted line) functional form.

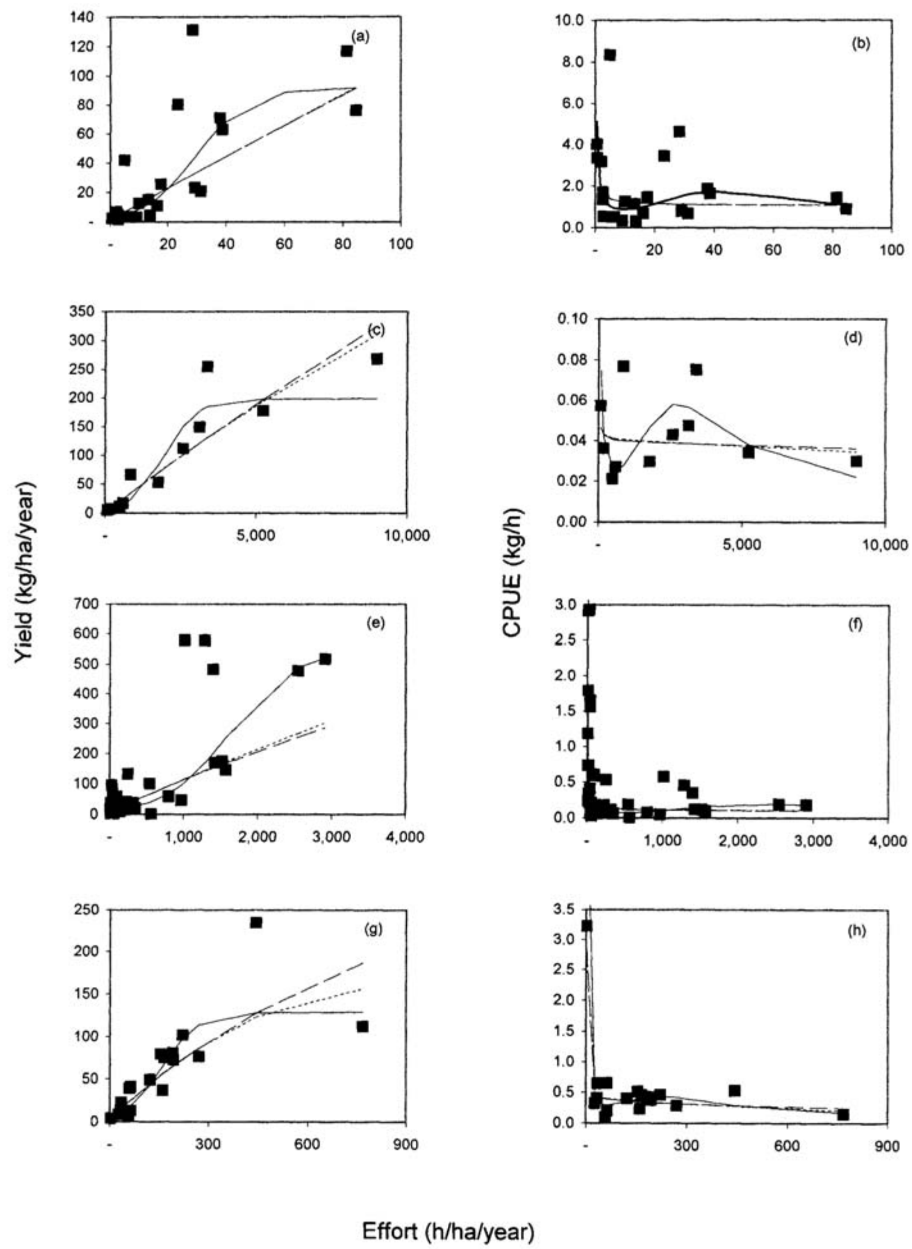

Figure 2 Relationships between fishing effort and yield (left had side) and catch per unit of effort (right hand side) in Amazon lake (a,b), Lao non-stocked (c,d) and stocked (e,f) lake, and Lao floodplain (g,h) fisheries. Lines indicate the fitted sigmoid (solid line), asymptotic (dashed line) and quadratic (dotted line) models.

