

# Migratory Fishes *of* South America

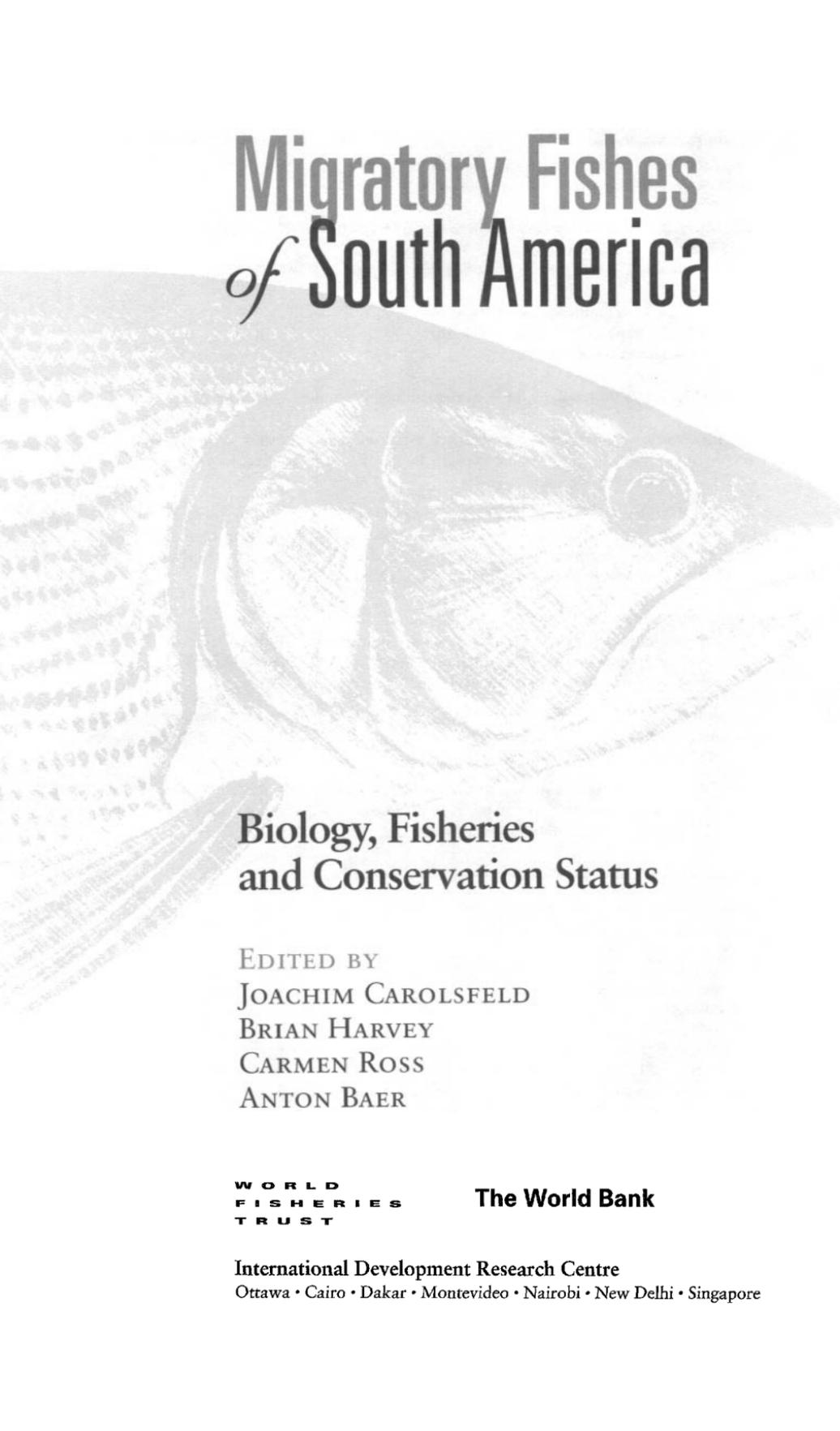
Biology, Fisheries  
and Conservation Status



EDITED BY  
JOACHIM CAROLSFELD  
BRIAN HARVEY  
CARMEN ROSS  
ANTON BAER

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## Biology, Fisheries and Conservation Status

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JOACHIM CAROLSFELD  
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**National Library of Canada Cataloguing in Publication Data**

Migratory Fishes of South America : Biology, Fisheries and Conservation Status / edited by Joachim Carolsfeld ... [et al].

Co-published by IDRC and the World Bank.

Includes bibliographical references.

ISBN 0-9683958-2-12

1. Fishes—Migration—South America. 2. Fishes—South America.
  3. Fisheries—South America. 4. Fishery conservation—South America.
- I. Carolsfeld, Joachim, 1955- II. International Development Research Centre (Canada) III. World Bank. IV. World Fisheries Trust

QL632.A1M53 2003

333.95'6'098

C2003-906143-4

Design and production by Alaris Design, Victoria, Canada  
Printed in Canada

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## ACKNOWLEDGEMENTS

**T**he preparation of this book was funded by the World Bank and the International Development Research Centre (IDRC). The editors and authors would like to thank M. Isabel Braga and Robert Schneider of the World Bank's Latin America and the Caribbean Environmentally and Socially Sustainable Development Unit for their enthusiasm and encouragement, and IDRC's Brian Davy for his unfailing dedication to small-scale fisheries in the developing world. The Canadian International Development Agency is also to be thanked for facilitating the networking needed to keep the team of authors together over the several years it took to produce this book.

# 1

INTRODUCTION

## Fishes of the Floods

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## The Idea Behind this Book

In 1996, the World Bank published *Freshwater Biodiversity in Asia, with Special Reference to Fish*, a technical review that has become a sourcebook for anyone interested in Asian migratory fish species.<sup>1</sup> The need for a companion volume on South American species was obvious, especially in a historical moment where the precarious status of inland water biodiversity was finally beginning to get the international attention it deserved. We approached the Bank, fortunately at a time when new and forward-looking ideas about water management were beginning to appear in its own reports and guidelines, and our proposal for a book on South America species, by South American authorities, was enthusiastically received. As biologists who had worked for many years with these species, both for conservation and for culture, we knew enough to side-step the task of writing the story of the migratory species ourselves – in Brazil alone, which takes up much of this book, the number of major river basins is so great, and the variety of species, life histories and lives affected so staggering, that no single author could do the subject justice. Fortunately, the region is blessed with fisheries scientists of very high calibre, and with interests broad enough that we were able to assemble a team of authors who covered most of the major river basins in Brazil, as well as the Colombian portion of the Amazon Basin. In some cases the authors worked alone; in others, their chapter is a team effort. In all cases, they were writing about their own back yards.

We believe that the material these authors provided, and which we have tried to assemble in a coherent whole, represents the first time the experience of so many local experts has been tapped and brought together to illuminate the lives of the remarkable migratory species of South America for an international audience. And there is much more here than just a wealth of biological detail. There are description of the rivers and the specific habitats the fish live in; there is discussion of the many and varied fisheries for the most important species; our authors list the threats

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<sup>1</sup> Kottelat & Whitten, 1996

to maintaining the fish as a sustainable resource, or, in many cases, threats to a species' very survival; they describe the legal and legislative instruments used to manage the fish; and finally each author provides a prescription for improving how these very special fish are understood and managed.

In our instructions to authors we were adamant that they describe not only the fish, but also their social importance, because the fishes' lives intersect with the lives of people at every turn, and the business of the World Bank, who commissioned this book, is in development for people. We believe that that admonishment has paid off in a volume that will be of great interest not only to other biologists, but to managers, policy makers, community groups and conservationists as well. In the final analysis, the more development is informed by understanding of the ecosystems it affects, the better the chances of that development being truly sustainable. As instigators and editors of *Migratory Fishes of South America*, we sincerely hope that we are contributing to that process.

## Important but Ignored

The migratory fish species of Latin America are a well-kept secret. However great their biological and cultural importance, outside their native range they are known only to biologists with a special interest in the tropics, and to the occasional especially intrepid sport fisherman or aquarist. Many people know about salmon and their prodigious migrations from the ocean to the place of their birth many kilometers upstream, but few outside South America have ever heard of the *dourado* or the *surubim*, species every bit as charismatic as salmon. True, some migratory species, like *pacu* and *tambaqui*, are farmed in Asia and the southern United States, and juveniles of these species are popular aquarium fish. But the farmed products have yet to catch on in a big way, and the baby fish grow up to be too large, and too unlovely, to keep.

But *pacu* and *tambaqui* and several dozen other large species have life histories every bit as awe-inspiring as the salmon's. Some of them migrate more than a thousand kilometers to spawn, and unlike the salmon they do it year after year. More important, the South American migratory species feed people too, and provide them with recreation, and have a place in the hearts of Latin Americans that is every bit as important as the

iconic role played by salmon in North America and Europe. Migratory species have always been mainstays of subsistence and small-scale commercial fisheries, feeding into distribution networks that put surubim from the Amazon onto dinner plates in São Paulo and Brasília. In the past decade these species have also stimulated the explosive growth of sport fishing that pulls in visitors not only from neighbouring cities but also from as far away as Japan and Russia.

This book is a comprehensive look at the lives, and the social importance, of the principal migratory freshwater fish species of large river systems in South America. It is unusual in several ways. First, it is written by leading Brazilian and Colombian fish biologists. Second, it covers a vast geographic area, including the Brazilian and Colombian Amazon, Paraná-Paraguay, São Francisco and Uruguay basins. Finally, it describes not only the state of current knowledge of the migratory fish species in each basin, but also their importance as food for local people.

It must be pointed out that the definition of “migratory” can be broad and varied.<sup>2</sup> Moreover, the species discussed by the authors of this book are by no means the only migratory ones in the rivers. The book concentrates on economically important species that appear to conduct obligatory reproductive migrations – in other words, those that spawn only after migrating between two distinct geographical areas. This definition of migratory fish is the one commonly accepted in Brazil, and is practical in that it identifies a group of fish that are clearly affected by alterations to their migratory routes. Most of these same species, as well as other species in the rivers and reservoirs, also carry out migrations between habitats for feeding and refuge, but these migrations are quite varied and appear to be more or less opportunistic. Evidence for and interpretation of this distinction varies between the river basins and authors, and in the present book is seen most strikingly in Chapter 7 on the Colombian Amazon.

However, there are species of less direct economic value and/or smaller body size, such as forage fish, that are migratory too. For example, *sardinhas* (*Pelota* spp.) are reported to lead the reproductive migratory *subienda* in the Upper Amazon (see Chapter 7), fishermen in the Mogi Guaçu (Upper Paraná River Basin) speak of migratory species of the

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<sup>2</sup> Lucas & Baras, 2001

*lambari* (*Astyanax* spp.) that lead the piracema in this river (unpublished). Small forage species leaving the flood-plain lagoons as they drain are the defining characteristic of the *lufada* phenomenon of the Brazilian Pantanal that coincides with the first stage of the reproductive migration of larger and economically important species. While these species are of obvious ecological importance, very little is known about them and they are not generally the targets of directed fisheries. They are not covered by most of the authors in this book.

## Migratory Strategies: Endless Variety

There is a staggering variety of migratory species in Latin America, and their life histories are incredibly diverse. The characids have scales. Some, like the dourado *Salminus*, look salmon-like. The big catfish, the pimelodids particularly prized for their flesh, are smooth-skinned. The diets of the two groups range from mud to fruits to other fish to plankton, and the spawning journeys they embark on every year, when the rains come and the rivers overflow their banks into the wetlands and forests, are bewilderingly various. Some species go upstream to spawn, while some go downstream. Some spawn in headwaters above the flooded areas of the Pantanal, the world's largest wetland, while others release their eggs in the rivers mainstem. A few have even managed to carry on reproducing despite the existence of numberless reservoirs that spatter the map of Brazil and testify to the colossal scale of hydroelectric development in the country. All of them, however, release their eggs to the currents, where they drift, and hatch, and feed with the rhythm of the rising and falling waters, coming and going from habitats that appear and disappear with the floods.

Readers of this book will be introduced to a group of fishes that has evolved a variety of strategies for using the transient habitats that result from the seasonal floods characteristic of the region. Floodplains and inundated forests are essential for larval and juvenile development of most of these species, and provide foraging opportunities once they have become adults. Most of the species depend absolutely on the cues associated with flooding, for it is these cues that trigger reproduction.

Migration is a spectacular phenomenon, with the shoals of adults heading upstream making a memorable picture. In larger rivers the system

is particularly complicated, with adults and juveniles travelling not only up and down the river mainstem, but also in and out of the tributaries and their associated floodplains. Some species travel more than 1000 km, at speeds up to 16 km per day.<sup>3</sup> Migrations that go up and down river channels (both mainstem and tributaries) are usually called “longitudinal”, while “lateral” migrations are those between the channel and the floodplain – although local terminology sometimes complicates the picture further.

The migratory strategies themselves vary between species and river basins. If there can be said to be a general pattern for reproductive migrations, it is an upstream spawning migration (piracema or subienda), followed by a downstream dispersion of eggs, larvae and spent adults into floodplain areas. However, there are many variations on this theme, with the most complex situation being in the Amazon, where there can be at least three separate phases of migration, with adults migrating both up and downstream, for reproduction or for feeding, in tributaries and in the mainstem river. Another variant occurs in the Upper Uruguay, where floodplains are less common and juvenile development takes place in the transient environments found at the mouths of tributaries backed up by flooding of the main river channel (in Chapter 4 the terms “longitudinal” and “lateral” are even used differently from the usual convention). The passive downstream drift of larvae and juveniles is common to most migratory patterns in South America, in contrast to salmon in North America, for example, where fry control their own movement downstream in response to developmental and environmental cues.

If a river is large enough there may even be separate upriver and downriver populations of a single species, which makes unravelling their migration patterns that much more complicated. Even today, drawing a simple diagram of a migration pattern for a given species, in a given river system, is difficult, because such a diagram requires detailed information on movements and genetic makeup that is in most cases lacking. The descriptions of migratory patterns provided by each of the authors in this book represent the best knowledge currently available, but they will undoubtedly be refined in the years to come. The new tools of DNA fingerprinting (to distinguish between separate populations of the same species) and radio-tagging (to track fish movement) are only now

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<sup>3</sup> Welcomme, 1985

beginning to be applied in Brazil, and it is over the coming decade of research that we will finally be able to draw the migration maps so necessary for sustainable management. Such tools, and the picture of migration patterns they can provide, are doubly important when one considers the effects of changing flow patterns, water extraction, and damming. Different species react to obstacles differently; some of them can negotiate fish ladders, and others may be able to establish separate populations in the smaller sections of river available to them after a dam is erected, or even spawn in a reservoir. In the absence of good data on migration, the true effects of these alterations to habitat can only be guessed at.

Apart from general similarity of reproductive patterns, many of the most abundant characid migratory species, which represent up to 70% of the fish biomass in South American freshwaters, share a dietary dependence on detritus or the fruit and vegetation of terrestrial plants, with only larval phases relying on plankton. Carnivorous migratory characids and catfish in turn prey on these fish, transferring nutrients between habitats and relying on seasonal input from inundated terrestrial areas. All these migratory species share the unfortunate attribute of being very poorly understood – a point that is made time and again by the authors of this book.

## Threats to Migratory Fishes

Like inland water biodiversity everywhere, the freshwater fishes of Brazil and Colombia are faced with a variety of threats. The migratory species, because of their wide-ranging habits, are probably the most vulnerable group of all, and the fact that these species provide food and income for local people makes their situation doubly significant.

Threats to migratory fishes in South America include industrial, domestic, and agricultural pollution, deforestation, alteration and obstruction of river flows, introduced species and overfishing. While all basins experience all of these threats, pollution is particularly severe in parts of the Paraná and Uruguay rivers, damming is especially intense in the Upper Paraná and the São Francisco rivers (many of the rivers in South America are so heavily dammed as to have become a chain of reservoirs), and overfishing is evident in parts of the São Francisco, Paraná,

and Amazon systems. Gold mining causes heavy metal pollution in the Upper Paraguay and in the Colombian and Brazilian Amazon. Large-scale works including dredging and pipelines have the potential for widespread habitat damage in the Paraná-Paraguay region. Pollution from hog and poultry farming is a special problem on the Upper Uruguay, and the use of herbicides to eradicate illegal crops has serious consequences for fishes in the Colombian Amazon. Pollution has left the Piracicaba River, which drains into the Paraná, biologically depleted and in some sections devoid of aquatic life. Exotic species like the *tucunaré*, an Amazonian native introduced to the Paraná and Paraguay basins, may confer economic benefits (for example, as commercial and sport fish) but compete for habitat and food with several native migratory species. Riverside deforestation has the unexpected effect of eliminating a food source for species that live on fruits and seeds borne to them by the river. Even climate change is potentially disastrous because it affects the rhythm of the waters, and for species that live and die with the annual flood, water is everything. Migratory fish populations appear currently to be healthiest in portions of the Amazon and Upper Paraguay basins.

An idea of just how vulnerable the migratory species are can be gained from an analysis published by Froese and Torres (1999). These authors used the data in FishBase, a large database on finfish, to analyze the biological characteristics of threatened fish species contained in the 1996 IUCN Red List. The result is nothing less than a profile of the kind of fish most likely to become extinct. Here are the characteristics of the unlucky winner:

- Freshwater (ten times higher threat than to marine fish).
- Migrates to spawn or feed.
- Feeds at lower trophic levels.
- Large, slow-growing and late-maturing.
- Doesn't guard its eggs.
- Occurs in countries with high population densities.
- Occurs in areas where there are many introduced fish species.

As a description of many of the migratory species of South America, the above list could hardly be improved on; for readers of this book, the following chapters will introduce species after species that fits the description.

## Fisheries

Fisheries on South American migratory species are classified as subsistence, sport, and commercial. The latter are carried out primarily for domestic markets, with the only significant “industrialized” export fisheries being in the Amazon. Subsistence fisheries generally use simple gear. Fisheries vary in importance in different basins: the Amazon currently contributes 54% of all documented Brazilian freshwater fisheries production, including aquaculture. The industrialized Amazonian fishery is based on only a few catfish species, whereas the subsistence, artisanal and sport fisheries utilize many species in all basins. Sport fishing is especially important to the economy of the Pantanal in the Upper Paraguay, but is also significant, and growing, in most other locations. Subsistence and commercial artisanal fishing are also becoming increasingly important for riverine communities in most basins, as access to agricultural land and other sources of income decreases.

Depletion of fish stocks (not necessarily by overfishing) is leading to conflict between sport and artisanal fishing groups in all basins, a conflict that is closest to resolution in areas of the Amazon where community-based management is practised, and in the Lower Pantanal. Throughout the region, managers are having to confront the different needs of the commercial and sport groups, both of which have different requirements of the resource. Greater inclusion of stakeholders in management will help, and is starting to happen, but the need for better monitoring of stocks and catches will not go away.

This book makes the ambitious attempt to categorize and describe the several kinds of fisheries in each basin and on each major species. In so doing the authors, despite their location in the basins themselves, faced a daunting task. Although inland waters are now generally accepted to support a huge variety of small fisheries with enormous significance for local livelihoods, any analysis of these fisheries is presently crippled by the lack of good reporting and statistics. The basins are vast, the people who catch fish are strung out along mainstems and tributaries, central landing sites are the exception rather than the rule, and the most one can confidently say about catch statistics is that they’re underestimates. Whether this means the fisheries are over-extended or actually healthier than is now believed is anyone’s guess.

Management of fisheries in the absence of reliable statistics is like minding a store with no record of sales and no inventory. Coates (2002) has analyzed the situation in Asia, where under-reporting of inland fisheries is the rule. In the eight countries he reviewed for FAO, Coates found that inland capture fisheries were under-reported by factors ranging from four to as high as twenty-one. A similar analysis of fisheries statistics for South America and the implications for management is urgently needed. For now, all we have is warning flags such as Araujo-Lima and Ruffino's note on catch reporting in the Brazilian Amazon (page 221), "the total catch from the Amazon may be as much as three times the values presented by IBAMA." If, as we suspect, the same situation obtains in other basins, conservation and sustainable management of the migratory species in South America are presently being hobbled by the most basic of needs – the need for information.

## Geographic Coverage and Aliases

The geographic coverage of South America by this book is not complete, and several major systems with important migratory species are excluded. The Orinoco River (Colombia and Venezuela), for example, like the Amazon arises on the eastern Andes and drains large tracts of rain forest and tropical savannahs before flowing into the Caribbean. Another major river not covered here, the Magdalena (Colombia), drains the moist central valleys of the northern Andes. The Parnaíba River (Brazil) drains arid lands and its relatively small discharge flows into the Atlantic between the Tocantins and the São Francisco rivers. The Essequibo River of Guyana is the largest of the three major rivers in Guyana. None of them are covered in this book. Several of them cross or form international boundaries, which leads to complicated issues of exploitation and conservation, especially when the river flow is altered. The Yacyreta Dam, a huge bilateral project on the Paraná River that is shared between Argentina and Paraguay, is a good example, as is the Itaipu Binacional on the border between Brazil and Paraguay.

Because this book is a collection of chapters, each one written by a different group of authorities, there is inevitably some overlap. Most obviously, many of the species occur in several or all of the six river basins.

Just how much overlap there is in species composition, and how many and varied are the aliases each goes by, can be seen at a glance in Appendix A. These tables show that their status, the threats they face, the kinds of fisheries on them and even their common names may be different in different places.

South America is just too big, and its geography and social ecology too varied, to allow a one-size-fits-all description of the life and times of *pintado* or tambaqui. Hence we have not only allowed repeated description of certain species, we in fact consider it one of the book's strengths. This way, each chapter is as complete as the author can make it, and for readers whose interests go beyond a single river basin, encountering the same fish in two different places will be like running across an old friend and looking out for changes since the last meeting.

The reason so many species inhabit geographically separate basins, of course, relates to the prehistory of the continent. Because the Amazon River originally drained into the Pacific, then into the Caribbean (through the present-day Magdalena River), and then into the northern coast of South America (through the present-day Orinoco River), many of the fish species in the different river systems are the same.<sup>4</sup> Present-day conditions developed from the rise of the Andes, starting about 89 million years ago. Studies of mitochondrial DNA, for example, suggest close genetic relationships between the *Prochilodus* species in the Paraná, Amazonas, Orinoco, and Magdalena basins.<sup>5</sup> Since so many of the same species occur in different basins, and because so many basins cross national boundaries, it should be no surprise that certain migratory species pose unique management problems. The *sábalos* (*Prochilodus* spp.) and the large catfishes (for example, *Pseudoplatystoma* spp.), both of which migrate extensively, are prominent examples of this problem.

## The Migratory Fishes as Examples of Freshwater Biodiversity

The contribution of inland waters to the global economy and local livelihoods is under-appreciated, and the migratory fish species are just

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<sup>4</sup> Lundberg et al., 1998

<sup>5</sup> Sivasunder et al., 2001

one part of a complex web of inland biodiversity. Despite their relative insignificance in terms of area (less than 0.5% of the world's water), inland waters contain 40% of all aquatic species. And, largely because of the “captive” geographic nature of inland waters that makes them so susceptible to habitat degradation, freshwater fish species by far outnumber marine ones on the current IUCN Red List (84% freshwater). Freshwater species face special risks, of which fishing is certainly not the greatest, yet they are less well known than marine ones. Those risks are not just the familiar ones of habitat loss and pollution – the impact of global warming on water levels will be profound, and for a group of species like the migratory fish whose biology is completely evolved around the ebb and flow of floodwaters, the implications are enormous.

One of the results of the shortage of information on global taxonomy is that it's difficult to compare the numbers of migratory and non-migratory South American species. In the one basin where guesses have been hazarded, namely the Amazon, estimates hover around 3,000 fish species and would seem to relegate the forty-six migratory species described by Araujo-Lima and Ruffino (Chapter 6) to part of a distinct minority. Incomplete identification of species, and deficient fisheries landing statistics, make it impossible to be more precise in this or any other South American basin.

Of course, the South American species are not the only migratory fishes in the world. Although the patterns are often different from those seen in South America, migration is a prominent feature of the lives of a huge variety of fish species in other parts of the world, and the effects of damming and redirecting rivers have been especially singled out for study. A cursory look at some of these species (in North America, Europe, Asia and Africa) is provided in Appendix B. For species in South America, Africa and Asia the exhaustive review by Welcomme (1985) is highly recommended.

## The Future

What is the future for the migratory fishes of South America? There is no simple answer, in large part because of the vast geographic area over which they are spread, and the great differences in status, use, and especially the

political and bureaucratic structure of local management systems. One certainty, however, is that the general lack of data is unlikely to change without better international awareness of these remarkable species. The migratory fish described in this book need to be promoted at home and on the world stage, in scientific meetings and in the popular media. As the profile of inland waters struggles upward, migratory fishes need to be more visible, and so do the communities that depend on them. Governments cannot be expected to push for research and management reforms for an obscure target. We hope this book will be the beginning of such an awareness.

The authors of each section offer their own detailed recommendations for conservation and management of the South American migratory fishes in their respective basins. Common elements of these recommendations are:

- Specifically and urgently address problems created by damming rivers, by regulating new development to ensure that floodplains remain accessible above reservoirs, improving fish passage, and developing water flow management protocols that re-instigate seasonal flooding patterns in downstream river sections. Several authors (although by no means all) recommend an improved stocking program for reservoirs in their area that includes monitoring of effectiveness and impacts;
- Reduce pollution, deforestation, floodplain destruction, and agricultural impact, including, in the case of Colombia, the use of herbicides to combat illicit agriculture. All authors felt that existing regulations could address many of the problems of environmental degradation, but that enforcement needs to be improved and that public education is an essential element in effecting that improvement.
- Improve knowledge of the migratory fish species, including better documentation of how they are affected by pollution, habitat loss, alterations of flow and overfishing;
- Implement fisheries management programs that accommodate the various interest groups in their development. In the Amazon, community-based management is recommended. Where a basin is shared between countries, as in the Paraná-Paraguay and Colombian

Amazon, authors stress the need for co-ordination amongst neighbouring countries. Both the Amazon authors and the Upper Paraná authors emphasize that agencies must consider more carefully the social implications of management regimes;

- Revise and implement broader biological survey and fisheries monitoring programs.

## A Note on Usage

The authors use the terms “fisherman” and “fisher.” While men do most of the fishing in the areas described in this book, women are heavily involved in processing, maintenance and marketing (see for example Nordi’s first-hand description of fishing on the São Francisco River, page 175). The fact that most current dictionaries have no entry for “fisher,” and define “fisherman” as “a person who catches fish,” indicates how unsettled the terminology is, so we have elected to allow the individual authors their preferences.

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MIGRATORY FISHES OF THE

# Upper Paraná River Basin Brazil

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## CHARACTERISTICS OF THE BASIN

### Geography and Geology

The Paraná River is formed by the junction of the Grande and Paranaíba rivers in south-central Brazil, and flows into the Rio de la Plata in Argentina. It is the tenth longest river in the world (4,695 km) and has a  $2.8 \times 10^6 \text{ km}^2$  drainage area that includes most of the south-central part of South America ( $18^\circ$  to  $34^\circ$  S;  $45^\circ$  to  $68^\circ$  W) from the Andes to Serra do Mar near the Atlantic Ocean (Figure 1). The Upper Paraná River includes approximately the first third of the Paraná River Basin, and lies completely within Brazilian territory, except for a stretch within the Itaipu Reservoir,



FIGURE 1. Map of the Upper Paraná River Basin showing location of principal dams

which borders Paraguay. The Upper Paraná River Basin has an area of 891,000 km<sup>2</sup> or 10.5% of the total area of Brazil. The river flows south-southwest, through the region of the greatest population density in Brazil. The climate in the Upper Paraná region is tropical/sub-tropical, with an annual average temperature of 15°C and more than 150 cm precipitation per year.<sup>6</sup>

The two rivers that form the Paraná River begin in the central plateau and run through sedimentary and volcanic rocks of the Paraná and Chaco sedimentary basins, which are bordered on the eastern side by the highlands of the Andes and on the north and east by the Precambrian rocks of the Brazilian Shield.<sup>7</sup>

## River Profile

The rivers that form the Paraná River are similar to other plateau rivers, with an average slope of 0.8 m per km, decreasing in the middle portion to 0.3 m per km.<sup>8</sup> The Upper Paraná River floodplain stretches from the Porto Primavera Dam to the upper part of the Itaipu Reservoir. This 230 km stretch is not dammed, and drops 0.2 m per km. This floodplain, especially on the western margin, may reach up to 20 km in width. Here the Paraná is braided with an accumulation of sediments in its channel forming sandbars and small islands, and a few large islands. The complex anastomosis in this stretch involves secondary channels, the Baía River and lower parts of tributaries on the western margin (Ivinheima, Amambai, and Iguatemi rivers). On the eastern margin, the main tributaries are the Tiête, Paranapanema, Ivai, Piquiri and Iguaçú rivers (Figure 1).

## Water Uses

In São Paulo State the estimated urban demand for water is 87 m<sup>3</sup>/s, with 50% returned to rivers. Only 8% of this water receives treatment. Industrial water demand in São Paulo State is 113 m<sup>3</sup>/s, with 68% returned to rivers. The demand for the irrigation of around 470,000 ha is also great.<sup>9</sup> Ever increasing demands for water for human consumption, agriculture and

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<sup>6</sup> IBGE, 1990

<sup>7</sup> Petri & Fulfaro, 1983

<sup>8</sup> Agostinho et al., 2000

<sup>9</sup> CERH-SR, 1990

cattle, the intense use of pesticides and fertilizers and the removal of riparian vegetation have all worsened water quality in the main tributaries and in the Paraná itself.

Dams are the most common signs of human interference on the physiography of the region. Over time there has been a steady increase in the inundated area.<sup>10</sup> Dams are present in all major tributaries (Grande, Paranaíba, Tietê, and Paranapanema rivers) and in the Paraná main channel as well. There are more than 130 major reservoirs in the region (dam > 10 m high); among these, 20% are larger than 10,000 ha. Four are in the Paraná main channel and range in area from 48,200 to 225,000 ha. The first large reservoir, the Edgard de Souza Reservoir on the Tietê River near the city of São Paulo, was formed in 1901. However, 80% of the reservoirs in the Upper Paraná River were built after the 1960s<sup>11</sup>.

## Habitats Used by Migratory Species

Three types of habitats are needed by migratory fish to complete their life cycles in the Upper Paraná Basin. They are:

### Spawning habitats

The spawning habitats, in general, are in the upper parts of large tributaries of the Paraná. Vazzoler et al. (1997a) showed this in two tributaries (Piquiri and Ivinheima rivers), where the number of reproducing individuals and eggs increased towards the upper parts of the main tributaries (Figure 2). Observations of fish spawning in the Upper Ivinheima River indicated that Characiformes prefer shallow water (less than 3 m), of relatively narrow width (less than 80 m) and usually with moderate turbulence. The river bed is usually rocky or of sand/gravel, and spawning takes place during floods, when water is turbid and conductivity and temperature are high. Although some Siluriformes spawn in similar habitats (for example *Rhynodoras dorbigny* and *Hemisorubim platyrhynchos*), most prefer the less lotic water and sandy bottoms of the Lower Ivinheima River.<sup>12</sup> Other species were found reproducing exclusively in the main channel of the Paraná (*Paulicea luetkeni*, *Piaractus mesopotamicus*).

<sup>10</sup> Agostinho et al., 1995a

<sup>11</sup> Agostinho et al., 1995a

<sup>12</sup> Vazzoler et al., 1997a; Nakatani et al., 1997

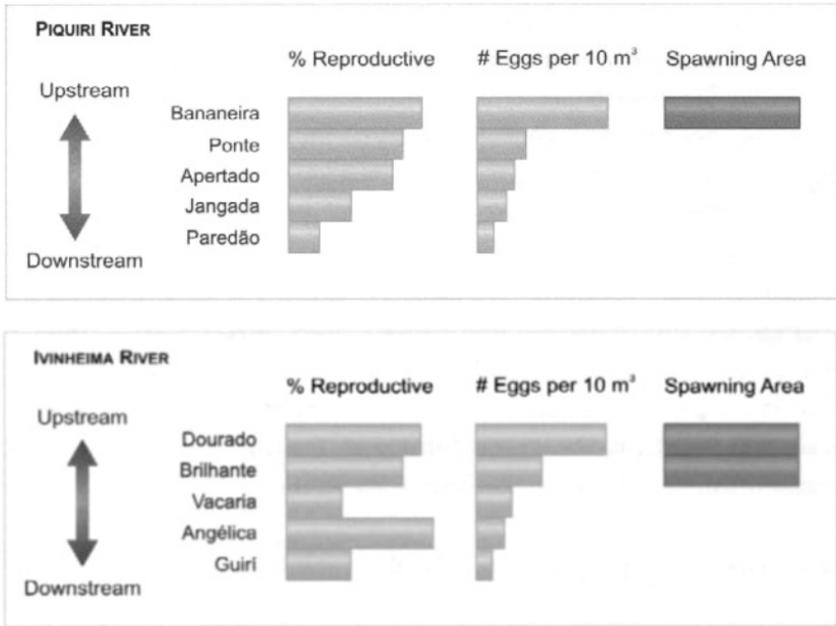


FIGURE 2. Frequency of reproductive individuals, egg density and designation of spawning areas in different portions of two tributaries of the Upper Paraná<sup>13</sup>

### Nursery habitats

Nursery habitats are generally lagoons in the lower parts of the tributaries and along the Paraná River banks and islands. These lagoons are heterogeneous in shape, area, mean depth, and degree of connection with the river. Drifting larvae reach these lagoons when the river overflows. Later, when the water is receding, fry may actively enter the lagoons through the remaining channels. Results from several habitat studies of the Upper Paraná floodplain suggest that lagoons are the environments richest in diversity of phytoplankton, periphyton, rotifers, aquatic macrophytes, benthos and fishes; the greatest abundance of phytoplankton, zooplankton, aquatic macrophytes and fishes is also observed here.<sup>14</sup> During high water, when the lagoons are deeper, thermal stratification may persist for more than 24 hours, leading to vertical stratification of nutrients and gases<sup>15</sup> and, frequently, anoxic layers close

<sup>13</sup> Modified from Vazzoler et al., 1997a

<sup>14</sup> Agostinho et al., 2000

<sup>15</sup> Thomaz et al., 1992; Lansac-Tóha et al., 1995

to the sediment.<sup>16</sup> During low water, complete mixing of the water column occurs during the night or morning when the lagoons are usually shallower than 2 m.<sup>17</sup> Despite low levels of dissolved oxygen in the lower water layers, lagoons provide a profusion of shelter and food for fish fry.

### Feeding habitats

Feeding habitats are places used for feeding by adult fish along the Upper Paraná, its tributaries and reservoirs. These habitats can be classified as the Paraná River channel, meandering rivers, rapid rivers, secondary channels, the Itaipu Reservoir, and small streams and creeks.

The bottom of the **Paraná River channel**, in the stretch free from dams (between downstream Porto Primavera Dam and upstream Itaipu Reservoir), is sandy or arenitic, and of low declivity. There are more than 300 islands and numerous sandbars, with a maximum water depth of 30 m. The main tributaries are meandering or rapid rivers.

**Meandering rivers** are located on the western margin of the Paraná. They have low slope, sandy bottoms, and, in general, are short (less than 400 km long). Springs in the sedimentary basin give rise to the Ivinheima, Iguatemi, and Amambai rivers.

**Rapid rivers** are located in the eastern margin, have high slopes, rocky bottoms, and are long (more than 400 km). Springs in crystalline rocks of the Serra do Mar give rise to the Piquiri, Ivai and Iguassu rivers.

**Secondary channels** are a net system (anostomosis) composed of the lower part of the tributaries on the western side of the Paraná and channels that connect the floodplain to the river. Substrate in the secondary channels is sandy or muddy. Discharge, flow direction, and limnological conditions depend highly on the flood regime and on the water level differences between the effluent basin/lagoon and the Paraná.

The **Itaipu Reservoir** marks the southern limit of the migratory fish populations in the unimpounded stretch of the Paraná. This reservoir is 150 km long, with an area of 1460 km<sup>2</sup>, an average depth of 22 m, a hydraulic retention time of 40 days, and limnologically acts as a warm mesotrophic and monomictic water body.<sup>18</sup> In its upper third, because of the influence of the Paraná, processes of transport predominate. Here it

<sup>16</sup> Thomaz, 1991

<sup>17</sup> Thomaz, 1991; Lansac-Tôha et al., 1995; Paes da Silva & Thomaz, 1997

<sup>18</sup> Agostinho et al., 1994a

is possible to catch all the migratory species, but most of them are low in abundance. Some species such as *Pterodoras granulosus*, *Rhaphiodon vulpinus*, *Prochilodus lineatus* and *Rhinelepis aspera* are very common in the reservoir and are important to the artisanal (or “professional”) fisheries.

Small streams and creeks, more conspicuous on the eastern side of the river, vary highly in gradient, substrate, size, proportion of riffles to pools, cover, and conservation of riparian vegetation. Juveniles of long-distance migrators may be observed only near the mouth of these systems (less than 5 km), and in low abundance. Only juveniles of *Leporinus obtusidens*, *Pimelodus maculatus* and *P. lineatus* have been recorded in creeks.

## MIGRATORY SPECIES AND MIGRATION PATTERNS

As in other river basins of Brazil, fish surveys in the Upper Paraná remain incomplete and controversial. The 221 fish species registered to date may become as many as 300 once the many taxonomic questions are resolved.<sup>19</sup> Information on aspects of ecology exists for only 86 of the 221 described species. Only 16 of these 86 species generally travel over 100 km in their migrations to reproduce. Of the remaining 70 species, some migrate moderate or short distances to reproduce (Figure 3).

These migratory species depend directly on upstream migration to complete the development of their gonads and to spawn. They fertilize externally, migrate long distances, and show no parental care. Generally they are large fishes (maximum standard length > 40 cm) with seasonal and total spawning, small eggs and high fecundity.<sup>20</sup> Winemiller (1989, 1992) calls these species “periodic strategists”.

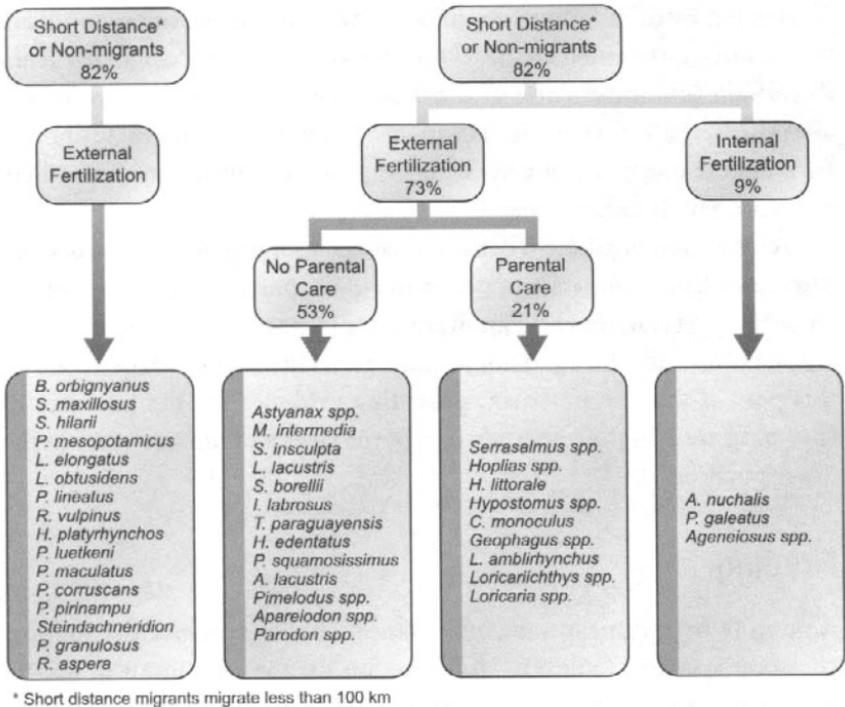
In addition to reproduction, other reasons for migration may include: temperature, feeding, ontogenetics, growth, refuge and avoidance of adverse environmental conditions. These factors may overlap and be dependent on one another,<sup>21</sup> but all are in some way related to the flood pulse.<sup>22</sup> The hydrological cycle is synchronised with biological events such as gonad maturation, migration, spawning and larval development,

<sup>19</sup> Agostinho & Júlio Jr., 1999

<sup>20</sup> Suzuki, 1992

<sup>21</sup> Bonetto, 1963

<sup>22</sup> Bonetto & Castello, 1985



**FIGURE 3.** List of species in the Upper Paraná River Basin according to migratory behaviour and reproductive strategy

growth and feeding<sup>23</sup> and a close relationship exists between recruitment success and the time, duration and intensity of floods.<sup>24</sup>

## Distribution

Surveys since 1982 have reported adults and juveniles of migratory species in diverse habitats in the Upper Paraná Basin. Most of the large migratory fishes occur throughout the basin. *P. luetkeni*, *P. mesopotamicus* and *R. aspera* primarily inhabit the main channel of the Paraná, reservoirs and major tributaries. Other species, such as *Salminus hilarii* and *Steindachneridion* sp., prefer lotic habitats in minor tributaries. Among these five species, *Steindachneridion* sp. is the least abundant and is

<sup>23</sup> Gomes & Agostinho, 1997; Agostinho & Júlio Jr., 1999; Agostinho et al., 2000

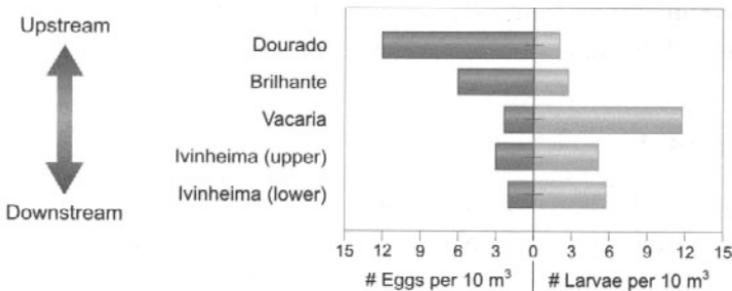
<sup>24</sup> Gomes & Agostinho, 1997

considered rare.<sup>25</sup> *P. granulatus* and *R. vulpinus*, on the other hand, are now widely distributed in the Upper Paraná, but came originally from the middle and lower parts of the basin, colonising the upper stretches after the Itaipu Dam (in 1983) inundated a natural barrier (Sete Quedas Falls). These two species are not however present in upstream rivers where dams were built before 1982.

A longitudinal gradient has been reported for eggs and larvae of large migratory fishes, from the upper to the lower parts of tributaries of the Upper Paraná (Figure 4).<sup>26</sup> Eggs were more frequent in the upper reaches and larvae in the lower. This trend was verified in all large rivers of this part of the Paraná Basin, providing evidence for the presence of spawning areas in the upper portion of the river and nursery areas in the lower portion.

## Feeding

Among 16 migratory species, information on diet exists for the 13 most common species (Table 1).<sup>28</sup> Information on the feeding of *S. hilarii*, *P. luetkeni*, and *Steindachneridion* sp. is inconclusive. Some of these species are naturally rare or live in habitats difficult to sample, such as rapids (*Steindachneridion* spp.) or at great depths (*P. luetkeni*).



**FIGURE 4.** Longitudinal gradient of egg and larval densities of migratory fishes in the Ivinheima River, a tributary of the Upper Paraná<sup>27</sup>

<sup>25</sup> Agostinho et al., 1994a

<sup>26</sup> Nakatani et al., 1997

<sup>27</sup> Nakatani et al., 1997

<sup>28</sup> Hahn et al., 1997; Agostinho et al., 1999a

**TABLE 1.** Dietary habits and principal food items of migratory fish from the Upper Paraná River Basin<sup>29</sup>

SPECIES	FEEDING CATEGORY	MORPHOLOGICAL MODIFICATION	PRINCIPAL FOOD ITEMS
<i>Brycon orbignyanus</i>	Insectivorous	Anterior mouth, conical teeth	Coleoptera, hemiptera
<i>Hemisorubim platyrhynchos</i>	Piscivorous	Wide mouth, dental plates	Small fishes
<i>Leporinus elongatus</i>	Omnivorous	Pronounced incisive teeth	Plants and insects
<i>Leporinus obtusidens</i>	Omnivorous	Pronounced incisive teeth	Plants and insects
<i>Paulicea luetkeni</i>	Piscivorous	Wide mouth, dental plates	Large and small fishes
<i>Piaractus mesopotamicus</i>	Omnivorous	Pronounced molar teeth	Plants, fruit and insects
<i>Pimelodus maculatus</i>	Omnivorous	Wide mouth, dental plates	Fishes, invertebrates and plants
<i>Pirirampus pirinampu</i>	Piscivorous	Wide mouth, dental plates	Small fishes and juveniles of large fishes
<i>Prochilodus lineatus</i>	Iliophagous	Protrusible mouth, gizzard and very long intestine	Detritus and sediments
<i>Pseudoplatystoma corruscans</i>	Piscivorous	Wide mouth, dental plates	Small bodied fishes and juveniles of other fishes
<i>Pterodoras granulosus</i>	Omnivorous	Wide sub-inferior mouth, long gut	Plants and molluscs
<i>Rhaphiodon vulpinus</i>	Piscivorous	Very developed canine teeth	Small fishes
<i>Rhinelepis aspera</i>	Iliophagous	Suctorial inferior mouth, very long intestine	Detritus and sediments
<i>Salminus hilarii</i>	Piscivorous	Wide mouth, large teeth	Fishes
<i>Salminus maxillosus</i>	Piscivorous	Wide mouth, large teeth	Small bodied fishes, juveniles of other fishes
<i>Steindachneridion</i> sp.	Piscivorous	Wide mouth, dental plates	Fishes

<sup>29</sup> Agostinho et al., 1995; Hahn et al., 1997, Agostinho et al., 1997

Among the migratory species, six have been identified as piscivores (*Salminus maxillosus*, *Pseudoplatystoma corruscans*, *R. vulpinus*, *H. platyrhynchos*, *P. luetkeni* and *Pirinampus pirinampu*). *S. hilarii* and *Steindachneridion* spp. can be added to this category based on the analyses of stomach contents<sup>30</sup> and gut morphology. Piscivores usually include the larger fish in the basin and also compose the most preferable group of fish in the commercial fisheries in the Upper Paraná. Some piscivores, such as *H. platyrhynchos* and *P. pirinampu*, are not as specialised in relation to their food intake. They may include plant and other non-fish groups in their diet; however, fishes composed at least 90% of the diet.

Five species were identified as omnivorous (*P. granulatus*, *Leporinus elongatus*, *L. obtusidens*, *P. maculatus* and *P. mesopotamicus*) feeding on plants, molluscs, aquatic insects and other invertebrates. Most of these feed opportunistically and may be interpreted erroneously as specialists when studies are conducted in restricted environments where some food items that may be taken as food are abundant. Before the Corumbá Dam closure, *L. elongatus* and *P. maculatus* were herbivorous and omnivorous, respectively, with a tendency to insectivory. After the dam closed and the reservoir began filling, *L. elongatus* was classified as omnivorous, with a tendency to piscivory and *P. maculatus* as piscivorous.<sup>31</sup> *P. mesopotamicus* is now rare in the Upper Paraná. Considered a frugivore in the Amazon Basin<sup>32</sup>, it eats plants and insects in the Upper Paraná.<sup>33</sup>

## Growth

Studies on growth of neotropical inland fish species are not numerous,<sup>34</sup> but are important information for fisheries management. Data on growth of migratory species in the Upper Paraná are limited to four species (*P. lineatus*, *P. maculatus*, *R. vulpinus* and *R. aspera*). Two further species (*P. corruscans* and *S. maxillosus*) were studied in other regions of the basin (Table 2). The maximum lengths registered for other species in the Upper Paraná are also listed in Table 2. *P. luetkeni* is the heaviest fish in the basin and may grow up to 150 kg.

<sup>30</sup> Agostinho, unpublished data

<sup>31</sup> Agostinho, unpublished data

<sup>32</sup> Goulding, 1980

<sup>33</sup> Hahn et al., 1997; Agostinho et al., 1997

<sup>34</sup> Lizama & Vazzoler, 1993

TABLE 2. Maximum total length and reproductive characteristics of migratory fish from the Upper Paraná River Basin<sup>35</sup>

SPECIES	MAXIMUM LENGTH (CM)	SIZE AT FIRST MATURATION (CM)	SPAWNING SEASON	SPAWNING TYPE	OOCYTE DIAMETER (MM)	EGGS DIAMETER (MM)	LARVAE LENGTH (MM)	MAX FECUNDITY (X10 <sup>6</sup> )	INCUBATION TIME (H-°C)
<i>B. orbignyana</i>	62.5	30.0	Oct – Jan	Total	1.5	3.1	3.5		391
<i>H. platyrhynchos</i>	62.5	30.1	Dec – Jan		1.0				
<i>L. elongatus</i>	61.0	27.1	Dec – Jan	Total	1.1	2.6	2.7	1.8	358
<i>L. obtusidens</i>	49.3	25.0	Nov – Jan	Total	1.0	2.5	2.8		326
<i>P. luetkeni</i>	144.0	70.0	Dec – Feb		1.3	2.0	3.5		451
<i>P. mesopotamicus</i>	62.6	34.0	Oct – Jan	Total	1.4	2.7	3.1	0.4	429
<i>P. pirinampu</i>	95.2	46.0	Dec – Jan	Total					
<i>P. maculatus</i>	45.0	19.5	Nov – Jan	Multiple	0.8	1.8	3.0		400
<i>P. lineatus</i>	77.9	28.0	Oct – Jan	Total	1.5	3.9	3.5	1.6	414
<i>P. corruscans</i>	152.1	66.6	Nov – Feb	Total	0.9	1.3	2.5	2.5	
<i>P. granulosus</i>	69.6	36.0	Jan – Mar	Multiple	1.1			0.3	
<i>R. vulpinus</i>	71.8	39.7	Out – Jan	Total	1.1				
<i>R. aspera</i>	54.2	25.0	Oct – Jan	Total	1.3	1.5	3.0	0.1	818
<i>S. hilarii</i>	42.0		Nov – Jan	Total	1.5	3.4	4.3	0.1	668
<i>S. maxillosus</i>	92.4	51.0	Oct – Jan	Total	1.4	3.2	3.5	2.6	383
<i>Steindachneridion</i> sp.	72.9		Dec – Feb		1.8	2.8			468

<sup>35</sup> Suzuki, 1992; Agostinho et al., 1995a, 1995b; Vazzoler et al., 1997a, 1997b; Nakatani et al., 2001

## Abundance

Surveys to assess the fish population abundance in different parts of the basin have included impounded stretches, such as in the Grande<sup>36</sup>, Corumbá<sup>37</sup>, Tietê<sup>38</sup>, Paranapanema<sup>39</sup> and Iguaçu<sup>40</sup> rivers. The unimpounded segment of the Paraná and unimpounded tributaries were also sampled.<sup>41</sup> Nupélia-Uem/Itaipu Binacional monitors landings of artisanal fisheries, useful for assessing the abundance of fishes, in the Itaipu Reservoir. The Companhia Energética do Estado de São Paulo and Furnas Centrais Elétricas collect the same information in other reservoirs of the Upper Paraná.

In impounded upper stretches of the Paraná migratory species are absent from, or sporadic in, experimental and artisanal fisheries. Two exceptions are *P. lineatus* and *P. maculatus*, which are found where there is a free-flowing stretch of river above a reservoir or where a large tributary empties into a reservoir.

Large migratory fishes are the second most abundant group in the stretch of river between Itaipu Reservoir and Porto Primavera Dam, including the floodplain and main tributaries, contributing 21% of the total catch.<sup>42</sup> In general, the abundance of migratory fish fluctuates according to flooding intensity and duration. The floodplain of the Upper Paraná, sampled for four years under different flood intensities, revealed that two of the years (1985–1987) were dry (low or absent floods) and the other two (1992–1993) were wet (high water levels). The abundance of most migratory fish was greater in the wet year.

Migratory species contributed 39–57% of the total catch to artisanal fisheries in the Itaipu Reservoir between the 5th and 17th year after dam closure (Figure 5). Among the ten most important species in the fishery, seven use the lotic environments upstream to reproduce,<sup>43</sup> where important unimpounded tributaries and a wide floodplain exist. Natural

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<sup>36</sup> Santos, 1999

<sup>37</sup> FUEM-Nupélia-Furnas, 1999

<sup>38</sup> CESP, 1996

<sup>39</sup> Dias, 1995; CESP, 1996

<sup>40</sup> FUEM-Nupélia-Copel, 1998

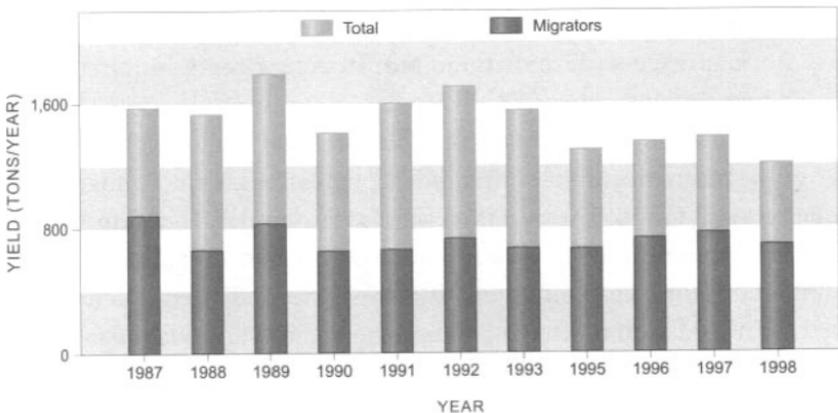
<sup>41</sup> Benneman et al., 1995; Agostinho et al., 1997

<sup>42</sup> Gomes & Agostinho, 1997

<sup>43</sup> Agostinho, 1994

and artificial variations in the flood regime over the floodplain are the main causes of changes in migratory species abundance.<sup>44</sup>

In the Iguazu River, an important tributary of the Paraná, large migratory fishes are absent, with the exception of *Steindachneridion* sp., a large pimelodid restricted to the lower river. The fish fauna in the Iguazu River evolved in a fluvial scenario. The river was fragmented by waterfalls and isolated from the remaining Paraná Basin by the Iguazu Falls, formed approximately 22 million years ago. Fragmentation by waterfalls is considered the main cause of the fish fauna isolation and further speciation through time, resulting in high endemism in headwaters.<sup>45</sup> The absence of large migratory fishes that are common in other parts of the basin was used as an argument that the construction of five dams in the Iguazu River would have little impact.<sup>46</sup> However, studies in Segredo Reservoir demonstrated that most of the species migrate short distances, entering small tributaries or reaching the fluvial zone of the reservoir to reproduce.<sup>47</sup> Similar behaviour is reported for non-migratory species in other reservoirs in the Upper Paraná Basin.<sup>48</sup>



**FIGURE 5.** Annual yield of the artisanal fishery of the Itaipu Reservoir<sup>49</sup>

<sup>44</sup> Gomes & Agostinho, 1997; Veríssimo, 1999

<sup>45</sup> Sampaio, 1988; Severi & Cordeiro, 1994; Garavello et al., 1997; Agostinho et al., 1997

<sup>46</sup> Agostinho et al., 1999c

<sup>47</sup> Suzuki, 1999

<sup>48</sup> FUEM-Nupélia-Itaipu Binacional, 1999; FUEM-Nupélia-Furnas, 1999

<sup>49</sup> Agostinho et al., 1994b; Petrere et al., 2002; Agostinho, unpublished data

## Migration Patterns

Migration plays an important role in reproductive success because it promotes the meeting and high concentration of both sexes in an area appropriate for egg fertilisation, development (high oxygenation) and low predation (low water transparency). Fish migration is therefore bound to the adequacy of the environment for the eggs and the advantages of collective spawning and the simultaneous releases of enormous numbers of gametes, thus improving fertilisation and chances of egg survival.

Tagging experiments in the Mogi Guaçu River revealed that some species migrate more than 1000 km.<sup>50</sup> Similar studies in the Paraná channel showed displacement in the order of 450 km for *P. lineatus*.<sup>51</sup> Figure 6 shows the ascending movements of *P. lineatus* starting from the Itaipu Reservoir. Individuals captured downstream and released in the reservoir were recaptured 180 km above it.<sup>52</sup> However, in an 80 km lotic stretch of the Paranapanema River between the Capivara and Salto Grande reservoirs, fifteen years after the construction of the dam schools of the migratory *S. maxillosus* and *P. corruscans* are still found during the reproductive period.<sup>53</sup> These results suggest that migratory fish populations vary widely in their requirements for a home range, depending on the species.

In the lower stretch of the Upper Paraná (230 km long), where the incoming tributaries are not impounded, populations of all the migratory fishes are still found. Three of these species (*P. lineatus*, *R. vulpinus*, and *L. obtusidens*) are among the most abundant in the region. In floodplain habitats the abundance of adults varies seasonally. Sixteen species that were restricted to the Middle Paraná before the Itaipu Dam was built expanded their range into the Upper Paraná after the Sete Quedas Falls were submerged in the reservoir.

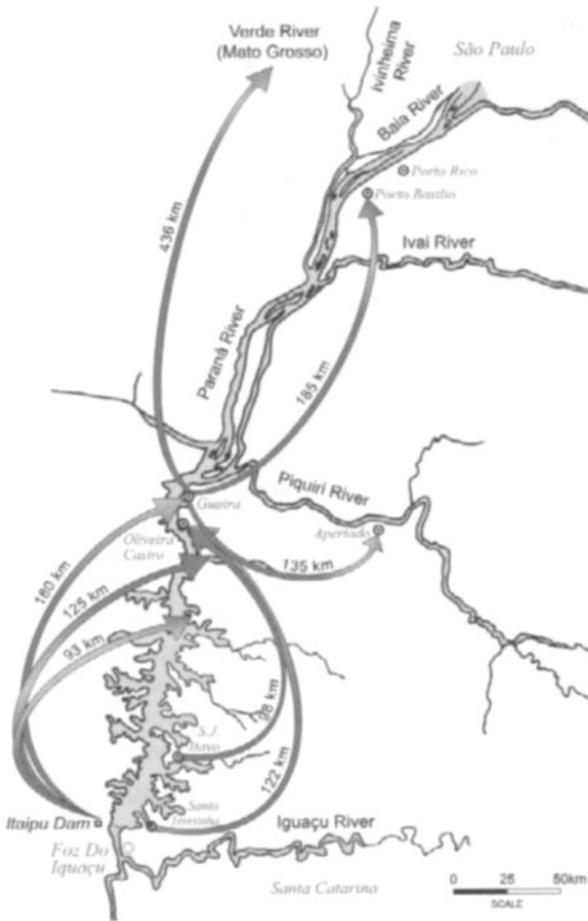
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<sup>50</sup> Godoy, 1975

<sup>51</sup> Agostinho et al., 1993a

<sup>52</sup> Agostinho et al., 2002

<sup>53</sup> João Henrique Pinheiro Dias, personal communication



**FIGURE 6.** Movements of *P. lineatus* tagged at the Itaipu Dam, Santa Teresinha, São João do Itavó and Guaira<sup>54</sup>

## Spawning

In the Upper Paraná, as in other tropical floodplain rivers, the flood pulse is the primary factor in fish reproduction. Monitoring of migratory fishes spawning at the Cachoeira das Emas, Mogi Guaçu River (Figure 1) from

<sup>54</sup> Agostinho et al., 2002

1943 to 1970 demonstrated that flooding is important as a synchronizing cue for spawning, and that lotic water is fundamental to oocyte fertilisation, fluctuation and drifting.<sup>55</sup>

All the migratory species considered in this study are broadcast spawners (external fertilisation without parental care) and generally show total spawning, releasing all of the oocytes at the same time. Migratory fishes may shed a great number of eggs – from 52,000 by *P. maculatus* to 2,600,000 by *S. maxillosus* – in fast-moving waters, in which the water movement facilitates gamete mixing and fertilisation. Hydration increases egg volume up to four times<sup>56</sup> and reduces specific weight, prompting flotation and drifting. In slow-moving water, however, even hydrated eggs sink. Hydrated eggs drift along the river, under conditions of increasing water level, and spill over onto the floodplain. There they complete their development as the larvae hatch and are carried onto the flooded area. Some species, such as *R. aspera*, although a broadcast spawner, release eggs, which after 10 or 15 minutes become adhesive and attach themselves to a substrate.

Synchronisation of spawning with periods of rain, when water levels begin to rise, is frequently mentioned in the literature.<sup>57</sup> Godoy (1975) reported that large migratory fishes do not spawn when the river water level is stable or falling. Other authors also mention this dependence. In monitoring young of the year (YOY) in temporary lagoons in the Upper Paraná floodplain, a complete absence of YOY of large migratory species during years without floods was reported.<sup>58</sup> There was also a positive correlation between the duration and timing (season) of the flood in the Upper Paraná floodplain and *P. lineatus* recruitment in the Itaipu Reservoir, located downstream of the floodplain.<sup>59</sup>

For species with similar reproductive strategies, Agostinho et al. (2001) used the annual average CPUE (catch per unit effort) of individuals with ripe and/or semi-spent gonads as an indicator of reproductive intensities in years of different flood intensities in the Upper Paraná (1985–1987 were dry years, whereas 1992–1993 were wet years). The abundance of

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<sup>55</sup> Godoy, 1975

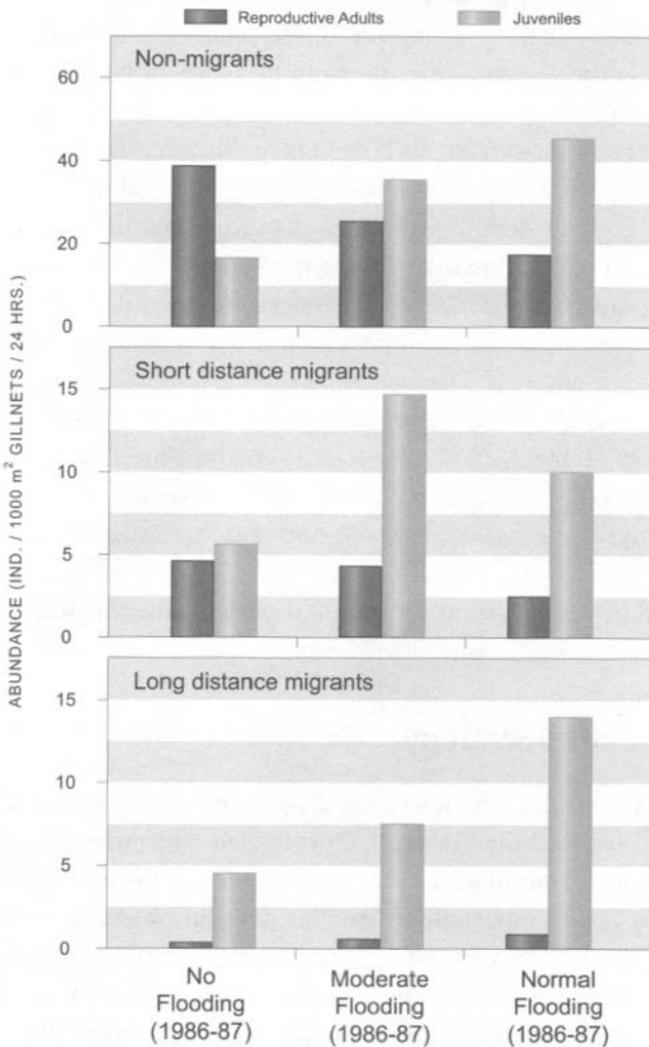
<sup>56</sup> Godoy, 1975

<sup>57</sup> Godoy, 1975; Vazzoler & Menezes, 1992; Agostinho et al., 1995a, 1999a; Araujo Lima & Goulding, 1998

<sup>58</sup> Verissimo, 1999

<sup>59</sup> Gomes & Agostinho, 1997

most migratory fish was greatest in the wet years. In terms of reproductive activity (Figure 7), it was concluded that (i) among sedentary species, which include those that spend their entire life cycle on the floodplain,



**FIGURE 7.** Annual variation of the abundance of reproductive adult fish and young fish of different migratory strategies in the Upper Paraná River relative to the extent of flooding<sup>60</sup>

<sup>60</sup> Agostinho et al., 2001; CPUE = catch per unit effort; 1986-87 = flood absent; 1987-88 = moderated flood; 1992-93 = normal flood

reproductive activity was greater during droughts; (ii) “reproducing” individuals among the long-distance migratory species were more abundant in the year of the highest flood; (iii) among short-distance migratory species, intermediary variation in abundance was verified. However, the abundance of juvenile forms was low for all the reproductive strategies in the floodless year, due to factors such as increased exposure to predation.<sup>61</sup>

Oocyte development up to, but not including, final maturation seems unrelated to hydrologic cycle. Gonads develop in ponds or even in some isolated lagoons, where they reach an advanced stage of maturation but undergo regression if no stimulus for spawning is registered. Vazzoler et al. (1997b) considers the increase of temperature and daylight as proximate factors related to the gonad maturation that, in general, occurs from August to November or December.

As size varies among the migratory fish species, so does size at first maturation (Table 2). For 25 species from the Upper Paraná, the size at first maturation is approximately 40% of the maximum length.<sup>62</sup> Most of the migratory fishes analysed here reach first maturation at a proportionally larger size, from 45% to 55% of the maximum size registered. *P. lineatus* is an exception, reaching maturity at 36% of the maximum length (28 cm).

## Reproductive Strategy

Besides high fertility, migratory fishes have small oocytes, short incubation times and small larvae (Table 2). Oocyte diameter varies little, ranging from 0.8 mm (*P. maculatus*) to 1.6 mm (*Brycon orbignyianus*). Other non-migratory fishes, especially those that develop parental care such as *Hypostomus* spp., have oocytes of more than 5.0 mm. Despite the bias arising from measuring eggs and oocytes preserved in formalin, hydration increases egg sizes by 42% (*P. corruscans*) to 170% (*P. lineatus*), except for eggs of *R. aspera* (just 11%), which do not float. Small eggs have a short incubation time and produce small larvae<sup>63</sup>. Egg development times depend on mean temperature. This time ranges from 326 degree-hours

<sup>61</sup> Agostinho et al., 2001

<sup>62</sup> Vazzoler et al., 1991

<sup>63</sup> Balon, 1984

for *L. obtusidens* to 818 degree-hours for *R. aspera*, compared to more than 4,200 degree-hours for non-migratory fishes, such as those with parental care (*Geophagus* spp). Larval size is greater among non-migratory fish and among species that have large eggs such as *Parauchenipterus galeatus*, whose larvae hatch measuring 4.9 mm.<sup>64</sup> Oocyte diameter, incubation time, larval size and hydration are important adaptations that allow eggs to float and drift, and to reach the nursery areas in lower parts of the basin.

In general, migratory fishes are total spawners. However, oocyte development, in contrast to that reported for non-migratory species with total spawning, is not synchronous. From studies of oocyte development of *P. lineatus* in ponds, it was concluded that during maturation eggs initially develop non-synchronously in the ovaries.<sup>65</sup> As maturation proceeds, a synchronous grouping of eggs that will be shed simultaneously occurs. This kind of development was observed in other large migratory species (*S. maxillosus* and *L. obtusidens*) and in short migratory species (*Astyanax bimaculatus*, *Apareiodon affinis* and *Leporinus friderici*) and has been classified as “non-synchronous cumulative development”.<sup>66</sup> We believe that this type of oocyte development gives migratory fishes the flexibility to spawn when the appropriate environmental conditions appear.

## Timing of Spawning

In the Upper Paraná Basin, migration and spawning occur between October and March, when flooding begins and peaks. Characiformes, in general, spawn earlier (Oct. to Jan.) than Siluriformes (Dec. to Mar.). Reproductive movements and spawning are rapid and their timing seems to be regulated by flooding. If the rain and flooding are delayed, most of the migratory species may start spawning in February. A failure of fish reproduction was reported<sup>67</sup> in the Upper Paraná as a consequence of the absence of flooding during the spawning season, despite the late increase in the river level (flooding from March to July).

<sup>64</sup> Nakatani et al., 1997

<sup>65</sup> Fenerich-Verani et al., 1984

<sup>66</sup> Suzuki, 1992

<sup>67</sup> Gomes & Agostinho, 1997

In the flooded areas, larvae and fry of migratory species find warm temperatures and ample food and shelter. As the water level drops, juveniles concentrate in floodplain depressions or swim out with currents into the main channel, where they search for lentic waters (bays and lagoons connected to the river). In general, juveniles inhabit these environments for a time that varies according to species. *P. lineatus*, for example, remains in these habitats for about two years.<sup>68</sup>

During decreasing water levels, mortality of juveniles is high. There are three major causes: (i) predation where water is flowing out of the floodplain (*vazantes* or *corixos*); (ii) mortality in lagoons that dry up completely, and (iii) predation by birds, mammals or reptiles in very shallow water bodies. Duration, regularity and timing of the floods all contribute to these types of mortality and subsequent recruitment to the adult population.<sup>69</sup>

After spawning, parental stock start returning downstream, but more slowly and by a sinuous route. They may go inside lagoons, apparently looking for food to replace energy lost in the migration upstream.<sup>70</sup>

## Spawning Sites and Migratory Behaviour

The minimum stretch required by migratory fish to complete their life history varies according to species and regional characteristics, and may even vary within the species itself. For example, parts of tagged schools of the migratory species *P. lineatus* and *S. maxillosus* remained for a long time where they were released in the Upper Paraná, suggesting that some populations of these species complete their life cycles without migrating, while others require long displacements upstream to maintain the population and spawn.<sup>71</sup> In the last free stretch of the Upper Paraná, below Porto Primavera Dam and above Itaipu Reservoir that has been isolated from the upper and lower stretches since 1994 some migratory fish (*S. maxillosus*, *P. corruscans*, *P. lineatus*, *L. elongatus*, and *B. orbignyanus*) were found reproducing.<sup>72</sup> However, not only the length of the stretch,

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<sup>68</sup> Agostinho et al., 1993a

<sup>69</sup> Gomes & Agostinho, 1997

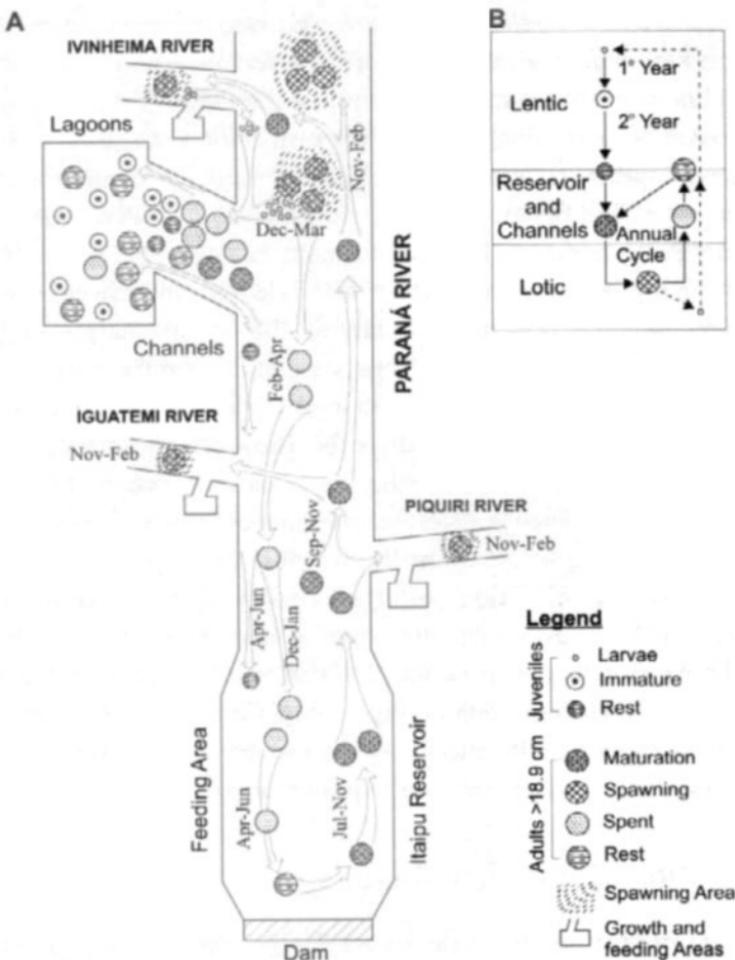
<sup>70</sup> Bonetto & Castello, 1985; Agostinho et al., 1993a

<sup>71</sup> Bonetto & Castello, 1985

<sup>72</sup> Agostinho & Zalewski, 1995; Vazzoler et al., 1997a; Nakatani et al., 1997

but also its characteristics, such as the availability of spawning sites, and more importantly nurseries, are vital.

Agostinho et al. (1993a) studied the migratory behaviour of the *curimbatá* (*P. lineatus*) in a 380 km stretch of the Upper Paraná Basin, which included the Itaipu Reservoir and the unimpounded stretch upstream (Figure 8). Juvenile fish, up to the time of their first maturation



**FIGURE 8.** Conceptual model representing the behaviour of *Prochilodus lineatus* in the Upper Paraná River Basin (A) and environments used during its life cycle (B)<sup>73</sup>

<sup>73</sup> Modified from Agostinho et al., 1993a

at age two, live in floodplain lagoons. They then migrate during flooding via the anastomosing floodplain channels to the main river, reach the main channel of the Paraná, and are finally recruited to the stock in the Itaipu Reservoir.

Neotropical migratory fishes seem to have less need to return to historical spawning sites than do salmonids. In the Piquiri River, upstream from Sete Quedas Falls (inundated by the Itaipu Reservoir), no schools of *P. lineatus* and *S. maxillosus* had been registered before the formation of Itaipu Reservoir. After the filling of the reservoir, schools inhabiting the 170 km downstream from the mouth of the Piquiri River started to use the river as a spawning ground.<sup>74</sup> The distribution of eggs and larvae of different species collected in the Upper Paraná Basin suggests that schools may enter different affluents simultaneously to spawn.<sup>75</sup> After the closure of Porto Primavera Dam (in the main channel of the Paraná) fish tagged during upstream migration and released downstream were recaptured 48 hours later in a tributary on the western margin, 40 km from where they were released. This suggests that during upstream migration, an obstacle may lead the fish to search for another place. However, histological examination of these fish showed a high frequency of atresic oocytes in the ovaries, indicating that if spawning occurred it would be less effective.<sup>76</sup> An intense regression in gonads of fish was also registered during the spawning season immediately below the Itaipu Dam.<sup>77</sup>

Details of the migration patterns of most of the other species, especially the big catfishes (*P. corruscans*, *P. luetkeni* and *P. pirinampu*) are still unknown. It appears nonetheless that flooding is also important in stimulating their migration and spawning. Complete understanding of these mechanisms, differences between species, and requirements for critical spawning and nursery areas require more study.

## Description of Principal Species

The migratory fish species in the Upper Paraná Basin consist primarily of fish with scales belonging to the Characiformes and fish without scales

<sup>74</sup> Agostinho et al., 1993a

<sup>75</sup> Nakatani et al., 1997

<sup>76</sup> Agostinho, unpublished data

<sup>77</sup> Agostinho et al., 1993b

belonging to the Siluriformes (catfish). Figure 3 lists species according to migratory behaviour and reproductive strategy. Principal species are described below, with maximum and maturation lengths summarized in Table 2.

### ***Brycon orbignyanus***

*B. orbignyanus* is a medium-sized characid known as *piracanjuba* in Brazil and *salmón criollo* in adjacent Spanish-speaking countries. The Brazilian name is derived from the native tupi-guarani language, referring to the fish's distinctive yellow head (*pira*= fish; *acanga*= head; *yuba*= yellow) and the Spanish name refers to the salmon-like pink colour of the fish's flesh. The meat is of excellent quality for human consumption and is much sought after.

The species was once common in the basin, but is now captured only sporadically in the fisheries of the Paraná River, and seems to be virtually absent in the upper<sup>78</sup> and lower<sup>79</sup> stretches. About 40 years ago, individuals of up to 80 cm (8 kg) were caught, but more recently the maximum size has been 63 cm.

The fish is omnivorous, with a preference for fruits and other plant parts. Insects and small fish are considered secondary in the diet.<sup>80</sup> However, in the stretch of the Paraná River without dams, where it is fished with hooks using fruit as bait, it is mainly insectivorous, with plants as secondary items.<sup>81</sup> The species is nevertheless strongly dependent on alloctonous food items<sup>82</sup> and reduced numbers have been attributed to the removal of riparian vegetation by agriculture, cattle ranching and damming in the basin. In the Itaipu Reservoir, the species was caught only during the first 14 months after reservoir formation, and in other reservoirs it is rare.<sup>83</sup>

Size of first maturation in the species is 30cm (2–3 yrs of age), with peak reproductive activity in December and January.<sup>84</sup> Ovaries at this time constitute more than 20% of body weight, with more than 850,000 oocytes

<sup>78</sup> Agostinho & Julio Jr, 1999

<sup>79</sup> Quirós, 1990

<sup>80</sup> Schubart, 1943; Godoy, 1975

<sup>81</sup> Hahn et al., 1997

<sup>82</sup> Godoy, 1975; Lowe-McConnell, 1986

<sup>83</sup> Agostinho et al., 1994b; CESP, 1996

<sup>84</sup> Vazzoler et al., 1997a

per individual (mean diameter of 1.5 mm). However, with annual variation in the hydrologic cycle, spawning may occur from October to January.

Duration and intensity of floods are important in determining recruitment of this species. Our unpublished data show that fry of *B. orbignyana* were abundant in months that followed the intense and long-lasting floods of 1983–84, 1990–91 and 1997–98, but were rare when floods were moderate or absent (1985–86; 1995–96; 1996–97).

The species is of considerable interest to aquaculture, so most of the current publications on the species are devoted to this topic, particularly dealing with nutritional aspects.<sup>85</sup>

### ***Hemisorubim platyrhynchos***

*H. platyrhynchos* is a medium-sized catfish commonly known in Brazil as *jurupoca*. It is the only species of this genus and is widespread within South America, from the Orinoco to the Paraná rivers. The snout is flattened and the back is brown, with elongated or oval dots along the body. In some environments the colour changes to yellowish brown on the back. It grows up to 63 cm, and is a nocturnal piscivore, feeding in lotic and lentic habitats. The first maturation is reached at 30 cm and spawning occurs in December and January, including November in some years, during the flood period. Ecology of the species is unknown, with publications dealing primarily with morphological and parasitological aspects.<sup>86</sup>

### ***Leporinus elongatus***

*L. elongatus*, known in Brazil as *piapara*, is a medium-sized characid (maximum length = 61 cm) that reaches first maturation at 27 cm. It is of moderate abundance in the dams-free stretch of the Paraná River, primarily occurring in the main channel of this river, but is also caught in the upper parts of the Paraná River Basin.<sup>87</sup> Juveniles are found in marginal lagoons of the river. Artisanal and sport fisheries target this species, and in cities along the Paraná River bank fishing tournaments for *piapara* are common.

<sup>85</sup> e.g. Esquivel et al., 1999; García et al., 2000; Cavalcanti et al., in press.

<sup>86</sup> Pavanelli & Rego, 1989; Lundberg et al., 1991; Chambrier & Vaucher, 1999

<sup>87</sup> Santos & Formagio, 2000

Early studies considered the species essentially herbivorous.<sup>88</sup> However, recent studies in the Upper Paraná River indicate that the species is omnivorous, feeding primarily on insects.<sup>89</sup> Changes in diet after alteration of the environment have been documented in the Corumbá River (a tributary of the Paranaíba River). The piapara in this river was apparently a herbivore, with a tendency towards insectivory, before the construction of the Corumbá Dam, but after dam closure and the formation of the reservoir, turned to omnivory with a tendency to piscivory.<sup>90</sup>

Spawning of the piapara occurs in the upper stretches of large tributaries during December and January, when the water level in the river is rising. During this period, ovaries represent up to 25% of the body weight and have more than 1.8 million oocytes of 1 mm mean diameter.<sup>91</sup> *L. elongatus* were second only to *P. lineatus* amongst migratory species in successful ascents of an experimental fish ladder at Itaipu Dam.<sup>92</sup>

This species is also a good aquaculture candidate, and most of the published information about it is related to cultivation in ponds.<sup>93</sup>

### ***Leporinus obtusidens***

*L. obtusidens*, popularly known in Brazil as *piavuçu* (*pi'au*=spotted skin, *uçu*=big in the tupi-guarani language) or piapara, is smaller than its congener *L. elongatus* (maximum length = 49 cm) and reaches first maturation at a smaller size (25 cm). It has moderate abundance in the basin, but is restricted to stretches with intact floodplains. It is frequent in lotic habitats but also occurs with moderate frequency in lagoons, thus differing from *L. elongatus*. Its preference for semi-lotic habitats is demonstrated by its abundance in meandering rivers like the Ivinheima and Iguatemi.<sup>94</sup> Juveniles live in marginal lagoons. Artisanal fisheries and weekend anglers target *L. obtusidens* in rivers, generally using hook baited with fruit (*Cecropia* sp.). Its importance for the fisheries in the Paraná River led the hydropower companies to stock the fish in reservoirs of the

<sup>88</sup> Godoy, 1975

<sup>89</sup> Hahn et al., 1997

<sup>90</sup> Gaspar da Luz et al., in press

<sup>91</sup> Godoy, 1975

<sup>92</sup> Fernandes, 2000

<sup>93</sup> Godinho & Santos, 1996; Sato et al., 2000

<sup>94</sup> Agostinho & Julio Jr, 1999

basin. However, except for the fluvial zone, *L. obtusidens* avoids reservoirs, and no data are available to evaluate the efficiency of the stocking programs.

Piavaçu is omnivorous, eating mainly plants and some insects, but may also feed on small fish, algae and detritus.<sup>95</sup> Spawning occurs from November to January, when gonads represent up to 18% of the body weight.

Little information is available about the biology and ecology of this species. Publications deal with nutrition of the fry,<sup>96</sup> condition factor,<sup>97</sup> cytogenetics<sup>98</sup> and semen characteristics.<sup>99</sup>

### *Paulicea luetkeni*

*P. luetkeni*, known in Brazil as *jaú* (*ya-ú*=big eater in the native language), is the heaviest fish in the basin, growing up to 144 cm in length and 150 kg in weight. In both the Paraná River<sup>100</sup> and the Amazon River<sup>101</sup> the fish carries out its whole life cycle in the main channel, sheltering primarily in deep areas as adults and in the mouth of creeks and other small tributaries as fry. Unlike other migratory species, fry of the species have not been found in marginal lagoons and channels of the Paraná River. Almost absent in the upper regions of the Upper Paraná Basin, it was an important species in early landings of the artisanal fisheries in the Itaipu Reservoir. During this time, juveniles were captured in the reservoir and adults in the riverine zone. However, yield of this species has reduced drastically over the last decade, probably due to overfishing of smaller sized individuals and thus preventing adequate recruitment. In the dam-free stretch of the Upper Paraná, weekend anglers still target this species in the main channel, using hooks baited with worms.

*P. luetkeni* is a nocturnal piscivore and reaches first maturation with 70 cm total length. It spawns from December to February. Information about biology and ecology of this species is scarce, and most of this is related to nutrition of the fry,<sup>102</sup> parasitology<sup>103</sup> or morphology<sup>104</sup>.

<sup>95</sup> Hahn et al., 1997; Agostinho et al., 1997

<sup>96</sup> Mello et al., 1999

<sup>97</sup> Araya, 1999

<sup>98</sup> Jorge & Moreira Filho, 1996

<sup>99</sup> Kabeya et al., 1998; Murgas et al., 1999

<sup>100</sup> Agostinho & Júlio Jr., 1999

<sup>101</sup> Santos & Ferreira, 1999

<sup>102</sup> Pelli et al., 2000

<sup>103</sup> Rego et al., 1986; Eiras et al., 1986; Rego, 1994; Takemoto & Pavanelli, 1994

<sup>104</sup> Lopes et al., 1994

### *Piaractus mesopotamicus*

*P. mesopotamicus*, popularly known as *pacu* in Brazil (“fast eater” in the native language), grows up to 62 cm, reaching first maturation at 34 cm. Originally endemic to the Paraná-Paraguay River Basin, it is now more widespread in distribution through aquaculture activities. It was found only sporadically in experimental fisheries in the Upper Paraná River, but it is more abundant downstream of the Itaipu Dam and in the Ivinheima River. The species was stocked in several reservoirs of the basin, but with unknown results. It prefers lotic and semi-lotic habitats and, while omnivorous, depends strongly on allochthonous food items. Adults feed on plants and insects, whereas fry and juveniles feed on microcrustaceans.<sup>105</sup> Anglers, however, use fruit as bait to catch the pacu.

Spawning of the pacu occurs from October to January.<sup>106</sup> The number of oocytes ranges from 59,000 to 426,700 per fish, according to the size of the fish, with an average diameter of the mature oocyte of about 1.4 mm.

A variety of information has been published on the species: it can tolerate temperature ranging from 15 to 35°C, but does not feed below 18°C;<sup>107</sup> it is reported to have an efficient pheromonal warning system for the presence of predators;<sup>108</sup> and it shows morphological and behavioural adaptations for survival under low oxygen conditions.<sup>109</sup> However, most of the studies on the species are on its artificial breeding,<sup>110</sup> nutrition<sup>111</sup> and parasitology and pathology.<sup>112</sup>

### *Pimelodus maculatus*

*P. maculatus*, a small catfish known in Brazil as the *mandi*, is widely distributed in the basin. It is abundant in rivers and the riverine zone of reservoirs, if the reservoirs have lotic stretches upstream or large lateral tributaries to spawn. The species needs less free river stretches than other migratory species, despite its ability to migrate more than 1000 km to spawn.<sup>113</sup> Females grow to more than 45 cm in length, with first maturation at 20 cm.

<sup>105</sup> Hahn et al., 1997

<sup>106</sup> Ringuelet et al., 1967; Lima et al., 1984; Romagosa et al., 1998

<sup>107</sup> Milstein et al., 2000

<sup>108</sup> Jordão & Volpato, 2000

<sup>109</sup> Saint Paul & Bernardino, 1988; Severi et al., 1997; Rantin et al., 1998

<sup>110</sup> Carolsfeld et al., 1988; Romagosa et al., 1990

<sup>111</sup> Canzi et al., 1992; Borghetti & Canzi, 1993; Macarin et al., 1994

<sup>112</sup> Boeger et al., 1995a; Pavanelli & Takemoto, 1995; Szakolczai et al., 1999

<sup>113</sup> Bonetto, 1963; Godoy, 1967

The mandi is omnivorous, feeding on insects, molluscs, small fish, and plants.<sup>114</sup> A tendency towards insectivory was recorded in the Corumbá River before the construction of the dam, but after the dam closure it was classified as a piscivore.<sup>115</sup>

The species spawns from November to January, with multiple spawning events during this period: a characteristic unusual for migratory species. It also possesses the smallest oocytes of migratory species (0.8 mm), which could be related to its success in reservoirs in that these may sink less quickly than the eggs of other species.<sup>116</sup> The number of oocytes per fish was estimated at around 70,000 for a fish of maximum size.<sup>117</sup> Other studies have been published on gonad maturation and reproductive cycle;<sup>118</sup> biometry and sex dimorphism;<sup>119</sup> induced spawning;<sup>120</sup> captive breeding;<sup>121</sup> growth curve;<sup>122</sup> and parasitology.<sup>123</sup>

### *Pinirampus pirinampu*

*P. pirinampu* is another medium-sized catfish known in Brazil as *barbado*, *barba-chata*, *Patí*, or *mandi-alumínio*. It has distinctive long band-like oral barbells with broad silvery membranous borders. The fish is widely distributed throughout the basin, including reservoirs in the Paraná River and its tributaries.<sup>124</sup> The abundance of the species in reservoirs increases toward the mouth of the Paraná, with the maximum abundance in the Itaipu Reservoir, where it is very important to artisanal fisheries in the riverine zone.

The fish grows to over 95 cm in length, with first maturation at 46 cm. It is caught by long-lines or hand-lines in impounded and unimpounded rivers with a special kind of fishing gear called the *cavalinho*. A *cavalinho* is a two meter-long trotline attached to a float with a single

<sup>114</sup> Agostinho et al., 1997; Hahn et al., 1997

<sup>115</sup> Gaspar da Luz et al., in press

<sup>116</sup> Agostinho et al., 1999a

<sup>117</sup> Godinho et al., 1977; Lamas, 1993

<sup>118</sup> Godinho et al., 1974a, 1974b; Colares de Mello, 1989; Carvalho & Grassiotto, 1995; Bazzoli et al., 1997

<sup>119</sup> Vignes et al., 1981; Barbosa et al., 1988

<sup>120</sup> Fenerich-Verani et al., 1984; Souza & Stiles, 1984

<sup>121</sup> Sato et al., 1999, 2000

<sup>122</sup> Fenerich et al., 1975

<sup>123</sup> Moreira et al., 1991; Petter, 1995a; Sato & Pavanelli, 1998, 1999; Gutierrez & Martorelli, 1999a, 1999b

<sup>124</sup> CESP, 1993; Agostinho & Julio Jr., 1999; Santos & Formagaglio, 2000

hook baited with live fish. Fishers watch from canoes nearby for the float to bob to indicate a bite.

The barbado is a particularly aggressive piscivore species, with diurnal<sup>125</sup> and pelagic habits<sup>126</sup> not found in other pimelodid catfish. No information is available on its reproduction, other than that individuals with ripe gonads are caught downstream from the Itaipu Dam during December and January.

Studies on *P. pirinampu* are restricted to parasitology<sup>127</sup> and cytogenetics.<sup>128</sup>

### *Prochilodus lineatus*

Known as curimbatá in Portuguese and sábalo in Spanish, *P. lineatus* is the most studied fish species in the basin. It has a wide distribution, including rivers, lagoons and reservoirs.<sup>129</sup> Its abundance in reservoirs is correlated with the presence of free stretches upstream or large lateral tributaries. In unimpounded stretches of the Paraná River, recruitment is extremely variable according to the annual flood regime that is controlled by dams.<sup>130</sup> Adults live in running waters and juveniles in marginal lagoons. Juvenile *P. lineatus* can represent more than 70% of the biomass in lagoons after an intense and prolonged flood period, whereas when flooding is short and/or weak, they may be entirely absent.<sup>131</sup>

The species grows up to 78 cm in length and reaches its first maturation at 28 cm, based on a variety of studies on ageing and growth.<sup>132</sup> It is iliophagous, feeding mainly during the day<sup>133</sup> and in shallow water<sup>134</sup> on detritus and sediments containing tiny particles of inorganic sediment, fine detritus and algae.<sup>135</sup> Food is taken from the bottom or from flooded vegetation,<sup>136</sup> with microorganisms in the detritus and periphyton an

<sup>125</sup> Hahn et al., 1997

<sup>126</sup> Agostinho et al., 1999a

<sup>127</sup> Kritsky et al., 1987; Rego & Pavanelli, 1992; Chambrier & Vaucher, 1999

<sup>128</sup> Swarça et al., 1999, in press

<sup>129</sup> CESP, 1993; Agostinho & Julio Jr, 1999; Santos & Formagio, 2000

<sup>130</sup> Gomes & Agostinho, 1997; Smolders et al., 2000

<sup>131</sup> Agostinho & Zalewski, 1995; Veríssimo, 1999

<sup>132</sup> Cordiviola de Yuan, 1971; Bayley, 1973; Toledo Filho, 1981; Hayashi et al., 1989; Domingues & Hayashi, 1998

<sup>133</sup> Hahn et al., 1997

<sup>134</sup> Lowe McConnell, 1975; Bowen, 1983

<sup>135</sup> Sverlij et al., 1993; Fugi et al., 1996

<sup>136</sup> Bowen, 1983

important nutrient source for the fish.<sup>137</sup> The fish has a significantly elongated intestine to deal with this kind of food source.<sup>138</sup> Based on studies of fatty acid composition, fry have diets based on zoo and phytoplankton, and detritus becomes gradually important as the fish grows.<sup>139</sup>

Spawning occurs in running waters of upper stretches of some of the large tributaries of the Paraná River from October to January (as water levels rise). During this period, ovaries may represent more than 20% of the body weight, and contain up to 1.5 millions oocytes with a mean diameter of 1.5 mm. After fertilization and hydration to a diameter of 3.9 mm, the eggs drift in the river current during embryonic development and wash into the flood plains of the lower parts of the tributaries as the larvae hatch. The fish stay in the lagoons that remain as the flood water recedes for up to two years, or until their first maturation is complete.<sup>140</sup> The ready availability of food and shelter in the lagoons during the first months of life are essential to avoid high mortality rates from predation.<sup>141</sup>

Numerous studies have been carried out on the migration of the curimatá.<sup>142</sup> Reproductive migration can cover distances of greater than 1000 km,<sup>143</sup> but in general, they migrate for 450 to 500 km (Figure 6).<sup>144</sup> The return migration after spawning is more irregular, and can include moving into the floodplains to feed and recover the energy spent during reproduction. This is one of the species of Brazilian migratory fish that is able to ascend fish ladders and other fish pass facilities quite readily.<sup>145</sup>

Other published information on this species include pesticide contamination;<sup>146</sup> genetics;<sup>147</sup> semen preservation and spermatogenesis;<sup>148</sup>

<sup>137</sup> Bowen et al., 1984

<sup>138</sup> Sverlij et al., 1993; Fugi et al., 1996

<sup>139</sup> Bayo & Yuan, 1996

<sup>140</sup> Agostinho et al., 1993a

<sup>141</sup> Gomes & Agostinho, 1997; Agostinho & Julio Jr, 1999

<sup>142</sup> Godoy, 1957, 1975; Bonetto & Pignalberi, 1964; Bonetto et al., 1971; Bayley, 1973; Roldan & Canon Veron, 1980; Bonetto et al., 1981; Bonetto & Castello, 1985; Delfino & Baigún, 1985; Petrere Jr., 1985; Quirós & Cuch, 1989; Espinach-Ros et al., 1990; Agostinho et al., 1993a, 1994a

<sup>143</sup> Godoy, 1975; Espinach-Ros et al., 1990

<sup>144</sup> Agostinho et al., 1993a; Sverlij et al., 1993

<sup>145</sup> Quirós, 1988; Borghetti et al., 1994

<sup>146</sup> Matsushita & Souza, 1994; Moraes et al., 1997a; Ranzani-Paiva et al., 1997; Rodríguez et al., 1997; Mazon et al., 1999; Fernandes et al., 2000, Colombo et al., 2000

<sup>147</sup> Pauls & Bertollo, 1983; Verani et al., 1990; Revaldaves et al., 1997; Dias et al., 1998; Cavallaro & Bertollo, 2000

<sup>148</sup> Coser et al., 1984

morphology;<sup>149</sup> respiratory metabolism;<sup>150</sup> and parasitology.<sup>151</sup> However, most of the publications are related to cultivation in hatcheries.<sup>152</sup>

### *Pseudoplatystoma corruscans*

*P. corruscans*, known in Brazil as the *pintado* or *surubim*, is the largest catfish in the Paraná Basin, with individuals up to 152 cm in length (slightly smaller than the maximum size encountered on the São Francisco River<sup>153</sup>), but with only females exceeding 130 cm in length.<sup>154</sup> The fish occurs in moderate abundance in the sport and artisanal fisheries in the dams-free stretches of the Paraná Basin, but can enter the riverine zone of reservoirs to feed. The species is very popular in the marketplace, particularly for restaurants, and is among the ten most captured species in the Itaipu Reservoir.

The *pintado* is a nocturnal piscivore in all habitats, sizes or seasons.<sup>155</sup> Juveniles and adults are most abundant in marginal lagoons and meandering rivers, but only adults are found in the main channel of the Paraná River.<sup>156</sup> The examination of 481 stomach contents revealed the presence of 38 other fish species, invertebrates and the occasional other small vertebrate.<sup>157</sup> Experimental studies on gastric evacuation demonstrated that it takes 7.6 to 14.6 hours to complete the evacuation, depending on temperature.<sup>158</sup> The fish stops feeding when temperature drops below 18°C. Growth curve parameters have been calculated.<sup>159</sup>

*P. corruscans* spawns in running and shallow waters, from November to February, when the ovaries represent about 6% of the body weight. The number of oocytes can be up to 2.5 million per individual,<sup>160</sup> each

<sup>149</sup> Leite et al., 1988; Rizzo et al., 1998; Nachi et al., 1998; Blasquaz et al., 1990; Barbieri et al., 1989; Moraes et al., 1997b

<sup>150</sup> Fernandes et al., 1995; Barrionuevo & Fernandes, 1998; Severi et al., 1998

<sup>151</sup> Ranzani-Paiva et al., 1995, 2000

<sup>152</sup> Castagnolli & Cyrino, 1981; Rocha et al., 1989; Pinto et al., 1989; Verani et al., 1989; Castellani et al., 1994; Tamelli et al., 1994; Kawamoto et al., 1996; Cestarolli et al., 1997; Rizzo et al., 1997; Nuñez & Verani, 1998; Furuya et al., 1999; Galdioli et al., 2000; Portella et al., 2000a, 2000b

<sup>153</sup> Godinho et al., 1997; Sato et al., 1997

<sup>154</sup> Godinho et al., 1997

<sup>155</sup> Marques, 1993

<sup>156</sup> Agostinho & Julio Jr, 1999

<sup>157</sup> Marques, 1993

<sup>158</sup> Marques et al., 1992

<sup>159</sup> Palmeira, 1990; Mateus & Petrere, in press

<sup>160</sup> Sato et al., 1997

with diameter of about 0.9 mm. Sexual maturity is reached at 67 cm.<sup>161</sup> The migratory behaviour of this species has been reported on by several researchers.<sup>162</sup>

Other published studies on this species are on parasitology and pathology;<sup>163</sup> contamination by pesticides;<sup>164</sup> cytology, histology and embryology;<sup>165</sup> genetics,<sup>166</sup> and cultivation.<sup>167</sup>

### *Pterodoras granulosus*

*P. granulosus* is an armoured catfish known in Brazil as the *armado* or *abotoado* due to a row of bony plates along each side and a large and robust dorsal spine. This is the principal species captured by the artisanal fishery in the Itaipu Reservoir. Originally from the middle and lower parts of the basin, it colonized the upper stretches of the Paraná after the Itaipu Reservoir inundated Sete Quedas Falls, a natural barrier to distribution upstream. The current northern limit to the distribution of this species is a stretch impounded before 1982 (Jupiá Dam in the Paraná River). In the floodplain, it can be found in all types of environment, except creeks. It is most abundant in the riverine zone of the Itaipu Reservoir and in meandering rivers.<sup>168</sup> The maximum size recorded for *P. granulosus* in the Upper Paraná River was 69.6 cm and the first maturation of females is reached at 36 cm.

The armado is omnivorous, feeding on plants (fruits, seeds, and leaves), filamentous algae, molluscs, crustaceans, insects and small fish.<sup>169</sup> In the riverine zone of the Itaipu Reservoir, juveniles are concentrated in the transitional zone between the tributary and the reservoir, whereas adults are more frequent in the main body of the reservoir. In this area, the juveniles feed primarily on filamentous algae and microcrustaceans,

<sup>161</sup> Suzuki, 1992

<sup>162</sup> Cordiviola, 1966; Bayley, 1973; Lowe-McConnell, 1986.

<sup>163</sup> Pavanelli & Rego, 1992; Moravec et al., 1993a, 1993b; Machado et al., 1994, 1995, 1996; Moravec et al., 1994; Petter, 1995b; Kritsky & Boeger, 1998; Rall et al., 1998

<sup>164</sup> Matsushita & Souza, 1994; Moraes et al., 1997a; Hylander et al., 2000

<sup>165</sup> Satake et al., 1994, 1995; Cardoso et al., 1995; Soares et al., 1995, 1996; Bazzoli & Godinho, 1997; Rizzo et al., 1998

<sup>166</sup> Souza et al., 1997

<sup>167</sup> Freire Filho et al., 1997; Miranda & Ribeiro, 1997; Ribeiro & Miranda, 1997; Rizzo & Bazzoli, 1997; Sato et al., 1997; Giovane et al., 1999; Tavares et al., 2000

<sup>168</sup> Agostinho & Julio Jr, 1999

<sup>169</sup> Hahn et al., 1992, 1997

whereas adults feed mostly on plants and molluscs.<sup>170</sup> The analysis of stomach contents from individuals caught in the floodplain upstream of the Itaipu Reservoir showed a large incidence of seeds, especially during the rainy season. Twenty seven plant genres were identified in the diet, dominated by plants of the Moraceae family and with *Ficus*, *Cecropia* and *Polygonum* the most abundant. The quantity of intact and viable seeds in the final portion of the gut suggests that this fish can be important for the dispersion of plant species<sup>171</sup> such as *Cecropia pachystachya*.<sup>172</sup>

The armado uses the area upstream of the Itaipu Reservoir, and probably the large lateral tributaries, to reproduce. The best records of individuals spawning are from a meandering tributary, the Iguatemi River. Spawning occurs repeatedly during the spawning season, which occurs later than that of other migratory species (January to March). During this period, ovaries constitute 6.6% of the body weight and contain about 724,000 oocytes per individual,<sup>173</sup> each with a diameter of about 1.1 mm.<sup>174</sup>

Tagging experiments with *P. granulatus* revealed that upstream movements occur from October to January, while downstream movement occurs from January to March.<sup>175</sup> Individuals of this species caught and tagged downstream of the Itaipu Dam and released into the reservoir were recaptured 180 km above the reservoir, demonstrating their ability to continue migration through a still water body. Bonetto et al. (1981) recorded displacement of up to 1000 km for this species.