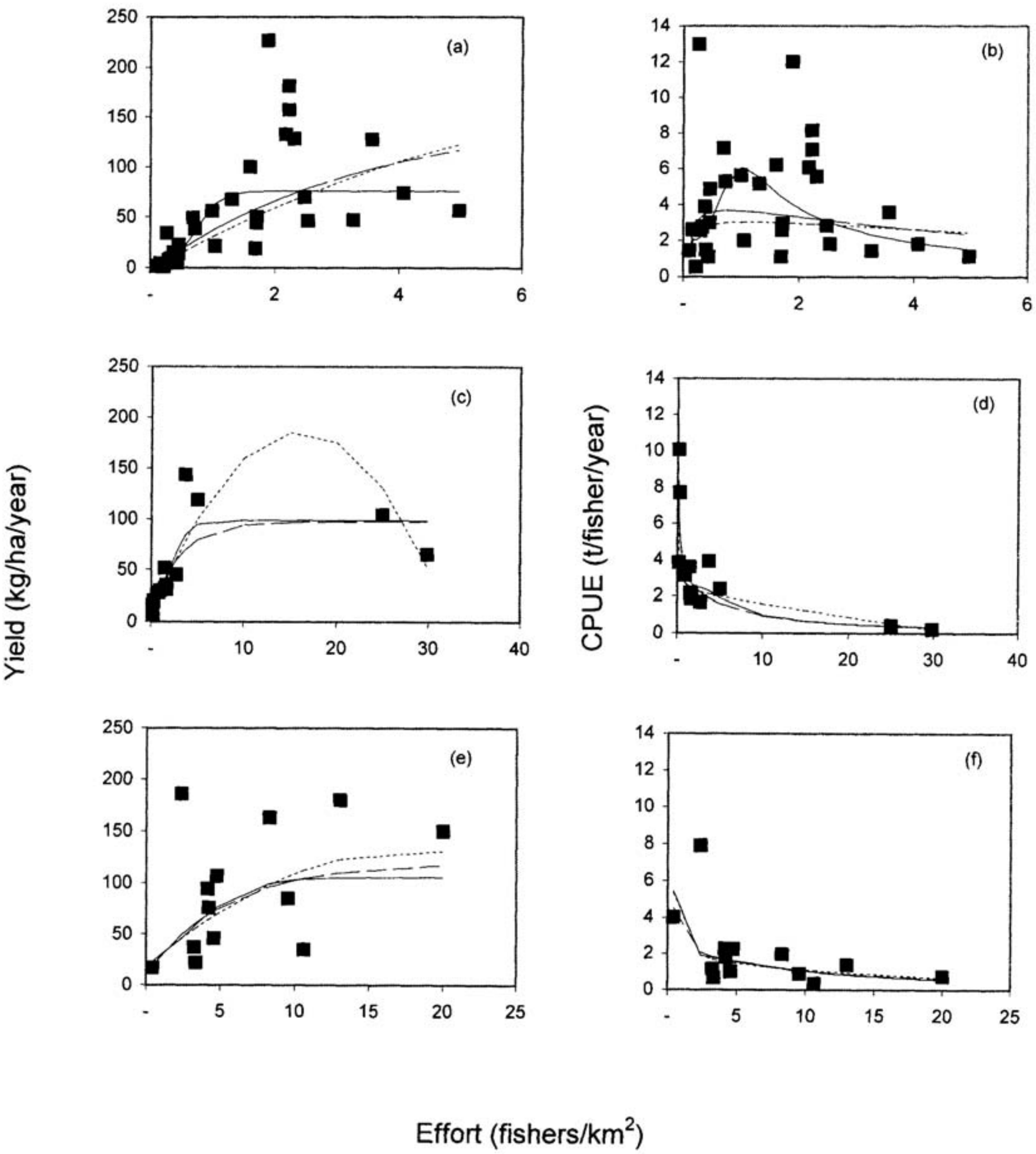

Figure 3 Relationships between fishing effort and yield (left had side) and catch per unit of effort (right hand side) in the African lake (a,b), river (c,d) and lagoon (e,f) fisheries data compiled by Bayley (1988). Lines indicate the fitted sigmoid (solid line), asymptotic (dashed line) and quadratic (dotted line) models.