Other published studies about the species are on parasitology<sup>176</sup> and hematology.<sup>177</sup>

### ***Rhaphiodon vulpinus***

*R. vulpinus*, a distinctive long-bodied and laterally compressed characid known in Brazil as the *dourado-cachorro*, *peixe-cachorro* or *facão* due to two large and prominent canine teeth. It inhabits open waters, and is currently an abundant fish in the Paraná Basin in both running water

<sup>170</sup> Agostinho & Julio Jr, 1999

<sup>171</sup> Stevaux et al., 1994

<sup>172</sup> Pilati et al., 1999

<sup>173</sup> Gosso & Iwaszkiw, 1993

<sup>174</sup> Suzuki, 1992.

<sup>175</sup> Agostinho et al., 1994a

<sup>176</sup> Thatcher, 1981; Lopes et al., 1991; Hoineff et al., 1992; Pavanelli et al., 1994; Petenusci et al., 1996; Moravec & Thatcher, 1997

<sup>177</sup> Satake et al., 1991

and reservoirs located in or close to the Paraná River.<sup>178</sup> In the Itaipu Reservoir, the fish is most abundant in the top 5 m of water and is important in the landings of the artisanal fisheries.<sup>179</sup> This species grows up to 71.8 cm in length with first maturation occurring at 40 cm. Growth curve parameters were estimated by Perez-Lizama (1994).

The dourado-cachorro is piscivorous, feeding primarily in running water at night, and generally hunting in shoals close to the bank where they capture small characins. Invertebrates are a secondary food item found in the stomach of juveniles.<sup>180</sup>

Spawning occurs in running waters, from October to January, when the ovaries represent more than 15% of the body weight,<sup>181</sup> and contain around 348,500 oocytes,<sup>182</sup> with diameters of 1.1 mm.<sup>183</sup>

Little other information is available about the biology and ecology of *R. vulpinus*, other than studies on parasitology<sup>184</sup> and morphology.<sup>185</sup>

### ***Rhinelepis aspera***

*R. aspera*, known as *cascudo preto* in Brazil, is another armoured catfish. At one time, this fish was widely distributed in the Paraná River Basin, living on rocky bottom in running waters. Many regional stocks were recognized, but most of these now appear to be extinct.<sup>186</sup> In 1959, the cascudo preto was the most important species in the fisheries of the Piracicaba River, contributing 50% of the landings.<sup>187</sup> In the 1980s it was also a prominent part of the fisheries in the Paranapanema River.<sup>188</sup> It is now absent in the commercial catches of both of these rivers, probably due to pollution, impoundments and overfishing.

In the case of the Itaipu Reservoir, this species historically supported an important fishery in the river immediately above the reservoir. In 1984, some daily catches approached a metric ton. From 1987 to 1991, *R. aspera*

<sup>178</sup> CESP, 1993; Agostinho & Julio Jr, 1999; Santos & Formagio, 2000

<sup>179</sup> Fuem.Nupélia/Itaipu Binacional, 1998

<sup>180</sup> Almeida et al., 1997; Hahn et al., 1997

<sup>181</sup> Suzuki, 1992

<sup>182</sup> Iglesias & Schubart, 1999

<sup>183</sup> Suzuki, 1992

<sup>184</sup> Moravec et al., 1993a, 1993b

<sup>185</sup> Nelson, 1949

<sup>186</sup> Agostinho et al., 1995b

<sup>187</sup> Monteiro, 1963, 1965

<sup>188</sup> Agostinho & Barbieri, 1987a, 1987b

was among the five most important species in the landings, averaging an annual catch of 64 metric tons. However, since 1991 the fisheries of this species has been declining, showing signs of overfishing.<sup>189</sup>

The cascudo grows up to 54 cm in length, and reaches its first maturation at a size of 25 cm. Growth curve parameters were estimated by Agostinho et al. (1991). The fish is iliophagous, feeding on finely grained detritus. It takes food in by suction, and possesses adaptations such as a respiratory membrane and well developed branchial rack<sup>190</sup>, rudimentary labial and pharyngeal teeth, thin stomach wall, and very long intestine to deal with this feeding habit.<sup>191</sup>

Spawning occurs from October to January after long migrations in running water. Ripe ovaries represent up to 15% of the body weight, and contain up to 180,000 oocytes, with diameters of 1.3 mm.<sup>192</sup> Suzuki et al. (2000) compared oocyte morphology and reproductive strategies of five species of lorcarid catfish and concluded that the cascudo preto differs considerably from the others with its reproductive migration, a curtailed spawning period, high fecundity, small eggs and broadcast spawning with no parental care.

Gill morphology and respiration of the cascudo preto have been extensively studied<sup>193</sup>. Other published studies addressed parasitology,<sup>194</sup> gonad histology,<sup>195</sup> cultivation<sup>196</sup> and systematics.<sup>197</sup>

### *Salminus hilarii*

*S. hilarii*, known in Brazil as the *tabarana*, is a migratory characid smaller than its better known congeneric *dourado* (*S. maxillosus*), with reported maximum sizes of 42 cm for females and 30 cm for males.<sup>198</sup> This species inhabits main tributaries of the Paraná River, and is extremely rare in the main channel of this river. The preference for small water bodies makes

<sup>189</sup> Agostinho et al., 1995b

<sup>190</sup> Castro et al., 1999

<sup>191</sup> Delariva & Agostinho, 2001

<sup>192</sup> Agostinho et al., 1991

<sup>193</sup> Santos et al., 1994; Perna et al., 1995; Perna & Fernandes, 1996; Armbruster, 1998a, 1998b; Takasusuki et al. 1998; Panepucci et al., 2000

<sup>194</sup> Ribeiro et al., 1989; Eiras et al., 1990; Moravec et al., 1992; Petter, 1994

<sup>195</sup> Agostinho & Barbieri, 1987a, 1987b

<sup>196</sup> Sato et al., 1998; Soares et al., 1998

<sup>197</sup> Armbruster, 1998a, 1998b

<sup>198</sup> Godoy, 1975

this species more susceptible than the dourado to local extinctions from pollution and impoundments.

The tabarana is a piscivore as an adult,<sup>199</sup> whereas fry feed on zooplankton and juveniles eat insects tending towards piscivory as they grow. Spawning occurs from November to January, with mature ovaries representing up to 15% of the body weight and 30,000<sup>200</sup> to 52,000<sup>201</sup> oocytes per individual. Magalhães (1931) reported that reproductive migration begins when the rainy season starts, ascending the upper stretches of the tributaries and concentrating to spawn in areas where the water is clean and shallow (<1.0 m deep).

Just one recent publication was found about this species, and this refers to parasitology.<sup>202</sup>

### *Salminus maxillosus*

*S. maxillosus*, known in Brazil as the dourado, is the largest characin of the Paraná Basin. Once common, it is now only caught sporadically in rivers such as the Paranaíba, Grande, Tietê and Paranapanema. In the dams-free stretches of the basin it has moderate abundance compared with other migratory species, and is targeted by artisanal and sport fisheries, particularly by weekend anglers. The species is the most valuable sport fish in these sections of the river, exemplified by a large annual international tournament in the first kilometers of the river below the Itaipu Dam. The maximum total length recorded in this area was 92 cm, but fish up to 116 cm have been reported.<sup>203</sup> Males are smaller than females, with a maximum length of 75 cm. Maturity in females is reached at 51 cm. Ageing and growth were studied by Sverlij and Espinach-Ros (1986).

The migratory behaviour of this species is conspicuous and has been mentioned by many authors.<sup>204</sup> Petrere Jr. (1985) reviewed the migration information for this and other species. *S. maxillosus* can migrate up to 1000 km at up to 21 km/day to reach spawning sites in the upper stretches of tributaries of the Paraná River. However, in an 80 km lotic stretch of the Paranapanema River, between Capivara and Salto Grande reservoirs,

<sup>199</sup> Godoy, 1975

<sup>200</sup> Godoy, 1975

<sup>201</sup> Nomura, 1973

<sup>202</sup> Kohn et al., 1997

<sup>203</sup> Godoy, 1975

<sup>204</sup> Bonetto & Pignalberi, 1964; Godoy, 1967, 1975; Bonetto et al., 1971; Bayley, 1973

schools of this species were still observed during the reproductive period, 15 years after the construction of these dams, without access to the upper tributaries. The Canoas Reservoir has now also impounded this last free stretch of the river.

Reproduction occurs from October to January, depending on the flood regime of the particular year. Ripe ovaries represent up to 16% of the body weight,<sup>205</sup> and contain up to 2.6 millions oocytes<sup>206</sup> with diameters of 1.4 mm.<sup>207</sup> According to Godoy (1975), this fish spawns in running water after the water levels have begun to rise. As with other characins, the eggs drift to the lower parts of the tributaries while undergoing embryonic development and are washed into the floodplains and marginal lagoons where the larvae complete development and juveniles find food and shelter.

The adult dourado is a top piscivore of the aquatic food chain, feeding in fast running water primarily during the twilight period.<sup>208</sup> Fry, on the other hand, may feed on zooplankton,<sup>209</sup> though they are also piscivorous in culture.

Other published information on the species refers to parasitology,<sup>210</sup> contamination by pesticides,<sup>211</sup> genetics,<sup>212</sup> and cultivation techniques.<sup>213</sup>

### ***Steindachneridion* spp.**

*Steindachneridion*, also known as *surubi* in Brazil, is a genus of pimelodid catfishes that includes an unknown number of species. The most popular is *S. scripta*. Similar to *S. hilarii*, it inhabits tributaries of the Paraná River and is never caught in the main channel of this river. Like other pimelodids, it prefers deep water in mid-sized streams with rocky bottoms. Traditional knowledge suggests that species of this genus are naturally rare, however, it is the only large migratory fish in the Iguaçu River, an important tributary of the Paraná.

<sup>205</sup> Vazzoler, 1996

<sup>206</sup> Godoy, 1975

<sup>207</sup> Suzuki, 1992

<sup>208</sup> Hahn et al., 1997; Agostinho et al., 1997; Almeida et al., 1997

<sup>209</sup> Godoy, 1975

<sup>210</sup> Boeger et al., 1995b; Petter, 1995a, 1995b; Pavanelli et al., 1995; Kohn et al., 1997; Molnar et al., 1998; Isaac et al., 2000

<sup>211</sup> Matsushita & Souza, 1994

<sup>212</sup> Margarido & Galetti Jr., 1999

<sup>213</sup> Coser et al., 1984; Amutio et al., 1986; Pelli et al., 1997

There is little published information on this genus. Unpublished data from the Iguaçu, Piquiri and Corumbá rivers (probably different species) show that the fish may grow up to 73 cm, is piscivorous, and spawns from December to February with oocytes of about 1.8 mm diameter. All the recent literature deals with taxonomy and systematics.<sup>214</sup>

## IMPACTS ON MIGRATORY SPECIES

### Fisheries Impacts

As in other basins in South America, data on fisheries are scarce for the Upper Paraná and information that is available from different parts of the basin, especially from reservoirs, is scattered. Long-distance migratory fishes in the Upper Paraná include all the large species and some of the medium-sized fishes present. Because of their size and excellent flesh, they bring the best price in the market and are therefore the preferred catches of artisanal fisheries. Sport fisheries also target most of them, in particular the large piscivores.

Surveys in the Upper Paraná Basin have identified three types of fishery:

- **Artisanal** – by fishers who live in small towns along the river bank.
- **Subsistence** – undertaken by small farmers or day workers who live on islands or along the rivers and reservoirs.
- **Recreational or sport** – by inhabitants of major cities in the region.

These three fisheries have been characterised in both reservoirs<sup>215</sup> and rivers.<sup>216</sup>

### Artisanal fisheries

**Reservoirs** – Reservoirs dominate the landscape in the Upper Paraná Basin. In the artisanal fishery, fish are caught mainly with nets (gill and trammel nets), but long lines and cast nets may be used to catch some species. In the Itaipu Reservoir, over 60 species may be exploited, seven of

<sup>214</sup> Lundberg et al., 1991; Oliveira & Moraes Jr, 1997; Figueiredo & Carvalho, 1999a, 1999b

<sup>215</sup> Agostinho et al., 1994b; CESP, 1996; Okada et al., 1996

<sup>216</sup> Petriere & Agostinho, 1993

the ten most important being migratory species (Figure 9).<sup>217</sup> Among the four most important species in the reservoir (accounting for more than 75% of the 1,560 tons landed annually), two are migratory: *P. lineatus* (caught with gillnets) and *P. granulosus* (caught with long lines), and make up 14% and 16%, respectively, of the catch.<sup>218</sup> *P. lineatus* was initially the most abundant in the fisheries when the reservoir first formed, but has now decreased and has been replaced by *P. granulosus* as the lead fishery. Migratory fish are caught primarily in the fluvial and transitional zones of the reservoir,<sup>219</sup> being virtually absent from the lacustrine zone.<sup>220</sup> Other than *P. granulosus* and *P. pirinampu*, the numbers of large migratory fish in the reservoir is decreasing, as indicated by a decreasing CPUE.

The maximum sustainable yield for all species from the Itaipu Reservoir has been estimated at 1,600 tons, with an optimum fishing effort of 96,000 fisher-days.<sup>221</sup> In 1993, fishing effort was 120,817 fisher-days (exceeding the optimum) with a catch of 1,500 tons, suggesting possible overfishing. Growth overfishing was identified for stocks of some migratory species (*P. granulosus*, *P. luetkeni*, *P. corruscans*) and recruitment and growth overfishing were identified for the stock of *R. aspera*, whose catches declined by 70% and in which only small individuals were landed by the end of the period.<sup>222</sup>

In spite of the high fishing effort, yield in reservoirs of the Upper Paraná Basin is low compared with other parts of the world. Estimates since 1986 indicated annual commercial yield averaged about 9 kg/ha. In contrast, commercial fishery yield averaged 152 kg/ha in reservoirs of northeastern Brazil<sup>223</sup>, 88 kg/ha in African lakes and reservoirs<sup>224</sup>, and 13 kg/ha in recreational fisheries in reservoirs in the USA.<sup>225</sup> Possible reasons for the low yield include low primary production, absence of lacustrine-adapted species, long food chains, high numbers of piscivorous species, and fishing effort and gear restrictions. Low hydraulic retention time of the reservoirs probably interacts with precipitation patterns to

<sup>217</sup> Agostinho et al., 1995a; Okada et al., 1996

<sup>218</sup> Agostinho et al., 1999b; Miranda et al., 2000

<sup>219</sup> Thornton et al., 1990

<sup>220</sup> Agostinho et al., 1999a

<sup>221</sup> Okada et al., 1996

<sup>222</sup> Okada et al., 1996

<sup>223</sup> Paiva et al., 1994

<sup>224</sup> Marshal, 1984

<sup>225</sup> Miranda et al., 2000

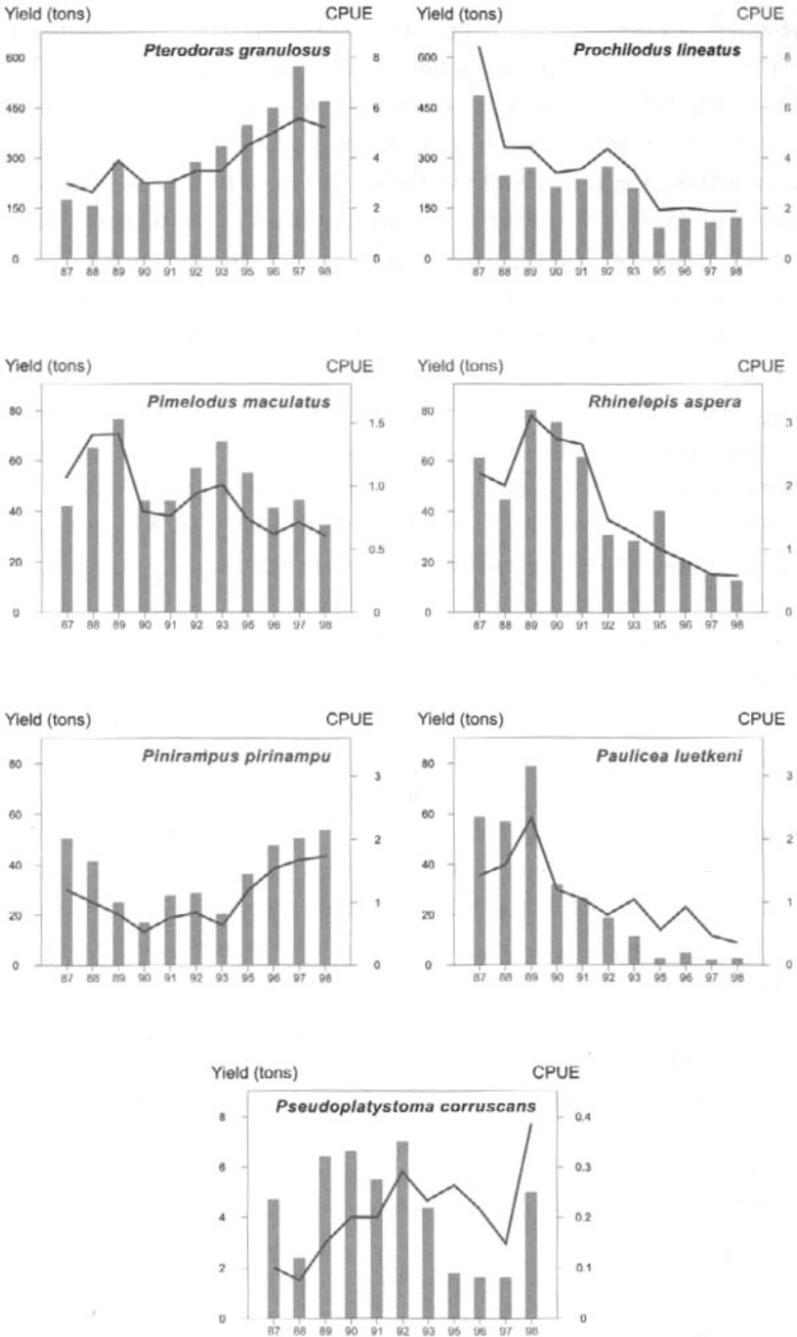
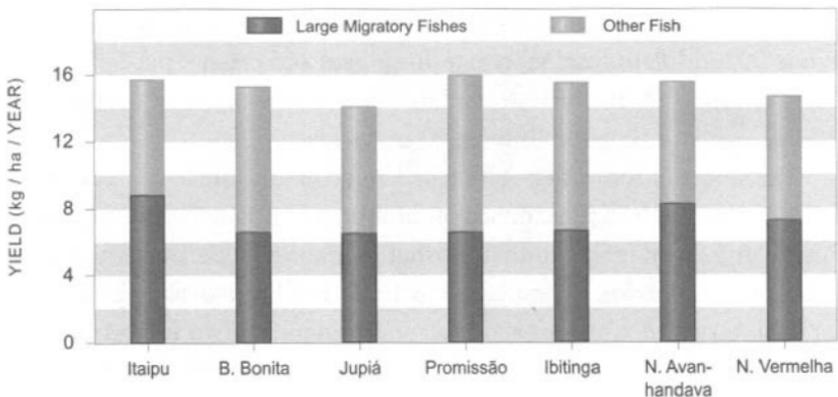


FIGURE 9. Annual catches of large migratory species in the artisanal fisheries of the Itaipu Reservoir as total yield (bar graph) and CPUE (line graph)

curtail primary production.<sup>226</sup> Fishery nonetheless remains important for the region because it is the sole protein source for local people, and because wages earned for most local jobs are inadequate for supporting a family.<sup>227</sup>

Surveys in seven reservoirs in the basin showed that migratory species are important components of the landings (Figure 10).<sup>228</sup> Reservoirs with greater fishery yields (around 11 kg/ha) are those with upstream stretches without dams (Itaipu and Barra Bonita reservoirs) or large lateral tributaries (Jupiá Reservoir). For large migratory species such as *P. lineatus*, *P. maculatus* and *P. granulatus*, the existence of free stretches upstream or large lateral tributaries are essential. Among these species, the most important for the artisanal fishery in all reservoirs is curimatá (*P. lineatus*). Its contributions to the total catch varied according to reservoirs, from 12% (5 tons/yr) in Ibitinga Reservoir to 37% (61 tons/yr) in Jupiá Reservoir. In the Itaipu Reservoir, where fishing is more intense, this species makes up 14% of the catch (224 tons/yr).

**Rivers** – Information on lotic fisheries in the Upper Paraná is sparse. Preliminary surveys indicate that artisanal fisheries in rivers differ from



**FIGURE 10.** Yield of large migratory fishes from reservoirs of the Upper Paraná River Basin<sup>229</sup>

<sup>226</sup> Fernando & Holcik, 1982; Paiva et al., 1994; Agostinho & Zalewski, 1995; Petrere, 1996; Gomes, 1999; Agostinho et al., 1999a

<sup>227</sup> Agostinho, 1994b; Agostinho et al., 1999b

<sup>228</sup> Torloni et al., 1993; Petrere & Agostinho, 1993; Agostinho et al., 1995a, CESP, 1996

<sup>229</sup> CESP, 1996; Agostinho et al., 1994a

those in reservoirs. Fishers target large catfishes (pimelodids, such as *P. corruscans*), a characid (*S. maxilloso*), anostomids (*L. elongatus* and *L. obtusidens*) and a prochilodontid (*P. lineatus*).

After the closure of the Itaipu Dam and dispersion upriver, *P. granuloso* (an armoured catfish) started to appear in the landings of the commercial fisheries. Four thousand eight hundred individuals of *P. corruscans*, totalling 24 tons, were taken and measured over one year (1987–1988) in the artisanal fishery of the Upper Paraná close to the town of Porto Rico, and it was concluded that this species seemed to be fairly abundant.<sup>230</sup> *P. corruscans* and *S. maxilloso* are caught with hooks baited with live fishes (*Gymnotus carapo*, *Hoplosternum littorale* and young *P. lineatus* may be used as bait). In fishing for *P. corruscans*, the most preferred species, fishers set their branch hooks late at night to avoid attacks on the bait by *piranha* (*Serrasalmus marginatus* and *S. spilopleura*). Fishers also follow the movements of *P. corruscans* schools, sometimes for more than 100 km.<sup>231</sup> *S. maxilloso* and *P. luetkeni* are also caught with hooks (long lines and hand lines), but these fisheries are usually performed during daylight in the Paraná channel where *piranhas* are less abundant.

*P. lineatus* and *P. granuloso* are caught with gillnets, and *P. granuloso* is also caught with long lines baited with fruit. During their migration upriver to reproduce, beach seining around sandbanks is used to catch *P. lineatus* and *R. aspera*. As winter progresses and catches per unit effort decrease, the fishers work floodplain lakes and secondary channels.<sup>232</sup> Absence of data allows no inferences on yields.

The stocks of some migratory fish depend on the integrity of the flood pulse. In studies of the influence of flooding on *P. lineatus* on the Itaipu Reservoir fishery, it was concluded that low water levels, persisting for a relatively long period (as observed in 1986–1987), might be responsible for the total absence of young-of-the-year, and thus failing recruitment.<sup>233</sup> This seemed to be the case for *P. lineatus*, whose stock decreased dramatically in commercial catches of the Itaipu Reservoir within a single year. In the year leading up to and including 1987 this species was the

<sup>230</sup> Marques, 1993; Petrere & Agostinho 1993

<sup>231</sup> Buck, 1988; Petrere & Agostinho, 1993

<sup>232</sup> Petrere & Agostinho, 1993

<sup>233</sup> Gomes & Agostinho, 1997

most important catch of the reservoir,<sup>234</sup> contributing about 500 tons, but in the next and following years it contributed only about 220 tons annually.

Fish are usually marketed at both local and regional levels. Most of the fishers are linked to middlemen that buy the catch. Data from the commercial fishery in the Itaipu Reservoir indicate that the middlemen pay low prices for the harvested fish and sell them for at least double the price, enjoying most of the profits.<sup>235</sup> Some of the catch goes to supermarkets in big cities in the region and some to neighbouring states such as São Paulo.

### Subsistence fisheries

Virtually all islanders and a considerable part of the riverine population fish for subsistence, as fish are their main protein source. Islanders employ basic gillnets and to a lesser extent hook and line or poles, to catch medium-sized species, including some migratory species such as *S. maxillosus*, *P. corruscans*, *P. mesopotamicus*, *L. obtusidens*, *L. elongatus*, and *P. granulosus*.

### Sport fisheries

The sport fishery along rivers occurs primarily during the weekend throughout the year. The river anglers target mainly *S. maxillosus*, *B. orbignyanus*, *P. mesopotamicus*, *L. elongatus*, *L. obtusidens*, *P. corruscans*, and *P. luetkeni*, and are restricted to the main channel and major tributaries. Techniques used are hook and line (poles), baited with live fish for catching *S. maxillosus* and *P. corruscans*, pieces of fish for *P. luetkeni*, seasonal fruit for *P. mesopotamicus*, and worms for the remaining species. Some tournaments are held in cities along the river bank, especially to catch *L. elongatus*. There is no information on their yields. The sport fishery in reservoirs is practised on small and medium sized sedentary fish by fishers from local and neighbouring cities.

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<sup>234</sup> Agostinho et al., 1994b

<sup>235</sup> Agostinho et al., 1999b

## Other Impacts

### Genetic effects

There is some uncertainty about the impact of impoundments and fish stocking on the genetic diversity of migratory fish populations in the Upper Paraná. Few studies have characterised the population or analysed possible effects. Over the last four decades more than 26 large reservoirs have been constructed in the basin and 25 species have been stocked, including migratory species (*P. lineatus*, *S. maxillosus*, *Leporinus* spp.), hybrids (*P. mesopotamicus* x *Colossoma macropomum*) and exotic species (*Plagioscion squamosissimus*, *Triporthesus angulatus*, *Hoplias lacerdae*, *Astronotus ocellatus*, *Oreochromis niloticus*).

After depletion of large migratory fish stocks in the higher reaches of the Upper Paraná Basin, especially in bigger tributaries such as the Tietê, Grande and Paranapanema, attention has been devoted to the possible loss of genetic variability. The loss could be a result of population fragmentation, loss of spawning sites, and especially the genetic quality of the hatchery fry used in stocking. In the stretch of the Upper Paraná free from dams, electrophoretic analysis of 19 enzymatic systems of *P. lineatus* from the Paraná and two tributaries (Ivinheima and Baia rivers) revealed that the three sub-populations share a high degree of heterozygosity and polymorphism.<sup>236</sup> The values for the Nei statistic,<sup>237</sup> used to estimate the degree of genetic similarity among populations, were high.<sup>238</sup> This suggests that these populations are a single stock, indicating their appropriateness for use as parental stock for the basin. However, the material analyzed in that study was collected from a short stretch of the Paraná Basin unaffected by dams. The authors of the study are currently developing a project to investigate the effects of damming on the genetic variability of *P. lineatus* in the Plata Basin. The aim is to examine the usefulness of RAPD in *P. lineatus* as a source of genetic markers to quantify genetic variability of the sub-populations that will be collected in some locations of the two most important rivers in the Plata Basin: the heavily dammed Paraná, and the Paraguay River, which has not been dammed.

<sup>236</sup> Revaldaves et al., 1997

<sup>237</sup> Nei, 1978

<sup>238</sup> Paraná x Ivinheima = 0.999; Baia x Ivinheima = 0.999; Paraná x Baia = 0.996

## Negative impacts of dams

Electricity plants in Brazil generate 78,000 MW annually. Presently 90% of the energy consumed in the country comes from hydroelectric power, of which dams in the Upper Paraná and other small basins in southeast Brazil generate more than 70%.<sup>239</sup> The main impacts on migratory fishes in the Upper Paraná are therefore a result of dam construction.

The series of dams in the main tributaries of the Upper Paraná has been blamed for the virtual absence of large migratory fish in the basin.<sup>240</sup> Abundant before the impoundments,<sup>241</sup> these species were important in artisanal fisheries along the upper tributaries of the Paraná.<sup>242</sup> Today, *S. maxillosus*, *P. luetkeni*, *P. corruscans*, *B. orbignyanus*, and *P. mesopotamicus* are caught only sporadically in rivers such as the Paranaíba, Grande, Tietê, and Paranapanema. However, *P. lineatus* and *Pimelodus maculatus* still make a reasonable contribution to the bulk of the catches in reservoirs, that have large tributaries or upstream stretches without a dam, where they may reproduce. Short-distance migrators such as *Hypophthalmus edentatus*, *A. bimaculatus* and *P. squamosissimus* (Figure 3) can also inhabit a reservoir, reproducing in lateral tributaries, upstream stretches or even the fluvial zone of the reservoir.<sup>243</sup>

Migratory neotropical species generally range widely, with spawning sites and growth areas up to 1000 km or more apart.<sup>244</sup> For the early life stages the species also require nurseries, which are lentic and more vegetated, usually between spawning sites and adult habitats. The most conspicuous impact dams have on migratory fish in the Upper Paraná is the separation of spawning grounds from nurseries and feeding sites. The intensity of impacts from damming will thus depend on the dam site in relation to the three types of habitats required by migratory species. Adults of migratory species may inhabit fluvial parts of reservoirs, and spawn when long stretches of unimpounded river exist upstream. However, the lentic conditions in the main parts of a reservoir are unfavourable to migratory fishes.

<sup>239</sup> Petrere et al., 2002

<sup>240</sup> Agostinho et al., 1999a

<sup>241</sup> Godoy, 1975

<sup>242</sup> Monteiro, 1963

<sup>243</sup> Agostinho et al., 1995a, 1999a

<sup>244</sup> Godoy, 1957; Bonetto, 1963; Petrere, 1985; Agostinho et al., 1994a

Besides blocking migratory routes, dams also alter the flood regime. Above the dam, the floodplain is permanently inundated by the reservoir. Below the dam, floods are reduced and time lags are introduced into the peaks (Figure 11). As a result, the area seasonally inundated is reduced, or is flooded at the wrong time, altering the connectivity between the river and important nursery habitats and interfering with the stimuli that lead to spawning.

### Positive impact of dams

The succession of reservoirs in the Upper Paraná tributaries appear to serve as settling chambers that improve the water quality. Thus, the intense pollution in the headwaters of the Tietê River from São Paulo City and from industries results in very poor water quality in the initial reservoirs, but is no longer detectable six reservoirs downstream where the river enters the Paraná.<sup>245</sup> These tendencies improve the quality of fish for human consumption, but decrease productivity due to the sedimentation of nutrients. Despite the virtual absence of large migrants in these reservoirs, production of fish biomass is greater than in the rivers, and intense artisanal and recreational fisheries are present.

### Agriculture and ginseng extraction

Intense agriculture and cattle-raising (mostly with inadequate soil management), the heavy use of agricultural chemical agents and the

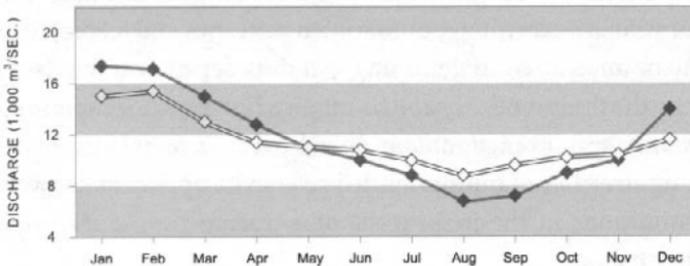


FIGURE 11. Natural and regulated discharges of the Paraná River upstream of the Itaipu Reservoir<sup>246</sup>

<sup>245</sup> Barbosa et al., 1999

<sup>246</sup> Agostinho & Zalewski, 1995

elimination of riparian vegetation have degraded water quality in the chief tributaries of the Upper Paraná, the spawning grounds for migratory fishes. In the stretch of the Upper Paraná that is not dammed, the environment is still altered significantly by changing water levels induced by upstream dams and by cattle-raising, irrigated rice culture, extraction of *Pfaffia* (Brazilian ginseng, a tuber used in the cosmetic industry), mining (sand extraction) and navigation.

Cattle enter the islands mainly during low water periods when landowners have difficulties keeping the cattle on their own pastures. Trampling compacts the soil, erodes the borders of the islands and destroys emerging vegetation, which can be important during the formation of temporary lagoons. Deforestation and fire (intended to favour growth of herbaceous vegetation) both worsen the situation. To find the *Pfaffia* shrub (the first species to emerge out of charred ground), extractors burn the riparian vegetation, an important food source for *P. mesopotamicus*. Rice culture in flooded areas involves draining and sometimes the use of chemical agents. Absorbing the *varzeas* (flooded forests) into agricultural production in these ways eliminates an important nursery area for migratory fishes.

### **Mining and navigation**

Although limited to the main channel of the Paraná, mining by nearly 30 companies has a significant impact on riparian vegetation and river channel habitats. Navigation projects for the Upper Paraná bring heavy traffic of medium-sized and big boats that ship agricultural products from the western and eastern regions of the states of Paraná and Mato Grosso do Sul, respectively, to the port of Santos in São Paulo State. These boats begin their trip in the Itaipu Reservoir, navigate along the free stretch of the Paraná, pass through locks of the Paraná and the Tiête rivers, and dock in the latter. Pollution from the ships and erosion of the river banks by their wake are expected consequences with the potential to affect migratory fish.

## MANAGEMENT AND MITIGATION

### Legislation

The São Paulo State Law Number 2250, dated December 28, 1927, Article 16, mandated the installation of fish ladders on dams. This Law was so controversial at the time that a specialist from the US (J. H. Brunson) was consulted to analyse the need for fish ladders in Brazil. In 1929, he concluded that fish ladders more than 9 m high were not efficient. This conclusion was based on the US experience because there was no information available for Brazil.<sup>247</sup> In 1934 a new Federal Law was promulgated,<sup>248</sup> which stated that all dams producing electricity should have mechanisms to allow the preservation and movement of fish. In 1938 a new law<sup>249</sup> stated that dams must have mechanisms that allow the preservation of ichthyofauna, either by the construction of fish ladders or by constructing hatcheries. As a result, and in light of Brunson's conclusions on the inefficiency of fish ladders, the hydroelectric companies built several hatcheries. In 1967, Decree Law 221 (28/02/67) delegated to SUDEPE (Federal Agency for the Development of Fisheries) the task of determining the best mechanism for the protection of the aquatic fauna. This agency, whose main purpose was fish culture development, through Resolution 46 (27/01/71) made one hatchery mandatory in each sub-basin where dams were built.

Consideration of Environmental Impacts Studies dates from 1981.<sup>250</sup> In 1983 it became mandatory to submit a Report of the Impacts on the Environment that would include a survey of the area, a description of the proposed action and alternatives, and identification, analysis and prediction of the major positive and negative impacts.

A new law<sup>251</sup> makes it a crime to kill, hunt, take or use wild fauna either native to the location or in migration, without official permission, licence or authorisation.

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<sup>247</sup> Alzuguir, 1994

<sup>248</sup> Decree number 24,643; July 1934; Article 143, named Water Code

<sup>249</sup> Decree Law number 794; October 19, 1938; Article 68

<sup>250</sup> Law Number 6938; August 31, 1981

<sup>251</sup> Article 11 of Decree Law Number 3179, September 21, 1999

Legislation to reduce exploitation of long-distance migratory fish juveniles and to protect spawning grounds prohibits fisheries during the spawning season and restricts the mesh-size of nets and the number of hooks used by fishers. More restrictive regulations are published annually to control fisheries during spawning (*piracema*) in state border rivers (Federal Agency) and rivers within a given state (State Agencies). The legislation is enforced by a State Environmental Agency. However, these regulations are unsuccessful because of the absence of exploitation/resource monitoring, because money and human resources are lacking, because there is no clear target for action, and because there is a shortage of information locally about the species.

In the unimpounded stretch in the Upper Paraná where migratory fish such as *S. maxillosus*, *P. mesopotamicus* and *L. elongatus* are valuable to the recreational fishery, the ban on fishing during spawning (November to February) is rarely enforced. No information exists on the number of illegal fishers or on how many fish are taken from the Upper Paraná during the ban. It is also not uncommon that in some years, when floods are delayed, the season reopens just when the fish are beginning to migrate or spawn.

In tributaries of the Upper Paraná, fisheries are regulated by different legislation. Artisanal fishing is not permitted in the Goiás and Mato Grosso do Sul states and is regulated in the Paraná, São Paulo and Minas Gerais states. Recreational fisheries however, are permitted in all of the states.

## Fish Passages

The adequacy of fish passage facilities as mitigative tools in the Paraná is doubtful, particularly because the reproductive strategies of migratory fishes rely on passive drifting of eggs and larvae until adequate development habitats such as shallow marginal lagoons are entered. The reservoirs that lie between the spawning sites and the nursery lagoons are usually calm water, causing the eggs to stop and sink before they reach the lagoons; because the water of the reservoirs is relatively clear, the eggs are seen by small omnivorous fishes and eaten.<sup>252</sup> Studies of eggs and larvae

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<sup>252</sup> Agostinho & Gomes, 1997

conducted by Nupélia/Universidade Estadual de Maringá in the first kilometer below the Itaipu Reservoir demonstrate that (i) the larvae registered originated from the reservoir, as demonstrated by the fact that they belonged to essentially two species (90% sardela and 8.5% curvina) that reproduce in this environment, with their adult and reproductive forms absent from the stretch below the dam, (ii) the rate of damaged larvae (mutilated and crushed) reached values greater than 30% of the total, suggesting high mortality, in as much as those fragmented were not kept back by the ichthyoplankton net and (iii) no large migrator larvae were recorded.<sup>253</sup> Thus, although adult migratory fishes may successfully use the passages, only a small proportion of their eggs may hatch out as fry.

Fish ladders are the device most relied on to mitigate impacts from dam construction in the Upper Paraná. The first fish ladder in Brazil was built in 1911 at the Itaipava Dam<sup>254</sup> and is 7 m high. In the 1920s, the second fish ladder (3 m high) was constructed at the Cachoeira das Emas Dam (on the Mogi Guaçu River, a tributary of the Paraná).<sup>255</sup>

Based on the US experience with salmonids, fish ladders became mandatory in Brazil in 1927.<sup>256</sup> The legislation stated that in every dam constructed (river, stream, or creeks), a facility to allow migratory fish to pass upstream was mandatory. But no studies were carried out on the fish fauna or appropriate ladder design. As a result, a fish ladder was constructed just above a 70 m high waterfall,<sup>257</sup> or in streams where no migratory fishes were registered.<sup>258</sup> Nor was evaluation performed after construction of the fish ladders, with a few exceptions. A few studies reported the high efficiency of the ladder in Cachoeira das Emas,<sup>259</sup> and it was reported that several fish species were able to reach the upper part of a 27 m high experimental fish ladder at Itaipu Dam.<sup>260</sup> However, the 11 m high ladder constructed at Salto Morais Dam (Tijucu River) was ineffective.<sup>261</sup>

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<sup>253</sup> Agostinho et al., 2002

<sup>254</sup> Pardo River, a tributary of Paraná River

<sup>255</sup> Godoy, 1985; Quirós, 1988

<sup>256</sup> Law No 2250/SP, 28/12/1927

<sup>257</sup> in Negro Stream, São Carlos, State of São Paulo

<sup>258</sup> Charlier, 1957

<sup>259</sup> Godoy, 1957, 1975

<sup>260</sup> Borghetti et al., 1993; 1994

<sup>261</sup> Godinho et al., 1991

Between 1957 and 1980, 23 ladders were built in dams in northeast Brazil, and all were reported to give satisfactory results.<sup>262</sup> However, other than recent data from the experimental fish ladder at the Itaipu Dam, there is no data on the efficiency of fish ladders in the big reservoirs of the Upper Paraná Basin. A fish ladder and elevator under construction in Porto Primavera Dam will be the first such facility in a large reservoir in the Upper Paraná.

Godoy (1985) concluded that ladders of less than 16 m in height would allow species to swim upstream, although problems in the ladder design could lead to malfunction. Data obtained by the Department of Environment of Itaipu Binacional<sup>263</sup> showed that a vertical slot experimental ladder at Itaipu Dam (27 m high; 155 m long; and velocity of 1.2 m/s) enabled 28 out of 68 species registered downstream of the dam to reach the top of the ladder. Among the migratory species (large and medium) abundant in the ladder were *P. lineatus*, *P. maculatus*, and *L. elongatus*. Other large species, such as *P. corruscans* and *B. orbignyanus* were observed sporadically. *P. mesopotamicus* and *P. luetkeni*, registered downstream, were not seen in the ladder. The authors suggest that these species could not get into the ladder because they were either too high along the spine (*P. mesopotamicus*) or too large (*P. luetkeni*).<sup>264</sup> The drive to spawn was suggested as an explanation for the high number of species and individuals in the ladder, as many of the fish had mature gonads. However, later work found a great number of juveniles, suggesting other factors may also be involved.

All the information available in the literature reported only the efficiency and ability of fish to use a ladder to reach reservoirs. No literature evaluated the influence of the ascended fish on the stocks upstream and downstream. Another problem associated with fish ladders and discussed only recently in Brazil is the continuation of migration once fishes reach a reservoir, specifically because the current that fish may need to navigate is greatly reduced in the reservoir. Tagging at Itaipu Reservoir<sup>265</sup> suggested that migrants caught downstream and released upstream were able to

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<sup>262</sup> Godoy, 1985

<sup>263</sup> Fernandez, 2000

<sup>264</sup> Borghetti et al., 1994

<sup>265</sup> Agostinho et al., 1993a

continue their journey.<sup>266</sup> Marked *P. lineatus* and *P. granulosus* from downstream of Itaipu Dam, released into the reservoir, were recaptured 180 km above the reservoir. Movement of these fish within the reservoir was slower than that of fishes released directly into the river. However, the velocity of fishes caught downstream and released into the reservoir was greater than the velocity of fishes caught and released within the reservoir. Seven of the nine recaptured individuals with the greatest displacement had been caught downstream and released upstream.<sup>267</sup>

## Fish Elevators

The elevator installed in Yacyretá Dam, in the Middle Paraná, seems to be working more satisfactorily than others in the river system.<sup>268</sup> In 1995, the elevator moved 44% of the species registered in the tailrace (totalling 1,767,000 individuals and 252 tons). These results have led to recent installation of elevators in the Porto Primavera Dam of São Paulo as well. The results of these installations are not yet known.

## Stocking

Stocking with exotic and native fish has been the most conspicuous strategy used by hydropower companies over the last decades to mitigate impacts on migratory fish in the Upper Paraná. Several hatcheries were constructed, billions of fry were stocked in most of the reservoir, and large amounts of money and effort were expended to restore fisheries. Initially stocking was done with exotic non-migratory species, of which more than two-dozen species were introduced from the Amazon Basin or from other continents. Fifteen of them are recorded in rivers and reservoirs of the Upper Paraná. However, only four species (*P. squamosissimus*, *Cichla monoculus*, *O. niloticus* and *Tilapia rendalli*) are harvested in commercial quantities. *P. squamosissimus* is currently the principal species in most of the artisanal fisheries of the Upper Paraná. Since 1980, species native to the basin have been stocked, but monitoring is restricted to only a few reservoirs and started only late in the decade.

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<sup>266</sup> 7,855 marked and 315 recaptured

<sup>267</sup> FUEM.Nupélia-Itaipu Binacional, 1990

<sup>268</sup> Convenio SECYT, 1996

Some native migratory species have also been stocked, especially *Leporinus* spp., *P. lineatus*, *B. orbignyanus* and pimelodid species. Among the native migratory species *P. lineatus* was the most stocked, making up 81% (up to 46,000,000 fry) of the total (Table 3). Other large migratory species used in stocking programs, but less intensely, were *P. mesopotamicus*, *L. obtusidens*, *S. maxillosus*, *P. luetkeni* and *R. aspera*.

**TABLE 3.** Number of fry released by the Companhia Elétrica de São Paulo in reservoirs of the Upper Paraná River Basin, 1979–1995<sup>269</sup>

RESERVOIRS	LARGE MIGRATORY	OTHERS
Água Vermelha	5,284,000	5,786,200
Bariri	1,382,700	2,578,600
Barra Bonita	741,700	9,227,500
Ibitinga	4,630,690	2,682,600
Nova Avanhandava	1,930,892	2,878,300
Promissão	22,498,300	13,206,220
Ilha Solteira	6,345,600	11,454,807
Jupia	7,991,150	4,289,800
Jurumirim	5,584,900	8,940,700
Total	56,389,932	61,044,727

Absence of monitoring or difficulties in distinguishing between stocked and unstocked fish in the catches do not allow conclusions on stocking efficiency, but current artisanal fisheries in the reservoirs are based on species that are not stocked.<sup>270</sup>

## Protected Areas

The importance of the last unimpounded stretch of the Upper Paraná to the maintenance of biodiversity, including the conservation of migratory fishes, was recently recognised by the federal and state governments through the creation of three conservation units: (i) Environmental Protection Area of the Island and Varzea of the Paraná (10,031 km<sup>2</sup>); (ii) Ilha Grande National Park, occupying the lower half of the Ilha Grande Island; and (iii) Ivinheima State Park, including the main nursery area at

<sup>269</sup> CESP, 1996

<sup>270</sup> Agostinho et al., 1999a

Mato Grosso do Sul State (700 km<sup>2</sup>). These conservation units have different levels of use restrictions. However, the effectiveness of this strategy is still unclear, and many problems still exist. Fire, cattle-raising and drainage are forbidden, but enforcement is poor. In addition, the effects of upstream dam operation are substantial but are not considered in the strategy.

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

The outlook for migratory fish in the Upper Paraná is worsening. A new government hydroelectric plan foresees several dams in the main tributaries that are not yet impounded.

The lotic segment of the Upper Paraná is the last remaining stretch with a viable population of migratory fishes in this river inside Brazilian territory. Studies show that the integrity of the Upper Paraná floodplain is fundamental for the maintenance of the present recruitment levels that sustain the basin fisheries, especially artisanal fisheries in the Itaipu Reservoir. These studies also show that many species present in the region are absent in stretches of the river further upstream due to impoundments and poor water quality.

The majority of the human activities in the area violate the present environmental legislation. Organisations created to protect the region are pressuring landowners to remove cattle from the varzeas and islands. Prohibition of *Pfaffia* extraction should also be promoted. State environmental secretaries are presently working with academic and non-governmental organisations to find solutions to provide a harmonious balance between regional development and floodplain integrity.

The maintenance of fish diversity in the last free stretch of the Paraná within Brazilian territory, particularly in regard to populations of the large migratory species, depends on the integrity of the floodplain. Maintaining this integrity needs to deal with the ongoing human occupation in the region and will rely on better management of dams upstream.<sup>271</sup> The newly created conservation districts in the floodplain are appropriate for improving the level of preservation of the migratory fish nurseries, but there is neither enough money nor personnel to manage the districts,

<sup>271</sup> Agostinho & Zalewski, 1996

which fail to take in the spawning areas in the upper parts of tributaries. The main problem in the region (flow regulation by dams) also cannot be controlled by the administration of conservation districts. The level of information on the biology and ecology of migratory fish is also poor.

## Proposed Conservation Strategy

A conservation strategy for the area should consider:

- Developing a research program to identify ecological zones that would provide information for decisions on alternative uses, and to evaluate the impact of anthropogenic activities;
- Evaluating the conservation status and biological/ecological requirements of migratory fish stocks;
- Identifying the potential users of migratory fish resources (i.e. sport and artisanal fisheries), their social, economic and environmental aspirations and constraints;
- Evaluating gear selectivity and impacts on fish stocks;
- Developing hatchery production of migratory species for stocking purposes, and methods for monitoring the genetic quality of the brood and the success of stocking programs;
- Identifying minimum instream flow and flood duration needed to trigger spawning and assure viability of eggs and larvae of the migratory species;
- Creating basin committees composed of municipal governments, research institutions, governmental and non-governmental organisations related to the environment, and others responsible for the management of the area. The purpose of these committees would be to propose guidelines to control the uses and occupation of the basin, including new impoundments and the operation of those already constructed;
- Requesting from power companies a broad research program before decisions on the siting of future dams in unimpounded tributaries are made, including areas critical to migratory fish spawning; and
- Promoting the restoration of spawning areas in the upper parts of the tributaries, in particular the rehabilitation of the riparian vegetation that has been illegally stripped.

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MIGRATORY FISHES OF THE

**Paraguay–Paraná Basin**  
**Excluding the Upper Paraná Basin**

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## CHARACTERISTICS OF THE BASIN

### Introduction

The Paraná-Paraguay Basin encompasses most of southeastern Brazil, Paraguay, eastern Bolivia, and northern Argentina. As such, together with the smaller Uruguay River, it drains most of the central part of the continent southward into the Rio de La Plata estuary on the east coast (Figure 1). In size, it covers 2,800,000 square kilometers, second only to the Amazon Basin in South America.



FIGURE 1. The Paraguay-Paraná River Basin, showing river sections and principal features discussed in text<sup>272</sup>

<sup>272</sup> Also see Chapter 2

The Brazilian highlands and adjacent plateaus of the center of the continent are drained to the south by the Paraguay and Parana rivers; the São Francisco drains these to the northeast and the Amazon to the north. These highlands were worn down to sea level during the Paleozoic Era but were then uplifted again to their present elevation as the Andes formed, variously stagnating water drainage in temporary saline lakes and seaways and changing directions and connectivity of river systems in the process.<sup>273</sup> The present topography ranges from level plateaus to rolling hills and deeply cut valleys.

Most of the drainage system of the Paraná-Paraguay Basin is hot and humid throughout the year, but with rains during the wet season primarily from October to March. Fifty percent more rain falls in the highlands than on the plains (respectively 1200 mm and 800 mm per annum), leading to substantial seasonal floods<sup>274</sup> that are important to the biology of the basin.

The Paraná River originates at the confluence of the Grande and Paranaíba rivers in southern Brazil, and then runs generally southwest for 3,998 km before draining into the Rio de La Plata estuary. Eastern tributaries in the upper part, such as the Tietê, Paranapanema, and Iguazu rivers, originate in the coastal mountains a short distance from the Atlantic but drain inland to contribute to the Paraná system. In some cases, as with the Tietê, the headwaters are situated in some of the most densely populated areas of the continent, and the upper reaches of the Paraná are the areas most intensively developed for hydroelectric generation.

The Paraná River can be divided into upper, high, middle, and lower sections,<sup>275</sup> each with distinctive geographic, social or biological characters. Of these, the Upper Paraná has historically been adequately separated from the rest of the basin by the falls of Sete Quedas to be recognized as a distinct ictiofaunistic "province".<sup>276</sup> This portion of the basin is also sufficiently distinct in terms of social character that it is treated separately in the previous chapter, whereas the remainder of the basin is discussed here.

The Paraguay River originates west of the Mato Grosso plain in south-central Brazil, at 298 m above sea level. It is the fifth longest river in South

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<sup>273</sup> Lundberg et al., 1998

<sup>274</sup> Lima Barros Dolabella, 2000

<sup>275</sup> Agostinho et al., 1995; Bonetto, 1998

<sup>276</sup> Bonetto, 1998

America (2,550 km), and is the principal western tributary of the Paraná. Its basin spreads over more than 973,000 square kilometers, including large parts of Brazil, Paraguay, and Bolivia. Throughout the basin, elevations rarely exceed 200 meters above sea level. The river is accessible to ocean-going ships and is plied mainly by local steamers travelling between the capitals of Argentina and Paraguay.

The Paraguay River has also been described in four sections by some authors, with the Upper and High Paraguay together constituting an ictiofaunistic province distinct from the rest of the basin.<sup>277</sup> However, the distinction of the subdivision of the two halves of the river are not as clear in the Paraguay as in the Paraná, so I have opted to use the more common terminology of simply the Upper and Lower Paraguay.

## Upper Paraguay

### Geography, geology and river profile

The basin of the Upper Paraguay lies in the west-central region of South America, with a catchment area of around 496,000 km<sup>2</sup>. Most of the basin lies within Brazil (358,514 km<sup>2</sup>) with the remainder in Bolivia and Paraguay.

Two great geological regions can be found in this portion of the Paraguay Basin: the highlands and the Pantanal, corresponding to Bonetto's (1998) "Upper" and "High" river sections. The Paraguay first becomes navigable (84 m wide, 6 m deep) about 240 km downstream from its source in Brazil, after its confluence with the Sepotuba River. Where the Jauru River joins it (another 30 km downstream), it enters the Mato Grosso Pantanal floodplain, skirting the Pantanal's western edge over a sandy bed and flowing around many islands. Important tributaries in this section are the Cuiabá, Taquari and Miranda rivers. Shortly before reaching Paraguay the river is joined by the Apa River, which flows in from the east and marks the end of the Upper Paraguay.

In the highlands, dense evergreen forest galleries grow along stream banks, whereas the Pantanal is a vast seasonally flooded plain. The fluctuation in water level over the plains depends largely on waters from the Pantanal to the north, with flood peaks from May to August and low

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<sup>277</sup> Bonetto, 1998

water from December to January. Geologically this portion of the river remained isolated from the Paraná Basin, draining into an inland salt-water lake where the Pantanal now stands, until the Paraguay River found a channel into the Paraná during the Holocene. The fish fauna of the Upper Paraguay therefore differs slightly from that of the Lower Paraguay and Paraná.<sup>278</sup>

## The Pantanal

The Pantanal is a vast, virtually level inland plain that is flooded a large part of the year, due to the very low slope (1–3 cm/km from north to south and 6–12 cm/km from east to west). The Pantanal covers almost 40,000 square miles or approximately 175,000 km<sup>2</sup>; with 80% in the Brazilian states of Mato Grosso do Sul and Mato Grosso and 20% in Bolivia and Paraguay (Figure 1). Geologically, the basin is a relatively new sedimentary basin, whose non-consolidated alluvial sediments were washed down from the highlands during the late Quaternary (12,000–13,000 years ago).<sup>279</sup> They are markedly sandy, with restricted areas of clay and organic deposits. Vegetation of the region is predominantly savannah, with scattered small trees and much grass. Plant species from the Amazon and from the Atlantic rainforests can be found in the Pantanal, along with typical Chaco vegetation.<sup>280</sup>

Despite its sandy character, the Pantanal floodplain is one of the largest and most complex wetlands of the world. There are surface lakes, floodable depressions, anastomosed channels, small temporary ponds, and the rivers themselves.

During the rainy season, the rainwater that comes from the highlands slowly covers the plain from north to south and from west to east, along the Paraguay River and its tributaries. When it rains intensely in the highlands and the plain at the same time, the Pantanal lies under a great sheet of water that leaves only the *cordilheiras* (low hills) dry. Unlike the grasslands of Rio Grande do Sul, which have been largely converted into pastures and wheat fields, the Pantanal has been left largely untouched, though it is used as a natural grazing land during the dry season.

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<sup>278</sup> Lundberg et al., 1998; Britski et al., 1999

<sup>279</sup> Ab'Saber, 1988

<sup>280</sup> Lima Barros Dolabella, 2000

The regional names for the Pantanal rivers include *corixo*, a temporary or permanent water channel that has its own river bed; *vazante*, a temporary river without its own bed that generally connects one lake to another during the rainy season; *baías*, temporary or permanent lakes; and *salinas*, saline lakes generally found in the Pantanal of Nhecolândia.<sup>281</sup> The rivers meander markedly, and there are many oxbow lakes and, on the western side, five large lakes; Uberaba (10,841 hectares), Gaíva (7,887 ha), Mandioré (13,765 ha), Vermelha (2,846 ha) and Jacadigo (4752 ha).<sup>282</sup>

The most important tributaries of the Paraguay in the Pantanal are the Jauru, Sepotuba, Cuiabá, São Lourenço, Itiquira, Taquari, Negro, Aquidauana, Miranda and Apa rivers. The confluence with the Apa River is the southern limit of the Pantanal and the start of the Lower Paraguay River.

Because of the trapping and holding capacity of its wetlands, the Pantanal acts as a large buffer that releases its water downstream slowly, supporting an abundant fish fauna and other animals that depend on the fish for survival. Based on the type of dominant soils, vegetation, flooding depth and flooding duration, at least eleven different regions in the Pantanal can be identified. One of the most beautiful is Nhecolândia, with its numerous lakes and abundant wild animals, including marsh deer, jabiru storks, capybaras and caymans. Fish, apart from their importance to humans, are also a food base for several of these species, including the cormorant, jabiru, wood storks, caymans and giant otters.

### Social characteristics

When the Bandeirantes, the pioneer European explorers of Brazil, first reached the west-central region in the early 1700s, the Mato Grosso area was inhabited by Bororo Coroado, Bororo Cabaçal, Bororo Campanha, Paresi, Umutina and Guató Indians. Today, the indigenous population has been reduced to the Paresi, Umutina and Bororo Coroado groups, living in seven of the eight indigenous reservation areas. The indigenous population in Mato Grosso do Sul State is made up of groups of Guarani-Kaiowá, Guató, Kadiwéu and Terena. The Guató population is estimated at 700 people, approximately 400 Living in urban areas (Corumbá and

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<sup>281</sup> Resende, 1998

<sup>282</sup> Resende, 1998

Cáceres) and the rest in the Guató Island Insua and in riverside regions along the Paraguay and São Lourenço rivers. The Kadiwéu reservation has an area of 538,536 hectares and is inhabited by 1500 natives of the Kadiwéu and Terena groups, who lease their lands to non-natives for agriculture and cattle rearing. The Terena indigenous group occupies 17,329 hectares distributed into seven areas. Their main cultivated crops are rice, beans, corn, cassava and cotton.<sup>283</sup> In some areas along the Miranda River, it is not uncommon that they lease the river out for fishing.

Approximately two million people now live in the Brazilian Upper Paraguay Basin, mostly in the highlands in a few large centres such as Cuiabá, Várzea Grande and Rondonópolis of Mato Grosso State. This region was accessible only by the Paraguay-Paraná rivers until the mid-1900s, and the isolated human populations developed mechanisms to adapt and survive that are still found in a few rural communities and on traditional cattle farms. Today, the population consists predominantly of immigrants or their descendants originating from all over Brazil.<sup>284</sup> Based on demographic indicators, a human population of 3,450,000 is estimated for the year 2025 for this part of the Paraguay Basin. Most will live in the highland cities.

The population of the Pantanal is about 206,000 inhabitants, at an average density of 1.8 inhabitants per square kilometer, which contrasts with the overall Brazilian average of about 17 inhabitants/km<sup>2</sup>. Settlement of the region has been largely dictated by the flood patterns, which make much of the region unsuitable for year-round occupation.<sup>285</sup> The population of the Pantanal plain is largely found on an estimated 3,500 cattle ranches, which, since the cattle range freely on natural pastures, employ very few workers.

Ninety percent of municipalities in the area have a reliable supply of water. However, treatment of solid waste, sewage and residual water is critically inadequate. Most of the urban houses use septic tanks for wastewater. In other situations wastewater is released directly to rivers without any treatment. In most cases the solid wastes collected by public services are spread on open fields or in trenches.<sup>286</sup>

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<sup>283</sup> PCBAP, 1997

<sup>284</sup> PCBAP, 1997

<sup>285</sup> Lima Barros Dolabella, 2000

<sup>286</sup> PCBAP, 1997

The main economic activities in the highlands are cultivation (primarily soybean and corn) and beef cattle ranching based on seeded pastures. Sugar cane is also of great economic importance for some municipalities in Mato Grosso. Gold and diamond mining are important in the northern regions.

In the Pantanal plain, the most important traditional economic activity is beef cattle rearing on natural pastures. Sport fishing has grown in the last ten years to become the second most important economic activity in the Pantanal, with 56,000 fishermen arriving each year in the South Pantanal. The number visiting the North Pantanal is unknown, but 65,000 are estimated for the whole of the Pantanal. Some cities, such as Corumbá, Miranda and Porto Murinho, depend on sport fishing for their economic survival.<sup>287</sup>

## Lower Paraguay

### Geography, geology and river profile

The Lower Paraguay begins at the confluence with the Apa River (Figure 1). It runs along the northeastern border of Paraguay for approximately 200 km before crossing Paraguay from north to south (more than 320 km). Crossing Paraguay, the eastern bank is elevated, while a low plain known as the Chaco Boreal spreads out on the west. The floodplain of this section is very poorly studied. Meeting the Pilcomayo at Asuncion, the river forms the southwestern border of Paraguay with Argentina for 330 km south to Corrientes, where it drains into the Paraná. Authors that divide the Lower Paraguay into two sections<sup>288</sup> do so with the division at Asunción.

From the Apa to the Paraná, the Paraguay flows on a broad, shallow bed, averaging about 600 m wide. In Argentina, where it broadens to 700 m, the banks are very low and floodwaters create a very large floodplain between 5 and 15 km wide. Similarly to the Lower Paraná, the climate changes from subtropical in the north to temperate in the south.

To the west of the Lower Paraguay and the Middle Paraná lies the Gran Chaco, an immense lowland plain. Composed of extremely deep unconsolidated sand and silt, nearly free of stones, the Gran Chaco is the

<sup>287</sup> PCBAP, 1997

<sup>288</sup> Bonetto, 1998

alluvial fill of a vast geosynclinal basin formed by downwarping or submergence of the area between the Andean Cordillera on the west and the Brazilian Shield on the east. It is largely uninhabited, arid and subtropical. Two main rivers, the Pilcomayo and Bermejo, cross its low forests and savannahs. Roads and rail lines are rare. The Gran Chaco covers about 730,000 square kilometers, of which slightly more than one-half lie inside Argentina, one-third in Paraguay, and the remainder in Bolivia.

No major obstacles have yet been built in this section of the river that alter water flow, and the major impacts recognized to date are due to agriculture and cattle rearing along the tributaries.<sup>289</sup>

The Bermejo and Pilcomayo rivers, which drain from the Andes foothills into the Gran Chaco, are typical of most rivers of the Chaco and are called "Chaco streams". Their courses are marked by countless sloughs, oxbow lakes, braided channels, sandbars and vast swamplands; losses from flooding, seepage, and evaporation are so high that little of their full flow reaches the mouth. Most of the Chaco is so poorly drained that the very shallow and irregular channels lead to rapid and extensive flooding during the very rainy summers and Andean draining. At the peak of these floods, as much as 15% of the Chaco may be under water.<sup>290</sup>

### **Social characteristics**

The upper portion of this part of the Paraguay Basin lies in Paraguay, the country with perhaps the most racially homogeneous population in South America. A large majority of the people are of mixed white (especially Spanish) and Guarani Native American descent. More than half live in rural areas. In the last census of 1993 the population was estimated at 5,070,856. The density is higher in the western region, on the left bank of the Paraguay River, and most sparse in the Chaco, on the right bank.

Farming is the principal industry of Paraguay. The main crops are cassava, sugar cane and soybean. Livestock breeding and forestry are other major occupations. The country has 7.8 million cattle and, in the late 1980s, about 8.2 million cubic meter of timber were cut yearly. Fishing is negligible, the annual catch being some 13,000 metric tons.<sup>291</sup> The

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<sup>289</sup> PCBAP, 1997

<sup>290</sup> Encyclopaedia Britanica, 1980

<sup>291</sup> CIH, 1997

Paraguay River is practically the only transport route by which fish caught in the Paraguayan Pantanal can reach the capital, Asunción.<sup>292</sup>

Carron (2000) writes that the natives of the region support themselves through a combination of fishing, hunting, farming, cattle-raising, and by working for large cattle ranches or with timber companies. Intrusion by cattle farmers is eroding the lands held by native groups, whose main subsistence resource is fishing. Large properties formerly owned by timber companies that concentrated on extracting quebracho wood for use in tannin production are now being sub-divided, attracting people of Brazilian origin and placing further environmental and social pressures on the region.<sup>293</sup>

The Pilcomaya and Bermejo Rivers provide water for drinking, irrigation, fishing and mining in Bolivia, though seasonal droughts and flooding are problematic.<sup>294</sup> Fishing itself is only a small component of the official Bolivian economy (total reported catch in 1995 of 6,300 tons: 0.04% of the GDP). Up to 40% of Bolivian fisheries have relied on a seasonal catch of migrating *Prochilodus* in the Pilcomaya River<sup>295</sup>, even though this fishery peaked in 1986 and the Bolivian Government now lists the fish stock as "vulnerable". The fish are probably also substantially contaminated with lead contamination.<sup>296</sup> Contamination from mining is a serious concern in the Pilcomaya River<sup>297</sup>, while erosion and siltation are of prime concern in the Bermejo.<sup>298</sup>

## High Paraná

### Geography, geology and river profile

The historical barrier to upriver fish movement in the Paraná River, and the traditional dividing point between the Upper and High Paraná River sections, is the Salto das Sete Quedas (Guaira Falls) and canyon in the Serra de Maracuja of southeastern Brazil. However, due to flooding by

<sup>292</sup> Carron, 2000

<sup>293</sup> Butler and Gaston, 1994. Cited in Carron, 2000

<sup>294</sup> Mochek & Pavlov, 1996; Civic, 1999

<sup>295</sup> Bayley, 1973; Espinach-Ros & Delfino, 1993

<sup>296</sup> Mochek & Pavlov, 1996

<sup>297</sup> Mochek & Pavlov, 1996

<sup>298</sup> Civic, 1999

the Itaipú Reservoir, the functional barrier is now the Itaipú Dam, just upriver of the confluence with the Iguazu River and the tri-national border corner of Brazil, Argentina and Paraguay. This is now also the logical start of the section of the river considered the "High" Paraná.<sup>299</sup>

The 1,944 km of river in this section<sup>300</sup> flow southwest and then west, forming the border between Paraguay and Argentina from the Iguazu River on. Flanked to the east by the Sierra de Misiones, it flows in a rocky river bed through patchy deposits of sedimentary material up to approximately Posadas. Tributaries that enter the river in this stretch include the Iguazu, Uruguay-í, Piray Mini, Piray Guazú, Paranay, and Capióví rivers from the west and the Acray, Monday, Nacunday and Tembey rivers from the east. All are characterized by falls close to their confluence with the Paraná, generally varying from 10–20 m in height (over 100 m for the Iguazu) and limiting fish passage upriver from the mainstem. Of these, the headwaters of the Iguazu and Uruguay-í have been dammed.

At Posadas, the approximate half-way point of the High Paraná, the river bed turns west and broadens, with sections of anastomosing creeks and oxbows, floodplains and islands alternating with more restricted sections that pass through basaltic formations. The river bed here lies in an ancient alluvial fan, and varies between a shallow rocky base and sandy substrate. Vegetation in this area is alternately savannah grassland and mixed jungle, with a distinctive riparian zone along the river.

The large and controversial Yacyretá hydroelectric project crosses the river mainstem in the mid-section of the High Paraná. This dam is designed as essentially a run-of-the-river barrage, with a set reservoir height and very low retention time for water (3–7 days). It was equipped with two fish elevators to help mitigate effects on the fish populations in addition to navigation locks.<sup>301</sup> The top of the 70 km-long reservoir is just downriver of the cities of Posadas in Argentina and Encarnacion in Paraguay.

Climate in the High Paraná River Basin is sub-tropical, hot, and humid, with only a short dry season in the winter (July–August). Mean precipitation is 1.8 m/yr, with air temperatures that vary between approximately 0–40°C and river water temperatures of 17–30°C.<sup>302</sup>

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<sup>299</sup> Agostinho et al., 1995; Bonetto, 1998; García, 1999

<sup>300</sup> García, 1999

<sup>301</sup> García, 1999

<sup>302</sup> García, 1999

## Social characteristics

The areas around the High Paraná are used primarily for agriculture both in Argentina and Paraguay. Principal cities are Posadas in Argentina and Encarnacion in Paraguay, with smaller cities and fishing villages distributed along the river. Many of the fishing villages and indigenous communities on islands in the river were displaced by the Yacyreta development.<sup>303</sup>

## Middle and Lower Paraná

### Geography, geology and river profile

Below the confluence with the Paraguayan River at Corrientes, the Middle Paraná turns south and runs through Argentina. It is a typical plains river in this stretch, banked by its own alluvial deposits and having an extensive floodplain on its eastern shore, with tracts up to 39 km wide. Its permanent bed, about four kilometers wide at Corrientes, also narrows to about 2,438 m at Bella Vista, about 2,100 m at Santa Fé, and about 1,830 m at Rosario in the lower river section. Throughout this stretch the river is strewn with chains of islands.

At Santa Fé the Paraná receives the last large tributary, the Salado River, and becomes the Lower Paraná. Between Santa Fé and Rosario the west bank rises as the river skirts the lowlands and turns to the east. This plains grassland flanks the river all the way to the delta at altitudes of 9 to 20 meters above the river. Due to the constant erosion of the west bank, which is higher than the east, the river becomes increasingly turbid and divided into many branches.

The delta of the Paraná begins as far north as Diamante (just south of Santa Fé), where the river begins to anastomose and turn southeast for the last 320 km into the Río de la Plata. About 18 km wide at its upper end, the delta is 64 km wide at its mouth. Covering 8,850 square kilometers in 1970, the Paraná delta appears to be advancing into the Río de la Plata at the rate of 70 m each year, due to an annual deposit of alluvial material estimated at 165 million tons. The most important branches in the delta are the two last great channels, the Paraná Gaçu and the Paraná de las Palmas. The islands of the delta, formed of the alluvial deposits, have

<sup>303</sup> Inter-America Development Bank, 1997

consolidated embankments covered with trees, but are still submerged during times of high water.

Formerly the velocity of the Paraná changed frequently throughout its course. However, the construction of large hydroelectric reservoirs has turned the Upper Paraná River into a succession of lentic water bodies (see Chapter 2), and has modulated the variability of flow in the rest of the river to some degree.

The water level in the Middle and Lower Paraná nevertheless still fluctuates between two to six meters, depending primarily on rainfall in the upper basins. Flooding generally occurs from March to April, followed by a low water season from August to October. During the dry season, the lakes of the alluvial plain are isolated from the main river channel. Such environments provide food and shelter for a large number of fish species, and this portion of the river is possibly the most productive of the basin.<sup>304</sup>

About 25% of the total volume of water of the Middle Paraná comes from the Paraguay River. High water normally occurs in February or March in the headwaters, slowly coming south and reaching the border of the country Paraguay in June/July. Low water begins in November or December with similar downstream delays. The Upper Paraná and the Paraguay reach their maximum flows at different times. The mountainous basin of the Upper Paraná drains so rapidly that water begins to rise at Corrientes in November and peak in February, whereas the swamps of the upper basin of the Paraguay absorb floodwaters and keep them from reaching Corrientes until May. The consequence is that the flow of the Middle and Lower Paraná is moderated throughout the year, and floods extend over months rather than weeks.

## Río de la Plata

### Geography, geology and river profile

The Río de la Plata is a submerged saline estuary, though it is sometimes called a gulf. The rivers that enter the estuary drain about one-fourth of South America, so a large portion of the upper part is fresh enough to support large numbers of fresh-water fish species. Montevideo, the capital of Uruguay, is on the northern shore of the estuary, and Buenos Aires, the

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<sup>304</sup> Bonetto, 1998

capital of Argentina, is on the southern shore. From where the delta of the Paraná and the mouth of the Uruguay meet in the Río de la Plata, the open Atlantic lies about 290 km to the east. The mean annual temperature is 55°F (13°C) and monthly averages never go below 50°F (10°C). However, winter frosts are frequent in the south and can range as far north as Asunción in Paraguay, and Paraná State in Brazil.

Every year the Paraná and Paraguay rivers bring down about 56,620,000 cubic meter of silt. The winds and the tides keep the suspended material from settling quickly, so the deposits form great shoals, banks, or bars of clay, sand, and organic matter. The water volume discharged into the Atlantic by the Río de la Plata is estimated at 22,000 cubic meters per second. Water depth varies from 1.8 m above the shoals to 20 m in the intervening channels.

Although the water of the tributary rivers is so widely distributed over the length and breadth of the estuary that variations in their volume do not affect the water level, the level is considerably affected by tides and winds. Rainfall is copious in all seasons, amounting to 990 mm a year.

### **Social characteristics of the Middle & Lower Paraná and La Plata basins**

Along these basins lie the Pampas, a lowland well suited for production of grains such as wheat, barley, oats and oilseed. Most of the Argentinean population of 18 million<sup>305</sup> lives in these basins, together with industries such as petroleum, chemical and agro-industrial plants. Wastewater treatment varies regionally from individual to public septic tanks. The water of the estuary is exploited for urban and industrial purposes as well as for navigation. Fishing, except for that of the abundant detritivore *curimbatá* or *sábalo* (*Prochilodus* sp.), appears to be of little overall commercial importance, though in some areas local populations may rely on the activity for their livelihood.<sup>306</sup>

### **Habitats Used by Migratory Species**

Migratory fishes use different habitats for food, for shelter and for reproduction. In the Upper Paraguay River Basin, the habitats used for

<sup>305</sup> 1991 census

<sup>306</sup> [www.ramsar.org/profiles\\_argentina.htm](http://www.ramsar.org/profiles_argentina.htm)

feeding are the floodable areas, temporary water courses, oxbow lakes along the rivers and large lakes found along the Paraguay River. The main river channel is used for migration and the headwaters for spawning.<sup>307</sup>

Bonetto and co-workers observed a similar pattern for the Middle and Lower Paraná River Basin and the Río de la Plata Basin.<sup>308</sup> During the flooding season, the Paraná River overflows its valley and forms many shallow lagoons, where the young and juveniles of important migratory fishes such as *Prochilodus platensis*, *Salminus maxillosus*, and *Pseudoplatystoma corruscans* can be found.

For freshwater fishes, the Upper Río de la Plata can be considered a continuation of the Middle and Lower Paraná and the Lower Uruguay River, as indicated by the results of tagging experiments on the principal migratory species (such as the sábalo (*Prochilodus lineatus*), the boga (*Leporinus obtusidens*), the dourado (*Salminus brasiliensis*), the patí (*Luciopimelodus pati*) and the common armado (*Pterodoras granulosus*)). This section of the Río de la Plata is an area of concentration for these species.<sup>309</sup>

## MIGRATORY SPECIES AND MIGRATION PATTERNS

Most of the economically important fish in the Paraguay-Paraná River are migratory. Species that are widely distributed geographically include the characins *P. lineatus*, *S. maxillosus*, *Piaractus mesopotamicus*, species of the genus *Leporinus* (*macrocephalus*, *friderici*), *Schizodon borellii*, *Brycon microlepis*, *Brycon orbignyanus* and catfish such as *P. corruscans*, *Pseudoplatystoma fasciatum*, *Paulicea luetkeni*, *Sorubim lima* and *Hemisorubim platyrhynchos*. Some differences can be found in fish fauna composition through the entire basin, and economic importance of the migratory species varies regionally. For example, *B. microlepis* and the *pacu-pevas* of sub-family Myleinae are economically important only in the cities of Cuiabá and Várzea Grande in Mato Grosso State, North Pantanal.

One of the most striking features of South American fish assemblages is the abundance of detritivorous fishes. The most prominent of these is

<sup>307</sup> Rondon, 1990; Resende et al., 1996a, 1996b; Resende & Palmeira, 1999; Lima et al., 1984a, 1984b

<sup>308</sup> Bonetto et al., 1969, 1970, 1971, 1981

<sup>309</sup> Ni6n, 1996

the curimatá (*P. lineatus*),<sup>310</sup> which feeds on detritus resulting from flooding in shallow areas. Detritus makes up more than 77% of its food, with algae and other items making up the rest. The large catfish *Pseudoplatystoma* spp. is commonly seen feeding on *P. lineatus* when it begins to leave the flooded areas and large lakes in which it remains during the flood season. The catfishes appear to leave the flooded areas when their prey starts to migrate upstream.

In the Paraguay River Basin, the first species that begin to migrate upriver are the characins, of which the best known is *P. lineatus*. Large shoals of *P. lineatus* moving upstream can generally be seen from September to October in a migration known as the *piracema*. By the end of the dry season they have reached the headwaters of the rivers, where they wait for the first rains, which usually fall from December to February. Their spawning is famous for the noise made by the males during mating.<sup>311</sup> In the warm river waters (generally 28°C in the Pantanal rivers) the eggs hatch within 24 to 48 hours. Carried passively by currents, the larvae and fry enter flooded areas, where they feed and find shelter from predators (Figure 2).

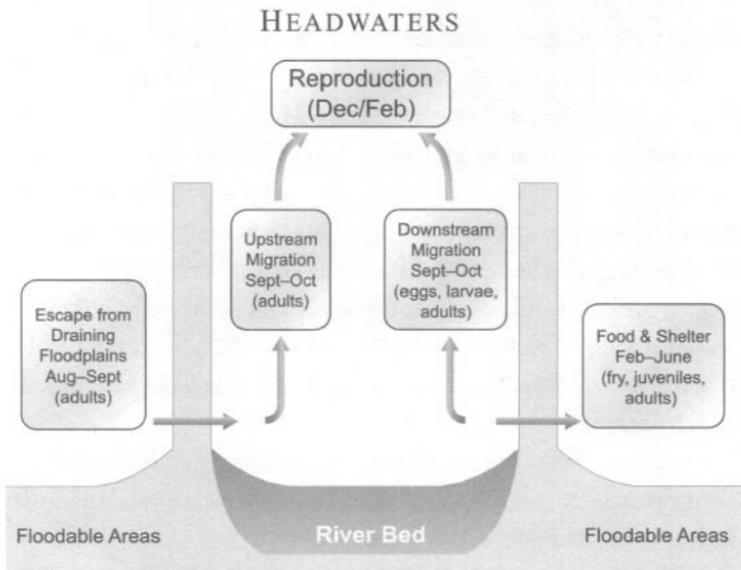


FIGURE 2. Migratory fish life cycle in the Pantanal

<sup>310</sup> Resende et al. 1996a

<sup>311</sup> Godoy, 1967; Bayley, 1973; Resende, personal observation

After spawning, the adults gather in preparation for downstream migration in a phenomenon known as *rodada*. They then move slowly back to the downstream floodplains, arriving in very poor condition. From February to May or June, depending on the extent and duration of floods, they feed. By June or July they are again in good condition and ready to return upstream to spawn, leaving the draining floodplain in what is known as the *lufada* (characterized most markedly by large numbers of small forage fish). Figure 2 presents the relationships between the rivers, their laterally floodable areas and the yearly flood cycle. The large catfishes, such as *P. corruscans* and *P. fasciatum*, follow the characins, migrating to the headwaters and spawning from December to February.

Young migratory fish remain in the lower stretches of the rivers until they become adults. In the floodplain they can be found in the temporary water courses known as *corixos* and *vazantes* or in permanent water bodies such as lakes and lagoons or oxbow lakes. Mortality in this phase depends on how much water remains in the water bodies during the dry season.

Migratory routes of fish in the Paraná River Basin are incompletely known, though some trends have been hypothesised based on tagging studies, fisheries data, and biological studies of adults and larvae (Figure 3). The information suggests that extensive reproductive migrations may occur (one tagged dourado, *S. maxillosus*, travelled from the Rio Plata Estuary over 1,440 km to Posadas, in the High Paraná<sup>312</sup>), but shorter routes are also likely. For example, migration of *P. lineatus* in the Pilcomaya River probably is restricted to the 450 km between the Andes foothills upstream of Villa Montes and the river's floodplains in the Gran Chaco, without involving the Paraguay River mainstem<sup>313</sup>; migratory stocks of the Pantanal probably only migrate between the headwaters of tributaries in the adjacent highlands and the Pantanal wetland<sup>314</sup>; and the High, Middle and Lower Paraná River may contain several distinct sections with regards to migratory routes of fish.<sup>315</sup>

The migratory fish species of the Paraná-Paraguay River Basin that are of importance to humans are primarily characids and silurids. In alphabetical order, the main species are:

<sup>312</sup> Sverlij & Espinach-Ros, 1986

<sup>313</sup> Bayley, 1973

<sup>314</sup> Resende, unpublished

<sup>315</sup> Espinach-Ros & Delfino, 1993; Sverlij & Espinach-Ros, 1986; Oldani, 1994

## Characids

### *Brycon* spp.

*B. microlepis*, previously classified as *B. hilarii*, is endemic to the Upper Paraguay Basin. This fish is particularly appreciated in the cities of Cuiabá and Várzea Grande in Mato Grosso State, where several restaurants specialize in grilled *pera*, a popular local name for this fish (otherwise



**FIGURE 3.** Examples of migratory patterns of fish hypothesised for the Paraná River Basin deduced from tagging experiments and/or fisheries data<sup>316</sup>

<sup>316</sup> Information presented is illustrative and likely to be far from a complete picture of migratory patterns in the basin; (1)–(4) adapted from Espinach-Ros & Delfino, 1993. (1) & (2) based on fisheries information and tagging experiments of dorado (*S. maxillosus*) by Sverlij & Espinach-Ros, 1986. (3) & (4) based on fisheries information and biological studies of sabalo (*P. "platensis"*) by Bayley, 1973; Payne & Harvey, 1989. No citation given for the Bermejo River information. (5) based on recent tagging experiments of the curimbatá (*P. lineatus*) by Agostinho et al., 2002; also see Chapter 2. (6) based on tagging experiments with curimbatá (*P. "scrofa"*) by Godoy, 1967 prior to the construction of recent dams. (7) is an example of migratory pattern of characids and silurids in the Pantanal, based on biological studies by Resende et al., 1996a; unpublished data.

known in Portuguese as *piraputanga* and in Spanish as *salmón*). The species is a good swimmer and comes to the surface in search of food. It is not uncommon to see it feeding on flowers that have fallen into the river from the riparian vegetation. The species is omnivorous.<sup>317</sup>

*B. orbignyanus* occurs only in the Lower Paraná River. While not very abundant, the species has great sport fishing value. Its food habits are probably similar to that of *B. microlepis*.

### ***Leporinus* spp.**

*L. obtusidens*, a characid known in Portuguese as *piava* and *piapara* and in Spanish as *boga*, is found throughout the Paraná-Paraguay Basin but not much is known of its biology in this area. It has an elongated body, and grows to a maximum size of around 40 cm. It normally weighs around 3 kg, though some specimens can grow to 6 kg. It inhabits both calm and running waters, and shelters among stones. Males and females in advanced stages of gonad development were captured in the Taquari River headwater falls, at Cachoeira das Palmeiras, in late September.<sup>318</sup> Vegetal remains were most abundant and frequent in the stomachs of fish captured in the Bento Gomes River, North Pantanal.<sup>319</sup>

*Leporinus macrocephalus* has only recently been described as a new species. It is a large *Leporinus* species that occurs throughout the Paraguay Basin and in the Paraná River, but is less frequent in the Upper Paraná Basin. It grows to a length of about 60 cm or more, and can be found in flooded areas, though it prefers running water.<sup>320</sup> It prefers a herbivorous diet,<sup>321</sup> but also feeds on crabs and freshwater aquatic snails, which are used as bait by fishermen. Vegetal remains were the only food found in the stomach of one specimen of *L. macrocephalus* caught in the Bento Gomes River, North Pantanal.<sup>322</sup>

*Leporinus friderici*, a third species of this genus, grows to more than 40 cm in length and occurs throughout the Paraná-Paraguay Basin. Little is known of its biology.

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<sup>317</sup> Silva, 1990

<sup>318</sup> Resende, unpublished

<sup>319</sup> Mesquita, 1992

<sup>320</sup> Resende, personal observation

<sup>321</sup> Resende et al., 1998

<sup>322</sup> Mesquita, 1992

### *Piaractus mesopotamicus*

*P. mesopotamicus*, previously also known as *Colossoma mitrei*, is the most representative fish of the Pantanal and occurs in almost every part of the region during the high water period. Known in Portuguese as *pacu-caranha*, or simply *pacu*, and in Spanish as *pacú*, it is a large characid that historically was found throughout the whole Paraná-Paraguay Basin. However, it has been absent from the La Plata River since the 1980s, and according to Quiros (1993), had practically disappeared from the Lower Paraná River, as well as from the La Plata and Uruguay rivers, by the time of his report.<sup>323</sup> It grows to 70 cm or more, with colours that can vary from almost black when in the flooded areas to bright yellow when in the river headwaters for reproduction. The body shape is oval to elliptical, and is distinctive by pronounced dentition capable of breaking hard fruits and seeds. It feeds on fruits, seeds and leaves of riparian vegetation and on crabs, molluscs and insects.<sup>324</sup> For example, adults are commonly seen feeding on the fruit of the caranda palm during the flood season,<sup>325</sup> and fruits and seeds of *Mouriri acutiflora*, a plant that grows in the floodable riverside areas, have been found in the stomachs of young fish during the flood season in Lake Acurizal of the Pantanal, in Mato Grosso State.<sup>326</sup>

Gonadal maturation of the pacu in the Upper Pantanal takes place from July to October, with spawning occurring in the river channel of the headwaters of the Cuiabá River in October-December, with a peak in November.<sup>327</sup> Reproductive adults have also been captured in the headwaters of the Taquari River.<sup>328</sup>

In a study on trends in abundance carried out for the Brazilian Pantanal, Agostinho et al. (unpublished) found that *P. mesopotamicus* is overexploited. Starting in 1994, to manage this overexploitation, the minimum capture size was increased by the Mato Grosso do Sul State government from 40 to 45 cm. At the time of the study *P. mesopotamicus* became the most captured fish, overtaking *Pseudoplatystoma* spp. In the Lower Paraná River, fishing for this species is currently prohibited entirely.

<sup>323</sup> Quiros, 1993

<sup>324</sup> Silva, 1985

<sup>325</sup> Resende, unpublished

<sup>326</sup> Conceição, 1988; Silva, 1985

<sup>327</sup> Lima et al., 1984a, 1984b

<sup>328</sup> Resende, unpublished

### *Prochilodus* spp.

Known in Portuguese as curimbatá, and in Spanish as sábalo, *P. lineatus* is also known as *P. platensis* in Argentina.<sup>329</sup> A second species, *Prochilodus scrofa*, is found in the Upper Paraná Basin, though the taxonomic distinction from *P. lineatus* is controversial. *P. lineatus* is widely distributed throughout the Paraná and Paraguay basins, and clearly represents the majority of the fish biomass. Bonetto et al. (1970) estimated a standing stock of 1,100 kg/ha of sábalo for the mid-region of the Paraná River: over 60% of the total fish biomass. In the review for the proposed Hidrovia project<sup>330</sup>, this was one of the migratory species most captured in the Middle Paraná Basin by traditional commercial fishermen in the Puerto Bajada Grande, Puerto Sanchez and Corrientes regions. The fish has also been important for fisheries in the Brazilian Pantanal, but in 1994, the fishing and commercialization of *P. lineatus* was prohibited in Mato Grosso do Sul for conservation purposes (see below).

Resende et al. (1996a) studied *P. lineatus* in the Upper Paraguay. In the Miranda-Aquidauana River system of this area, it is clear that only adults migrate to the headwaters to spawn, with young adults probably migrating later in the season than the older fish. Reproductive migration begins with rising water levels as early as September and October, but spawning only occurs later, usually between December and February. The timing of peak spawning varies from year to year depending on the rains in the river headwaters.

In the Pilcomayo River, a tributary of the Middle Paraguay,<sup>331</sup> "*P. platensis*" migrates approximately 450 km upstream from the Gran Chaco floodplain into the river headwaters, where it has been observed spawning in large schools in a narrow, shallow, but slow-moving and mud-bottomed tributary in October–November. Peak migratory activity at Villa Montes, on the border of the Andes foothills with the Chaco, is seen earlier, in July/August, also with young adults in later schools. Spent fish move downriver again with the first major floods at the end of November–December. This species grows to six to seven years of age in this system, becoming reproductive at two and a half to three years.

<sup>329</sup> Cabrera and Candia, 1964; Cordiviola, 1971

<sup>330</sup> CIH, 1997

<sup>331</sup> Bayley, 1973

In the La Plata River downstream of Buenos Aires,<sup>332</sup> both migratory and resident "*P. platensis*" have been described. Migratory fish are smaller (maximum size of 40 cm vs. 72 cm for resident fish) and reported to move south in the summer and north in the winter.

### *Salminus maxillosus*

The sub-family Salmininae of the Characidae is represented by only one genus and one species in the Pantanal, *S. maxillosus*. Its common names, dourado in Portuguese and *dorado* in Spanish, are due to its golden colour. It grows to a length of one meter or more, and is highly prized by sport and commercial fishermen alike. It is one of the few South American fish widely recognized by the international sport fishing community. A very active predator, it feeds on any fish it can capture. It occurs throughout the Paraná-Paraguay Basin, although catches have been decreasing since the late 1940s throughout the lower basin in Argentina, despite restrictions on commercial fishing. Conflicts between sport and commercial fishermen have been increasing, and the trophy size of *Salminus* has been decreasing at the confluence of the Paraná and Paraguay rivers, though total fishing effort seems not to have increased.<sup>333</sup>

Principal prey of *S. maxillosus* in the La Plata River has been reported as the small catfish *Parapimelodus valenciennesi*, whereas in the Lower Uruguay the fish preyed primarily on the detritivorous characids *P. platensis*, *Curimata* sp. and *Lycengraulis olidus*.<sup>334</sup> The authors in these areas found only immature or non-reproductive *S. maxillosus*, but this included fish of up to 6 years of age.

In the Miranda River of the Upper Paraguay region, young *S. maxillosus* in oxbow lakes were preying on small fish (*Trachydoras paraguayensis*, *Serrasalmus marginatus*, and *Crenicichla lepidota*) and *Macrobrachium* spp. shrimp.<sup>335</sup> While migratory patterns in the Pantanal are not well known, reproductive adults have been captured in the headwaters of the Taquari and Miranda rivers. Fish tagged in the La Plata River in March moved throughout the estuary, but one tagged in December of the study year migrated 1,440 km up the Paraná River to

<sup>332</sup> Cabera & Candia, 1964

<sup>333</sup> Quirós, 1993; Sverlij & Espinach-Ros, 1986

<sup>334</sup> Sverlij & Espinach-Ros, 1986

<sup>335</sup> Resende et al., 1996b

Posadas.<sup>336</sup> Cordiviola (1966) reports that female dourado in the Middle Paraná tend to be larger and older than the males. Migration in the Paraná River may extend up to 1,400 km, From the Rio Plata to the High Paraná,<sup>337</sup> but is probably more restricted in general.<sup>338</sup>

### *Schizodon borellii*

This abundant characid, related to the *Leporinus* spp., is known in Portuguese as *ximboré* and in Spanish as *piava*. It is an herbivorous fish, feeding on vegetation, roots, and other plant parts in the southern<sup>339</sup> and northern Pantanal.<sup>340</sup> While common and a prominent component of migratory schools in rivers of the area, the fish is not highly prized for food. However, it is considered by some as a possible alternative to the grass carp for control of aquatic vegetation.

## Silurids (catfish)

### *Hemisorubim platyrhynchos*

*H. platyrhynchos*, known in Portuguese as *jurupoca* and in Spanish as *tres puntos*, occurs throughout the Paraná-Paraguay River Basin, with the exception of the Rio de la Plata. It grows to 50 cm in length and feeds mainly on fishes. As with *S. lima*, very little is known about its biology. Fish swallowed whole were the main food of *H. platyrhynchos* in the oxbow lakes of Lower Miranda River.<sup>341</sup> In the Taquari River headwaters, males and females with ripe gonads have been found from late October to the beginning of December.<sup>342</sup>

### *Paulicea luetkeni*

*P. luetkeni*, known in Portuguese as *jaiú* and in Spanish as *manguruyú*, is the largest of the catfishes in the Paraná-Paraguay Basin. It has practically disappeared from the Lower Paraná River, as well as from the La Plata River and Uruguay rivers.<sup>343</sup> It has been absent from the La Plata River

<sup>336</sup> Sverlij & Espinach-Ros, 1986

<sup>337</sup> Sverlij & Espinach-Ros, 1986

<sup>338</sup> Espinach-Ros & Delfino, 1993

<sup>339</sup> Resende et al., 1998

<sup>340</sup> Mesquita, 1992

<sup>341</sup> Resende et al., 1996b

<sup>342</sup> Resende, unpublished

<sup>343</sup> Quirós, 1993

Basin since the 1980s. No biological studies are available about this species in the Paraná-Paraguay River Basin, but commercial fishermen indicate they can be captured in the deepest parts of the river. The species is known to be piscivorous. In a study by Agostinho et al. (unpublished) the species was found to be overexploited in the Brazilian Pantanal, and its fishing is prohibited in the Lower Paraná.

### ***Pimelodus* spp.**

*Pimelodus* spp., small catfish known in Portuguese as *mandi* and in Spanish as *bagre*, are important to the Paraná River fishery.

### ***Pinirampus pirinampu***

*P. pirinampu*, known in both Portuguese and Spanish as *patí*, is important to the Paraná River fishery (see Chapter 2 for description).

### ***Pseudoplatystoma* spp.**

*P. corruscans*, the catfish known in Portuguese as *surubim* and in Spanish as *surubí*, is found throughout the Paraná-Paraguay Basin. *P. corruscans* is becoming scarce in La Plata River, where captured individuals never exceed 60 cm in total length.<sup>344</sup> It is one of the migratory species most captured in the Lower Paraná Basin. The adults are usually found in the main river beds while their young remain in the corixos and small rivers. Generally these fish migrate upriver following shoals of *P. lineatus* (*curimbatá*) from October to December, which form their main food in this season. On the other hand, Cordiviola (1966) reports that this species migrates upriver in the Middle Paraná starting in March, with males migrating before females, and the downstream movements occur in spring (December).

*P. fasciatum*, known in Portuguese as *cachara* and in Spanish as *surubí atigrado*, is a catfish that is very similar to the *surubim*, but is not found in the Upper Paraná River Basin, and is becoming scarce in La Plata River. In the Pantanal it frequents the same habitats as *P. corruscans*, but, according to experienced fishermen, prefers to stay near submerged tree trunks and branches. As with *P. corruscans*, captured individuals never exceed 60 cm in length in the Lower Parana Basin, though the species is known to grow to over one meter in length in the Upper Paraguay Basin.

<sup>344</sup> Quirós, 1993

### ***Pterodoras granulosus***

*P. granulosus*, a medium-sized thorny catfish known in both Portuguese and Spanish as armado, contributes to the fisheries in the Paraná River (see Chapter 2 for description).

### ***Sorubim lima***

*S. lima* is a small catfish found in the Paraná and Paraguay rivers, some zones of the Bermejo, in the zone of confluence with the Paraguay River, and in small interior tributaries of the large rivers. It can grow to 50 cm and 2 kg. The species is carnivorous, preferring crustaceans and small fish: fish and shrimp were found in stomach contents of *S. lima* captured in the oxbow lakes of the Lower Miranda River.<sup>345</sup> It is also one of the migratory species most captured in the Lower Paraná Basin. In the Taquari River headwaters, males and females with ripe gonads arrive by late October.<sup>346</sup>

## **IMPACTS ON MIGRATORY SPECIES**

### **Fisheries**

#### **Fishing in the Pantanal**

Fishing is a traditional activity in the Pantanal. The first people to fish were the native Indians. When the bandeirantes arrived, they also used fish as a protein source. Total consumption at this time was very low, and there was no export.

The fish harvest today varies regionally in the Paraguay-Paraná River Basin. Fishing effort is generally greater near the big cities such as Cáceres, Corumbá and Porto Murtinho in the Paraguay River in Brazil. Concepción, Asunción, Villeta, Alberdi and Pilar are the largest fishing ports in Paraguay; Corrientes, Paraná, Rosario and Buenos Aires are the largest freshwater fishing ports in Argentina; and Villa Montes is the main fishing port in Bolivia. Fishing also takes place on the Pilcomayo River in Bolivia.<sup>347</sup>

The first published report on fish and fisheries in the Pantanal was by

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<sup>345</sup> Resende et al., 1996b

<sup>346</sup> Resende, unpublished

<sup>347</sup> Bayley, 1973

Aguirre (1945), who gave an account of the methods used by local populations, such as hooks on lines hung from river shorelines or from small boats, and the bows and arrows used by the local Indians. Only in Aricá, a small settlement, did fishermen use a kind of trawl net of 50 to 100 m, to catch piraputanga (*B. microlepis*), pacu-pevas (*Mylossoma paraguayensis*, *M. orbignyanum* and some *Metynniss* spp.), curimatá (*P. lineatus*) and other species. In some stretches of the Cuiabá River local fishermen put manihot or corn into the river to attract fish.

In the 1970s, when the federal government built roads between the west-central and the southeastern regions of the country (including São Paulo State), fishing began to increase. Table 1 gives an idea of the evolution of fish consumption in Cuiabá fish market and exports to other parts of Brazil. In 1980, half of the production was consumed locally and half was exported; but by 1983, about 70% of the catch was exported to other states (Table 1), mainly to São Paulo and Goiás State. These are the only statistics available for the part of the North Pantanal that lies within Mato Grosso State.

TABLE 1. 1980–1983 fish landings in and exports from Mato Grosso State<sup>348</sup>

YEAR	CUIABÁ FISH MARKET		EXPORTED		TOTAL
	CATCH (KG)	% OF TOTAL CATCH	CATCH (KG)	% OF TOTAL CATCH	
1980	1,520,400	47.9	1,652,408	52.1	3,172,808
1981	630,846	21.9	2,254,061	78.1	2,884,907
1982	817,496	29.5	1,956,041	70.5	2,773,537
1983	1,444,470	26.6	3,992,082	73.4	5,436,552

The catches summarised in Table 1 were captured mainly in the Cuiabá River, along a stretch of 139 km between Barra do Aricá and Guia, fished throughout most of the year. In the flood season the captures came from the Lower Cuiabá River, where the fish feed in the flooded areas. Local traditions assign fishing rights to particular fishing points and times that are traded or passed from generation to generation. The Cuiabá area is also distinguished by the use of traditional preservation methods. Because they have no ice, the fishermen use large *jacás* - baskets made of bamboo and suspended in the river to keep fish fresh up to the time of sale.

<sup>348</sup> Lima & Chabalin, 1984

When Mato Grosso do Sul State was created in 1979, the INAMB (Instituto de Controle e Preservação Ambiental) was formed and made responsible for the regulation and control of environmental issues, including the monitoring of fisheries. Fish statistics from 1979 to 1983<sup>349</sup> and from 1979 to 1984,<sup>350</sup> based on records of transport of commercially captured fish, are shown in Tables 2 and 3.

Most of the fish during this period were caught commercially for local consumption or for export mainly to São Paulo State. The two large *Pseudoplatystoma* species were the most captured, followed by *P. lineatus*. For 1982 to 1984, local consumption increased from 48 to 61%. However, concerns of overexploitation resulted in the prohibition of gillnets for commercial

TABLE 2. Species contribution to 1979–1983 fish landings from the Pantanal<sup>351</sup>

SPECIES	FISH LANDINGS (KG)				
	1979	1980	1981	1982	1983
<i>P. corruscans/fasciatum</i>	413,456	725,409	843,777	1,349,441	1,290,391
<i>P. luetkeni</i>	26,364	35,213	13,654	44,640	37,441
<i>S. maxillosus</i>	106,156	166,176	194,419	97,301	123,073
<i>P. mesopotamicus</i>	101,671	217,875	208,029	113,197	184,414
<i>P. lineatus</i>	305,982	334,550	429,838	438,800	481,748
Other fishes	52,810	68,137	21,684	12,650	19,120
Total	1,006,439	1,547,360	1,711,399	2,056,029	2,136,187

TABLE 3. Utilization of 1979–1984 fish landings from the Pantanal<sup>352</sup>

YEAR	LOCAL CONSUMPTION		EXPORTED		TOTAL CATCH (TONS)
	TONS	% OF TOTAL CATCH	TONS	% OF TOTAL CATCH	
1979					1,006
1980					1,545
1981					1,713
1982	1,152	48.1	1,245	51.9	2,397
1983	1,225	59.2	844	40.8	2,069
1984	1,176	60.6	763	39.4	1,939

<sup>349</sup> data of Vieira, 1986, published in Silva, 1986

<sup>350</sup> Resende, unpublished

<sup>351</sup> Fisheries data collected by Vieira, 1986; published in Silva, 1986

<sup>352</sup> Resende, 1986, unpublished

fishing in 1986 and the restriction of cast nets to the *P. lineatus* fishery.

In 1986 INAMB was shut down and fisheries statistics were no longer collected. Fish data collection did not start again in Mato Grosso do Sul until 1994, and then only after a great effort. From 1994–1998 *P. mesopotamicus* became the most captured fish, overtaking *Pseudoplatystoma* spp. (Table 4). In the 1990s, the fishing systems prevailing in the region also changed. Sport fishing expanded to become the second most important economic activity in the Pantanal, with an annual value of more than R\$ 60 million. In Corumbá City, there are now almost 70 fishing hotel boats for sport fishermen. More and more, cities like Corumbá, Miranda, Aquidauana and Porto Murtinho are largely dependent on sport fishing, and the same is happening in Mato Grosso State to the north. From 1995

**TABLE 4.** Species contribution to sport fishing in the Pantanal, 1995–1998<sup>353</sup>

SPECIES	1995		1996		1997		1998	
	CATCH (KG)	% OF TOTAL CATCH	CATCH (KG)	% OF TOTAL CATCH	CATCH (KG)	% OF TOTAL CATCH	CATCH (KG)	% OF TOTAL CATCH
<i>Piaractus mesopotamicus</i>	336,605	35.1	288,628	27.9	287,800	23.3	292,594	23.7
<i>Pseudoplatystoma corruscans</i>	161,547	16.8	140,010	13.5	172,859	14.0	159,957	12.9
<i>Pseudoplatystoma fasciatum</i>	73,999	7.7	63,971	6.2	90,073	7.3	64,291	5.2
<i>Salminus maxillosus</i>	45,495	4.7	74,310	7.2	127,481	10.3	148,877	12.0
<i>Pinirampus pirinampu</i>	35,514	3.7	72,918	7.0	100,851	8.2	92,762	7.5
<i>Leporinus macrocephalus</i>	128,418	13.4	96,142	9.3	168,129	13.6	157,793	12.8
<i>Pygocentrus nattereri</i>	40,176	44.2	49,567	4.8	54,965	4.4	58,185	4.7
<i>Paulicea luetkeni</i>	30,230	3.1	15,920	1.5	23,185	1.9	21,801	1.8
<b>Total</b>	<b>959,897</b>		<b>1,034,184</b>		<b>1,236,167</b>		<b>1,236,635</b>	

<sup>353</sup> Sistema de Controle de Pesca de Mato Grosso do Sul, Embrapa Pantanal/Sema-MS/Polícia Florestal-MS

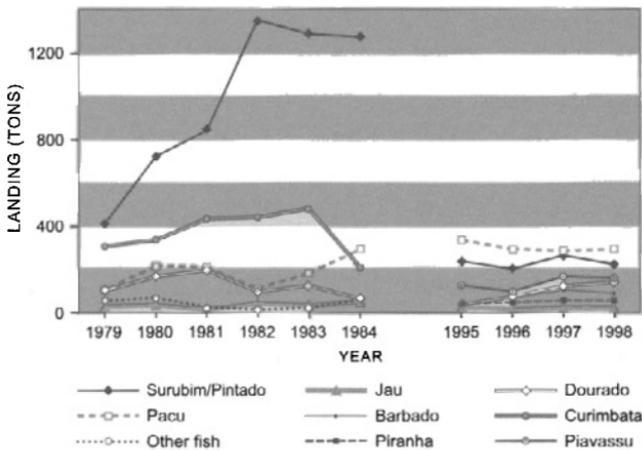
to 1998, commercial fishing decreased to 13.5% of the total fish catch in Mato Grosso do Sul (Table 5). In 1994, the fishing and commercialization of *P. lineatus* was also prohibited in Mato Grosso do Sul.

Figure 4 summarizes fisheries data available for the Pantanal, covering the period of 1979–1998. Commercial fishing predominated in this period

TABLE 5. Total fish landings from the Pantanal, 1995–1998<sup>354</sup>

YEAR		CATCH (KG)	% OF TOTAL CATCH	# FISHERMEN	CATCH/ FISHERMAN (KG)
1995	Commercial	309,534	24.4	1,419	218.1
	Sport	959,897	75.6	43,921	21.8
1996	Commercial	190,892	15.6	1,748	157.4
	Sport	1,034,184	84.4	51,561	20.1
1997	Commercial	217,216	14.9	1,875	157.6
	Sport	1236,167	85.1	57,172	21.6
1998	Commercial	193,018	13.5	1,358	222.5
	Sport	1,236,635	86.5	56,713	21.8

FIGURE 4. Fish landings in South Pantanal, by fish species<sup>355</sup> and year<sup>356</sup>



<sup>354</sup> Sistema de Controle de Pesca de Mato Grosso do Sul, Embrapa Pantanal/Sema-MS/Polícia Florestal-MS

<sup>355</sup> Surubim/Pintado: combined catch of *P. fasciatum* & *P. corruscans*; jaú: *P. luetkeni*; Dourado: *S. maxillosus*; pacu: *P. mesopotamicus*; barbado: *P. pirinampu*; curimbata: *P. lineatus*; piranha: *Pygocentrus nattereri*; paivaçu: *L. macrocephalus*

<sup>356</sup> Fisheries data of Vieira (1986), published in: Silva, 1986; Sistema de Controle de Pesca de Mato Grosso do Sul, Embrapa Pantanal/Sema-MS/Polícia Florestal-MS

until 1984. In these years, gear such as cast nets and gillnets were used for commercial fishing; drift gillnets were very efficient at capturing large catfishes such as *pintado* and cachara (*Pseudoplatystoma* spp.), while cast nets were efficient at catching *P. lineatus*. Unfortunately we have no data from 1984 to 1995, the years in which the transformation from commercial fishing to sport fishing occurred.

Presently in both Mato Grosso and Mato Grosso do Sul, only hook and line and rod and reel can be used to catch fish for both commercial and sport fishing. Following the 1986 prohibition of drift gillnets, cast nets were banned in 1994. Small-mesh cast nets can be used only by commercial fishermen and then only to catch bait.

Illegal fishing is known to take place in the Pantanal, mainly in the Taquari River Basin in the South Pantanal. Based on spot surveys, E. Resende (unpublished) estimates that the same amount taken by the legal fishery (~170 tons/year) is taken from this river illegally. No further estimation of the degree of illegal fishing is available.

### Non-Brazilian fisheries

In Argentina, the total fish catch for the Paraná River from 1945–1984 was estimated as 3,979 tons/year, of which *P. lineatus* comprised 40%, and for the Río de la Plata 11,119 tons/year, of which *P. lineatus* comprised 73%.<sup>357</sup> Data from the Instituto Nacional de Estadística y Censos, Anuario 1993 (Table 6) show fish landings ranging from a minimum of 8,024 tons in 1989 to 11,777 tons in 1990. In 1990, 39% of the fish came from the Paraná River (including the Paraguay River), 30% from the Río de la Plata and 21% from the Uruguay River. The data from 1976 (Table 7) differed slightly from 1990. In 1976, 50% came from the Paraná River, 26% from the Río de la Plata and 23% from the Uruguay.

TABLE 6. Fluvial and lacustrine fish landings in Argentina<sup>358</sup>

YEAR	LANDINGS (TONS)
1980	8,407
1981	4,270
1982	15,395
1983	14,568
1984	9,286
1985	9,274
1986	8,112
1987	8,024
1988	9,831
1989	4,303
1990	11,777

<sup>357</sup> Quirós & Cuch, 1989

<sup>358</sup> Instituto Nacional de Estadística y Censos; cited in CIH, 1997 ( vol 4)

**TABLE 7.** Fresh-water fish production in Argentina, from rivers and provinces, 1976<sup>359</sup>

RIVER	ANNUAL CATCH (KG)	% OF TOTAL CATCH
Paraná	4,670,600	50.6
La Plata	2,427,887	26.3
Uruguay	2,114,465	22.9
Paraguay	8,005	0.1
Total	9,220,957	

PROVINCE	ANNUAL CATCH (KG)	% OF TOTAL CATCH
Federal Capital	293,000	3.2
Buenos Aires	2,430,866	26.4
Corrientes	378,973	4.1
Chaco	107,209	1.2
Entre Rios	3,688,786	40.0
Formosa	8,005	0.1
Misiones	20,618	0.2
Santa Fé	2,293,500	24.9
Total	9,220,957	

Espinach-Ros and Delfino described the fisheries of the Paraná and Paraguay rivers outside of the Pantanal and the Upper Paraná (see Chapter 2), as they existed in 1993, for the different river sections<sup>360</sup>:

In the **High Paraná River**, upstream of Posadas, Argentinean commercial fishing is not very intense (40–50 fishermen over 360 km), carried out primarily with a variety of types of longlines. Smaller catfish species (*Pimelodus* spp.) and boga (*L. obtusidens*) are captured along the river margin, while dourado (*S. maxillosus*), pacu (*P. mesopotamicus*), patí (*Leucopimelodus pati*), surubí (*P. fasciatus*), and manguruyú (*P. luetkeni*) are captured in the main channel. Sábalo (*P. lineatus*) and baitfish are caught with cast nets and gillnets in shallow water. Catches in the 1980's were about 2,000 kg/yr/fisherman, with an increase as the Itaipu Dam was completed. The catch has since declined, coinciding with the completion of the Yacyretá Dam. Paraguayan commercial fishing in this area is carried

<sup>359</sup> Instituto Nacional de Estadística y Censos and the Anuario, 1993; cited in CIH, 1997 (vol. 4). 1976 is the only year for which this breakdown of total landings is available.

<sup>360</sup> Espinach-Ros & Delfino, 1993

out with rod and reel and boats powered with outboard motors, targeting primarily dorado and surubí, but also catching some pacu. The activity increased with the construction of the Yacyretá Dam, with 160 fishermen registered by 1991. Productivity for Paraguayan fishermen in this area averaged 42–160 kg/day/fisherman in the late 1980s.

From the Yacyretá Dam to the confluence with the Paraguay River the High Paraná is mostly taken up by sport fishing reserves, and commercial fishing is not significant. Sport fishing is particularly intense below the Yacyretá Dam, outside of the 3 km safety perimeter.

Commercial fishing in the **Middle Paraná River**, between the Paraguay River and Diamantes, is also limited by sport fishing reserves to a 140 km stretch downstream of the confluence of the two rivers and small stretches near the cities of Helvecia, Paraná, and Diamantes. The activity is most active in the first of these stretches, near Corrientes and Barranqueras, with 200 to 250 registered fishermen in 1992. The commercial fishing at the time of the report targeted primarily catfish, working out of canoes with small inboard motors with the *mallón* net<sup>361</sup> in stretches of the mainstem river clear of obstacles (*canchadas*) and a variety of longlines in shallower water. Catch in 1992 averaged 3,000 kg/yr/fisherman, with 90% represented by surubim and patí and 10% by 10 to 16 other species. Sport fishing in this stretch is quite intense, with 6,500 licences issued in the Corrientes province in 1992, targeting dourado, surubí, and pacu, and, by 1997, up to 5,000 fishermen on the river every weekend.<sup>362</sup> At present, dorado fishing in the vicinity of the city of Corrientes is one of the principal internationally recognized sport fishing activities of South America, and is the site of numerous fishing derbies with international participation.

Commercial fishing in the **Lower Paraná River** has two components: a hook and line fishery in the river channel for catfishes (surubí, *armado comun* and patí) and the boga (*L. obtusidens*), and a net fishery in the floodplains for the sábalo (*P. lineatus*). Both are most active during the upstream migrations of the fall and winter. The river channel fishery is concentrated near cities, primarily Rosario (with 200 registered fishing families in 1991). A variety of long-line techniques are employed, depending on the species and environment. The floodplain fishery is

<sup>361</sup> A coarse gillnet that is either set or dragged along the bottom of the river

<sup>362</sup> CIH, 1997

concentrated in the province of Entre Lagos near the city of Victoria, with an estimated 174 active fishermen in 1990 (423 licensed fishermen) landing 1,580 kg/month/fisherman (95% sábalo). Similar numbers of commercial licences for net fisheries were issued in 2000 and 2001 (491 and 450, respectively), with approximately an additional 200 commercial licences for hook fisheries in each year.<sup>363</sup> The trammel net<sup>364</sup> was reported as the most common gear for this area in the early 1990s, either towed behind canoes or set overnight<sup>365</sup>, but simple gillnets and hook and line are also used, and the mallón gillnet, rather than the trammel net, is currently listed officially as the most common commercial gear for artisanal fisheries in this province.<sup>366</sup> Commercial fishing is mostly seasonal or part-time (25–90% dedication),<sup>367</sup> supplemented primarily by tending cattle and hunting. Nevertheless, the sábalo landings for the province of Entre Lagos, primarily through the port of Victoria, increased in the early 1990s from about 1000 tons to 5–8,000 tons in the second part of the decade (depending on the year) with an increasing proportion being exported, primarily to Brazil and Bolivia.<sup>368</sup> Sport fishing is also increasingly important in the Lower Paraná River, with the number of licences issued increasing from about 5,500 in 1997 to about 7,500 in 2000.<sup>369</sup> About 25% of these are for out-of-province licensees.

The freshwater fishery of the Plata River has been dominated in the past by beach seine and purse seine fisheries for sábalo (*P. lineatus*) for production of fishmeal and fish oil. At its peak in the 1940s, this fishery landed about 11,100 tons annually and supplied 10 processing plants. However, despite a brief resurgence in the 1980s, this fishery has ended, at least in part due to contamination from agricultural and industrial pollution. A comparable fishery continues in the Lower Uruguay River (see Chapter 4). A cast net fishery for sábalo and boga by the perjerry fishing fleet in the Plata River during their off-season also peaked in the

<sup>363</sup> [www.entrierios.gov.ar/produccion/dpesc07.htm](http://www.entrierios.gov.ar/produccion/dpesc07.htm)

<sup>364</sup> Three-layered gillnets with small-meshed inner panels sandwiched between two coarser-meshed panels. These nets are particularly efficient, as they entangle fish between the panels, but are controversial in that they also catch many small fish. They are called *tres telas* in Portuguese and *tresmallas* in Spanish.

<sup>365</sup> Espinach-Ros & Delfino, 1993

<sup>366</sup> [www.entrierios.gov.ar/produccion/dpesc07.htm](http://www.entrierios.gov.ar/produccion/dpesc07.htm)

<sup>367</sup> Espinach-Ros & Delfino, 1993

<sup>368</sup> [www.entrierios.gov.ar/produccion/dpesc07.htm](http://www.entrierios.gov.ar/produccion/dpesc07.htm)

<sup>369</sup> [www.entrierios.gov.ar/produccion/dpesc07.htm](http://www.entrierios.gov.ar/produccion/dpesc07.htm)

1950s, and had been reduced to less than a third (10–15 boats) by the early 1990s.<sup>370</sup> Hook and line fisheries for other species (primarily dourado, pacu, and catfish species) have shown a similar trend, purportedly due to reduced number and size of high-value species.<sup>371</sup> By 1997, the Argentinean fisheries in the La Plata River were reduced to three traditional fishing families with less than 50 people dependent on commercial fisheries,<sup>372</sup> though sport fishing has continued and is expanding. A small commercial fishery continues on the Uruguayan shore for the higher-priced freshwater species<sup>373</sup>, in part as a supplement to the estuarine fishery for croaker (*Micropogonias furnieri*).<sup>374</sup>

Paraguayan fisheries were studied by Bayley in the early 1980s<sup>375</sup> and by Espinach-Ros and co-workers in the early 1990s.<sup>376</sup> Bayley estimated landings of 16,000 tons per year, based on a survey of fish consumption in communities on the Paraguay and Parana rivers. Earlier surveys indicated substantially lower consumption in 1965 and 1978,<sup>377</sup> but Bayley found that while fish consumption close to the rivers was increasing, it continued low throughout much of the country in 1984, probably due to both distribution problems and continued dietary preference for red meat. Espinach-Ros and co-workers report that, in the early 1990s, the fishery of the Paraguay River was expanding.<sup>378</sup> According to these authors, the principal gear used is the mallón,<sup>379</sup> dragged along the bottom in clear stretches of the river or left as gillnets in tributaries when the water is too high for fishing the mainstem. Mesh size of the nets varies with area being fished, with smaller mesh sizes used in the more intensely fished vicinity of Asunción. A variety of hook and line devices are also used, and cast nets are used to catch bait-fish. Larger-bodied fish are targeted, with, in the early 1990s, *Pseudoplatystoma* spp. representing about 50% of the landings.<sup>380</sup> Similarly, the CIH survey in 1997 reported approximately

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<sup>370</sup> Espinach-Ros & Delfino, 1993

<sup>371</sup> CIH, 1997

<sup>372</sup> CIH, 1997

<sup>373</sup> Espinach-Ros & Delfino, 1993

<sup>374</sup> Wells & Daborn, 1997

<sup>375</sup> Bayley, 1984

<sup>376</sup> Espinach-Ros et al., 1991

<sup>377</sup> Min. de Salud Publica, 1978. Cited in Bayley, 1984

<sup>378</sup> Espinach-Ros & Delfino, 1993

<sup>379</sup> Coarse gillnet set or dragged along the bottom

<sup>380</sup> Espinach-Ros & Delfino, 1993

1,000 commercial fishermen in the vicinity of Asunción and 430 in the vicinity of Concepción, fishing surubí (*Pseudoplatystoma* spp.), dourado (*S. maxillosum*), manguruyú (*P. luetkeni*), pacu (*P. mesopotamicus*) and boga (*Leporinus* spp.). Brazilian fishermen from Porto Murtinho also contribute to the fishery in this stretch of the Paraguay River, but little data is available on their activity.

Sport fishing is popular in the Asunción region, through eight *Clube de Pesca* associations that lease boats and equipment to their members. More than 200 are out on a typical weekend, with 2 to 4 persons per boat. In Concepción, sport fishermen tend to use private boats and gear, and prefer large catfish, providing a market for live bait fish.<sup>381</sup>

The **Bolivian fishery** for migrating sábalo (*P. lineatus*) of the Pilcomayo River has probably been the most important single fishery of the country, at one time representing over 40% of the national landings.<sup>382</sup> The fishery started as a traditional trap fishery in the Villa Montes region, based on fish traps made with rocks.<sup>383</sup> The fishery was updated in the 1960s to include beach seines and expanded to the downstream floodplains.<sup>384</sup> Landings increased substantially with this technology, but peaked at about 2,000 tons in 1986<sup>385</sup> and gradually declined to an all-time low in 1998.<sup>386</sup> This population of *Prochilodus* was listed as vulnerable in 1993 by the Bolivian government,<sup>387</sup> but is apparently also substantially contaminated by heavy metals.<sup>388</sup> Other species fished commercially in the area include the boga (*L. obtusidens*), *Pimelodus* sp. catfish, the dourado (*S. maxillosum*), the surubí (*P. corruscans*), and the pacu (*P. mesopotamicus*).<sup>389</sup> Fisheries for the sábalo and up to 70 other species in the Chaco reaches of the Lower Pilcomayo and Berjemon rivers are also important to indigenous Wichi tribes of northern Argentina<sup>390</sup>, who make seasonal use of migrating schools, at times fishing with traditional cactus-fibre nets.<sup>391</sup>

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<sup>381</sup> CIH, 1997

<sup>382</sup> Payne & Harvey, 1989

<sup>383</sup> Bayley, 1973;

<sup>384</sup> Payne, 1986. Cited in Espinach-Ros & Delfino, 1993

<sup>385</sup> Payne & Harvey, 1989

<sup>386</sup> Mochek & Pavlov, 1996

<sup>387</sup> Camacho, 2002

<sup>388</sup> Quevillon et al., 1995

<sup>389</sup> Espinach-Ros & Delfino, 1993.

<sup>390</sup> Barbaran, 2000

<sup>391</sup> Lindsay, 2002

## Trends in abundances

One of the few studies on trends in abundance in the Parana-Paraguay Basin is that of Agostinho et al. (in preparation) that has been carried out for the Pantanal in Brazil since 1994. Using the statistical data from the Fishing Control System of Mato Grosso do Sul (SCPESCA/MS) and the Schaefer model for the maximum yield, they found that the pacu (*P. mesopotamicus*) and the jaú (*P. luetkeni*) are overexploited. To manage this overexploitation, the minimum capture size was increased in Mato Grosso do Sul from 40 to 45 cm for *P. mesopotamicus* and from 90 to 95 for *P. luetkeni*. It is highly probable that the same trend towards overfishing is true in Mato Grosso, but no further data were found for the rest of the river basin.

For other species there is no concrete evidence of overexploitation, though both commercial and sport fishermen are complaining that fish are disappearing. For example, the rodada and lufada phenomena, which were common in the past, particularly in the northern Pantanal, are now rarely seen.

## Other Impacts

### Impacts in the Upper Paraguay

It is generally believed that in floodplains such as the Pantanal, fish production is directly related to flooding. Years of high flooding lead to high fish production and years of low flooding lead to low fish production. However, the magnitude of floods is unpredictable. From 1960 to 1974, the Pantanal had a long period of reduced flooding, but at that time the fish stocks were not as exploited as they are today. In 1998 and 1999, the flooding was also very low. The consequences of long-term low flooding could be an economic disaster for the local human population and a major disruption of fish feeding and reproductive patterns.

The Upper Paraguay River Basin Conservation Plan (PCBAP), co-ordinated by IBAMA, outlines five main problems in the region: sedimentation, dams and dyking, water contamination, illegal fishing, and large-scale works (river dredging and the liquid gas pipeline that crosses the Pantanal).<sup>392</sup> Most development impacts on migratory fish in

<sup>392</sup> Lima Barros Dolabella, 2000

the Upper Paraguay Basin are caused by agricultural development, especially in the highlands. Roads that open up areas for settlement also lead to the cutting of gallery forests, resulting in erosion. The lack of soil conservation techniques causes soil erosion and consequent silting of the rivers in the Pantanal, raising the river bed, changing the river courses, and leaving large bodies of perennial standing water where formerly the land was dry enough during the dry season to allow cattle to graze.

Gold mining in Mato Grosso State is concentrated in the city of Poconé and diamond mining in the cities of Diamantino and Alto Paraguay. Both areas lie in the headwaters of the Paraguay River. Mercury contamination has been identified as problematic in the Poconé area, though natural levels may be high in some lagoons.<sup>393</sup> The government of Mato Grosso is working on regulatory means to minimise the environmental impact of mining wastes. Water quality is also threatened in particular by population growth, especially around large cities like Cuiabá and Várzea Grande, which dump untreated waste directly into the Cuiabá River. In Concepción the urban houses use septic pits for wastewater, and in Asunción wastewater goes into a public septic pit.

### **Impacts in the Pantanal**

The Pantanal is almost unaltered by development, without structures such as dams or reservoirs. The only hydroelectric dam is on the Manso River, a tributary of the Cuiabá River in the highlands. This dam was recently finished and closed during the 1999/2000 fish reproduction period (piracema). The immediate effect of this closure on the fish population appears to have been substantial, but long-term effects on the area's ecosystem are not yet known.

There are, however, potential problems in addition to hydropower development. One is the liquid gas pipeline running across the Pantanal from Bolivia to Brazil, whose first phase concluded in February 1999. A major leak from this pipeline could have severe impacts on the Pantanal<sup>394</sup>, but safety features of the pipeline make such a leak very unlikely. The Hidrovia project that proposed opening up over 3,442 km of the Paraguay and Paraná rivers for navigation of barge convoys has now been abandoned due to public protest and predicted environmental

<sup>393</sup> Tümpling et al., 1995

<sup>394</sup> Lima Barros Dolabella, 2000

impacts. It was felt that draining of the Pantanal wetlands, which would arise as a consequence of the faster currents achieved by deepening the channels and blasting obstructions, would lead to erosion, water contamination, the disruption of natural communities and natural cycles, and that the long-term costs of these alterations would outweigh the economic gains from lower shipping costs. It was also predicted that flooding would worsen significantly downstream, as the two-to-three-month delay between the Paraguay River's flood peak and the Paraná River's flood peak (due to the buffering capacity of the wetlands) would be reduced. Water quality for the millions of people downstream would also likely worsen due to the destruction of the natural sewage-treatment capacity of the wetlands. Fisheries, of course, were also expected to be damaged.

Gottgens (2000) considers that despite the cancellation of the Hidrovia project, other smaller, isolated hydrological projects to dredge the Paraguay River and its tributaries may have cumulative effects that are worse than those foreseen in the original mega project. Despite opposition to the environmental destruction, various interests continue to push for a commercial waterway into the Pantanal. While it appears that no single all-embracing decision will be made for development, many small decisions may have the same environmental effect.<sup>395</sup> Destruction of the Pantanal will most likely occur if local inhabitants are given no sustainable options for development.

The PCBAP study concluded that the economic activities best suited to the Pantanal are cattle-raising on the natural pastures, and sustainable tourism, fishing and hunting.

### **Impacts in Argentina**

In Argentina most fishery problems are related to water pollution and degradation caused by development along the Paraná River. Quirós (1993) studied impacts on the fishery in the Rio de la Plata system and concluded that the evidence pointed to impacts from toxic substances used in agriculture and industry. Relatively high levels of heavy metals and agricultural pesticides were found in fish tissues and periodic massive fish kills were reported from the Lower Paraná Delta and the Rio de la Plata. Low oxygen levels and massive fish kills were also found in the

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<sup>395</sup> Gottgens, 2000

Lower Paraguay River. No water quality data are available for the Upper Paraguay Basin.

Quirós also writes that fruit and seed eating species of the genera *Colossoma* (now *Piaractus*) and *Brycon* and the large catfish *P. luetkeni* have disappeared from the Lower Paraná River, and from the La Plata and Uruguay rivers. According to Quirós, marine fish species of the *Basilichthys* and *Lycengraulis* genera, which usually move upriver in winter, have also practically disappeared from the commercial catches in the Middle Paraná. As well, although commercial fishing for *S. maxillosus* has been highly restricted, this species has been decreasing in catches since the late 1940s throughout the lower basin. The size of the large catfish of the *Pseudoplatystoma* genera has been decreasing for the last three decades in the Lower Paraná. Conflicts between sport and commercial fishermen have been increasing, and the trophy size of *Salminus* has been decreasing at the confluence of the Paraná and Paraguay rivers, though total fishing effort seems not to have increased.<sup>396</sup>

Studies of the effects of the Yacyretá Dam on fish have recently been published, demonstrating reduced energy stores and sexual development in detritivorous fish at the base of the dam, compared to stations further downriver.<sup>397</sup> Mortality from gas bubble disease has also been reported,<sup>398</sup> and significant pollution from slaughterhouses in Encarnacion may be problematic.<sup>399</sup> Original artisanal fisheries and fishing communities were disrupted by the hydroproject,<sup>400</sup> but long-term impacts on fish stocks are not yet clear, and data on present levels of fishing have not been published. However, some reports suggest that productivity of migratory fish above the dam is well below original levels. It has been suggested that initial seeding of the reservoir by migratory species was poor, as the Yacyretá Dam was finished during a year of poor larval recruitment and at a time of year when migratory stocks were below the dam in feeding areas.<sup>401</sup>

Effective fish passage could theoretically alleviate this problem. Preliminary information on the effectiveness of the fish elevators for fish passage that were installed on this dam indicates that 44% of the species

<sup>396</sup> Quirós, 1993

<sup>397</sup> Bechara et al., 1999; Terraes et al., 1999

<sup>398</sup> Domitrovic et al., 1994; Bechara et al., 1996

<sup>399</sup> Environmental Defense, 1999

<sup>400</sup> Inter-American Development Bank, 1997

<sup>401</sup> Oldani, 1994; Oldani et al., 1992

registered in the tailrace were transferred at least to some extent (a total of about 252 tons or 1,767 million fish in 1995). The passage was used primarily by the small catfish *Pimelodus maculatus* (72%) and *P. granulosus* (12%),<sup>402</sup> although the dourado (*S. maxillosus*) and the curimatá (*P. lineatus*) were also significant users.<sup>403</sup> However, Oldani et al. (pers. comm.) suggest that the two elevators, operating at their current average efficiency of 50,000 fish/month, only transport one-fortieth of an estimated annual total of 12 million migrating fish that would normally pass this point in spring and early summer.

Entrapment of larval fish by pumps for irrigation projects was considered a problem in Santa Fé as early as 1952–1954, leading to regulations for appropriate screening. These pumps were killing an estimated 400 tons of juvenile fish annually. The issue was raised again in 1996, and is still currently being studied.<sup>404</sup>

The introduced species *Cyprinus carpio* was the most important in biomass in the experimental catches in the La Plata River, and its catch has been increasing in the Middle Paraná. Introduced species are also predicted to have effects on the fish in the Lower Paraná,<sup>405</sup> though what these effects will be is not known. In particular, Bonetto (1998) feels that the fish *Plagioscion squamosissimus* (originally from Piauí) and *P. scrofa* will gradually invade the Lower Paraná Basin from the upper basin, facilitated by the submersion of the Sete Quedas by the Itaipu Reservoir, and the common carp is already a significant component of the Rio de la Plata fauna. In addition, the Asian freshwater mussel *Limnoperna fortunei* and freshwater clam *Corbicula* spp. were introduced to the Rio de la Plata (probably in the early 1990s and late 1980s, respectively), and are now rapidly invading the rivers of the Paraná-Paraguay Basin. These are having significant effects on hydroelectric and irrigation installations, but Bonetto (1998) suggests that they may also provide a substantial new source of food for fish and may thus have a beneficial effect on the ictiofauna in the near future. In fact, *Leporinus* species have recently been found to feed on *Corbicula* spp. extensively, to the point where mass mortalities result from intestinal blockages with *Corbicula* shells.<sup>406</sup>

<sup>402</sup> Convenio SECYT, 1996

<sup>403</sup> Oldani, 1998

<sup>404</sup> Bonetto, 1998

<sup>405</sup> Bonetto, 1998

<sup>406</sup> A. Agostinho & J. Senharini, personal communication

## Impacts in Paraguay

In Paraguay, water quality problems are restricted primarily to the area of Asunción, where human population, industrial and commercial activities are concentrated.

An international proposal to link the Atlantic with Pacific Ocean ports in Chile by a road through the Chaco could bring with it major environmental impacts, from road construction, the passage of hundreds of trucks daily, and from the arrival of new colonists.<sup>407</sup>

Although there is ample legislation in Paraguay protecting wetlands and the environment, many feel that widespread disregard has led, among other consequences, to illegal transfers of ecological reserves (Rio Negro National Park) to private individuals, and to destructive clearing and burning of land.<sup>408</sup>

## MANAGEMENT AND MITIGATION

### Legislation: Argentina, Paraguay and Bolivia

#### Legislation: Argentina

Fisheries are under provincial jurisdiction in Argentina, with no national legislation. Each province sets its own regulations, which regulate licensing, fishing areas and seasons, size limits, and species-specific restrictions. Sport fishing reserves are common to many of the provinces in the Paraná Basin,<sup>409</sup> as are restrictions on some species such as the pacu (*P. mesopotamicus*), jaú/manguruyú (*P. luetkeni*), and dorado (*S. maxillosum*). For example, the Entre Lagos province has an extensive set of fishery regulations for both commercial and sport fisheries, prohibiting all fisheries and transport of pacu and manguruyú, establishing sport fishing reserves and areas of no fishing, regulating fishing seasons for dorado and sábalo, and regulating gear, minimum fish size and catch limits.<sup>410</sup>

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<sup>407</sup> Carron, 2000

<sup>408</sup> Carron, 2000

<sup>409</sup> Espinach-Ros & Delfino, 1993

<sup>410</sup> [www.entferios.gov.ar/produccion/dpesc07.htm](http://www.entferios.gov.ar/produccion/dpesc07.htm), [www.portalbioceanico.com/er\\_turismo\\_global\\_inventario\\_superestructura\\_docl01.htm](http://www.portalbioceanico.com/er_turismo_global_inventario_superestructura_docl01.htm)

### **Legislation: Paraguay**

Law no. 799/96, established in 1996, regulates fisheries in Paraguay.<sup>411</sup> This law defines subsistence, commercial, sport, and scientific fisheries, as well as aquaculture, and regulates licensing, fishing gear, size limits, fishing reserves (e.g. nets are prohibited in river mouths and lagoon openings and long lines are prohibited in canchadas – stretches of rivers cleaned of obstacles by fishing co-operatives for net fishing), transport and handling of fish and fisheries products, and the introduction of non-native fish species. The law also mandates the annual determination of fishing seasons, and permits species restrictions.

### **Legislation: Bolivia**

The 1975 Bolivian law no. 12301 regulates Wildlife, National Parks, Hunting and Fishing.<sup>412</sup> Implementation of the law has been varied,<sup>413</sup> initially under the auspices of the Department of Fisheries Development created in 1975, and then under the Fisheries Development Centre (CDP) established in 1984. The law was supplemented by a variety of regulations, most substantially in 1990 with a Fisheries and Aquaculture Regulation.<sup>414</sup> The law defines subsistence, commercial, sport, and scientific fisheries, regulates the importation and introduction of non-native aquatic organisms, and permits the concession of aquatic bodies to private use, but mandates that each productive water body have its individually designed detailed fisheries regulation.

### **Legislation: Brazil**

In the Brazilian Constitution of 1988 a specific chapter on the environment deals with the common use of natural resources essential for a healthy quality of life, and outlines the duty of the common people and the government to protect and preserve the environment for future generations. The chapter deals with the protection of fauna and prohibits uses that place the ecology at risk or cause species extinction. In this light, migratory fishes are protected significantly in the national legislation.

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<sup>411</sup> [www.geocities.com/derechopy/reglamentopesca.txt](http://www.geocities.com/derechopy/reglamentopesca.txt)

<sup>412</sup> [www.elwa.org/resources/printable.asp?id=1233](http://www.elwa.org/resources/printable.asp?id=1233)

<sup>413</sup> Palin, 1999

<sup>414</sup> Palin, 1999

Any activity that can cause significant environmental degradation is subject to environmental impact assessment, which needs to be communicated to all that are interested or can be affected. The Brazilian Constitution states that both federal and state governments have the right to legislate concurrently on forests, hunting, fishing, fauna, nature conservation, environmental protection and pollution control, with the most restrictive legislation taking priority. Based on this article, states such as Mato Grosso do Sul and Mato Grosso have developed their own environmental legislation related to fishing. Each fisherman that goes to these states requires a state permit, the income from which is used in Mato Grosso do Sul for enforcement by *Polícia Militar Ambiental*, and for the maintenance of the SCPECSA, the fish statistics collection system.

Law no. 6938, of August 1981, *Política Nacional do Meio Ambiente* (National Environmental Policy), includes as objectives not only social and economical development but also the preservation of environmental quality and ecological equilibrium, the maintenance and recovery of environmental resources for rational use, and the permanent availability of natural resources to preserve ecological equilibrium as life support. The law also places responsibility for recovery of damaged areas on those who pollute and promote degradation, and levies taxes on users that exploit natural resources for commercial purposes. One of the most important aspects of this law is the requirement for permits for activities that have high pollution potential, high natural resource use and a high potential for environmental degradation. The building of reservoirs for hydroelectric generation thus requires environmental impact assessments and mitigation measures to prevent the disappearance of migratory fishes, including ensuring their reproductive migration.

The maintenance of natural conditions in rivers is one of the biggest challenges for maintenance of river fish populations, particularly as it relates to riparian vegetation. In this respect, Law no. 4771 of the Forestry Code (September 1965) defines riparian vegetation as areas of “permanent preservation”, which means that they cannot be removed or destroyed. The width of riparian vegetation that cannot be removed varies with river width: the larger the river, the greater the band of riparian vegetation that must be preserved. This is of particular importance for fish that feed on

leaves, seeds or fruits from riparian vegetation. Unfortunately this law is largely ignored, and farmers continue to cut and burn to the river banks.

Law no. 8171 on Agricultural Policy (Política Agrícola), enacted in 1991, includes such objectives as protecting the environment, guaranteeing rational use, and stimulating recovery of natural resources. Some aspects that are particularly significant are the promotion of technologies for natural resource conservation, particularly for fauna (including fish) and flora. According to this Law, companies that build reservoirs or dams are responsible for any environmental effects and for the recovery of the natural resources in the watersheds. One article states that the government must implement programs that promote fish-rearing activities in order to increase food production and preservation of species.

Law no. 7679 (November 1988) defines fishing prohibition periods, minimum capture sizes, catch quotas, permissible gear, and fishing permits for natural fish populations. Another important recent law is the Lei das Águas (Water Law of 1997), whose geographic scope for implementation is the watershed. Each watershed will have a Water Commission that will discuss the competing water uses, aiming for the best results for the whole community. If the planning unit is the watershed, it is possible that gains in water management can be achieved, particularly for fisheries resources.

One of the most recent laws, the Law of Environmental Crimes, or the Law of Nature of 1998, defines environmental crimes and the punishment for each. For fish and fisheries, to fish in prohibited places or in prohibited periods, the punishment will be prison for one to three years, or a fine, or both. The same will happen to someone who captures protected species, harvests sizes smaller than permitted or in amounts greater than permitted, who uses prohibited gear or methods or who markets or processes fishes caught with prohibited gears or methods. If the fishing is done during the night, on holidays or Mondays, punishment can be increased by one third. However, community service, a temporary injunction of rights, partial or total suspension of activities, fines or in-house arrest can be substituted for prison terms. It is not considered a crime if the fishing is done for subsistence.

Under the Convention on Biological Diversity Brazil has prepared a manual for assigning an economic value to environmental resources.

## Regulation of Fishing in the Pantanal

The Mato Grosso and Mato Grosso do Sul governments, concerned about migratory fish reduction and extinction, have banned the capture of migratory fish during the spawning period, which generally lasts from the first of November to the end of January. For Mato Grosso do Sul, this ban extends to the end of February in the river headwaters. Table 8 shows the minimum allowable capture size, for commercial and sport fishing, based on the size needed for reproduction. Size restrictions for *L. frederici*, *L. obtusidens*, *S. borellii*, *H. platyrhynchos* and *S. lima* have not yet been imposed.

The amount that each sport fisherman can capture on each trip to the Pantanal is 15 kg or one specimen in Mato Grosso do Sul State and 20 kg or one specimen in Mato Grosso State. In Mato Grosso State, each commercial fisherman can transport 100 kg/vehicle or 1000 kg if transporting for a fishermen's association, independent of fish species.

In parts of the Negro River (Mato Grosso do Sul) the only fishing allowed is "catch and release". The "catch and release" was extended to the Abobral, Perdido and Salobra rivers in 2000.

In Mato Grosso State, in addition to seasonal and geographical restrictions, it is a crime to fish with explosive or toxic substances, within 500 meters of sewer outfalls, or within 200 meters of rapids, waterfalls, or fish ladders.

## Conservation of Wetlands in Brazil

Since 1993 Brazil has substantially updated environmental laws and institutions to meet its commitments under the Ramsar Convention on Wetlands<sup>415</sup>, and now has a national environment policy aimed at the sustainable use of natural resources, including water resources. Five sites have been designated for the Ramsar List, covering 4,536,623 hectares, which is the fifth largest total area among Ramsar member states.<sup>416</sup>

The Water Law of 1997 recognizes water basins as the basic unit for planning and implementation. Planning of a national strategy for wetlands is underway, based on several initiatives of the Ministry for the

<sup>415</sup> The Convention on Wetlands, signed in Ramsar, Iran, in 1971

<sup>416</sup> [http://www.ramsar.org/about\\_five\\_parties.htm#braz](http://www.ramsar.org/about_five_parties.htm#braz)

**TABLE 8.** Minimum capture sizes in Mato Grosso do Sul

SPECIES	MINIMUM CAPTURE SIZE (CM)
<i>Prochilodus lineatus</i>	38
<i>Brycon microlepis</i>	30
<i>Leporinus macrocephalus</i>	38
<i>Salminus maxillosus</i>	55
<i>Piaractus mesopotamicus</i>	45
<i>Pseudoplatystoma corruscans</i>	80
<i>Pseudoplatystoma fasciatum</i>	80
<i>Paulicea luetkeni</i>	90

Environment. The first stage is the setting up of a database on the geography of Brazilian wetlands. A national wetland strategy will be established through a resolution of the National Environmental Council (CONAMA) and the Brazilian Agency for Environment Protection (IBAMA). Environmental agencies in the federal states will be responsible for implementation.

In 1986, based on Brazil's 1981 law for environmental impact assessment, which is applicable to all sectors, CONAMA made environmental impact assessments obligatory for activities that significantly affect wetlands. Programmes are being implemented to restore and rehabilitate wetlands, including the sustainable development of the Pantanal. Legislation also promotes participation of the private sector in the establishment and management of protected areas, many of which are private. Local communities and NGOs participate in the decision-making process through management committees, especially with regard to protected areas.

In Brazil, the Environmental Protection Agency maintains both broad scope programs, such as the one that created a national inventory of wetlands in 1988, and special programs, such as those designed for teaching the population the importance of protecting water and marine resources. One such program is the Movimento dos Cidadões por l'Água Organization (Citizenship Organization for Water), which was created by the Ministry for the Environment in 1996. In addition, a national program of environmental education (PRONEA) provides formal and informal education. Focusing on identifying training needs at the sectoral level, Brazil has developed a training program specifically for wetlands.

As part of their National Reports and based on COP6 recommendations, ten Contracting Parties to the Ramsar Convention announced steps to include under-represented wetland types in the Ramsar List of protected sites. A feasibility study was begun on the listing of new sites in the Brazilian states of Alagoas, Bahia, Goiás, Maranhão, Mato Grosso do Sul, Paraná, Pernambuco, Rio de Janeiro, Rio Grande do Sul.

## Relevant Conservation Programs in Argentina and Trans-boundary Programs

Argentina joined the Ramsar Convention in 1992. Three sites were designated for the Ramsar List of Wetlands of International Importance, and two more were added in 1995, another in January 1997 and 5 more by 2002, making a total of eleven sites covering 2,669,589 hectares.<sup>417</sup>

Argentina has a subregional training programme funded by the Wetlands for the Future Initiative, and is currently focusing on promoting changes in land use, for economic activities ranging from cattle grazing to tourism. Argentina is also preparing to list two new Ramsar sites as part of the commitment to include under-represented wetland types in the Ramsar List, and has been co-operating with Paraguay for the management of common watersheds and fishery resources. Other regional agreements include the Amazon Co-operation Treaty, the River Plate Basin Treaty and Mercosur.

According to the National Reports, Argentina is the only Contracting Party to all environmental conventions. Brazil, Colombia, and Uruguay are parties to some of these conventions: the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the World Heritage Convention and the Convention on Migratory Species.

Argentina is also co-operating with Paraguay to manage joint fish resources and watersheds, while Argentina, Brazil, and Uruguay are co-operating in the preparation of joint projects on migratory species as management indicators for wetlands in the Southern Cone.

## Mitigation of the Effects of Dams

The National University at Misiones, the National University of the Northeast, the National University at Asunción and CERIDE/CONICET

<sup>417</sup> [http://www.ramsar.org/profiles\\_argentina.htm](http://www.ramsar.org/profiles_argentina.htm)

carry out the Yacyreta power authority's program for mitigation. Fish populations, migration, and adaptation to the artificial reservoir and the System of Fish Transfer have also been studied. Fish culture stations are being built to produce and stock species whose populations have declined because of the dam. To aid migration, two elevators have been built, one at each end of the dam. As the fish cross the dam they can be identified and quantified, and samples measured, weighed, and marked in order to learn the migratory patterns and other aspects of the populations. Predictive water-quality models are also being developed.

Along the Aña Cúa branch, where three mini-dams are planned, it is hoped to minimize the impact that a decrease in the water level at specific times in the year would generate. Nevertheless, the Yacyreta Dam remains controversial.

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

**T**he biology of the migratory fishes in the basin discussed needs more study. Basic biological information is lacking for important species such as *L. obtusidens*, *L. macrocephalus*, *L. friderici*, *S. borellii*, *B. microlepis*, *B. orbignyanus*, *P. luetkeni*, *S. lima*, and *H. platyrhynchos*. The role of the great lakes of the Pantanal is still unclear: are they really nursery areas and feeding ground for both young and adult fishes? Interrelationships between migratory and sedentary fishes and how these fishes are organized on assemblage or community level should also be studied.

To understand what is happening to migratory fish stocks more statistical data needs to be collected in the entire basin including in Mato Grosso State, Paraguay and Argentina. Genetic studies, based on DNA, are fundamental for stock discrimination, conservation and management programs. It is highly desirable that countries of the Paraná-Paraguay River Basin have the same or similar legislation to protect migratory fishes. There is also a need for the collection and sharing of statistical data on fishing.

Development plans for hydroelectric reservoirs are another area of concern. If existing Brazilian environmental legislation is properly put into practice through increased enforcement efforts, environmental

degradation will probably be reduced and conditions for migratory fishes will be improved.

Finally, environmental education will improve perception of the importance of fish. Not only fishermen but also farmers and others in the highlands that cause environmental degradation and put at risk the survival of migratory fishes should be educated in the consequences of continued degradation.

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# 4

MIGRATORY FISHES OF THE  
**Uruguay River**

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## CHARACTERISTICS OF THE BASIN

### Geography

The Uruguay River rises in the Serra Geral Mountains as the Pelotas River, near the southern coast of Brazil, at an altitude of approximately 1,800 m. It runs inland along the southern border of Santa Catarina State (Figure 1) until it joins the Canoas River, which drains Central Santa Catarina State. Below this confluence with the Canoas the river is generally considered to become the Uruguay. Continuing along the border between Santa Catarina and Rio Grande do Sul states, the Uruguay flows 938 km to the mouth of the Peperi River.<sup>418</sup> From the Peperi River confluence the Uruguay flows south for 1,324 km, marking the borders between Brazil and Argentina,<sup>419</sup> and Uruguay and Argentina, until it meets the Paraná River to form the estuary of the Plata River, which flows into the Atlantic Ocean (Figure 1).

The watershed of the Uruguay lies between the temperate latitudes of 28°10' S and 37°08' S, with a total course of 2,262 km. For the purpose of this study the beginning of the Uruguay River is considered to be the confluence of the Canoas and the Pelotas rivers 1,816 km from the mouth.<sup>420</sup>

The Uruguay is one of three rivers that form the Plata watershed,<sup>421</sup> which has an area of 3.1 million km<sup>2</sup>; the other two rivers are the Paraná and Paraguay. Between the mouth of the Uruguay and the Atlantic Ocean lies an area of approximately 18,000 km<sup>2</sup> that includes the Rio de la Plata, a saline estuary whose depth varies between 4 and 18 m.<sup>422</sup>

The total area of the Uruguay watershed is approximately 365,000 km<sup>2</sup>. One hundred and seventy-six thousand km<sup>2</sup> are in Brazilian territory

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<sup>418</sup> Santa Catarina, 1997a

<sup>419</sup> ELETROSUL, 1979

<sup>420</sup> Boschi, 1989

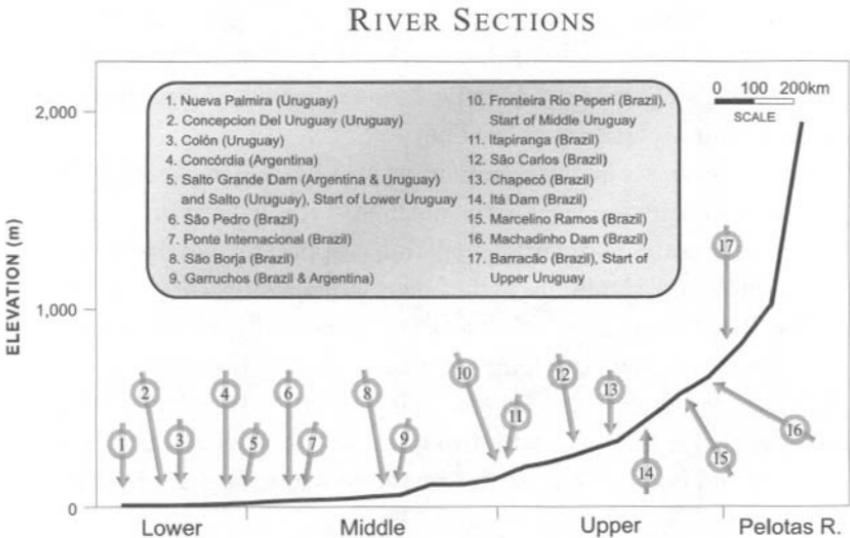
<sup>421</sup> OEA, 1969

<sup>422</sup> Boschi, 1989



geotectonic characteristics are associated with the two predominant lithological blocks of sedimentary rocks and basalt. The soil normally has a high clay content and, in general, has little depth.<sup>426</sup>

The river is a series of pools and rapids, formerly highlighted by the Augusto César Gorge (1,493 km from the mouth), just below the confluence with the Peixe River, which dropped 8 m in only 7 km.<sup>427</sup> This gorge was flooded by the reservoir of the Itá Hydroelectric Dam, which began to fill in December 1999. The Yucumã (or Moconá) Falls, below the mouth of the Peperi River, marks a drop of 12 m through a diagonal crevice, forming rapids approximately 1,800 m long, the widest in South America. Below the mouth of the Quarai River, the former Salto Grande Falls (353 km from the mouth of the Uruguay) dropped 9 m in only 3 km<sup>428</sup>; these rapids were flooded in 1979 after construction of the Salto Grande Dam. The Yucumã Falls divide the Upper and Middle Uruguay, while the Salto Grande is considered the border between the Middle and Lower Uruguay (Figures 1 and 2).



**FIGURE 2.** Vertical profile of the Uruguay River, showing river sections and locations discussed in the text

<sup>426</sup> ELETROSUL, 1981

<sup>427</sup> ELETROSUL/CNEC, 1990

<sup>428</sup> CARU, 1993

## River Profile

As a result of its rather broken profile and abundance of rapids, the Uruguay is less navigable than the other rivers of the Plata Basin. Currently, after dredging stretches of the Lower Uruguay, a canal 7 m deep runs from the mouth to the port of Concepción del Uruguay (184 km). Commercial navigation with small boats extends 252 km up the river, and, except for at low water, boats with a draft of up to 2 m can reach the Salto region (390 km upriver).<sup>429</sup>

As suggested by the vertical profile (Figure 2), the different sections of the watershed have considerably different hydrological conditions. The upper river is steep, with an average drop of 1.76% and primarily fast water. The rocky terrain and the topography of the drainage basin result in considerable and sudden variations in flow. In the upper river the maximum average flow is 9,387 m<sup>3</sup>/s; the highest historic peak flow in the region exceeded 23,000 m<sup>3</sup>/s. Flooding occurs between June and October, although great annual variations in water level can be observed (Figure 3).

The Middle Uruguay, on the other hand, begins approximately 130 m above sea level and flows nearly 800 km with an average drop of only 0.16%, with some rapids. In the Lower Uruguay, the river runs nearly 350 km with a total drop of less than 1m.

In the lower basin, the average monthly variation in water level is less than 2 meters between dry periods and high water. In the upper and middle sections the combined average variation is approximately 10 m.

Hydrological conditions of the Lower Uruguay are strongly influenced by the Salto Grande Hydroelectric Dam. Historically the variation in the river level was small, dropping only 1.2 m during droughts. In spite of this, large floods exceeded 10 meters in height. Ports above Fray Bentos were for that reason built with two levels, to allow operation in times of drought and flood.<sup>430</sup> Vast floodplains accompany the main river stem.

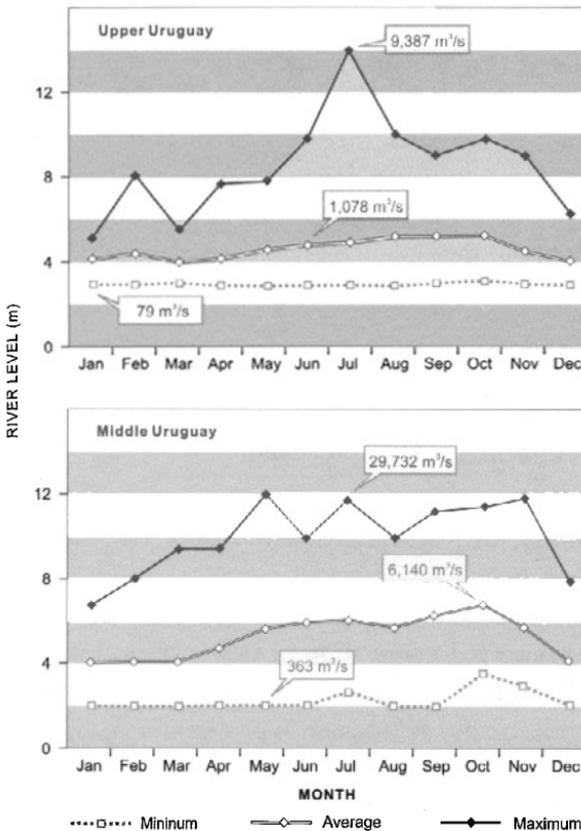
## Water Quality

According to ELETROSUL/CNEC (1990) and the Administrative Commission for the Uruguay River, or Comissão Administradora do Rio

<sup>429</sup> CENNAVE, 2000

<sup>430</sup> CENNAVE, 2000

Uruguai (CARU, 1993), the water of the Uruguay has, on average, a low level of pollutants. However, near the large cities, contamination from untreated sewage, and, in the upper watershed, contamination by hog and poultry farming effluents, produce locally high levels of contamination. Dissolved oxygen is normally at near-saturation levels. The pH of the water is close to neutral, while electrical conductivity and alkalinity increase along the river (Table 1).



**FIGURE 3.** Multi-year mean of average, maximum and minimum monthly water levels of the Upper Uruguay River<sup>431</sup> and the Middle Uruguay River<sup>432</sup>, showing representative water flow magnitudes<sup>433</sup>

<sup>431</sup> Water levels for Upper Uruguay River taken at Itá (1,529 km from the mouth), between 1940–1998.

<sup>432</sup> Water levels for Middle Uruguay River taken at Uruguaiiana (580 km from the mouth), between 1931–1992.

<sup>433</sup> DNAEE ([www.dnaee.gov.br](http://www.dnaee.gov.br))

**TABLE 1.** Physico-chemical characteristics of the Uruguay River water<sup>434</sup>

	UPPER URUGUAY		MIDDLE AND LOWER URUGUAY	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
pH	6.7	7.4	7.1	7.8
Conductivity ( $\mu\text{S}/\text{cm}$ )	26.2	73.1	69.6	210
Alkalinity ( $\text{mgCaCO}_3/\text{l}$ )	10.7	24.6	26.5	130
Dissolved Oxygen ( $\text{mg}/\text{l}$ )	9.3	10.6	7.6	12.6
Temperature ( $^{\circ}\text{C}$ )	11.5	30.0	13.0	30.0

In situations free of human impact, the low phytoplankton production of the Uruguay is due to a strong current, relatively low concentration of nutrients and high turbidity.<sup>435</sup> The productivity of aquatic macrophyte communities is also quite low due to the scarcity of pools and the near-absence of marginal lagoons. The low primary production makes aquatic communities highly dependent on organic material originating on land, even more so than in other rivers of the Plata Basin.<sup>436</sup>

## Social Aspects

### Human occupation of the river basin

European colonization of the Uruguay River Basin began in the mid-sixteenth century, when Spanish and Portuguese settlers established small villages along the lower river and mixed with indigenous peoples. Difficulty navigating to the upper basin impeded colonization until 1620, when Jesuit priests led a migration of Guarani Indians south from the lands east of São Paulo.<sup>437</sup> After 1633, Caboclos, an ethnic group that sprang from the mixing of indigenous people and Europeans, moved in. Their principal activities were subsistence agriculture, the cutting of *yerba maté* for tea, cattle-raising and transport. After 1894 incipient settlement began, intensifying after 1917 when the Brazilian government, with participation of the German and Italian governments, paid the travel expenses of European immigrants. Settlement was based on 20 to 30 hectare agricultural lots, which remain characteristic of the region.

<sup>434</sup> ELETROSUL/CNEC, 1990; CARU, 1993

<sup>435</sup> Quirós & Luchini, 1982

<sup>436</sup> Di Persia & Neiff, 1986

<sup>437</sup> ELETROSUL/CNEC, 1990

Agricultural development was accompanied by exploitation of the forests that covered the entire region. During the high water season, long rafts of cedars (*Cedrella fissilis*), *angicos* (*Parapiptadenia rigida*), *grápias* (*Apuleia leiocarpa*) and Brazilian pines (*Araucaria angustifolia*) were floated down the Uruguay to Argentina.<sup>438</sup> In 1940 large sawmills were built, but after years of extraction the forests were depleted and the sawmills shifted to other regions.

After 1960, hog and poultry farms began to consolidate into large conglomerates, which have since dominated the Brazilian food market. Integrating with producers, these large agri-businesses have continued to stimulate the regional economy and have steadily increased productivity in hog- and poultry-raising.

In the Upper Uruguay agriculture revolves around soybeans, corn and black beans. In the Middle and Lower Uruguay, extensive cattle-raising and cultivation of soybean and rice prevail. Only fragments of the old forest remain along the boxed river valleys and on the steepest hillsides that people have been unable to occupy. In the Brazilian section of the river basin, primary and secondary vegetation cover nearly 17.5% of the land. Reforested areas, principally pines (*Pinus elliottii*), occupy another 3%. Compared with its original vegetation, with the exception of a few small remaining patches of primary forest nearly the entire region has been replanted to secondary vegetation, croplands and pasture.

The population density of the Uruguay River Basin is approximately 39 inhabitants per square kilometer. Nearly 45% reside in the rural areas.<sup>439</sup> Despite the wealth and the stable economy, small economically depressed regions persist, mainly in the drainage basins of the Pelotas and Canoas rivers.

## Habitats used by Migratory Fish

### Upper and Middle Uruguay

The upper and middle sections of the Uruguay River occupy a fairly steep-walled valley with only a small floodplain that gradually flattens towards the headwaters. These characteristics directly influence the diversity and abundance of fish. The river bed is deeply channelled, broken up by waterfalls, rapids and narrows, and there are few islands or riparian

<sup>438</sup> ELETROSUL/CNEC, 1990

<sup>439</sup> Santa Catarina, 1997a ; Atlas Mirador, 1987

grasslands. The number of species found along the Uruguay River Basin probably surpasses the 150 species previously described.<sup>440</sup> Data on fish productivity are not available, but the lack of floodplains in the Upper Uruguay suggests it is low.

Tributaries of the upper and middle section are normally short and broken by waterfalls. Migratory species and large fish are therefore generally restricted to the main river and to the lower section of the tributaries.

The migratory species present in the Lower Uruguay River normally rely on floodplain lakes for larval and juvenile rearing. As these lakes are absent from the steep valleys of the Upper and Middle Uruguay, the species appear to have adapted by using the mouths of tributaries as rearing areas. These areas of confluence take on lentic characteristics when the mainstem of the river floods, and backs up the waters of the smaller tributaries. Water transparency and temperatures tend to be significantly higher in these regions,<sup>441</sup> which leads to greater planktonic production and conditions favourable for larval and juvenile rearing.

### Lower Uruguay

The Lower Uruguay resembles the Lower Paraná, which lies at the same latitude and a little farther west, and the fish species are practically the same. In both, species diversity and total fish biomass are high,<sup>442</sup> considering the sub-tropical climate. The high productivity may be due to a low profile and extensive floodplain, favouring the formation of shallow seasonal lakes and pools that accumulate nutrients.

Between the cities of Colón (236 km) and Fray Bentos (102 km) many large islands break up the Uruguay. 110 km from the mouth, at the outlet of the Gualeguaychú River, the islands disappear and the river widens substantially, reaching 8 to 12 km in breadth over a flat plain. A series of channels links the Uruguay and Paraná rivers in this stretch, with the Plata River strongly influencing the speed and direction of the currents in the Uruguay.<sup>443</sup> During low water season, tidal influence is seen above the port of Paysandu, 204 km from the mouth.<sup>444</sup> Since the construction

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<sup>440</sup> Di Persia & Neiff, 1986

<sup>441</sup> Zaniboni Filho et al., 2000

<sup>442</sup> Bertoletti, 1985

<sup>443</sup> Sverlij et al., 1998

<sup>444</sup> CENNAVE, 2000

of the hydroelectric dam at Salto Grande, these tidal effects have become more pronounced, particularly when water volumes released by the dam are reduced.

At Nueva Palmira, the Uruguay spills into the Rio de la Plata, a saline estuary covering approximately 18,000 km<sup>2</sup>. The temperature of the Plata varies between 10 and 24°C.<sup>445</sup> Phytoplankton production is generally low and the ichthyofauna is composed primarily of sediment-eating, or iliophagic, fish.<sup>446</sup> Euryhaline species predominate, and the presence of fresh-water species is low.<sup>447</sup>

## MIGRATORY SPECIES AND MIGRATION PATTERNS

The fish community of the Uruguay is very similar to that of the Paraná River. Characiforms and Siluriforms predominate.<sup>448</sup> In 1986, 150 species of fish were described for the Uruguay River Basin, including exotic, anadromic and estuarine fish.<sup>449</sup> However, Hahn and Câmara (2000) identified 251 species in a brief bibliographic review of the Uruguay River.

Today, more than 100 species of fish are registered for the Upper Uruguay.<sup>450</sup> The fish community of the Lower Uruguay is characterized by species of marine origin, such as Mugiliforms, Clupeiforms, flounders and rays. However, the species of the greatest biomass is the freshwater *curimbatá* (*Prochilodus lineatus*), a characid, which is fished intensely, sustaining industrial production of fishmeal and oil. As sampled by trawler, the curimbatá was found to be the most abundant species, occurring at a relative frequency of 23%. The *voga* (*Schizodon nasutus*) and the armoured catfish (*Pterodoras granulosus*) were second and third most abundant, at 4% and 3% respectively.<sup>451</sup> Other migratory species of commercial or recreational importance are the *piava* (*Leporinus obtusidens*), *dourado* (*Salminus maxillosus*) and *Patí* (*Luciopimelodus patí*).

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<sup>445</sup> Boschi, 1989

<sup>446</sup> Quirós & Baigun, 1985

<sup>447</sup> Boschi, 1989

<sup>448</sup> Ringuelet, 1975

<sup>449</sup> Di Persia & Neiff, 1986

<sup>450</sup> Zaniboni Filho, et al., 1997

<sup>451</sup> Amestoy & Fabiano, 1992

Knowledge of the fish fauna of the Middle Uruguay is limited to the study by Bertoletti et al. (1989) of the stretch downstream from the Brazilian municipality of São Borja. In five sampling expeditions between 1988 and August 1989, 71 species were captured, with a composition intermediate to those of the Lower and Upper Uruguay. The species of the lower stretch, such as the ray (stingray) *Potamotrygon brachyura*, the clupeid *Lycengraulis* sp., the sciaenoid *Pachyurus bonearensis* and the flounder of the *Achirus* genus are of marine origin. Siluridae of the Doradidae family and some Pimelodidae such as *Zungaro zungaro* (sometimes used as a synonym for *Paulicea luetkeni*) are also typical of the Lower Uruguay. Characiforms such as *Steindachnerina brevipinna*, *Apareiodon affinis*, and the siluriforms of the *Ancistrus* and *Hemiancistrus* genera are characteristic of the Upper Uruguay. Among the migratory fish, three species are considered commercially important in this upper reach: the piava (*L. obtusidens*), the curimatá (*P. lineatus*) and the dourado (*S. maxillosus*). However, information on reproduction of the migratory fish in this region is not available. Near the city of Uruguaiiana, in the Middle Uruguay, young of *Pseudoplatystoma corruscans* were observed in the small tributaries, which are probably feeding grounds of the young form of this species.<sup>452</sup>

## Migratory Behaviour

Despite the similarity of the fish communities in the Uruguay and Paraná rivers, the life cycles of the fish and their migratory behaviour in the two rivers appear quite different. Bonetto and Pignalberi (1964), who tagged fish in the Argentine section of the Paraná, suggest that in this river there is a feeding migration downriver and a reproductive migration upriver. This behaviour appears common in the majority of tropical and subtropical rivers and is closely linked to the seasonal rains. Summer water levels in the Paraná allow upriver migration and the flooding of areas for the growth of larvae and fingerlings.

In contrast, the Upper Uruguay lacks the well-defined dry season typical of the Paraná headwaters. Rains fall throughout the year, and floods are swift and brief, due to the deep valleys and the absence of marginal

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<sup>452</sup> Enrique Querol Chiva, personal communication

lakes and floodplains along much of the river. The migratory behaviour of the fish of the Uruguay, such as the dourado and the *piracanjuba* (*Brycon orbignyanus*), though still not well understood, is thus quite different from that of the same species in the Paraná. While the species form large schools that usually move upriver for reproduction and downriver to feeding areas, they may also be found moving in opposite directions at the same time.<sup>453</sup>

Monitoring of eggs and larvae in the Lower Uruguay region suggests that reproduction occurs between October and March, with one peak downstream of the Salto Grande Dam in the spring, and a second in the upper section of the Salto Reservoir at the beginning of the summer.<sup>454</sup> Tagging studies in the Lower Uruguay indicate that the principal populations of migratory fish reproduce in the Middle Paraná River, rather than the Uruguay.<sup>455</sup>

There are also two forms of migration: mainstem, in which the fish remain in the main river, and tributary, in which the fish turn up the tributaries. The species can therefore be classified as either mainstem or tributary migratory species.

## Principal Mainstem Migratory Species

### *Salminus maxillosus*

The dourado (*dorado* in Spanish) is found throughout the Uruguay, as far as the Canoas and Pelotas rivers. Considered the best fishing trophy in the Uruguay River Basin, this species also brings one of the highest prices in the market. Despite its regional importance, however, there is a tremendous scarcity of information about its biology in the river basin.

The dourado is mostly restricted to the mainstem of the Uruguay, and is recorded only in the larger tributaries of the middle and lower basin such as the Negro, Quaraí, Ibicuí and Ijuí rivers. In the tributaries of the Upper Uruguay, dourados are recorded only near their confluences with the Uruguay, except for the Canoas and Pelotas rivers. The dourado is found throughout the year along the whole of the mainstem of the river, and fishermen have developed specialized techniques for their capture. Most are taken during migration when they concentrate near the rapids.

<sup>453</sup> Di Persia & Neiff, 1986

<sup>454</sup> Espinach-Ros & Ríos, 1997

<sup>455</sup> Sverlij et al., 1998

The dourado is carnivorous and an excellent swimmer. For most of the year it is solitary or moves in small schools, concentrating in fast waters where it ambushes slower-swimming prey. During the upstream migration to reproduce, large schools of dourado gather below natural obstacles, where they await higher water. Along the Uruguay only three rapids originally blocked the dourado during low water: Salto Grande (353 km from the mouth), Salto do Yucumã (or Moconá) (1,215 km from the mouth) and the Augusto César Gorge (1,493 km from the mouth). The other rapids can be easily passed by this fast-swimming species, which can leap small waterfalls. Nonetheless, dourados are commonly found gathered in stretches of strong current, probably attracted by the greater ease of capturing prey.

Dourado reproduce in spring and summer (November–February), a phenomenon closely linked to the rains. Gonadal maturation and the start of migration appear to depend on water temperature, and is earlier or later according to the coldness of the winter. After the water warms, movement upstream is limited only by the water level. Mature males and females have been recorded along most of the 1,500 km of the river, although no specific spawning grounds have been reported other than the stretch of the river below Salto do Yucumã.<sup>456</sup> In surveys conducted between 1995 and 2000, fish in the final stage of gonadal maturation were found in different stretches of the river basin, indicating a variety of spawning locations.

Dourado tagged near the Salto Grande Dam travelled a maximum distance of 850 km in 41 days, corresponding to an average velocity of up to 21 km per day. The dourado is one of the two species tagged to move upriver in the reservoir.<sup>457</sup>

### ***Brycon orbignyanus***

The piracanjuba or *bracanjuba* (*pirapitá* in Spanish) was once recorded in the entire river basin. Reports from fishermen and residents of the Upper and Middle Uruguay indicate that large schools of piracanjuba once travelled upriver in the pre-reproductive period, when, gathered below natural barriers, many were easily caught. However, the species has

<sup>456</sup> Fuentes & Ros, 1999

<sup>457</sup> Delfino & Baigun, 1985

now practically disappeared from the Lower<sup>458</sup> and Upper Uruguay.<sup>459</sup> Despite its sporadic occurrence in small numbers over a few river stretches, the piracanjuba is now recorded consistently, but in low abundances, only near the Turvo Forest Reserve in Brazil. Currently, despite efforts to collect brood stock for this species, only three specimens are being maintained at the São Carlos Hatchery (in Santa Catarina State in Brazil).

Despite the value and abundance of the species in earlier times, the biology of the species in the Uruguay River Basin has not been studied. Some information on its ecology is, however, available from other river basins, and growing interest in cultivating *B. orbignyanus* in captivity has encouraged studies of its biology, summarized below.

*B. orbignyanus* is omnivorous, but prefers fruits and seeds. Studies indicate that the species has an enormous capacity to digest and assimilate vegetable proteins.<sup>460</sup> Like the dourado, the piracanjuba produces semi-dense eggs that depend on flowing water during the entire incubation phase and the initial stages of larval development, a period of approximately two days. The eggs must hatch in flowing waters, which keep the eggs and larvae in suspension for that time. Larvae are carnivorous, like those of the dourado, selecting food from among zooplankton and showing a high propensity for cannibalism at the first feeding. The change to a more omnivorous and frugivorous diet probably occurs in juvenile fish.

Piracanjuba spawn in spring and summer (November–February), apparently in close relation to the rains and water temperatures. Maturation appears to depend on water temperature, and is delayed or advanced according to the coldness of the winter. Once temperatures are warm enough, migration depends on water flow adequate to allow the fish to move upriver; like the dourado, they also congregate below major rapids. There are no records of specific locations for spawning of piracanjuba along the Uruguay, although mature specimens have been caught in the Turvo Reserve (1,215 km from the mouth).

In fish surveys conducted in the Upper Uruguay between 1986 and 1987<sup>461</sup> and between 1995 and 2000,<sup>462</sup> no piracanjuba were captured. In

<sup>458</sup> Espinach-Ros & Rios, 1997

<sup>459</sup> Zaniboni Filho et al., 2000

<sup>460</sup> Meurer, 1999, Cavalcanti, 1998

<sup>461</sup> Bertolotti et al., 1989

<sup>462</sup> Zaniboni Filho et al., 2000

addition, no piracanjuba have been captured by fishermen in the stretch between Itá (1,529 km) and the confluence of the Canoas and Pelotas rivers (1,769 km) since approximately 1980, though some have been recorded near the confluence with the Peperi River (1,225 km). This disappearance of the piracanjuba from much of the Uruguay indicates a lack of tolerance for an altered environment. According to Espinach-Ros and Rios (1997), the loss of forest along the river banks is likely one of the principal factors. The situation of piracanjuba in the Uruguay is critical, and urgent measures are required for its conservation.

### *Prochilodus lineatus*

The curimbatá or *grumatão* (*sábalo* in Spanish) feeds on detritus and encrusting algal growth (phytobenthos). It thus prefers slower waters, where suspended material settles out and a robust benthic ecosystem can develop. These areas are most common in the lower stretch of the Uruguay, where the river bed flattens and the floodplain widens, resulting in extensive areas of still water and shoals. However, the species also occurs in pockets throughout the entire basin. In the upper part, where the river is boxed into a steep valley, pools with muddy bottoms and calm waters alternate with shoals and strong currents. Both areas are used by the species for feeding.<sup>463</sup> The rapids form small areas of still water that remain more exposed to sunlight at low water levels, and phytobenthos on the rocky bottom is frequently abundant.

As with the other migratory species in the Uruguay, few studies of the biology of the curimbatá in the Uruguay River Basin have been conducted. It is, however, known that populations of the Middle and Upper Uruguay migrate upriver to reproduce. Mature fish are caught in different locations along the river; however, their spawning or nursery sites are not known. Where natural barriers impede migration the curimbatá also form large schools that mix with other species (such as the dourado) at the base of rapids and falls until floods arrive.

Curimbatá eggs are semi-dense and require flowing water during the entire incubation phase. Approximately 4 days after spawning, the larvae begin external feeding. In the first days they require planktonic organisms, then graduate quickly to consuming benthic organisms. Individuals from three to six years of age dominate Curimbatá populations in the Lower

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<sup>463</sup> Zaniboni Filho, et al., 2000

Uruguay. A maximum age of nine years was observed. There is also evidence for the co-existence of two populations of curimbatá with different growth rates in this area.<sup>464</sup>

*Prochilodus* species make extensive migrations. In the lower river basin, *P. platensis* tagged in the region of the Salto Grande Reservoir were recaptured at a maximum distance of 620 km from where they were released.<sup>465</sup>

*P. lineatus* in the Salto Hydroelectric Reservoir increased after dam construction, probably due to an increase in feeding areas and sedimentation of organic detritus.<sup>466</sup> Abundant curimbatá eggs were found in the upper third of the reservoir, while larvae were distributed throughout the reservoir, indicating that the spawning areas were upstream.<sup>467</sup> Considering that the reservoir is the only one in the Middle and Lower Uruguay with a long stretch of flowing water upstream, the growth of the curimbatá populations can be explained by more food having become available in the reservoir and by the spawning areas remaining accessible. New hydroelectric projects upstream could alter this situation irreversibly.

In the Lower Uruguay River Basin, tagging of the principal migratory species present indicate that their principal spawning areas are actually in the Paraná River.<sup>468</sup> Considering the low declivity of the lower stretch of the Uruguay, saltwater influx at low water levels and the greater predictability of floods in the Paraná, it may be more advantageous for the species to feed in the Lower Uruguay and return to the Paraná annually to reproduce. This strategy appears to sustain large populations of curimbatá in the Lower Uruguay River Basin. According to Sverlij et al. (1998), the species has the largest biomass of fish caught in the region, and indeed sustains commercial fishing. However, the more recent study of Fuentes and Espinach-Ros (1999) found larvae of *Prochilodus* in the Lower Uruguay, although in low numbers.

### ***Leporinus obtusidens***

The piava or *piapara* (*boga* or *boga común* in Spanish) is restricted to the Middle and Lower Uruguay River Basin, though it was once abundant

<sup>464</sup> Sverlij et al., 1992

<sup>465</sup> Delfino & Baigun, 1985

<sup>466</sup> Espinach-Ros & Rios, 1997

<sup>467</sup> Espinach-Ros & Rios, 1997

<sup>468</sup> Sverlij et al., 1998

throughout the basin. In the Upper Uruguay, the species has been recorded only near the Yucumã Reservoir. It is relatively easy to find in the fish market in the city of Itapiranga (1,240 km from the mouth). In the Lower Uruguay it is important to both commercial and recreational fishing. It reproduces in the spring, migrating longitudinally. Fuentes and Espinach-Ros (1999) found the highest piava reproduction intensity in the Lower Uruguay where 11% of all eggs and larvae counted were attributed to this species.

As with other migratory species of the Uruguay, regional biological studies of the piava are rare, despite the interest in fishing for the species. Through the analysis of eggs and larvae from fish culture, we can suggest that its reproductive behaviour resembles that of the dourado, piracanjuba and curimatá, and piava are found exclusively in migrations together with these species. Its eggs are semi-dense and require flowing water for the entire incubation phase. Hatching occurs about 18 hours after fertilization, and external feeding begins four days after hatching. The post-larvae are able to select zooplankton and can eat benthic organisms.

The feeding of the young and the adults is diversified. They are considered omnivorous, although their small mouth allows the ingestion of small food items only. Seeds, aquatic insects and molluscs are the principal food; given this preference we can suppose that the piava was always abundant in the middle and lower river basin. In the Upper Uruguay, the geological and hydrological characteristics limit the availability of autochthonous food, and the species remains more dependent on fruits and seeds. Deforestation through unsuitable agricultural techniques can be cited as the principal cause of the near elimination of piava stocks in the Upper Uruguay.

In tagging studies near the Salto Grande Dam, the maximum distance between the area of release and recapture of the *L. obtusidens* was 540 km. The piava and the dourado were the only species that swam upstream in the reservoir.<sup>469</sup>

### Long distance migratory catfish

Six species of migratory catfish are found in the Uruguay River: *pintado* (*P. corruscans*; *surubí* in Spanish); *surubim* (*Pseudoplatystoma fasciatum*, *surubí atigrado* in Spanish); *jaú* (*Paulicea luetkeni*; *manguruyú* in Spanish);

<sup>469</sup> Delfino & Baigun, 1985

*surubi* (*Steindachneridion inscripta*; *bagre cabezón* in Spanish); and *armado* or *abotoado* (*P. granulosus*; *armado* in Spanish).

*P. granulosus*, an armoured catfish, is one of the most abundant species in the Lower Uruguay, constituting 3% of the total catch. Tagging studies indicate that the species uses both the Paraná and the Uruguay systems, and it is found throughout the Plata Basin, especially between October and March. However, during CARU's monitoring, mature armados were caught only in the Paraná, and fish marked in the Paraná delta migrated as far as 700 km upriver. It appears that the Uruguay is used only as a feeding ground, while the reproductive areas of this species are in the Paraná.<sup>470</sup>

Other migratory catfish are abundant in the middle and lower river basin, and pintado, surubim and surubi are listed among the most frequent species in the catches of the Lower Uruguay and in the Salto Grande Reservoir.<sup>471</sup> All three species are fish-eaters, nocturnal, and prefer to inhabit deep pools of still water.

In contrast to the Lower Uruguay, interviews with fishermen and residents along the river indicate that pintado, surubim, and jaú were always rare in the upper river basin. Inventories of the fish fauna in the upper river basin between 1986 and 1987<sup>472</sup> and between 1995 and 2000<sup>473</sup> caught no specimens of these species. The existence of pintado and jaú (~1,450 km from the mouth) can only be substantiated through the observation of single specimens of each species frozen by fishermen who keep the individuals as trophies. Eggs and larvae of migratory catfishes in the Lower Uruguay region are found throughout October to March, although in low densities. Larvae were caught in trawls at night, principally between Colon and Gualeguaychu, in the same nursery areas as other species such as the curimbatá.<sup>474</sup>

Through studies in fish culture, all the catfishes are known to have semi-dense eggs that must remain in flowing water until hatching (more than 17 hours). Larvae of pintado and surubim are smaller than larvae of other migratory fish such as the curimbatá, dourado, piava and piracanjuba, and in the first phases of life must rely on very small food items, such as rotifers. Despite this, the larvae are very cannibalistic in

<sup>470</sup> Amestoy & Fabiano, 1992

<sup>471</sup> Sverlij et al., 1998

<sup>472</sup> Bertolletti et al., 1989

<sup>473</sup> Zaniboni Filho et al., 2000

<sup>474</sup> Espinach-Ros & Ríos, 1997

culture, although they are not able to ingest an entire larva, and commonly die themselves in the process. Nevertheless, cannibalism is still a principal source of mortality in the larviculture of these species.

The pintado and surubim produce large quantities of small eggs (between 0.7 and 0.8 mm in diameter), and a typical 10 kg female releases an average of 600,000 eggs at each spawning.<sup>475</sup> Jaú and surubi have larger eggs, averaging 1.7 mm in diameter, and larger larvae at hatching. Jaú nevertheless have large ovaries and produce a large number of eggs at each spawning (a typical 10 kg female produces about 500,000 eggs). The surubi have small ovaries, and a 5 kg female releases approximately 40,000 eggs at each spawning.<sup>476</sup>

Migratory catfishes of the Uruguay apparently travel only short distances to reproduce. The maximum distance travelled by a tagged surubim in the Salto Grande Reservoir and recapture was 75 km, corresponding to maximum average velocities of 1 km/day. Tagged specimens were also recaptured downstream of the dam, indicating that they are able to pass through the turbines or over the dam.<sup>477</sup>

## Principal Tributary Migratory Species

### *Pimelodus maculatus*

The *mandi-pintado* or pintado (*bagre amarillo* in Spanish) is a small catfish found throughout the Uruguay River and in small and medium-size tributaries. It is an abundant species important to regional fishing and spawns throughout spring and summer. In studies of its life cycle in the Upper Uruguay region,<sup>478</sup> adults were observed to migrate laterally, leaving the main river to spawn in the tributaries. Gonads mature between September and March when the water temperature is high, but spawning peaks occur in the winter, probably due to hydrological conditions.<sup>479</sup> Gonadal maturation and spawning of the *mandi-pintado* in the Paraná River has been reported to depend on rainfall.<sup>480</sup> After spawning, adult individuals concentrate in the main river where they feed intensely. The

<sup>475</sup> Zaniboni Filho, 1998a

<sup>476</sup> Zaniboni Filho, 1998b

<sup>477</sup> Delfino & Baigun, 1985

<sup>478</sup> conducted by Cassini, 1998

<sup>479</sup> Cassini, 1998

<sup>480</sup> Basile-Martins et al., 1975

young are most frequent in the lower section of the tributaries and in the confluence with the main river.<sup>481</sup> In the Lower Uruguay larvae were found at highest frequency in the confluence of the tributaries with the main river and the tributaries and bays of the Salto Grande Reservoir.<sup>482</sup>

Mandi-pintado eggs resemble those of *P. corruscans*, being semi-dense and of small diameter. In culture, incubation requires flowing water until hatching. Larvae have a small yolk sac, and once they begin to feed depend on small food such as rotifers. They show cannibalism in the first larval stages in culture.

### ***Rhamdia quelen***

The *jundiá* (*bagre sapo* or *bagre negro* in Spanish) has been recorded throughout the Uruguay Basin, including the upper portions of the tributaries, and is important for fishing throughout the river. In the Upper Uruguay, spawning occurs throughout the year, though at greater intensity in the spring and primarily in the tributaries.<sup>483</sup> *R. quelen* is carnivorous, feeding mostly on fish and crustacea, and feeds more intensely in the autumn and winter.<sup>484</sup>

Jundiá generally feed in the main river until the beginning of gonadal maturation, whereupon they migrate laterally up the tributaries, taking advantage of flood peaks. Final gamete maturation occurs in the tributaries. After spawning the fish return to the feeding grounds in the main river. In spring, at higher water temperatures and coinciding with the floods, the majority of the population spawns,<sup>485</sup> but migration and spawning also occur throughout the year.

Jundiá eggs are semi-dense and remain suspended in flowing water after hydration. Fecundity is low compared with the majority of migrating fish, averaging 70,000 eggs/kg per female. The eggs hatch nearly two days after fertilization, and, in contrast to other migratory species described above, they hydrate less and can remain for some time on the bottom. Larvae begin feeding about 4 days after hatching, selecting food from the plankton and benthos. Unlike the other migratory catfish, jundiá larvae are not cannibalistic in culture.

<sup>481</sup> Cassini, 1998

<sup>482</sup> Espinach-Ros & Ríos, 1997

<sup>483</sup> Silva, 1997; Cassini, 1998

<sup>484</sup> Meurer & Zaniboni Filho, 1997

<sup>485</sup> Cassini, 1998

## IMPACTS ON MIGRATORY SPECIES

### Fisheries Impacts

Commercial fishing in the Uruguay Basin is currently only important in the lower stretch of the river. An industrialized beach seine fishery of the curimbatá, for use in fishmeal and fish oil,<sup>486</sup> landed between 1,000 and more than 5,000 tons annually between 1945 and 1988. The capture of 10 to 30 tons of fish per set in this fishery was common, with occasional catch of over 100 tons. The fishery is Argentinean, and is legislated to occur in the summer and fall, between October and April. It has declined since the late 1980s, when the similar fisheries of the La Plata River was shut down, and continues on only a relatively small scale.<sup>487</sup> In the rest of the basin, fishing is primarily recreational, and, for small groups of residents, for subsistence. Associations that represent fishermen along the middle and lower section of the river basin are registered, though data on catches are not available. On the Brazilian section of the Middle Uruguay there is no official commercial fishing,<sup>488</sup> though unregistered fishing may be substantial.<sup>489</sup>

Inland landings in the Brazilian states of Santa Catarina and Rio Grande do Sul, which includes the Upper Uruguay Basin and represents sport and artisanal fishing, were 2,414 tons in 1995. Only 7.5% were of the longitudinal migratory species such as *S. maxillosum*, *P. lineatus*, *L. obtusidens*, *P. corruscans* and *S. inscripta*. Species that conduct only lateral migrations, such as *R. quelen* and *P. maculatus*, made up more than 15% of the total catch.<sup>490</sup>

Despite the low importance of fishing for wild stocks in the upper river basin, fish culture in this region makes it one of the largest producers of fresh-water fish in Brazil. Fish culture production exceeded 7,000 tons in 1995 (although more than 97% of the total produced were introduced species).<sup>491</sup> Santa Catarina State, currently the second largest Brazilian producer of fresh-water fish, in 1998 produced 14,400 tons based equally on Chinese carp, common carp and tilápias.<sup>492</sup> Of the mere 2% of Brazilian

<sup>486</sup> Espinach-Ros & Delfino, 1993

<sup>487</sup> [www.entrierios.gov.ar/produccion/dpesc07.htm](http://www.entrierios.gov.ar/produccion/dpesc07.htm)

<sup>488</sup> IBAMA, 1997

<sup>489</sup> Hahn & Cámara, 2000

<sup>490</sup> IBAMA, 1997

<sup>491</sup> IBAMA, 1997

<sup>492</sup> EPAGRI-CIRAM, 1999

fish used in fish cultivation in the region, the majority came from other hydrographic basins.

However, the regional market price of native migratory species in the Uruguay is 3 to 7 times higher than the price of cultivated exotic species. The major impediment to the development of native species culture is the lack of technology to produce fingerlings. Only in 1998 were the first fingerlings of migratory species from the Uruguay Basin produced by the Fish Hatchery of São Carlos, Brazil.<sup>493</sup>

## Other Impacts

The greatest impact on the migratory fish community is from habitat alteration following dam construction and deteriorating water quality from pollution. Habitat changes have the gravest long-term impact on the fish fauna. Chemical contamination of the water and organic pollution are theoretically reversible.

It is important to emphasize that the changes in the upper stretch of the river will permanently affect the indigenous fauna. The Upper Uruguay appears to be an area with high levels of endemism, and each year new species are described. In general, the biology of these new species is unknown and the effects of the hydroelectric projects on them are unpredictable. Some of them may disappear before they are studied.

## Dams

Dams block reproductive migration. They alter migratory and reproductive behaviour by changing the natural flow of waters that, among other factors, trigger migration. By retaining nutrients in the reservoir, they interfere in the river's metabolism downstream. Adult and young fish passing through the turbines suffer high mortality. Dams alter the extension and location of spawning and growing areas, and they change the limnology by transforming a lotic environment into a lentic environment, altering temperatures, oxygen concentrations, current speeds, and sedimentation rates.

Three hydroelectric projects dam the Uruguay: the Salto Grande in the Lower Uruguay, inaugurated in 1979, and in the Upper Uruguay, the Itá and Machadinho, which began to operate in 2000 and 2002,

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<sup>493</sup> Zaniboni Filho, 1998a

respectively. Five more dams planned for the Upper Uruguay will transform a fast-running river into a chain of slow water environments.

In Espinach-Ros and Rios (1997) investigation of altered fish fauna in the Salto Grande Dam, the period from 1981–1984 (soon after dam closure) was compared with that of 1990–1995. The most visible changes were a greater abundance of pelagic species (*Parapimelodus valenciennis*), two iliophagous fish of the *Prochilodus* genus and *casquados* of the *Hypostomus* and *Loricaria* genera. Benthophagous species (*Iheringichthys westermanni*, *P. bonariensis*) and small predators (*Acestrorhynchus altus*, *Cyrtocharax squamosus*, *Astyanax* spp.) also increased. A parallel study of the distribution of fish eggs and larvae indicated that these species are able to complete their life cycle in the tributaries that flow into the reservoir or in the reservoir itself, spawning in the area of transition from lotic to lentic.

The effect of the reservoir varies according to species. Some, such as *P. corruscans*, *Oxydoras kneri* and *Sorubim lima* disappeared gradually from catches after dam closure, and had disappeared altogether 15 years later. Two frugivorous species, the *pacu* (*Piaractus mesopotamicus*) and the *piracanjuba* (*B. orbignyanus*) were absent in experimental catches during reservoir filling, possibly due to the destruction of the vegetation along the Uruguay Basin. Agostinho (1997) reports the same observation for the Itaipu Reservoir on the Paraná River, where *pacu* and *piracanjuba* disappeared two years after dam construction. Nevertheless, some migratory species have maintained stable and abundant populations in the 15 years since the flooding of the Salto Reservoir, including *S. maxillosus* and *L. obtusidens*. Catches of others, such as *P. lineatus* and *L. pati*, have increased considerably.<sup>494</sup>

To mitigate the impact of the Salto Grande Dam, fishways have been built to the design of those used in Europe and the United States for the movement of salmonids (Borland type). A study of their efficiency revealed that *dourado* (*S. maxillosus*) and *surubim* (*P. corruscans*) do not enter the lock chambers.<sup>495</sup> Only the *curimbatá* (*P. lineatus*) was found in small quantities in the entrance and exit chambers. Of the 62 species found in the reservoir only 23 were captured in the ladder chambers. The most abundant species were small Siluriformes (*P. valenciennis*, *Auchenipterus nuchalis*) and Clupeiforms (*Lycengraulis* sp.). All of these species are

<sup>494</sup> Espinach-Ros & Rios, 1997

<sup>495</sup> Espinach-Ros & Rios, 1997

considered pelagic. This may indicate that the fish, mainly the benthic species, have difficulty in finding the ladder entrances.

The Itá and Machadinho dams, on the Upper Uruguay, are the first hydroelectric projects in the upper river basin. The Itá Reservoir extends to the Machadinho Dam, obliterating the lotic stretch of river between them. The Itá Dam is 126 meters high, and ladders and other structures for fish movement downstream to upstream were not planned in the project. The planning of other new dams calls for the complete elimination of lotic stretches along the entire Uruguay, making it probable that current-dwelling species like dourado and curimatá will no longer find the lotic stretches they need upstream. The importance of these lotic areas for their reproduction has been demonstrated by a study of the distribution of eggs and larvae in the Salto Grande Reservoir.<sup>496</sup> Consequently, the populations of these species are likely to decrease much more in the new reservoirs of the Upper Uruguay than was observed at Salto Grande.

### Agriculture

Hog- and poultry-raising presents a special problem on the Upper Uruguay, principally in Santa Catarina State, which has the largest production of these animals in Brazil. The average density of hogs in the region is 82 hogs/km<sup>2</sup>. In some watersheds, as in the Jacutinga River Basin, up to 1,909 hogs are concentrated per square km.<sup>497</sup> From 1993 to 1996 the growth in stock was 41%, and the hog population in the basin is now 3,120,000, or 69% of the hogs in the entire state. These animals produce some 26,000 m<sup>3</sup> of waste per day.<sup>498</sup> Based on the biochemical demand for oxygen (DBO), this corresponds to a population equivalent of 10.8 million people. The 1997 census shows a regional population of 1.8 million people.

The poultry population in the Catarinense section of the Upper Uruguay region is 58,100,000 birds, averaging 1,460 birds/km<sup>2</sup>, although in the Jacutinga River Basin it reaches 34,800 birds/km<sup>2</sup>. Between 1986 and 1996 poultry-raising grew by 57%. The quantity of manure produced by the birds is nearly 7,000 tons/day, or equivalent to the pollution of 6.68 million people. As of 1996 the watershed raised 68% of the poultry in Santa Catarina State.

<sup>496</sup> Espinach-Ros & Rios, 1997

<sup>497</sup> Santa Catarina, 1999

<sup>498</sup> BRASIL-IBGE, 1997

Not surprisingly, the level of organic pollution is high in the Upper Uruguay, principally in the Peixe and Canoas rivers. High coliform levels are present in the stretch of the Upper Uruguay from near Concórdia (1,529 km) to the Peixe River (1,620 km), with an average coliform index of  $10^4$  NMP/100 ml. This is probably caused by agriculture (hog-raising) and not by human sewage, given that the largest hog-producing region corresponds to the points with the highest concentrations of fecal coliforms.<sup>499</sup>

### Industry and human habitation

Mercury levels nine times the acceptable limit for waters free from contamination were detected in the Upper Uruguay Basin, in the Canoas, Peixe, Pelotas and Uruguay rivers.<sup>500</sup> The source is probably cellulose factories in these river basins.

Stretches of the river downstream from the large cities are the principal concentrations of contamination. Agricultural and industrial activities contribute to the dumping of pesticides, herbicides, nutrients and heavy metals (particularly chromium, from tanneries) and most domestic sewage is released into the river without any treatment. This has a number of consequences, such as the creation of an environment favourable to cholera. Once introduced, the *Vibrio* virus can remain virulent for decades. The organic overload of some stretches of the river also provokes eutrophication, resulting in toxic algal blooms and other similar problems.

Copper was detected only in some of the samples from the rivers with industry, such as the Peixe, and in the agricultural river basins, such as Forquilha, which have levels above the established standards (20 mg/l). Copper is associated with agricultural chemicals, principally fungicides. High levels of sediment contamination by copper were noted. Some regions have nickel concentrations two times greater than that permitted for environments considered to be free of pollution, while the levels of zinc exceeded by seven times the standard value and that of copper was nine times higher than the limit for waters free of pollution. The principal origin of these products is probably agricultural pesticides and herbicides, galvanization plants and metallurgy.<sup>501</sup>

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<sup>499</sup> ELETROSUL/CNEC, 1990

<sup>500</sup> CONAMA, 1986; EPA, 1972

<sup>501</sup> ELETROSUL/ CNEC, 1990

CARU, which initiated a water-quality monitoring program in the Middle and Lower Uruguay in 1987, considers this section of the river to be generally clean.<sup>502</sup> There are isolated cases of contamination. The areas of higher pollution are downstream from the cities and industrial centers such as Salto-Concórdia, Paysandu-Colón and the mouth of the Gualeguaychú River. Heavy metals and agricultural chemicals of the organophosphate and organochloride groups were not found at elevated levels and are not considered problems for the lower stretch. Nevertheless, in the study by Angelini et al. (1992), which analyzed the presence of organochlorides in various aquatic species of the Lower Uruguay, high concentrations of organochlorides were found in a single individual from the Paysandu region. Metabolites of DDT in this individual reached 11.1 mg/g muscle tissue, heptachlor 2.2 mg/g, chlordane 2.8 mg/g, and dieldrin 0.2 mg/g. PCBs were found in all of the samples but not quantified.

The average total phosphorus concentration in the water varies between 93 mg/l and 130 mg/l (maximum values of 720 mg/l), indicating eutrophication. Total nitrogen follows this trend, averaging 336 mg/l and 941 mg/l (maximum of 5,430 mg/l)<sup>503</sup>. Pintos et al. (1992) detected problems related to organic pollution in the region of Paysandu (204 km from the mouth), where the release of domestic and industrial sewage causes high concentrations of phosphorous and nitrogen in the water. Dissolved oxygen here is only 14% of saturation, while solids have modified the granularity of the sediment and influenced the zoobenthic community.

## MANAGEMENT AND MITIGATION

### Fisheries Legislation

On the Brazilian section of the river a decree published annually by IBAMA prohibits fishing during the spawning season. The ban applies from November 1 to January 31 and prohibits fishing in the rivers, tributaries and marginal lakes, except for fishing using simple hooks. The regulation limits the catch and transport to 5 kg of a single type of fish and one additional individual of any size.

<sup>502</sup> CARU, 1993

<sup>503</sup> CARU, 1993

Sport fishing in the region is well developed and frequently conducted without compliance with the law. The lack of conservation awareness compounded by the lack of the inspectors in the region has led to great pressure on the fish stocks. The need to improve inspection capacity was made clear in a study by Hahn and Câmara (2000), which describes an inspection operation by IBAMA, SUDEPE and the Army during the ban on fishing in the municipality of Itapiranga, SC in 1988. Ten thousand meters of gillnets were confiscated in a short stretch of 1 km of the river. It was estimated that a single family caught between 3,000 and 4,000 kg of fish per week at a time when fishing was prohibited.

## Actions to Reduce Water Pollution

In the 1980s the Upper Uruguay was highly contaminated by industrial and urban effluents. Some of the principal tributaries, such as the Peixe and Canoas rivers, had long anoxic stretches periodically covered by foam.<sup>504</sup> Paper and cellulose factories, tanneries and other industries release residues without the necessary treatment. The fish community was certainly strongly affected by the contamination, causing fishing to shift from an economic to a recreational activity. Various reports confirm that during the phase of extreme pollution there was a long interruption of recreational fishing, due to the scarcity of fish and the poor appearance of the water. A 1986–1987 survey of the fish fauna between 1,510 and 1,770 km from the mouth, which includes the principal tributaries of the region, was unable to capture any of the principal migratory species of the Uruguay such as dourado, curimatá and piava.<sup>505</sup>

At the end of the 1980s, a large mobilization of the community and governmental authorities to reverse this situation resulted in a gradual improvement of the water quality of the region's rivers. In fish surveys in the same region from 1995–1998, Zaniboni Filho et al. (2000), observed *S. maxillosus*, *P. lineatus* and *L. obtusidens*, though this may have also been due to an expanded fishing effort and more collection sites than in the

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<sup>504</sup> Godoy, 1987

<sup>505</sup> Bertolotti et al., 1989

earlier survey. The improvement in water quality affected the structure of the fish community and there was a large alteration in species composition. Figure 4 shows a comparative analysis between the relative percentage of the 10 species that contributed most in biomass to catches between 1995 and 1998<sup>506</sup> compared with 1986 and 1987.<sup>507</sup>

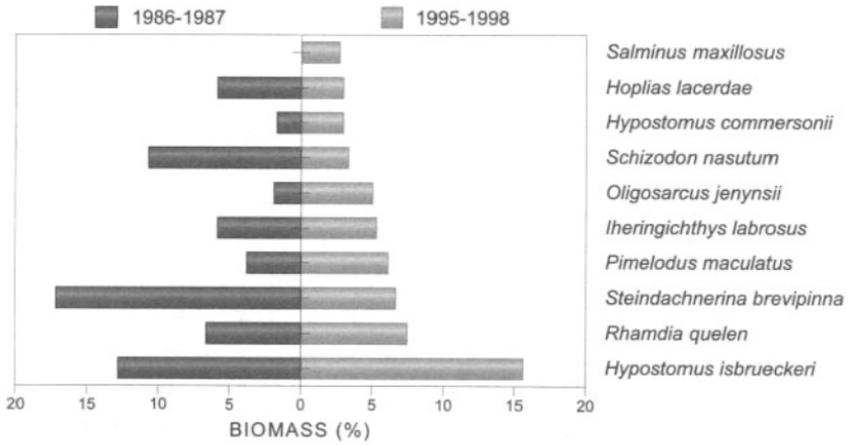


FIGURE 4. Relative fish biomass harvested in experimental fisheries of the Upper Uruguay in the 1980s<sup>508</sup> and in the 1990s<sup>509</sup>

Reduced water contamination resulted in increased populations of larger species, which are of greater interest for recreational fishing. The dourado, absent in the catches conducted in the 1980s, accounted for 3% of the biomass collected in the late 1990s. In contrast to the 1980s, where the fish community was based on species with short life cycles, environmental improvements in the 1990s made possible the establishment of a more complex fish community, including larger species, species with protracted life cycles, and migratory species. Nevertheless, despite the difference in composition of the fish communities observed in the two periods of collection, the overall catch per unit of effort were similar ( $\sim 30 \text{ g/m}^2/\text{day}$ .)

<sup>506</sup> Zaniboni Filho et al., 2000

<sup>507</sup> Bertoletti et al., 1989

<sup>508</sup> Bertoletti et al., 1989

<sup>509</sup> Zaniboni Filho et al., 2000

## The (EPISCar) Fish Hatchery

Despite the partial recovery of stocks, the migratory fish population of the Upper Uruguay continues to deteriorate. To aid in their recovery, the “Preservation of the Migratory Species of the Uruguay River” Project was implemented. Financed by the Brazilian Environment Ministry, construction began in 1995 on the São Carlos (EPISCar) fish hatchery in the Santa Catarina municipality of São Carlos, 1,380 km from the mouth. It is the only fish hatchery in the river basin that works exclusively with species of fish native to the Uruguay. Brood stocks were assembled for various species such as dourado, piava, curimbatá, mandi-pintado, piracanjuba and surubi. In addition to conservation *in vivo*, the genetic diversity of the fish stocks also began to be preserved *in vitro* through the storage of cryogenically preserved semen. The fish culture station aims to study and produce these species, both to support future programs for repopulating the upper stretches of the river basin and to promote the cultivation of these species instead of the exotic species presently cultivated.

Environmental education is another important activity at the fish hatchery. Their plans include aquaria and awareness materials on fish fauna and on the importance of preserving the Uruguay and address the varying interests of visiting groups. This activity has had enormous importance in the region, considering that a large part of the population is more familiar with the exotic species used in fish culture than with the species native to the basin.

## Minimum Flow Requirements for the Itá Dam

A sluice valve or “bottom outlet” was installed in the bottom of the Itá Dam. It was designed to regulate downstream flow during the filling phase, which began in December 1999, and minimize the environmental impact of the dam closure. It guaranteed a water flow in the old river bed equivalent to 80% of the minimum historic flow for the region. This inaugural use of the valve by the Itá Hydroelectric Project has proven efficient in reducing the impact on the downstream fish community.<sup>510</sup> Without the valve, a 20 km stretch of the Uruguay River would have dried out

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<sup>510</sup> Zaniboni Filho et al., 2000

completely. This type of valve has recently become a requirement by Brazilian legislation.

## Establishment of the Turvo Reserve

Future mitigation measures must also focus on the conservation of non-impacted areas. The preservation of the Turvo Reserve is therefore a high priority. Along the entire Uruguay River the 17,000 hectare Turvo State Park, nearly 1,200 km from the mouth, remains the only large reserve on the margins of the river. On the Argentine side there are five forest reserves totalling 84,000 hectares. The principal tourist attraction of the park is the Yucumã Falls, a longitudinal waterfall of about 1,800 m and up to 12 m high in the dry season, below which a crevice 90 m deep has formed.<sup>511</sup> The river crosses the park for approximately 40 km.

The Yucumã Falls are only a temporary obstacle to migrating fish. All evidence indicates that for various populations of migratory fish the area acts as a reserve from which fish move upstream and downstream. The excellent condition of the vegetation along the river banks appears to be the key. Because of the ecological importance of the park for the fish community, the preservation of the region and the protection of the fish stocks within the park are high priorities.

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

**I**n August 1999 the Administrative Commission for the Uruguay River, or Comissão Administradora do Rio Uruguai (CARU), held an international workshop to prepare a project that sought the conservation of biodiversity and the prevention and control of pollution in the river basin. The principal problems were identified as the need for information, loss of biodiversity, water quality, and deficiencies in institutions and management.

It was noted that the need for information is divided into two parts: the lack of systematization of the data already available and the lack of

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<sup>511</sup> Gonçalves, 1999

information itself. Data important to the management of the river basin exist in all three countries that encompass the Uruguay. This information, however, is spread through various federal, state and private institutions. It is extremely important to gather this information in a central database.

Information is lacking on knowledge of organisms, geological history and the various environments. There is still no complete information on the composition of the native and exotic flora and fauna, the levels of endemism, life cycles of the migratory species and genetic diversity of the populations, making comparisons of the current state of the fauna and flora with historic conditions impossible. Evaluation of the loss of biodiversity and of human impact is incomplete and based on a short time-frame, and the varying environments of the main river bed, tributaries, islands, marshes, and banks are insufficiently characterized.

The loss of biodiversity, even when restricted to a short-term evaluation, is difficult to quantify. The effects of using the river for navigation, fishing and irrigation are not well known, and activities leading to loss of biodiversity from agricultural, industrial and urban pollution must be identified and quantified.

The importance of biodiversity and its economic and ecological role is still underestimated by politicians. Consequently, there is little political will to apply environmental legislation. Actions for environmental inspection and control must be intensified. A management plan for the river basin is needed which will include the control of management techniques and land use, with permanent control and monitoring of the river and its principal tributaries.

Weak points in existing legislation include overlapping responsibility of authorities in environmental management and control, lack of harmonization of international and national legislation on natural resource use, lack of conservation strategies (such as the formation of an ecological corridor along the river), lack of conservation areas, and lack of policies on ecotourism.

The future management of the Uruguay must be based on factors that encompass the entire river basin. CARU co-ordinates the collection of fisheries data, carries out various studies to improve understanding of the basin's ictiofauna, and can act as a mechanism to regulate fisheries when stocks are threatened and conservation measures are necessary. The current activities of CARU are concentrated on the Lower and Middle

Uruguay, although in the future they should also take in the Upper Uruguay and intensify activities on the Brazilian side. The hydroelectric projects already begun or planned will completely change the ecosystem. The management of fish stocks should be adapted to this new situation in an effort to mitigate the effects of dams. Research projects that investigate the life cycle of the principal migratory species are therefore a high priority.

Other recommended actions include:

- 1) Investigation of the importance of the Turvo Reserve for the fish populations of the Middle and Upper Uruguay;
- 2) Developing an international program for tagging on all stretches of the river;
- 3) Broadening studies of the distribution of eggs and larvae, spawning locations and larval growth;
- 4) Researching biotelemetry methods for the mapping of species distribution and evaluating the importance of different environments in the life cycle;
- 5) Investigating "homing" behaviour;
- 6) Monitoring proposed re-population programs and guaranteeing restoration of the habitats required;
- 7) Evaluating methods to transport fish over the dams where possible;
- 8) Establishing *in vivo* and *in vitro* genetic banks for conservation of the threatened stocks;
- 9) Developing technology for fish-culture of native species and programs for re-populating critical areas of the river basin;
- 10) Undertaking studies to determine the existence of singular or distinct populations;
- 11) Launching a broad public awareness campaign to publicize the problems of the river basin;
- 12) Studying the influence of instream flow and the water level of hydroelectric reservoirs on the life cycle of the ichthyic community to determine the cycle desired to meet the interests of the fish fauna; and
- 13) Establishing a temporary ban on all net fishing in the region (there are efforts on the Brazilian side to enact this measure).

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MIGRATORY FISHES OF THE  
**São Francisco River**

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## CHARACTERISTICS OF THE BASIN

### Geography

The São Francisco River was first encountered by Europeans on the 4th of October, 1501 – Saint Francis' Day – by Américo Vespúcio and Gaspar Lemos, hence the river's current name.<sup>512</sup> Its basin covers an area of 631,133 km<sup>2</sup>, or 7.4% of Brazil's territory. The headwaters lie in the Canastra Hills, in the southern part of the state of Minas Gerais. After running north for about 2,300 km, through the states of Minas Gerais and Bahia, it turns east to run another 400 km between the states of Bahia, Pernambuco, Sergipe, and Alagoas to empty into the Atlantic Ocean.

The basin lies between 21° 00' and 7° 00' degrees of latitude (Figure 1) and at altitudes of up to 1,600 m above sea level. This area encompasses diverse climate conditions: annual average air temperatures of 18 to 27°C, relatively high evaporation rates of 2,300 to 3,000 mm/year, 2,400 to 3,300 hours of light/year, ecological domains ranging from Atlantic forest to Cerrado and Caatinga, and climates varying from the humid tropical to semi-arid.<sup>513</sup>

### Geology

The variety of soil types in the São Francisco Basin is due mainly to the diversity of geological formation and topography. Latosols and podzolyc soils predominate from the headwaters down to Petrolina, where the river turns towards the Atlantic. These soils are usually covered with *cerrado* and *caatinga* vegetation, the latter in the semi-arid regions. Detailed description of the São Francisco Basin soils is given in PLANVASF (1989).

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<sup>512</sup> Théry, 1980

<sup>513</sup> CODEVASF, 1991



**TABLE 1.** Main characteristics of the geographic regions of the São Francisco River Basin<sup>515</sup>

CHARACTERISTIC	UPPER	CENTRAL	SUB-CENTRAL	LOWER
	(HEADWATERS – PIRAPORA, MG)	(PIRAPORA, MG – REMANSO, BA)	(REMANSO, BA – PAULO AFONSO, BA)	(PAULO AFONSO, BA – MOUTH)
Altitude (m) <sup>1</sup>	1,600–600	1,000–400	400–300	500–0
Length <sup>2</sup> (km)	630	1,090	680	274
Change in elevation <sup>2</sup> (m)	700	50	250	200
Riverine conditions <sup>3</sup>	Fast, cool, oxygenated waters	Highland river, low flow, subjected to large floods	Almost entirely in reservoirs	Plains river, slow flow, under marine influence
Tributaries <sup>4</sup>	Perennial	Mostly perennial	Mostly seasonal	Mostly seasonal
Climate <sup>4</sup>	Humid tropical	Semi-arid tropical	Semi-arid tropical	Semi-humid tropical
Rainy season <sup>4</sup>	Nov.–Apr.	Nov.–Apr.	Nov.–Apr.	Mar.–Sep.
Rain <sup>1</sup> (ann. avg., mm)	1,500–1,200	1,400–800	800–400	1,300–400
Temperature <sup>1</sup> (ann. avg., °C)	18	27	27	25
Evaporation <sup>1</sup> (ann. avg., mm)	2,300	2,900	3,000	2,300

During the summer, the upper-central and lower segments of the river are prone to flooding caused by rains either on the headwaters or on the lower part of the river, respectively. Annual average river discharge is in the order of  $100 \times 10^9 \text{ m}^3$  or  $3,150 \text{ m}^3/\text{s}$ .

Brazil has over  $3 \times 10^6$  ha of reservoirs of which more than 23% are located in the São Francisco Valley. The large Três Marias, Sobradinho, Itaparica, Moxotó, Paulo Afonso complex and Xingó are large dams that have been built across the mainstem of the São Francisco River (Figure 1). Six further smaller dams have been built on tributaries of the Upper and Central São Francisco. Only two of these smaller dams have had demonstrable effects on migratory fish (Cajuru on the Pará River and

<sup>515</sup> MG = state of Minas Gerais, BA = state of Bahia; <sup>1</sup> PLANVASF, 1989; <sup>2</sup> Paiva, 1982; <sup>3</sup> Silva, 1981; <sup>4</sup> CODEVASE, 1991

Gafanhoto on the Paraopeba River); the remaining dams are beyond the natural distribution of these fish.

## Water Characteristics

### Upper São Francisco River and tributaries

Limnological parameters of the São Francisco main river channel in the stretch between the towns of Três Marias and Pirapora, in the state of Minas Gerais, are shown in Table 2.

**TABLE 2.** Limnological parameters of different habitats in the São Francisco River<sup>516</sup>

PARAMETER	RIVER	MARGINAL	MARGINAL	RESERVOIRS		
	CHANNEL <sup>1</sup>	LAGOONS <sup>2</sup>	LAGOONS <sup>2</sup>	TRÊS	SOBRA	ITAPARICA/ PAULO
	(UPPER)	(UPPER)	(CENTRAL)	MARIAS <sup>3</sup>	DINHO <sup>4</sup>	AFONSO <sup>5</sup>
Water Temp (°C)	18–29	...	24–30	24–30	26–30	27–28
Visibility (m)	...	...	...	1.0–4.1	0.4–1.6	0.3–1.4
Turbidity (mg SiO <sub>2</sub> /L)	...	6–174	...	...	...	...
Conductivity (µS/cm)	36–76	34–140	95–360	30–55	...	60–75
pH	6.3–8.2	6.1–7.2	6.7–8.3	6.1–7.7	5.5–6.8	7.3–8.0
Dissolved oxygen (mg/L)	...	...	5.0–7.2	6.5–8.9	4.4–7.0	7.0–7.5
α Chlorophyll (mg/L)	...	...	...	.82–4.50	...	...
Total P (mg/L)	...	...	...	6.3–30.7	...	...

In the das Velhas River, an important São Francisco tributary, water temperature and turbidity are similar to those of the São Francisco. However, during the dry season the pH may reach 12 and conductivity 300 µS/cm, due to the limestone nature of the region. In the other tributaries, the Paraopeba and Pará, these values did not substantially differ from those of the São Francisco.<sup>517</sup>

<sup>516</sup> <sup>1</sup>CETEC, 1983; <sup>2</sup>Sabará, 1996; <sup>3</sup>Esteves et al., 1985; <sup>4</sup>Pinheiro, 1981; <sup>5</sup>UFRPE, 1999

<sup>517</sup> CETEC, 1983

## Marginal lagoons

Physico-chemical parameters of several marginal lagoons of the Upper São Francisco were obtained by Sato and co-workers (1987) and, over a three year period, by Sabará (1996) for three marginal lagoons in the Central São Francisco. The three lagoons of the central river section, the Curral de Vara, Cajueiro and Juazeiro, were connected to the main river channel during the 1993/1994 floods. Two years later two of these still had large water volumes, but the Juazeiro dried up completely after just over one year. Conductivity in the Curral de Vara was higher than in the other marginal lagoons, probably because it is located in a carbonate-rich karstic landscape (Table 2).

## Três Marias Reservoir

Três Marias Reservoir is warm, oligotrophic, and monomictic: it is vertically stratified in November-February when the temperature difference between the epilimnium and hypolimnium is always greater than 3°C, and destratifies in July with vertical mixing during the dry season. Data on some parameters of this reservoir are shown in Table 2., together with characteristics of the Sobradinho, Itaparica and Paulo Afonso reservoirs.

## Habitats Used by Migratory Species

### Role of floodplains in migration

In tropical rivers, the floodplains – areas seasonally inundated by the lateral overflow of rivers and lakes<sup>518</sup> – are used by a large part of the fish community as habitat for feeding, reproduction and refuge.<sup>519</sup> During the dry season the flooded plains become isolated from the main channel. Some of these areas are perennially filled with water while the remaining dry out until the next flood. Colonisation by fish occurs during flooding and, as the waters recede at the start of the dry season, fish tend to return to the river. For those fish that remain after the connection with the river is cut off, high levels of predation, gradual exhaustion of food supply, and, in some cases, reduced oxygen levels and progressively less water<sup>520</sup>

<sup>518</sup> Junk et al., 1989; Junk & Welcomme, 1990

<sup>519</sup> Welcomme, 1979

<sup>520</sup> Junk et al. 1989

lead to gradual elimination of species in a sequence that may vary from lagoon to lagoon.

The São Francisco River is rich in floodplains and marginal lagoons, particularly in the stretch between the town of Pirapora, MG, and the Sobradinho Reservoir. Welcomme (1990) estimated that below Três Marias Dam the floodplains occupy an area of about 2,000 km<sup>2</sup>. The widest overflows are registered in the Central São Francisco (2–18 times the river width, averaging 9 km, and reaching 16 km at Januária, MG and 84 km at Xique-Xique, BA).

The importance of the São Francisco floodplains as migratory fish nursery habitat has long been recognised. Travelling in the area in 1817, Saint-Hillarie was probably the first to document the marginal lagoons,<sup>521</sup> created when the river overflows its banks between September and January, most intensely in December.

After adults reproduce in the mainstem and tributaries, eggs and larvae of the migratory fishes are carried downstream and, borne by floods, reach the marginal lagoons, which provide good habitat for the young with abundant live food (phytoplankton, zooplankton and other micro-organisms) and relatively high temperatures.<sup>522</sup> Under such conditions growth is rapid, and in a few weeks the juveniles are ready to re-enter the river. Since Moojen, many have recognised the floodplains, especially their lagoons, as special fish nurseries.<sup>523</sup>

In order to examine the role of lagoons in the recruitment of fishes into the reservoir, Sato et al. (1987) estimated fish richness in 81 marginal lagoons along a 130 km segment of the Upper São Francisco above Três Marias Reservoir. Twenty-eight of the lagoons were permanent, whereas the remaining ones dried up during the dry season. They varied from 3 to 70 ha in size and from 1.5 to 4 m in depth. Thirty-seven fish species were identified, representing 50% of the species present in Três Marias area.<sup>524</sup> Among the thirty-seven species, ten were migratory, and of these, juveniles of *Salminus brasiliensis* (<600 g), *Leporinus elongatus* (<40 g), *Prochilodus affinis* (<80 g), *Prochilodus marggravii* (<70 g) and *Pseudoplatystoma corruscans* (<600 g), captured in the lagoons, were not

<sup>521</sup> Sato et al., 1987

<sup>522</sup> Moojen, 1940

<sup>523</sup> for review see Menezes, 1956; Godinho, 1986; Sato et al., 1987

<sup>524</sup> Britski et al., 1984

present in the Três Marias Reservoir. At the time of the study, 25% of the biomass caught in experimental fisheries in the reservoir were of the adults of migratory species, indicating that their recruitment originated from marginal lagoons above the reservoir rather than from reproduction in the reservoir.

Pompeu (1997) carried out a recent two-year study on the effect of floodplain dryness on the fish communities of three marginal lagoons in the Central São Francisco. All three lagoons were connected to the main channel in the rainy season of 1993/1994 and thereafter remained isolated for the remaining period of study. The water level in two (Curral de Vara and Cajueiro) did not change substantially during the study, whereas the other (Juazeiro) dried out. Forty-eight species were captured, 44 in Curral de Vara and 34 in each of Cajueiro and Juazeiro. Seven of these were migratory: *Brycon lundii*, *Leporinus reinhardti*, *Leporinus taeniatus*, *P. affinis*, *P. marggravii*, *P. corruscans* and *S. brasiliensis*. Progressive reduction in species richness was registered in all lagoons throughout the study, caused probably by natural mortality and illegal fishing. In Cajueiro, migratory species disappeared significantly faster than non-migratory ones. Although the same tendency was observed in the other two lagoons, the differences were not significant.

### Upper São Francisco River

**Três Marias Reservoir** – The Três Marias Reservoir, filled in 1960, was the first large hydroelectric reservoir built in Brazil. It was originally constructed for flood control in the Central São Francisco, but now also generates electricity. The reservoir extends 100 km south in the state of Minas Gerais, covering an area of 105,000 ha.

The fish community lives only in the littoral zone of the reservoir, as there are no naturally occurring pelagic species in the São Francisco River. During the lowest water levels, the surface area of the reservoir is reduced by 20%, exposing extensive areas of dry land that is colonized by terrestrial vegetation – primarily grass. As the reservoir is devoid of rooted aquatic macrophytes, this vegetation functions as a temporary refuge and food for fish as the water levels rise. Due to the oligotrophic conditions of the reservoir, the flooded grass may constitute the main source of food for some species. Periphyton growing on submerged trees also constitutes a significant food source.

The reservoir also receives a number of tributaries of various sizes other than the main river. The largest of these is the Paraopeba River, which provides fluvial habitat for the fish of the reservoir.

The Três Marias Dam is 75 m high and has no mechanism for fish passage, effectively splitting the Upper São Francisco River into two parts.

**Above Três Marias Reservoir** – The first part of the Upper São Francisco River extends 150 km above the Três Marias Reservoir to the river source in the springs of the Canastra. Although located at higher elevations, in many places this part of the river is lined with marginal lagoons that are subject to periodic flooding. In the past, 28 of these lagoons were permanent.<sup>525</sup> However, 20% have now been drained for agriculture, with a corresponding reduction in fish production.

**Below Três Marias Dam** – The first part of the river below the Três Marias Dam extends about 140 km downstream to the town of Pirapora. The riparian vegetation here is probably the best preserved of the entire river. Many islands and rapids are present, and the stretch receives the first significant tributary, the Abaeté River, a rocky-bottomed highland river with many falls, about 32 km below the dam. Both the main river and the tributary are practically devoid of floodplains.

During most of the rainy season (the period of migratory fish reproduction), the water temperature from Três Marias Dam to the Abaeté River is usually 3–6°C below that of the Abaeté. This is because the reservoir is thermally stratified at this time<sup>526</sup> and water for the turbines is taken from the bottom of the reservoir. Many migratory species appear to spawn in the Abaeté River, but spawning apparently does not occur in the main São Francisco channel between Três Marias Dam and the Abaeté River.

### Central São Francisco River

The Central São Francisco River is a long stretch of about 1,200 km in which the river runs slowly and freely without significant falls or other obstacles, enabling navigation between Pirapora, MG and the Sobradinho Reservoir in Bahia. It is also characterised by many floodplains. The most important tributaries are on the west bank: the Paracatu, Urucuia, Carinhanha,

<sup>525</sup> Sato et al., 1987

<sup>526</sup> Esteves et al., 1985

Corrente and Grande rivers. On the east bank, there are two further main tributaries: the das Velhas and the Verde Grande rivers. Of these, the Paracatu River is particularly notable for its important fisheries and extensive floodplains. In addition, the relatively small Pandeiros River, a tributary from the east that joins the São Francisco close to Januária, MG, contains a swamp that is a particularly important nursery habitat for migratory fishes.

The Sobradinho Reservoir, the largest hydroelectric reservoir in Brazil (approx. 420,000 ha in surface area and up to  $34 \times 10^9 \text{ m}^3$  in volume), takes up the northern (downstream) end of the central section of the São Francisco River. Constructed to regulate river flow and feed downriver hydroelectric plants, the waters are shallow and the dam has no mechanism for fish passage (although the navigation lock may serve this purpose). The rising waters of the reservoir obliterated extensive floodplains when the reservoir was filled in the early 1970s.

Relative to the Três Marias Reservoir, the Sobradinho is considerably shallower. During low water, the surface area of the reservoir is reduced by as much as 70%, which reduces fish habitat and fish production. Three sections of the reservoir are recognised, based on differing characteristics.<sup>527</sup> Section 1, adjacent to the dam, includes 60% of the reservoir area. This region has an average depth of 15 m and is devoid of aquatic vegetation. Strong SE–NW winds make fishing difficult in this section. The next adjacent upriver section, Section 2, includes 30% of the reservoir area, with an average depth of 8 m. This section is extensively covered by aquatic macrophytes, providing ample fish refuge and food. In 1987, 75% of the reservoir fishery production came from this section.<sup>528</sup> Section 3 contains the junction between the river and the upper reservoir. This area contains numerous marginal lagoons, and in 1987 was considered the principal nursery area for migratory species of the region.

The Semiarid Project has proposed diversion of water for irrigation to northeastern Brasil from the Sobradinho Reservoir, as well as from the downstream Itaparica and Xingó reservoirs and the river at Cordobó. This proposal was first put forward in the 19th century and has been very controversial for over 80 years, but currently appears to be experiencing a revival. Studies on potential impacts on fish fauna are presently under way, but have not yet been made public.

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<sup>527</sup> CEPED/PROTAM, 1987

<sup>528</sup> CEPED/PROTAM, 1987

### Sub-central and Lower São Francisco River

This portion of the São Francisco extends from the Sobradinho Reservoir to the ocean, dropping 450 m in approximately 950 km. The first stretch, from the Sobradinho Dam to the Itaparica Dam 450 km downstream, has no floodplains, only small and seasonal tributaries, and is greatly influenced by the operation of the Sobradinho hydroelectric power plant. Downstream of the Sobradinho Reservoir, in the region of Petrolina, one of the largest irrigation projects of the São Francisco supports extensive fruit growing. From the Itaparica Dam to the Xingó Reservoir, the river has a complex series of hydroelectric dams, and migratory species have practically disappeared from this stretch. The final dam on the river, the Xingó, was finished in 1994. This reservoir is located within the São Francisco canyon, and does not cover a much greater surface area than the original river bed. Below the Xingó Dam, the São Francisco River runs for a short distance in the canyon before reaching flatter land near the Atlantic Ocean. This area historically included a large number of marginal lagoons, but many of these have now been converted into agricultural land. Exotic fish species, especially Nile tilapia, have been introduced into all of the reservoirs.

## MIGRATORY SPECIES AND MIGRATION PATTERNS

**T**his section summarises the present status of migratory fish species in the various regions of the São Francisco Basin.

The fish fauna of the São Francisco River is composed of about 152 species.<sup>529</sup> About 8% of the species migrate to reproduce. Among these, seven species are probably long-distance migrants and the most important commercial fishes. They are the Characiformes *B. lundii*, *S. brasiliensis*, *L. elongatus*, *P. affinis* and *P. marggravii* and the Siluriformes *Conorhynchus conirostris* and *P. corruscans*. Of these, *B. lundii*, *S. brasiliensis*, *C. conirostris* and *P. corruscans* are listed as “presumably threatened” species of the state of Minas Gerais.<sup>530</sup>

<sup>529</sup> Travassos, 1960; Britski et al., 1984; Sato & Godinho, 1999

<sup>530</sup> Lins et al., 1997

Reproductive migration of fish appears to be a universal phenomenon in most South American rivers.<sup>531</sup> The fish, which migrate annually in the São Francisco, travel up the main river channel or in tributaries towards their spawning grounds. Their migration is a cyclic phenomenon that is most pronounced from October to January during the rainy season, when the water levels tend to rise,<sup>532</sup> temperatures are higher and the days are longer.

Despite its undoubted importance, the migration of South American fresh-water fishes has not attracted the attention of scientists as much as it has that of the communities living along the rivers. Along the São Francisco, all residents are familiar with the migratory phenomenon, known locally as *piracema* (an indigenous word meaning *pira* = fish, *cema* = jump), but about which no more than a few scientific papers have been published. As a result, important aspects of the São Francisco River *piracema*, such as feeding and reproductive habitats, shoal composition and structure, and homing and distances travelled between habitats remain poorly understood.

Migratory fishes of the São Francisco are group-synchronous spawners, i.e., they spawn only once in a reproductive period, and are iteroparous, i.e., they are able to spawn again for at least several more years. Records of actual natural breeding are not available in the literature and consequently spawning sites have not been registered for most of these fishes. Nonetheless, it is believed that they spawn in the river channel. The actual breeding phenomenon, known locally as *carujo*, has only been described by fishermen. In the case of *surubim* (*P. corruscans*), the female is described to stand upside-down at the water surface for short periods of time, liberating eggs that are fertilized by several males that swim over her abdomen in erratic patterns. This behaviour appears to be repeated several times a day by each female.

A study that demonstrated the great migratory capacity of *juçá* (*P. marggravii*),<sup>533</sup> tagged 1,012 fish on the São Francisco River at the future site of the Sobradinho Dam. About 10% of the marked fishes were recaptured. After 85 days one tagged *P. marggravii* was recaptured

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<sup>531</sup> for review see Petrere Jr., 1985

<sup>532</sup> Aguire, 1936

<sup>533</sup> reported by Pinheiro, 1981

800 km upriver,<sup>534</sup> and after 186 days, another was found 1,100 km upriver.<sup>535</sup>

The most important migratory species for commercial fishing in the São Francisco are listed below. Other species, commercially important in other neotropical basins but not in the São Francisco, were not considered in this chapter. Amongst these is the *mandi-amarelo* (*Pimelodus maculatus*), which is considered migratory in some basins, but apparently only carries out short distance movements in the São Francisco during the reproductive period. We feel the fish does not present the characteristic strategies of long distance migrators in the São Francisco and thus we have not discussed it at length in this chapter.

### ***Brycon lundii***

Known in Portuguese as *matrinchã*, this species is an omnivorous fish endemic to the São Francisco River Basin, reaching up to seven kg in weight with females larger than males.<sup>536</sup> Natural stocks of *B. lundii* are significantly reduced in some areas of the São Francisco River Basin, but the species remains important to both sport and commercial fishers near Três Marias Dam in Minas Gerais State.

### ***Salminus brasiliensis***

Known as *dourado* in Portuguese for its bright yellow colour, this species is also endemic to the São Francisco River Basin. The second largest species of the São Francisco, it is essentially a piscivore. The species can reach 1.4 m in length and 30 kg in body weight,<sup>537</sup> with females growing much larger than the males.

### ***Leporinus elongatus***

This species, known in Portuguese as the *piau-verdadeiro*, is the only large migratory fish amongst the three genera of Anostomidae found in the São Francisco, and is the largest known member of this family of fish. It is native to two of the largest South American rivers, the trans-national

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<sup>534</sup> above the town of Januária, MG

<sup>535</sup> above the town of Pirapora, MG

<sup>536</sup> Sato et al., 1997

<sup>537</sup> Ihering, 1968

Paraná-Paraguay and the São Francisco.<sup>538</sup> The species is distinguished by transverse stripes on the body and three dark spots that are faint or absent in larger specimens. The fish is omnivorous, limited in its diet by its relatively small mouth. It can reach up to 7.5 kg in body weight,<sup>539</sup> with females growing larger than the males.

### ***Prochilodus affinis* and *Prochilodus marggravii***

*P. affinis* and *P. marggravii*, known in Portuguese as *curimatá-pioa* and *curimatá-pacu*, respectively, are endemic to the São Francisco River. The latter is the largest member of the Prochilodontidae family, reaching more than 15 kg in body weight. *P. affinis* may grow above 6 kg, but apparently is not as important to the São Francisco fisheries as *P. marggravii*. All fish of this family are bottom (mud) feeders of great importance to river and reservoir fisheries in all of Brazil. In the 1980s, the Prochilodontidae, primarily *Prochilodus* spp., represented almost 20% of all Brazilian freshwater fishery biomass.<sup>540</sup>

Both species of *Prochilodus* in the São Francisco River are probably long-distance migrants, and both are commercially significant. The lower segment of the Upper São Francisco River, below the confluence with the Abaeté River, is a particularly important fishing and spawning area. Production of this species in the Três Marias and Sobradinho reservoirs was extremely high for an initial period after flooding, but has since declined dramatically.

### ***Conorhynchus conirostris***

*C. conirostris*, known in Portuguese as the *pirá*, is a unique catfish species endemic to the São Francisco,<sup>541</sup> distinctive for its lack of dorsal flattening typical of catfish, an unusual proboscis-like mouth, and a blue soft outer skin. The species feeds mainly on molluscs, but also eats insect larvae and pupae, worms and micro-crustaceans.<sup>542</sup> The fish is still significant to fisheries below the Três Marias Dam, but appears practically extinct above it.<sup>543</sup>

<sup>538</sup> Fowler, 1950

<sup>539</sup> Godoy, 1975

<sup>540</sup> IBGE, 1988

<sup>541</sup> Fowler 1951, Travassos, 1960

<sup>542</sup> Ihering, 1933, 1936, 1938, Ihering & Azevedo, 1934, Azevedo & Vieira, 1938

<sup>543</sup> Sato et al., 1987

### *Pseudoplatystoma corruscans*

This large piscivorous catfish is known locally as surubim, and is the largest and most valuable commercial fish in the São Francisco. The fish reaches 3.3 m in length<sup>544</sup> and over 100 kg in body weight, with females growing larger than the males.<sup>545</sup> The species appears to be a long-distance migrant, with the section of the river below the confluence with the Abaeté River particularly important to its reproduction and fishery. Yields of surubim from the Sobradinho Reservoir were high for several years after flooding, but have declined considerably since, though still relied on by commercial fishermen. Elsewhere on the river, surubim is also scarce: it constitutes just under 0.4% of total catch below Xingó Dam, and it is listed as a presumably threatened species of the state of Minas Gerais.

## IMPACTS ON MIGRATORY SPECIES

### Fisheries Impacts

**T**he São Francisco Basin is one of the most important locations for inland Brazilian fisheries. In the 1980s the basin supported about 25,000 professional fishermen.<sup>546</sup> Fisheries have evidently declined in recent decades, along with the number of fishermen. In the 1970s, landings in the São Francisco were around 25 kg/fisherman/day, while in the 1980s they were reduced to about 11 kg/fisherman/day in the central segment.<sup>547</sup> Since no long-term catch statistics are available, it is impossible to make good comparisons, but there is reason to believe the harvest continues to decline.

### The professional fisherman of the Upper-central São Francisco

Fisheries in the São Francisco River are carried out for subsistence, for income, and for recreation. The second of these categories is termed a “professional” fisherperson, defined legally and licensed as someone whose principal source of income is from fishing. However, the techniques

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<sup>544</sup> Ihering 1946

<sup>545</sup> Zarur, 1947 in Menezes, 1956

<sup>546</sup> PLANVASE, 1989

<sup>547</sup> Sato & Osório, 1988; Godinho et al., 1997

employed by these professional fisherpersons are largely artisanal, and N. Nordi (pers. com.) has recently (1997) described the professional artisanal fishermen of the Upper-central São Francisco thus:

“Four São Francisco “fishing colonies” have been organised in the state of Minas Gerais. A recent survey indicates that only approximately 600 fishermen fish regularly at present. However, this number should be considered with caution since non-registered professionals or even amateurs illegally fishing as professionals make it difficult to determine the true number.

The fisherman works with artisanal equipment made by his family. He paddles a small wooden canoe; motorized canoes are seldom seen. Species-specific equipment such as cast nets and hook and line predominate and are directed towards the most valuable species. Multi-species gear (gillnets) are also used, although the catches take non-commercial species as well. The cast nets are typically 3 m high, 30 m in circumference and 8–17 cm in mesh size. The gillnets are typically 30 m long, 3.5 m high and 12–20 cm in mesh size.

The fisherman’s daily working journey is dictated by nature, especially by fish behaviour. It is discontinuous but takes most of the day, preventing other activities from being carried out simultaneously. This apparent absence of non-stop effort and purposeful motion induces outsiders to feel, erroneously, that fishing is an indolent and disorganised activity.

A large portion of the catch is sold fresh to intermediaries. Only a few fishermen have refrigerators or freezers. The catch is usually not salted since there is no market for salty fish. Value is generally not added.

The family is made up of the fisherman, his wife and their children. The man is the head of the family. The wife, who is economically active, does her work in the husband’s company and in support of him. The lack of working opportunities outside of fishing maintains strong ties amongst family members. The families live aggregated in urban areas, usually in the poorest borough and in the poorest home of the street. The radio is the main entertainment and informative medium. Bicycles are the principal vehicle for travelling by land. The families do not consider the possibility of giving up fishing but do hope for this possibility for their children. A fixed job for their sons is a strong family aspiration and towards this end much of the family’s effort is put into their children’s formal education.”

## Upper São Francisco

Partition of the Upper São Francisco by the Três Marias Dam resulted in a drastic modification of the fish fauna, especially of migratory species. In the 10–15 years that followed dam closure, Três Marias Reservoir fisheries were still based on the same migratory species found in the lower parts of the river.<sup>548</sup> By the 1980s, however, the capture pattern had changed. Sedentary species such as the *piau-branco* (*Schizodon knerii*) and *corvina* (*Pachyurus squamipinnis* and *Pachyurus francisci*) replaced migratory species, with the exception of *curimatã* (*Prochilodus* spp.). In 1986, one hundred and fifty-eight active professional fishermen captured a total of about 400 metric tons/year in the Três Marias Reservoir.<sup>549</sup>

Although the fishing season in the reservoir is usually longer than that of the river, its productivity is lower and relies on small sedentary species of low value, except for *Prochilodus*. The reservoir fishermen's income is thus lower than that of the river fishermen (Table 3).

Três Marias Reservoir fisheries presently rely on *tucunaré* (*Cichla* spp.; peacock bass in English), *peçada-do-piauí* (*P. squamipinnis*), *mandi-amarelo* (*P. maculatus*) and *curimatã* (*Prochilodus* spp.). Tucunaré is a sedentary piscivorous Amazonian cichlid introduced into the São

TABLE 3. Fisheries yields from Três Marias Reservoir and from the area of the São Francisco River below the reservoir in 1986<sup>550</sup>

PARAMETER	RESERVOIR	RIVER
Area (ha)	80,000	2,000
Days of fishing	240	180
Production: kg/ha/year	5	117
kg/fisherman/year	2,640	2,000
Price of fish (Cr\$/kg)	7	16
Number of professional fishermen	158	130
Annual fisherman income (Cr\$)	18,400	32,000
Main species (order of importance)	1. piau-branco (s) 2. corvina (s) 3. curimatã (m)	1. curimatã (m) 2. dourado (m) 3. surubim (m)

<sup>548</sup> SUVALE, 1973

<sup>549</sup> Sato & Osório, 1988

<sup>550</sup> s = sedentary, m = migratory; Adapted from Sato & Osório, 1988 in H. P. Godinho, 1998

Francisco River Basin at the end of the 1970s probably for fish cultur and sport fishing. It was first caught in experimental fisheries in the Três Marias Reservoir in 1984<sup>551</sup> and, in less than 10 years, reached the important position it holds for fisheries today. As a consequence of the tucunaré introduction, however, the populations of some small-sized fish species, such as *Acestrorhynchus lacustris*, *Curimatella lepidura* and *Triportheus guentheri*, have experienced heavy declines<sup>552</sup>. Other long-distance migratory species appear in the professional catch of the reservoir, but always at low frequencies. This may mean that the floodplain area above the reservoir still functions as nursery grounds for these species, but at a much reduced scale.<sup>553</sup>

The lower segment of the Upper São Francisco River, below the Abaeté River, is an important fishing and spawning area for long-distance migratory species.<sup>554</sup> Since there are no floodplains in this area, eggs and larvae are carried down to the Central São Francisco where they can find suitable habitat for development. Fisheries are based on the migrants *P. marggravii*, *P. corruscans* and *S. brasiliensis*, which together make up about 95% of the catches. In 1980, 130 full-time professional fishermen captured 234 metric tons/year in this area.<sup>555</sup>

### Central São Francisco

The Central São Francisco remains the section of the river where migratory species are most abundant. Records of the Pirapora Professional Fishermen Colony indicate that catches in the Pirapora area in the 1980s were mainly of the migrants *P. corruscans*, *C. conirostris*, *S. brasiliensis* and *Prochilodus* spp.,<sup>556</sup> representing 96% of the total catch. However, only a small portion of the catch was brought to the Colony for marketing, which suggests that the data presented in Table 4 are underestimates with regard to the fish production of the entire area.

To study fishing practices and productivity a fishing boat of the Pirapora Professional Fishermen Colony was accompanied for 1 week/month over a period of 6 months in 1987.<sup>557</sup> The boat had a crew of 8–10 fishermen and the capacity to hold 2 tons of refrigerated fish. Fishing

<sup>551</sup> Sato & Godinho, 1988

<sup>552</sup> H. Godinho, unpublished observations

<sup>553</sup> Sato et al., 1987

<sup>554</sup> CODEVASE, 1988

<sup>555</sup> CODEVASE, 1988

<sup>556</sup> Godinho et al., 1997

<sup>557</sup> Godinho et al., 1997

5 days/week, the boat travelled about 180 km. Fishing efforts were aimed at *P. corruscans*, the most valuable table fish in the São Francisco, by employing a specialized bottom drift net – the *tarrafão*. A large cast net held vertically in the river by two fishermen from a drifting canoe, the mouth of the net facing downstream and its lower rim touching the river bed. When a fish is encountered, it is ensnared by releasing the top edge of the net. A characterization of the catch in this study is shown in Table 5.

Lower in the Central São Francisco, in the transitional area between the river and Sobradinho Reservoir, *P. corruscans* was the principal species caught in the marginal lagoons.<sup>558</sup> The tucunaré has now also been found in marginal lagoons of the Central São Francisco<sup>559</sup> and of the Paracatu

**TABLE 4.** São Francisco fish captures registered at Pirapora professional fishermen colony from July to December, 1987<sup>560</sup>

SPECIES	YIELD	
	KG	%
<i>Pseudoplatystoma corruscans</i>	8,749.3	91.3
<i>Conorhynchus conirostris</i>	187.0	2.0
<i>Salminus brasiliensis</i>	157.4	1.6
<i>Prochilodus</i> spp.	122.5	1.3
Others	367.4	3.8
Total	9,583.2	

**TABLE 5.** Fisheries yields of an artisanal fishing boat operating in the Central São Francisco (1week/month) during the period of July to December, 1987<sup>561</sup>

SPECIES	FISHING GEAR				YIELD	
	DRIFT NET	TARRAFÃO	HARPOON	GILLNET	KG	%
<i>Pseudoplatystoma corruscans</i>	1,557.7	284.4	105.2	0.0	1,947.3	88.6
<i>Prochilodus</i> spp.	18.5	98.1	0.0	9.5	126.1	5.7
<i>Conorhynchus conirostris</i>	61.7	29.0	1.2	0.0	91.9	4.2
<i>Salminus brasiliensis</i>	14.8	8.0	0.7	0.0	23.5	1.1
<i>Brycon lundii</i>	3.7	0.0	0.0	0.0	3.7	0.2
<i>Leporinus elongatus</i>	3.0	0.0	0.0	0.0	3.0	0.1
Total	1,659.4	419.5	107.1	9.5	2,195.5	
%	75.6	19.1	4.9	0.4		

<sup>558</sup> for review of old literature see Menezes, 1956

<sup>559</sup> Pompeu, 1997

<sup>560</sup> Godinho et al., 1997

<sup>561</sup> Godinho et al., 1997

River. As this introduced species is a particularly aggressive piscivore, there is great concern that its presence will negatively impact recruitment of migratory species that rely on the lagoons as a nursery.<sup>562</sup>

### **Sub-central and Lower São Francisco**

**Fisheries of the Sobradinho Reservoir** – The fishery productivity of the Sobradinho Reservoir was relatively high (50 kg/ha/year) for six years after the dam was completed in the early 1970s, but declined drastically during the following three years to approximately half of this value.<sup>563</sup> The early high productivity was thus probably due to the increased primary productivity and decomposition of organic detritus typical of newly formed reservoirs. The large catchment area of Sobradinho Reservoir could also have contributed to the high yields, particularly of the large migratory fishes, *P. marggravii* and *P. corruscans*, which made up over 70% of the total catches.

Although no current catch statistics are available, informal information from fishermen indicates that present fisheries for migratory species in the Sobradinho have sunk to a very low level. Today the non-migratory pescada-do-piauí (*Plagioscion squamosissimus*) introduced from the Paranaíba River by government agencies, is the main fish caught in the reservoir.

**Fisheries between Sobradinho and Xingó** – Fisheries are almost absent in this portion of the São Francisco River, with the exception of a small fishery for introduced tilapia in the Itaparica Reservoir.

**Fisheries below Xingó Hydroelectric Dam** – Fishing in this part of the Lower São Francisco is a traditional activity involving many part-time and full-time professional fishermen. As in other parts of the river, complaints of decreased catches are often heard, especially following closure of the Xingó Dam in 1994. However, the scarcity of data on fish catches in the Lower São Francisco permits no accurate analyses of long-term trends. Early reports by Schubart (1944) and reports by various northeastern Brazilian organisations in the 1990s<sup>564</sup> comprise the sole literature available on the subject.

<sup>562</sup> Godinho et al., 1994

<sup>563</sup> CEPED/PROTAM, 1987

<sup>564</sup> Costa & Coelho, 1998

In 1997, the total catch was estimated to be about 333 metric tons/year, of which the fishing colonies at Propriá, Penedo and Piaçabuçu were responsible for more than 85%.<sup>565</sup> *Prochilodus* sp. (locally known as *xira*, *curimatã* and *bambá*) and the marine *Anchoviella* (*pilombeta*) were the main species caught, representing, respectively, 35.1% and 32.6% of the total production.<sup>566</sup> According to the same report, other native freshwater migratory fish comprising less than 4% of the catches in professional fisheries were *Leporinus* spp. (*piau*), juvenile *Prochilodus* spp. (*bambá*), and *P. corruscans* (*surubim*) (Table 6). The introduced species *Colossoma macropomum* (*tambaqui* – an amazonian migratory fish), *Oreochromis niloticus* (*tilápia*), *Cichla* spp. (*tucunaré*) and *P. squamosissimus* (*pescadado-piaui*) made up 8.5% of the total catch (Table 6).

**Fisheries of the freshwater prawn *Macrobrachium carcinus*** – Very important to the Lower São Francisco fisheries is the large freshwater prawn *Macrobrachium carcinus* (locally known as *pitu*). Together with *surubim*, *pitu* is the most valuable species and the principal item in the fisherman's income. Although there are also complaints about the reduction in its capture, there have been no significant variations in production over the last few years (at Propriá, monthly production varied from 142.7 kg in 1994 to 200.7 kg in 1997).<sup>567</sup> However, as with the fish catches, the available data allows no prediction of production trends.<sup>568</sup>

**Sport fisheries in the São Francisco** – Although the São Francisco River and some of its tributaries are traditionally one of the main spots for Brazilian anglers, Godinho (2000) is the only known report on this activity. This study sampled two sites, one close to the Três Marias Dam and the other at the town of Ibiai, near the mouth of the das Velhas River. During the period of March, 1999 to April, 2000 *dourado* was the principal species caught at both sites, followed by *mandi-amarelo*, *surubim* and *curimatã* at Três Marias and by *mandi-amarelo*, *surubim*, and *piau* (*Leporinus* spp.) at Ibiai. Each angler caught 1.9 kg of fish/day at Três Marias and 1.0 kg of fish/day at Ibiai.

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<sup>565</sup> Costa & Coelho, 1998

<sup>566</sup> Costa & Coelho 1998

<sup>567</sup> Coelho, 1998

<sup>568</sup> Coelho, 1998

**TABLE 6.** Fisheries yields in the Lower São Francisco (below Xingó Dam) in 1997, showing contribution of migratory species<sup>569</sup>

SPECIES	POPULAR NAME	YIELD	
		TON	%
<i>Prochilodus</i> sp. <sup>1</sup>	Xira, curimatã, bambá	116.9	35.1
<i>Anchoviella</i> sp. <sup>2</sup>	Pilombeta	108.4	32.6
<i>Colossoma macropomum</i> <sup>1 3</sup>	Tambaqui	17.4	5.2
<i>Leporinus</i> sp. <sup>1</sup>	Piau	9.7	2.9
<i>Oreochromis niloticus</i> <sup>3</sup>	Tilápia	8.7	2.6
<i>Hoplias</i> sp.	Traíra	8.3	2.5
<i>Cichla</i> sp. <sup>3</sup>	Tucunaré	6.7	2.0
<i>Hypostomus</i> sp.	Cari	3.5	1.1
<i>Pimelodus maculatus</i> <sup>1</sup>	Mandim	3.0	0.9
<i>Plagioscion squamosissimus</i> <sup>3</sup>	Pescada-do-piaui	2.2	0.7
<i>Serrasalmus</i> sp.	Piranha	1.6	0.5
<i>Pseudoplatystoma corruscans</i> <sup>1</sup>	Surubim	1.3	0.4
Others		45.3	13.6
Total		333.0	100.0

## Other Impacts

The main threats to the fish fauna in the state of Minas Gerais, through which the São Francisco flows, were recently pointed out in a workshop at Belo Horizonte, MG that included representatives of most of the stakeholders involved in the fishery and its management.<sup>570</sup> These threats were ascribed to human activities that modify habitat quality, such as hydroelectric dam construction and operation, pollution and deforestation. Introductions of species not native to the watershed are also becoming a serious threat, particularly with the rapid growth of fee fishing aquaculture – currently the main source of such introductions.<sup>571</sup>

## Upper São Francisco River

In the part of the Upper São Francisco River that extends 150 km above Três Marias Reservoir, 28 of the marginal lagoons subject to periodic

<sup>569</sup> <sup>1</sup> migratory species, <sup>2</sup> marine species, <sup>3</sup> introduced species; Adapted from Costa & Coelho, 1998

<sup>570</sup> A. L. Godinho, 1998

<sup>571</sup> Alves et al., 1999

flooding used to be permanent. Twenty percent of these have now been drained for agriculture. Riparian deforestation has occurred throughout this section, and large industrial complexes (mainly sugar and acetylene plants) that pollute the catchment have been built.

The Paraopeba River, one of the two significant tributaries emptying into the river above Três Marias Dam, drains part of a highly populated area with very active industry and iron mining, and also supports large sand-extraction operations. Consequently the watershed is now in an advanced stage of deterioration, and fishing in this river has been closed for several years due to pollution.

The Pará River, the other important tributary of the São Francisco River above the Três Marias Dam, was once a valuable fishing ground. Today this dam and other small hydroelectric dams, together with agriculture, sand extraction and urban and industrial pollution have considerably reduced the catches. Below the Três Marias Dam, the Abaeté, an important rocky-bottomed highland tributary with many falls, has been affected by disturbance from diamond mining.

### **Central São Francisco**

The Central São Francisco region has suffered intense deforestation over recent decades, resulting in continuous sediment deposition in some important tributaries and in the main channel. Large irrigation projects in the area also draw on São Francisco waters.

The Urucuia, Carinhanha, Corrente and Grande rivers are less impacted by these activities, although they also run through areas of extensive agricultural development (especially the Corrente and Grande). However, intense agricultural activity has almost completely deforested the catchment of the Paracatu River, leading to heavy sediment deposition, and indiscriminate use of lead in gold mining has polluted this river further. The das Velhas River, which drains a largely industrialised and populated urban area, also carries a heavy pollutant load into the São Francisco, and the Verde Grande River occasionally dries out due to excessive water diversion for irrigation.

### **Lower São Francisco: Xingó Dam to the river mouth**

Due to river regulation, most of the original floodplains from the Xingó Dam to the river mouth are now occupied by agriculture and irrigation

projects. Fishing communities have blamed declining catches on the absence of the original flooding pattern. As a consequence, the introduction of artificial flooding regimes in this section is now being considered by CHESF (Centrais Eletricas do São Francisco).

## MANAGEMENT AND MITIGATION

### Fisheries Regulation and Management

**F**isheries management in the São Francisco, as in many other river basins, is based on fishing regulation and re-stocking. Despite having been in operation for decades, these management tools are frequently applied without adequate scientific basis. Management mistakes have thus been made in the São Francisco, as in other Brazilian river basins.

Brazilian fisheries regulations and fisheries development have historically been the exclusive responsibility of the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA). In 2000, however, fisheries and fish culture were placed under the jurisdiction of the Ministry of Agriculture. Practical consequences of this change have not yet been observed. A few states such as Minas Gerais have now also established their own regulations, which apply only to state rivers, i.e., those that run solely within state borders. In the case of the state of Minas Gerais, this legislation is very similar to the federal legislation, with some differences on, for example, a more restrictive fishing season in state rivers. The main regulatory measures used for fisheries management to date are these:

#### Seasonal limitations

Fishing is limited during the reproductive period of the main migratory commercial species. This season usually extends from mid-November to mid-February, but exact dates are set every year by IBAMA with, at times, additional restrictions from the state agency.

#### Size and catch limits

Minimum size limits for the main commercial migrants are shown in Table 7. These size limits apply to both commercially and sport-caught fish, but limits on the amount of fish that can be kept (catch limits) vary with the time of year and the class of fishermen. For professional

fishermen, there are no catch limits except during the reproductive period, while sport fishermen are limited to 30 kg of fish plus one fish of any weight. During the reproductive period, both professional and sport fishermen are limited to 5 kg plus one fish of any weight.

**TABLE 7.** Minimum size allowed for capturing the main commercial migratory fish of the São Francisco Basin<sup>572</sup>

SPECIES	SIZE (TOTAL LENGTH, CM)
<i>Brycon lundii</i>	22
<i>Salminus brasiliensis</i>	60
<i>Leporinus elongatus</i>	30
<i>Prochilodus marggravii</i>	40
<i>Prochilodus affinis</i>	30
<i>Conorhynchus conirostris</i>	45
<i>Pseudoplatystoma corruscans</i>	80

### Closed areas

Fishing is prohibited at distances of less than 1 km below and above dams, waterfalls and rapids, for both safety reasons and, as the fish aggregate in these places, to avoid potentially excessive impacts on the fish stocks. Fishing is also permanently prohibited in two large São Francisco tributaries, the das Velhas and the Paraopeba, due to alleged pollution.

### Fishing gear

The main gear used in professional fisheries of the São Francisco are gillnets and cast nets, with restrictions on mesh size, and, for gillnets, on length and height. Sport fishermen are allowed to only use hook and line, and during the reproductive season, both professional and sport fishermen are limited to the use of only hook and line.

Two further gear types, while illegal, are also used extensively in the São Francisco by professional fishermen. These are the tarrafão and the harpoon. The tarrafão, described earlier, is generally used near the shore in stretches of river previously cleaned of bottom debris, such as submerged tree trunks. This gear is highly selective for bottom-dwellers like *P. corruscans* (Table 5). Harpoons are used particularly for valuable species like *P. corruscans* and *S. brasiliensis*.

<sup>572</sup> IBAMA, 1995

## Effectiveness of enforcement

Enforcement is a state responsibility borne by federal IBAMA and state environmental agencies. The Forestry Police, a segment of the state military police, are the principal enforcement agents. Often, as in the case of the state of Minas Gerais, the number of enforcement officers is ineffective and most of them lack specific training. Adequate equipment is also not always available. Fishing out of season is probably the most common violation of the law, mainly committed by the professional fishermen. Illegal fishing gear (primarily gillnets that are too long) is also very common among these fishermen. Sport fishermen usually commit violations such as keeping fish of sub-legal size and fishing in prohibited areas.

## Fish Passages

Fish ladders have been built in some Brazilian river basins, mainly in the Paraná River. Evaluation of their efficiency, however, has generally not been done.<sup>573</sup> Only two fish ladders have been constructed in the São Francisco Basin. The oldest is a small fish ladder located in the headwaters of the Pandeiros River; it appears not to be currently in operation and no reports on its efficiency are available. Judging by its location and design, the ladder can be presumed to have only minor, if any, favourable impact on the migratory fish fauna of the region.

A small fish ladder was also recently built in a dam on the Paraopeba River close to a thermal electric plant near the town of Igarapé. An evaluation of the ladder's effect on the Paraopeba migratory fish stocks was begun before its completion in 1994 and is still underway. The capture of marked *P. affinis* and *L. elongatus* above it have demonstrated its efficiency for these species,<sup>574</sup> and experimental fisheries before and after construction have shown increased yields of migratory fishes above the ladder. However, the increased yields may have resulted exclusively from displacement of fish from below the dam; marginal lagoons and suitable reproductive area are absent in the section of river made accessible by the ladder.

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<sup>573</sup> Godinho et al., 1991

<sup>574</sup> Alves & Vono, 1997; Alves, personal communication

## Re-stocking Programs

The São Francisco River has been re-stocked with hatchery-reared fish since the early 1980s by the federal agency for the development of the São Francisco Valley (Companhia de Desenvolvimento dos Vales do São Francisco e do Paranaíba, CODEVASF), which has 6 hatcheries in operation along the São Francisco River and the Hydroelectric Company of the São Francisco (CHESF) has one. The mandate of these hatcheries is to produce fingerlings both for fish farms in the São Francisco Valley and for re-stocking the river and reservoirs. Fingerlings of introduced species are also produced by some of these hatcheries for the same purposes.

The Três Marias Hatchery station, located at the Três Marias hydroelectric power plant in the Upper São Francisco, was built as a legal requirement to mitigate the effects of the dam on fish. It is the principal CODEVASF hatchery that is devoted to production of fingerlings exclusively of species native to the São Francisco watershed. Technology for large-scale propagation of the principal commercial species of the river (primarily migratory species) has been developed here, and since 1983 about 7 million fingerlings (~10–20 cm in length) of *P. marggravii*, *P. affinis*, *L. elongatus*, *B. lundii*, *S. brasiliensis* and *P. corruscans* have been produced. These have been stocked primarily in the Upper São Francisco above the Três Marias Dam. The technology for mass production of *C. conirostris* is also being developed and this species will also be re-stocked in the near future.

Although the São Francisco re-stocking program is almost 20 years old, there are no quantitative reports on its efficiency, though qualitative reports indicate they are having an effect. For example, artisanal, sport and experimental catches indicate that *B. lundii* stocks, which were practically extinct locally, have been tenuously re-established above Três Marias Dam after re-introduction began in 1988. Others species, such as *L. elongatus*, *P. marggravii* and *P. affinis*, that were rare in early catches above the Três Marias Dam, have also been increasing in number following re-stocking that began in the 1980s.

Some re-stocking has also taken place in urban areas. Pampulha Lake, a 3 km<sup>2</sup> urban reservoir in Belo Horizonte that was originally constructed

for water supply, is in the catchment of the Upper São Francisco. In 1990 it was re-stocked with fingerlings of *Prochilodus* sp., *L. elongatus*, *B. lundii* and *S. brasiliensis*. Experimental and sport fisheries 23 months after re-stocking (Table 8) caught representatives of all species, apparently after good growth.<sup>575</sup>

**TABLE 8.** Growth of fish re-stocked at Pampulha Lake, Belo Horizonte, in the 1990s<sup>576</sup>

SPECIES	SIZE AT STOCKING		SIZE AT CAPTURE	
	STANDARD LENGTH (CM)	BODY WEIGHT (G)	STANDARD LENGTH (CM)	BODY WEIGHT (G)
<i>Brycon lundii</i>	~10	...	...	890
<i>Salminus brasiliensis</i>	18.7	105	59.0	4,000
<i>Leporinus elongatus</i>	10.2	20	36.5	1,200
<i>Prochilodus marggravii</i>	~10	...	39.1	1,700
<i>Prochilodus affinis</i>	11.4	400	38.5	1,600

## Water management

Water management is an important tool to increase fisheries production.<sup>577</sup> One approach, used effectively for rivers in some areas of the world, is the provision of artificial floods to enhance natural spawning of migratory species, as has been achieved in some other regions of the world.<sup>578</sup> This approach has not yet been tried in Brazil, though it is likely that such an approach would revitalize marginal lagoons and augment nursery habitats in both central and lower portions of the river and stimulate spawning in the lower river section, where river fluctuations are currently absent. Studies on these applications have started: CODEVASF has requested a proposal from the US Bureau of Reclamation for implementing artificial flooding below the Xingó Dam, and projects studying the needs for flooding marginal lagoons in other portions of the river have been recently proposed.

<sup>575</sup> Godinho et al., 1992

<sup>576</sup> Godinho et al., 1992

<sup>577</sup> Welcomme, 1989; Alves, 1995

<sup>578</sup> Welcomme, 1989

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

### Conservation Status of São Francisco Migratory Fish Species

In a recent workshop in Bolivia, attempts were made to identify priorities for conservation actions in large geographic areas of high freshwater biodiversity in Latin America and the Caribbean.<sup>579</sup> It was pointed out that over 85% of the freshwater biodiversity in the region is seriously threatened, more so than terrestrial biodiversity. The study indicated that the complex São Francisco ecoregion is regionally outstanding and ranked its conservation status as “endangered”. The basin was assigned a high priority for conservation at the regional scale.

At a workshop held to establish conservation priorities in the state of Minas Gerais, the fish fauna was included in such discussions for the first time.<sup>580</sup> The São Francisco River main channel and associated floodplains, from Três Marias Dam to the border with the state of Bahia, were indicated as having special biological importance. The Peruaçu River and Pandeiros River wetlands also fell into this category. The large tributaries in the region – Carinhanha, Paracatu, Urucuia, Verde Grande and das Velhas – were placed in the category of extreme biological importance because they include spawning habitats, have high species richness, and are essential to the integrity of the São Francisco floodplain areas.

### Proposed Conservation Actions

An overview of the conservation status of the various segments of the São Francisco River is shown in Figure 2. Actions proposed to prevent further damage of the São Francisco River should be directed toward controlling pollution, providing sustainable fisheries, and promoting recovery of the original riparian vegetation. Since the ecological balance within the basin is already precarious, any plans to divert its waters will drastically affect it.<sup>581</sup>

<sup>579</sup> Olson et al., 1998

<sup>580</sup> Costa et al., 1998

<sup>581</sup> Olson et al., 1998



Considering the present conservation status of the fish fauna in the São Francisco River Basin, we have the following specific recommendations for actions:

- Obtain data on the biology of migratory fishes and their respective habitats, including stock identification, population structure, identification of nursery, feeding and reproduction habitats, reproduction potential and establishment of specific parameters needed for fisheries regulation.
- Improve enforcement of existing environmental laws relevant to the basin, with special attention to fisheries, fish culture and fish introductions.
- Extend conservation priorities proposed for the state of Minas Gerais to areas in the rest of the river basin.
- Re-establish adequate flow rates and patterns to increase migratory fish populations. The São Francisco is now a regulated river devoted to hydroelectric energy production, where high flow peaks during the rainy season are almost absent. It is time to reconcile the country's demands for electric energy with the requirements of the migratory fishes to fulfil their life cycle. Studies are urgently needed on flow rates and patterns that are adequate to imitate natural episodic peaks for stimulating reproduction and flooding of marginal lagoons in the Central and Lower São Francisco.

## ACKNOWLEDGEMENTS

**T**he authors wish to thank CNPq/PADCT/CIAMB III (Grant no. 62.0088/98-2) for supporting the research described in this chapter and C. B. M. Alves and A. L. Godinho for their criticism of the manuscript.

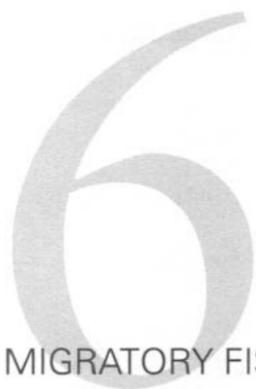
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MIGRATORY FISHES OF THE  
**Brazilian Amazon**

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## CHARACTERISTICS OF THE BASIN

### Geography

The Amazon drainage basin covers 7.05 million km<sup>2</sup> between latitudes 2° N and 15° S, occupying approximately 39% of the South American land mass. About 72% of the basin is in Brazil (5.1 million km<sup>2</sup>).<sup>582</sup> The basin is so broad that it cuts almost through the whole continent; from its far west (Andes Cordillera) to the Atlantic Ocean in the east. The main course of the Amazon River runs approximately parallel to the Equator at 2° south (Figure 1), changing names at least four times: Ucayali, Amazon, Solimões, Amazon. The river enters Brazil, near the Colombian-Peruvian border, as the Solimões River and changes to the Amazon River after meeting the Negro River. The river in its entirety will be referred to as the Amazon River unless otherwise indicated. The Amazon is currently connected to the Orinoco Basin through the Cassiquiare channel in the Upper Negro River. Menezes (1970) suggested that connections exist between the Amazon Basin and the Paraná Basin through the headwaters of the Madeira River, and in 1995 Ribeiro et al. reported an important watershed divide between the Amazon, São Francisco and Paraná basins in the headwaters of Tocantins River. However, during parts of the Miocene (23 to 5 million years ago) the Orinoco, Paraná and Amazon basins were also connected via a seaway.<sup>583</sup>

### Geology

The basin is composed mainly of four different geological formations. The Central Amazon is made up of weathered, re-deposited Tertiary and Pleistocene sediments of fluvial and lacustrine or perhaps marine origin.<sup>584</sup> Bordering the Central Amazonian sedimentation zone are two old

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<sup>582</sup> IBGE, 1992

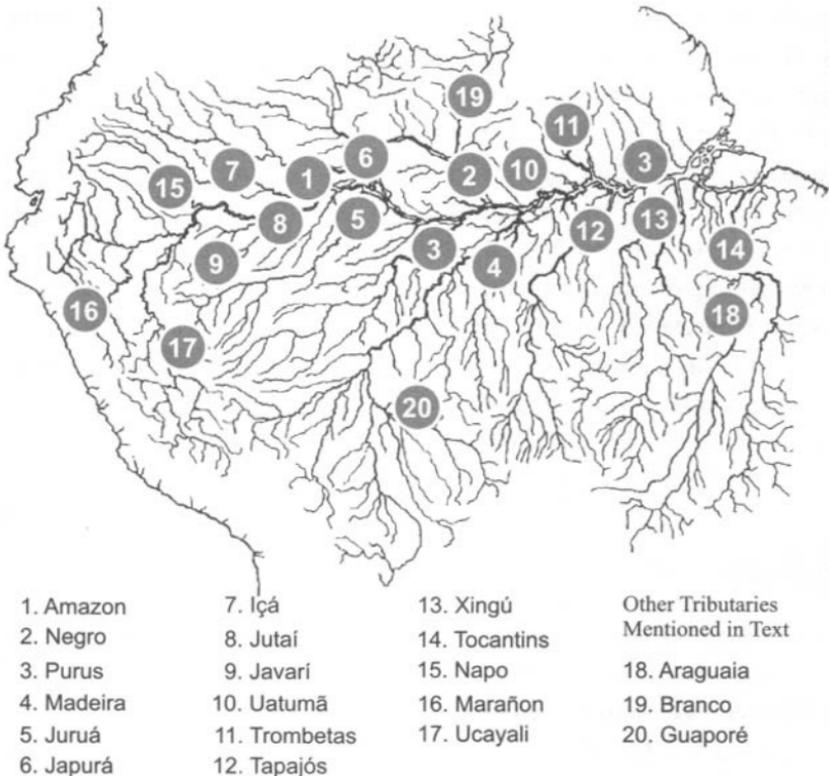
<sup>583</sup> Webb, 1995; Rossetti & Toledo, 1998

<sup>584</sup> Fittkau et al., 1975; Webb, 1995

Precambrian shields: the Brazilian shield in the south and the Guyana Shield in the north, both marked at their edges by cataracts in the rivers. In the most westerly region, the Tertiary zone is replaced by a broad Pre-Andean and Andean zone. Quaternary sediments eroded from these areas are deposited along the Amazon River and some of its tributaries.

## Physical Characteristics of the River

The Amazon River has 19 major tributaries, fourteen of which are in Brazil (Figure 1). The Tocantins River is geographically classified by the IBGE (Brazilian Institute of Geography and Statistics) as an independent basin, but since its fish fauna is very similar to that of the Amazon, we consider it here as part of the Amazon Basin.



**FIGURE 1.** The Amazon basin and its main tributaries

Rainfall is the main source of water in the Amazon Basin. Annual precipitation is higher in the western and eastern edges of the Amazon (> 2400 mm/y) and lower in the Central Amazon.<sup>585</sup> In sites near Manaus, in the Central Amazon, streams were found to drain 25% of the precipitation directly; leaves intercept another 25% and 50% is transpired by the plants back into the atmosphere.<sup>586</sup> Approximately 50% of the rainfall thus becomes runoff.

Large rivers are characteristic of the Amazon Basin, but they owe their flow and chemical load to a dense network of streams and small rivers. The streams, the first runoff collectors, vary in density throughout the basin. An area near Manaus, for example, has close to 2 km of stream per km<sup>2</sup>.<sup>587</sup> Water flow depends on the catchment area, but water storage is generally small and transit times short, so storms create temporary and short-term local floods. The streams of the Brazilian Amazon drain intensely weathered soils and are generally poor in nutrients (black and clear waters), again with variation according to the general categories of the watersheds. Sediment load in the water is usually quite low.

Preliminary surveys suggested that the streams are morphologically diverse. Most studies concentrated on streams of above the fourth order (Horton order). In relatively low-gradient terrain, streams follow meandering courses through flat-bottomed valleys bounded by flooded forest, but in other cases these streams run into steep valleys. The flooded forests of streams and small rivers cover as much as 1 million km<sup>2</sup> or 14% of the Amazon Basin.<sup>588</sup> The fish species of commercial value visit streams and small rivers seasonally, but spend most of their time in the larger rivers and their floodplains.

The Amazon River and its main tributaries, including the floodplains, covers 300,000 km<sup>2</sup>.<sup>589</sup> Seasonally flooded savannahs, in the southern and northern parts of the Amazon, account for another 250,000 km<sup>2</sup>. Therefore, 6% of the basin area is continuously subjected to inundation by medium and large rivers. Aerial and satellite imagery evaluation of the Brazilian part of the Amazon River mainstem and its tributaries revealed

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<sup>585</sup> Salati, 1989

<sup>586</sup> Salati, 1989

<sup>587</sup> Junk, 1993

<sup>588</sup> Junk, 1993

<sup>589</sup> Junk, 1993

that river channels and lakes occupy approximately 17% and 11% of this area, respectively; the remaining area is periodically inundated floodplain.<sup>590</sup> Lakes larger than 2 km<sup>2</sup> make up more than 50% of the total lake area.

Floodplain lakes in the Amazon Basin are not homogeneous. Some were formed in the ancient floodplain as isolated arms of the river, while others are formed by the inundation of valleys by small tributaries that drain highland forest. These tributary lakes have small catchment area and backed up water from the main river controls their flow.

Air temperature in the Amazon Basin ranges from 24 to 32°C. During the austral-winter, they may drop to 20°C or lower for a few days.<sup>591</sup> Mean water temperatures in the basin are 27–29°C, but in shallow and still water they reach over 34°C.

The mean annual discharge from the Amazon River (including the Tocantins River) is 210,000 m<sup>3</sup>/s,<sup>592</sup> whereas the discharge of the Solimões River fluctuates between 70,000 and 130,000 m<sup>3</sup>/s and the Negro River, the largest Amazon River tributary, flows at between 5,000 and 50,000 m<sup>3</sup>/s.<sup>593</sup> In each section of the river, water level in the floodplain is correlated with river discharge. Water level in the river fluctuates seasonally in a monomodal flood curve (Figure 2), being elevated for 7 months of the year. A gauge installed near Manaus has measured water levels ranging from 13.6 to 29.7 m above sea level (a.s.l.) during the last century. The mean annual water level change is 8 m near Iquitos and 10 m near Manaus; the change is less downriver.

Water levels in the central basin peak, rather predictably, in June, but peak earlier in the west and later in the east (low water levels occur between September and November). The inundation area varies between years, depending on the river water level and also on local rainfall.<sup>594</sup> Near Manaus, rising water levels can increase the flooded area eight fold.<sup>595</sup> The floodplain stores considerably more water than the main channel and contributes 30% of the flow of the mainstem, as shown by runoff calculations and isotopic studies.<sup>596</sup>

<sup>590</sup> Bayley & Petreire, 1989; Sippel et al., 1992

<sup>591</sup> Araujo-Lima & Goulding, 1997

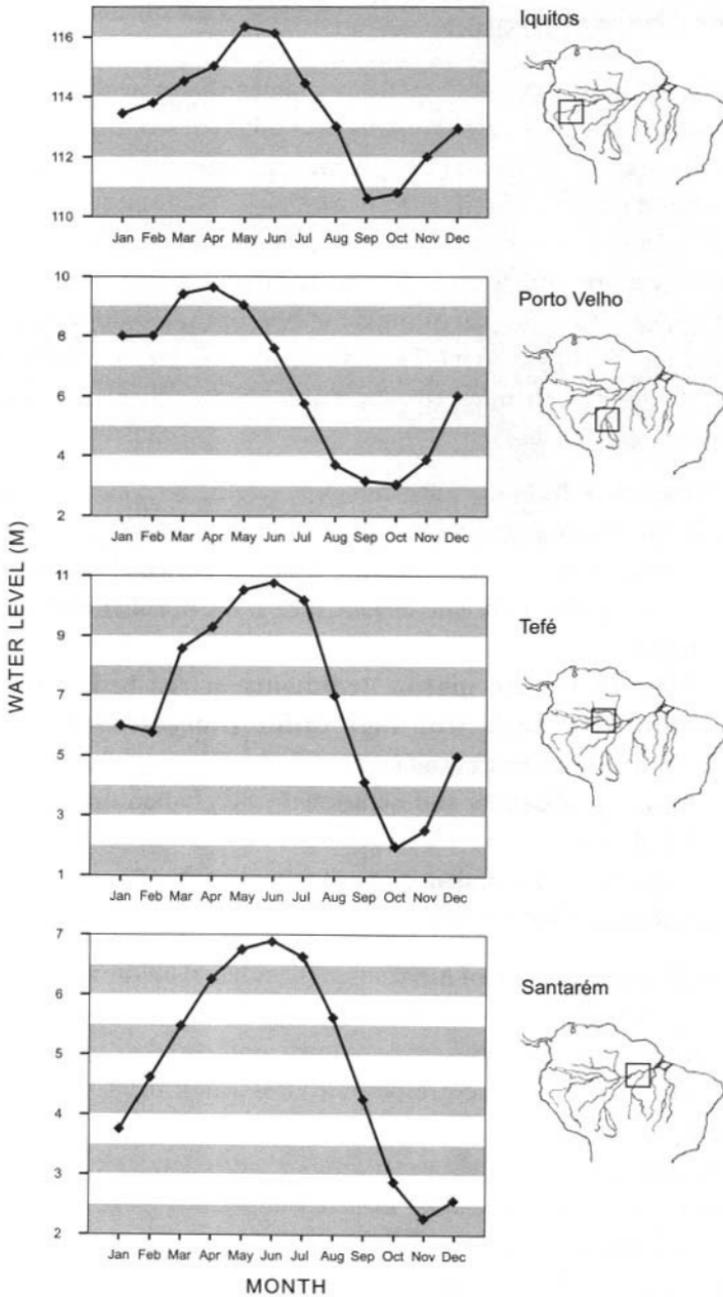
<sup>592</sup> Richey et al., 1986, 1997

<sup>593</sup> Richey et al., 1989

<sup>594</sup> Sippel et al., 1992

<sup>595</sup> Melack et al., 1999

<sup>596</sup> Richey et al., 1989



**FIGURE 2.** River water level fluctuation in four areas of the Amazon Basin<sup>597</sup>

<sup>597</sup> Adapted from Barthem & Goulding, 1997. Note: Iquitos River baseline for water levels differs from the Brazilian baseline.

## Water Characteristics

Amazon tributaries often have extensive drainage basins with a variety of different soils, and thus they have a range of different sediment loads and dissolved ion contents. Gibbs (1967) correlated these characteristics with the relief and the type of soil in the basins.

Stallard and Edmond (1987) further detailed the chemical analysis of tributary waters and found that alkalinity, silica and two anion concentrations ( $\text{Cl} + \text{SO}_4$ ) accounted for 99% of the variation in major dissolved ions of their waters. These three features are associated with soil weathering and chemical transport and can broadly place the rivers into four classes (Table 1):

- 1) Rivers that drain the most intensely weathered soils, such as the tertiary sediments, show high levels of Fe, Al, H and very low concentration of anions, and are relatively enriched in silica;
- 2) Rivers that drain siliceous terrain, such as the Brazilian and Guyana Shields;
- 3) Rivers that drain marine sediments or red bed, a type of sedimentary rock, with high cation concentrations, minor evaporites, carbonates and reduced shales. These exhibit high levels of Ca, Mg, alkalinity and occasionally  $\text{SO}_4$  (when draining areas with shale).
- 4) Rivers that drain massif evaporites enriched in Na and Cl (rock originating from evaporated seawater).

An older classification of Amazonian rivers based on the water surface colour<sup>598</sup> correlates roughly with this grouping scheme. "White water" rivers are alkaline with high sediment loads, and correlate with classes 3 and 4. "Clear water" rivers correspond to class 2 and "black water" rivers to class 1.

The dark colour of black water rivers is not related to geochemical processes, but rather to a heavy load of dissolved organic compounds (humic and fulvic acids). The humic material is produced in sandy soils (podzols), occurring mainly in *campina* and *igapó* forests (sparsely vegetated forest and flooded forest of black water rivers, respectively).

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<sup>598</sup> Wallace, 1853; Sioli, 1968

These have a surface humus layer, a bleached quartz horizon up to several meters thick and an underlying aluminous clay lens cemented with humic material.<sup>599</sup> The soils are highly acidic and generally wet, which results in the slow decay of the organic matter and allows continual leaching of humic material. The concentration of humic acid is over five times higher in black water rivers, such as the Negro and Jutáí rivers, than in the rivers with high sediment load, such as the Amazon, Juruá or Purus rivers. The

**TABLE 1.** Characteristics and classification of major Amazon tributaries and the Amazon mainstem<sup>600</sup>

RIVER	COLOUR	Q X 10 <sup>3</sup> (M <sup>3</sup> /S)	TSS (PPM)	TZ+ (UEQ/L)	PH	ALK (UEQ/L)	HEADWATER	CLASS
Marañón	W		500	1,183	7.2	926	Andean	4
Ucayali	W		800	3,590	7.4	1,459	Andean	4
Nanay	B			67	5.1	40	Lowland	1
Napo	W			450	6.8	427	Andean	4
Javari	W			327	6.4	277	sub-Andean	3
Amazon (Içá)	W	46.5	456 <sup>1</sup>	910	7.1	715	—	—
Içá /Putumayo	W	8.8	85 <sup>1</sup>	180	5.9	120 <sup>2</sup>	Andean	4
Jutáí	B	3.0	17 <sup>1</sup>	125	5.6	80 <sup>2</sup>	Lowland	1
Juruá	W	8.4	178 <sup>1</sup>	566	6.7	711 <sup>2</sup>	sub-Andean	3
Japurá/Caquetá	W	18.6	55 <sup>1</sup>	529	6.5	137 <sup>2</sup>	Andean	4
Tefé	B		8	80	5.9	67 <sup>2</sup>	Lowland	1
Coari	B			120	6.2	121 <sup>2</sup>	Lowland	1
Purus	W	11.0	74 <sup>1</sup>	295	6.2	301 <sup>2</sup>	sub-Andean	3
Negro	B	28.4	7 <sup>1</sup>	68	5.1	19 <sup>2</sup>	Shields	1
Uatumã	B					103 <sup>2</sup>	Shields	1
Madeira	W	31.2	627 <sup>1</sup>	420	6.7	410 <sup>2</sup>	Andean	4
Trombetas	C	2.6	9 <sup>2</sup>	190	6.2	146 <sup>2</sup>	Shields	2
Amazon (Óbidos)	W	168.7	230	422	6.6	440 <sup>2</sup>	—	—
Tapajós	C	13.5		145	6.8	96	Shields	2
Jari	C	1.9					Shields	2
Xingú	C	9.7	9.7	250	6.7	184	Shields	2
Tocantins	C	15.0				73 <sup>2</sup>	Shields	2

<sup>599</sup> Leenheer, 1980

<sup>600</sup> data marked with<sup>1</sup> are Martinelli et al. 1989a, 1989b;<sup>2</sup> are from Forsberg et al., 1988; all else from Stallard & Edmond, 1987. W=white water, B=black water, C=clear water, Q= mean discharge, TSS= mean total suspended solids, TZ+= total cations, ALK= alkalinity. See text for river classification details.

fine sediment particles in these latter rivers adsorb and neutralize the dissolved humic acids.<sup>601</sup>

The input of nutrients to the floodplain depends largely on the water the floodplains receive. Rivers with high sediment load and high alkalinity, such as classes 3 and 4 in Table 1, have higher concentrations of nitrogen and soluble reactive phosphorus than rivers that drain the tertiary and siliceous sediments (black and clear water or classes 1 and 2).<sup>602</sup>

Floodplains have two main water sources: the main river, and streams draining upland areas. Floodplains on islands in the river typically have small local catchment areas and are generally dependent on river water throughout the year. Nutrient inputs from most upland streams are very low because they drain the upland tertiary sediments, so the river water regulates floodplain fertility. In white-water floodplains where mainstem river water is alkaline and stream run-off is acidic, Forsberg et al. (1988) used alkalinity as an indicator of the source of the water in floodplains. In this manner, they showed that during high water the floodplain contains mostly water from the river, whereas during low water stream inputs to floodplain lakes dominated (depending on the ratio of the area of the lake to the area of the local drainage basin).

## Social Aspects of the Basin

Although the numbers are disputed, the human population of the basin before 1500 is estimated to have been between 0.5 to 5 million people.<sup>603</sup> The population density was especially high in the Amazon floodplain (15 people/km<sup>2</sup>), but the indigenous population was decimated very early upon contact with Europeans and little is known of its culture. The first European voyagers, who traded with local populations to obtain food, noticed the abundance of fish, turtles and other game in the basin.<sup>604</sup>

The human population of the Brazilian Amazon has grown to 11 million over the last 500 years.<sup>605</sup> Average population density in this region is only 2.2 inhabitants per km<sup>2</sup>, but 55% of the population is highly aggregated in 40 cities of more than 50,000 inhabitants.

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<sup>601</sup> Ertel et al., 1986

<sup>602</sup> Forsberg et al., 1988

<sup>603</sup> Carneiro da Cunha, 1998

<sup>604</sup> Porro, 1998

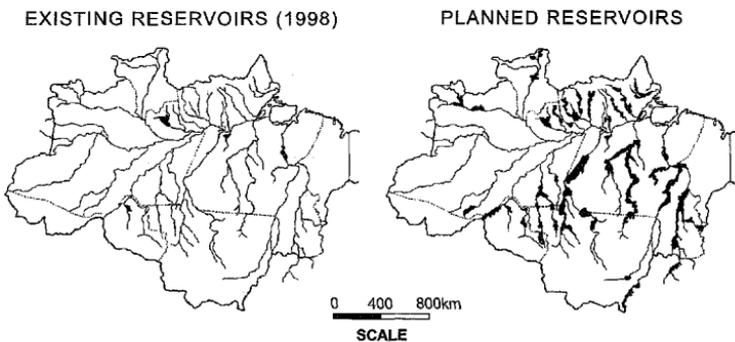
<sup>605</sup> IBGE, 1992

People fish intensively in the Amazon, not just as full-time professionals or for sport, but also as part-time employment or to supplement their diet. One reason for this is the proximity to large water bodies and the abundance of fish. Many farmers living on river banks, for example, have properties that include lakes or share floodplain lakes with their neighbours, so fresh fish can be caught only a few meters away from home.

## Habitats Used by Migratory Species

The main habitats used by migratory fishes are the river and its floodplain. Migratory catfish, with the exception of *Hypophthalmus* spp., concentrate in the river channels and estuary. The caracids migrate and spawn in the river channels but feed mostly in the floodplain. Floodplain habitats can be divided into three main mesohabitats: the open water of lakes, herbaceous vegetation and flooded forests. Herbaceous plants depend on high nutrient input, so in rivers with black and clear waters, such as the Negro River, this mesohabitat is much less developed.

Light penetration and nutrient input drive the algal primary production of habitats. The Amazon River and most silty tributaries are turbulent and turbid with a euphotic zone of less than 1 m, so phytoplankton production is almost nil. The floodplain, however, contributes part of its primary production to the river when waters are receding. Tributaries with low sediment loads have higher light penetration and support more primary production.<sup>606</sup> In floodplains the euphotic zone



**FIGURE 3.** Existing and planned reservoirs in the Amazon Basin<sup>607</sup>

<sup>606</sup> Putz & Junk, 1997

<sup>607</sup> Adapted from Fearnside, 1995

increases up to four meters as suspended solids settle out.<sup>608</sup> Plankton production is high in this habitat, particularly in rivers receiving nutrient-rich water. The flooded forest, with its easily accessible litter, plays an important role in supplying carbon to the food chain.

Another type of habitat in the Amazon Basin are man-made lakes. There are presently four large and three small reservoirs in the Brazilian Amazon, and a further 75 are planned.<sup>609</sup> The total area of the existing reservoirs is 5,700 km<sup>2</sup>, just under 0.01% of the whole basin (Figure 3). If all 75 planned projects are implemented the total area will rise to approximately 114,000 km<sup>2</sup>.<sup>610</sup>

## MIGRATORY SPECIES AND MIGRATION PATTERNS

### Catfish (Siluriformes)

#### *Brachyplatystoma vaillantii*

This fish is known as the *piramutaba*, *pira-botão*, and *mulher ingrata* in Brazil, *pirabutón* in Colombia and *manitoa* in Peru. It was described by Eigenmann and Eigenmann (1890) and commented on by Britsky (1981).

*B. vaillantii* occurs mainly along the mainstem of the Amazon River and its Andean and sub-Andean white water tributaries in the Brazilian, Peruvian and Colombian Amazon, as well as in the Orinoco and Maroni rivers (French Guiana). It is rarely found above rapids, except in the Madeira River,<sup>611</sup> and above the Middle Tocantins River.<sup>612</sup>

The fish is a medium sized riverine piscivore (max. 100 cm)<sup>613</sup>. It rarely visits the floodplain, preferring to inhabit the mainstem of the rivers.<sup>614</sup> Its migration has been investigated by tagging, field observation and fishery studies. Tagging conducted during the late seventies failed to produce any useful results, probably due to the large distances involved.<sup>615</sup>

<sup>608</sup> Putz & Junk, 1997

<sup>609</sup> Fearnside, 1995

<sup>610</sup> Fearnside, 1995

<sup>611</sup> Lauzanne et al., 1990

<sup>612</sup> Leite, 1993

<sup>613</sup> SL = standard length: length from tip of nose to end of vertebral column

<sup>614</sup> Barthem & Goulding, 1997

<sup>615</sup> Godoy, 1979

Fishery reports and field observations suggest that this species migrates 3,500 km upriver from the mouth of the Amazon River to spawn in Andean tributaries (400 m altitude), such as the Ucayali and Japurá rivers.<sup>616</sup>

Newly hatched larvae (< 10 mm) have not been found. However, large larvae and young juveniles (13–30 mm)<sup>617</sup> have been caught in the mainstem of the Amazon River, near Manaus and Tefé and near the mouth of the Xingú River.<sup>618</sup> Near Manaus, these juveniles were found at depths of 10–20 m, but only during the low water season, between September and November. None were observed during the high water season between March and July.<sup>619</sup> Juveniles less than 40 mm in length thus live in the mainstem and estuary of the Amazon, but large size classes (50–150 mm) have been found only in the estuary. Adults have been found throughout the Amazon River and its white water tributaries, but there are few accounts of sexually mature fish. Only a few mature females have been reported in the Solimões River near Tefé and in the Japurá River (the Caquetá River in Colombia).<sup>620</sup>

Upstream migration occurs between May and October. In the estuary *B. vaillantii* avoids salt water and during the low water season when the freshwater recedes, the fish move to the inner estuary.<sup>621</sup> During all life stages *piramutaba* lives primarily near the river bed.

**Landings**—Landings for *B. vaillantii*, which represent the longest fisheries time series for the Amazon Basin, were measured by SUDEPE beginning in the early 1970s. Currently, different institutions in Pará, including the Museu Paraense Emilio Goeldi in Belém, are collecting the data, which are then compiled by IBAMA.<sup>622</sup> Statistics in Pará State (> 70% of the catch) are relatively easy to collect because a relatively small fleet of large boats with few landing points carries out the fishery. The situation in other areas of the basin is less organized and only recently have landings begun to be monitored.

Piramutaba is the main fish caught, by weight, in the Amazon since the 1970s (Figure 4). Landings increased after 1972, peaking at

<sup>616</sup> Barthem & Goulding, 1997

<sup>617</sup> FL = Fork length, length from tip of nose to fork of tail

<sup>618</sup> Barthem, 1984; Barletta, 1995; Barthem & Goulding, 1997

<sup>619</sup> Barletta, 1995

<sup>620</sup> Barthem & Goulding, 1997

<sup>621</sup> Barthem & Goulding, 1997

approximately 29,000 tons in 1977. They decreased irregularly until 1992, but have since recovered to 20,000 ton/y (Figure 4). Because approximately 30% of the industrial fleet catch is rejected, it has been suggested that the total catch has been higher and in 1977 reached 32,000 tons.<sup>623</sup> Effort, however, has been increasing, and therefore catch per unit effort (CPUE) has been consistently decreasing.

This species is considered to be overexploited.<sup>624</sup> Indications of overexploitation are the high catch-to-biomass ratio of trawls in the estuary and the decreasing size of landed fish. The maximum sustainable yield calculated using the Schaeffer model from two sources were 19,929 tons/y and 20,900 tons/y, with a maximum effort of 48 boats and 5,900 days, respectively.<sup>625</sup> Both figures have been surpassed often in the last 25 years, which has always resulted in a subsequent decrease in the landings (Figure 4).

### ***Brachyplatystoma filamentosum***

*B. filamentosum* is known in Brazil as *piraiiba* or *filhote* (for individuals less than 80 kg), as *zúngaro salton* in Peru and as *pirahiba*, *lechero* or *valentón* in Colombia. It is a very large riverine piscivore (max. 300 cm), distributed through the whole Amazon Basin, including nutrient-poor tributaries of the Amazon River, the Tocantins and Araguaia rivers and the estuary.<sup>626</sup> Young juveniles of *B. filamentosum* were reported in the mainstem of the Amazon and Negro rivers.<sup>627</sup> Large juveniles and adults are found mostly in the mainstem of rivers and visit the floodplain only occasionally.<sup>628</sup> The migration pattern of *B. filamentosum* is not known.

**Landings** – Filhote is an important catfish in the fishery of Amazonas State. Average filhote landings between 1994 and 1996 in Manaus market were 4 tons/y.<sup>629</sup> Rezende (1998) reported a mean landing of 300 tons/y of filhote in seven fish-packing plants near Manaus, suggesting that Manaus harbour took in only 1% of the total landings in 1995 and 1996.

<sup>622</sup> Dias Neto & Mesquita, 1988; IBAMA, 1997, 1998, 1999; Anonymous, 1999

<sup>623</sup> Anonymous, 1999

<sup>624</sup> Anonymous, 1999

<sup>625</sup> IBAMA, 1997; Anonymous, 1999

<sup>626</sup> Barthem & Goulding, 1997

<sup>627</sup> Barletta, 1995; Garcia, 1995

<sup>628</sup> Zuanon, 1990

<sup>629</sup> Batista, 1998

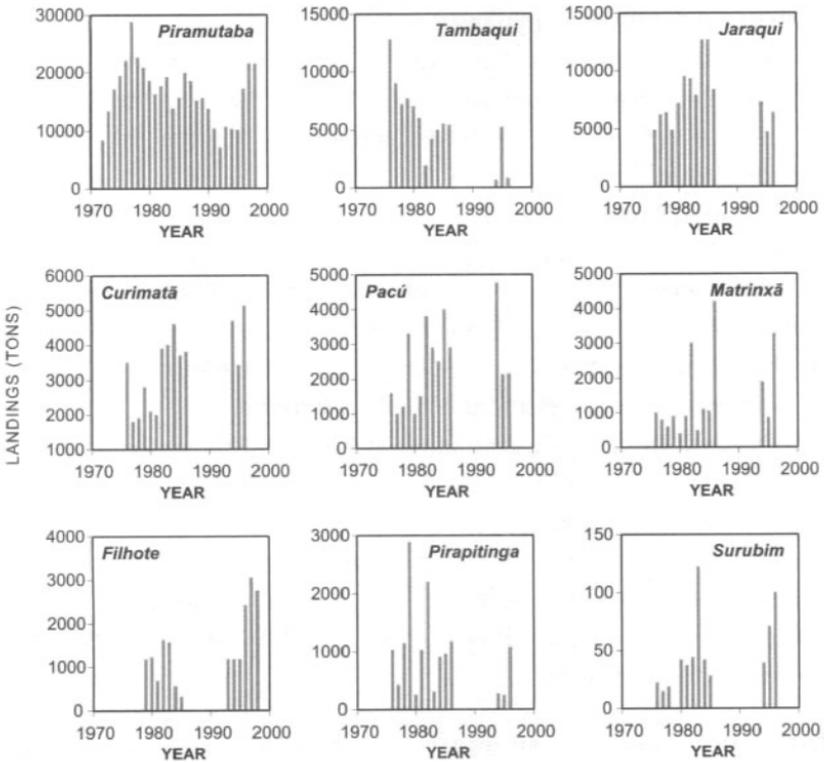


FIGURE 4. Long-term trends in yearly landings of representative fisheries products 1972–1998<sup>630</sup>

This confirms earlier expectations<sup>631</sup> that landings in Manaus are a small fraction of the total landings for filhote. However, figures from the packing plants have only recently been sampled and no reliable time series are available. In Santarém, filhote landings reached 150 tons/y in 1993.<sup>632</sup> The fish is relatively less important in Pará.<sup>633</sup>

### *Brachyplatystoma flavicans*

*B. flavicans* is known as the *dourada* in Brazil, *zúngaro dourado* in Peru and *dorado* or *plateado* in Colombia.

<sup>630</sup> Píramutaba landings refer to Belém (Anonymous, 1999) and other products to Manaus (Mérona & Bittencourt, 1988; Batista, 1998)

<sup>631</sup> Bayley & Petrere, 1989

<sup>632</sup> Ruffino et al., 1998

<sup>633</sup> IBAMA, 1998, 1999

The species is also a large riverine piscivore (max. 180 cm) that occurs in the Amazon River, from its estuary to its headwaters, including the tributaries of the Negro River, the Madeira River, the Tocantins River and others.<sup>634</sup> A very similar species or perhaps the same is found in the Orinoco River.<sup>635</sup>

Young juveniles (6 cm) have been found in the mainstem of the Amazon River,<sup>636</sup> and older juveniles (19–96 cm) were reported in the estuary,<sup>637</sup> where they occupy the upper strata of the water column. Large juveniles and adults (38–144 cm) are found in the mainstem and lower reaches of the tributaries, but the largest fish were reported only in the headwaters of tributaries and the Western Amazon.

The migration of the *dourada* is still poorly known. Barthem and Goulding (1997) hypothesized that schools of juveniles leave the estuary (the nursery ground) and disperse for two years in the Central Amazon where they feed and grow. After this period in the river channels the fish migrate upstream to spawn in the headwater of the Amazon River, the Madeira River, the Japurá River and other tributaries. The larvae drift downriver to the estuary.

**Landings** – *Dourada* is an important fish in the Amazonian fisheries statistics, and is landed especially in Pará State, where it reached over 5000 tons in 1998. Landings in Manaus in the same year were 1800 tons and in other cities such as Tefé, Manacapuru and Itacoatiara were negligible.<sup>638</sup> In Amazonas State, Rezende (1998) registered total landings in six fish-packing plants of 798, 929 and 1,155 tons in 1995, 1996 and 1997, respectively. This suggests a slight increase during this period. Catch per unit effort varied from 9 to 64 kg/fisher/day. Increased landings have also been reported in Santarém, Pará State. The figures jumped from 482 tons in 1992 to 793 tons in 1999.<sup>639</sup> However, values for the Belém market, probably the most important port for *dourada*, are not yet available.

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<sup>634</sup> Garcia, 1995; Goulding, 1980; Leite, 1993; Barthem & Goulding, 1997

<sup>635</sup> Garcia, 1995; Goulding, 1980; Leite, 1993; Barthem & Goulding, 1997

<sup>636</sup> Barthem & Goulding, 1997

<sup>637</sup> Barthem & Goulding, 1997

<sup>638</sup> SUDEPE, 1986; Barthem, 1999; Bittencourt, 1999

<sup>639</sup> Unpublished data from Projeto Iara/IBAMA

### *Hypophthalmus* spp.

Popular names for *Hypophthalmus* spp. in Brazil are *mapará* and *mapará bico de pena*, which refer to at least three species: *Hypophthalmus edentatus*, *H. marginatus* and *H. fimbriatus*. The three species are medium size planktivores (max. ~40 cm).

*Hypophthalmus* species are found in the Amazon River and its tributaries, but have not been reported in the upper part of some tributaries, such as the Trombetas,<sup>640</sup> Negro<sup>641</sup> and Juruá rivers.<sup>642</sup> A fourth species, *H. perperosus*, has been reported in the Tocantins and Araguaia rivers, but is probably *H. edentatus*.

Adults and juveniles of *H. edentatus*, *H. fimbriatus* and *H. marginatus* were sampled near the bottom of the Amazon and Negro rivers during most of the year, but are more abundant in the open water habitats of the floodplain.<sup>643</sup> Larvae of *Hypophthalmus* spp. were found drifting in the Amazon River in the flood season and also in floodplain lakes, including those of nutrient-poor rivers. Barletta (1995) reported larvae and juveniles in the Amazon and Negro rivers during the flood season (December to June), but only in the Negro River during the high and receding water season (July to September). Garcia (1995) mentioned high densities of juveniles in a floodplain lake of the Negro River in May. Juveniles have not been found among the macrophytes of the floodplain of the Amazon River;<sup>644</sup> they may occupy the open water of the lakes, which have not been sampled for all size classes.

Carvalho and Mérona (1986) studied the size distribution and movements of *H. marginatus* in the Lower Tocantins River before the filling phase of Tucuruí Reservoir and made inferences about its migration. They found young fish in the mouth, and adults in the Middle Tocantins River in January and February, in relatively homogeneous schools. Between March and October (the low water period) the schools of young fish swim upstream to the Middle Tocantins River, where they disperse. In November, maturing fish migrate upstream from the Middle Tocantins

<sup>640</sup> Ferreira, 1993

<sup>641</sup> Goulding et al., 1988

<sup>642</sup> Silvano et al., 2000

<sup>643</sup> Carvalho, 1980a, 1980b; Garcia, 1995

<sup>644</sup> Sánchez-Botero, 2000

River and spawn near the rapids in January and February. The eggs and larvae are believed to drift downriver to the mouth of the Tocantins River.

**Landings** – Mapará landings have only recently been reported. In seven fish-packing plants near Manaus, landings averaged approximately 400 tons/y between 1995 and 1997.<sup>645</sup> In Santarém, Pará State, landings were 810 tons in 1993.<sup>646</sup> Data for Belém were not available, but IBAMA reported landings ranging from 2,400 to 3,100 tons/y.<sup>647</sup>

### *Pseudoplatystoma* spp.

This group of species is generally known as *surubim* in Brazil, but in the Amazon *Pseudoplatystoma fasciatum* is *surubim* (max. 110 cm) and *P. tigrinum* is *caparari* (max. 130 cm). Both species are usually grouped in the landing reports as *surubim*. For convenience we will consider them together. Other names are *surubim lenha* or *surubim tigre* in Brazil, *pintado*, *rayadao*, *pintadillo* or *bagre tigre* in Colombia, and *zúngaro doncella* or *zúngaro tigre* in Peru.

Both species are piscivores and widely distributed in the Amazon Basin, excluding the estuary. *P. tigrinum* seems more concentrated in the lower reaches.<sup>648</sup> There are few accounts of larval distribution and juveniles. Adults have been found in the floodplains and in the mainstem of the Amazon River and tributaries.<sup>649</sup> The migration pattern of both species is unknown.

**Landings** – *Pseudoplatystoma* is an important catfish in the landing statistics of Amazonas State. The landings of *surubim* in Manaus market averaged less than 100 tons/y between 1986 and 1996 (Figure 4). Rezende (1998) reported a mean landing of 700 tons/y of *surubim* in seven fish-packing plants near Manaus, suggesting that Manaus harbour took in only 10% of the total landings in 1995 and 1996. However, figures from the packing plants have only recently been sampled and no reliable time series is available. In Tefé, *surubim* landings averaged 18 tons/y between 1991 and 1994.<sup>650</sup>

<sup>645</sup> Rezende, 1998

<sup>646</sup> Ruffino et al., 1998

<sup>647</sup> IBAMA, 1996, 1997, 1998, 1999

<sup>648</sup> Lauzanne et al., 1991; Barthem & Goulding, 1997

<sup>649</sup> Zuanon, 1990; Mérona & Bittencourt, 1993

<sup>650</sup> Barthem, 1999

In Santarém, surubim reached 500 tons/y in 1993.<sup>651</sup> The fish is relatively less important in Pará.<sup>652</sup> The average landing of *P. tigrinum*, which represents 6% of the total landing in Santarém, was 215 tons between 1992 and 1996.<sup>653</sup> The average catch per unit effort (CPUE) was 3.7 kg/fisher/day. The same authors, using a yield per recruit model, considered this species to be overexploited.

## Characids

### *Brycon* spp.

*Brycon* spp. are called *matrinxã*, *matrinchã*, *matrinchão*, *jatuarana*, and *piracanjuba* in Brazil, and *sábalo* in Peru.

The *matrinxã* is distributed throughout the Amazon Basin, comprising at least eight species in the Amazon<sup>654</sup> with unresolved taxonomic controversy. The present chapter uses taxonomy outlined in two relatively recent reviews of the genus,<sup>655</sup> but readers consulting the scientific reports will not always find the same nomenclature and distribution.

*Brycon cephalus* (max. 46 cm) is perhaps the most abundant species of *matrinxã* in the mainstem of the Amazon River and is the most studied. The other species in the mainstem are *B. melanopterus* (max. 28 cm), also known as *jatuarana*, *B. erythropterus*, which lives in the Peruvian Amazon, and *Brycon* sp., which occurs only in the Madeira River.<sup>656</sup> Both are smaller than *B. cephalus*, *B. brevicauda*, *B. carpophagus* and *B. falcatus* (max. 35 cm), which were reported in the Tocantins River and its tributaries, the Araguaia and Branco rivers.<sup>657</sup> *B. pesu*, a species listed in inventories of the Trombetas River and Branco River<sup>658</sup> may not be a distinct species,<sup>659</sup> but is also less important to fisheries. All species are omnivores/frugivores.

The larvae of *B. cephalus* are found in the mainstem of the Amazon River, and possibly in other high-nutrient tributaries.<sup>660</sup> Juveniles live in

<sup>651</sup> Ruffino et al., 1998

<sup>652</sup> IBAMA, 1998, 1999

<sup>653</sup> Ruffino & Isaac, 1999

<sup>654</sup> Howes, 1982; Géry, 1977; Géry & Mahnert 1992

<sup>655</sup> Howes, 1982; Géry & Mahnert, 1992

<sup>656</sup> Géry & Mahnert, 1992

<sup>657</sup> Costi et al., 1977; Ferreira et al., 1998; Leite, 1993

<sup>658</sup> Ferreira et al., 1988; Ferreira, 1993

<sup>659</sup> Howes, 1982; Géry & Mahnert, 1992

<sup>660</sup> Moura, 1998; Leite, 2000

the adjacent floodplain, mostly under the floating macrophytes. Adults are distributed throughout the floodplains, including the flooded forests of white and black water rivers.

The migration of this species is complex, apparently similar to that of *Semaprochilodus* spp.<sup>661</sup> Near Manaus, *B. cephalus* joins multi-species schools and migrates downriver from the Negro River to spawn in the Amazon River in December and January, as water levels there begin to rise.<sup>662</sup> A similar pattern was also observed for *Brycon* sp. in the Madeira River.<sup>663</sup> The embryos and larvae develop while drifting in the Amazon River, and probably get washed into the white water floodplains.<sup>664</sup> After spawning (February to March) the adult fish return to the black-water tributaries. Later in the year (May to August) these fish move downstream again from the Negro River or other nutrient-poor tributaries into the Amazon or Madeira rivers, where they remain until the end of the wet season in September. At this time, they move upstream again to the next nutrient-poor tributary and into forest streams, where they spend the dry season<sup>665</sup> before the next spawning migration.

The migratory movements of other *Brycon* species are less known. Borges (1986) suggested that *B. melanopterus* does not migrate downriver to spawn.

**Landings**—Matrinxã are important in landings in Manaus, varying from 500 to 5,100 tons in recent decades (Figure 4), and with a general increase since the 1970s.<sup>666</sup> In Tefé landings of matrinxã averaged 26 tons/y in 1992, 1993 and 1994.<sup>667</sup> During 1997 landings of matrinxã in three cities (Manacapuru, Itacoatiara and Parintins) totalled 60 tons.<sup>668</sup>

### *Colossoma macropomum*

*C. macropomum* is known as *tambaqui* in Brazil, *gamitana* in Peru, *pacu* in Bolivia, and *cachama* or *cachama negra* in Colombia. This species is

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<sup>661</sup> Petrere, 1985a

<sup>662</sup> Borges, 1986; Villacorta Correa, 1987

<sup>663</sup> Goulding, 1979, 1980

<sup>664</sup> Araujo-Lima, 1990

<sup>665</sup> Goulding, 1979; Borges, 1986; Villacorta-Correa, 1987

<sup>666</sup> Petrere, 1978b; Mérona & Bittencourt, 1988; Batista, 1998

<sup>667</sup> Barthem, 1999

<sup>668</sup> Bittencourt, 1999

widely distributed throughout the Brazilian Amazon, and is most abundant west of the Xingú River. It is found up to the headwaters of the nutrient-rich Madeira, Juruá, Purus and Içá rivers but seems restricted to the lower 300 km in nutrient-poor rivers.<sup>669</sup> It is a rather large omnivore/ frugivore fish (max. ~110 cm).

Larvae were reported in the Amazon River mainstem at the beginning of the flood season. However, young juveniles (10 cm) were found in the floodplain of other white water rivers, suggesting that larvae are also present in other nutrient-rich rivers such as the Purus and Madeira rivers.<sup>670</sup> Juveniles live under the aquatic macrophytes, which grow in the floodplains. Larger juveniles (greater than 30 cm), small juveniles and adults are all found in flooded forest during the flood season. However, juveniles stay in the floodplain during low water season, when adults leave for the adjacent river.<sup>671</sup> In the headwaters of the Madeira River juveniles and adults have been reported in flooded forests and in savannahs similar to those reported in the Orinoco Basin.<sup>672</sup>

The migration of tambaqui differs slightly from that of other characids (Figure 5). The adults feed in the forest during high water. As the water recedes the tambaqui migrate to the river where they remain until high water returns. They then slowly move upstream in schools and hide between fallen trees along woody shores until the spawning season (November to February). After spawning the fish stay in the river until the water floods the forest. Spawning seems to occur along the woody shores of nutrient-rich rivers,<sup>673</sup> and larvae drift in the river until transported to the adjacent floodplain. The pattern described in the Guaporé River, a tributary of the Madeira River, is similar.<sup>674</sup>

**Landings** – Schools of tambaqui are now hard to find in the river. The tambaqui fishery was very important in the 1970s, but landings in Manaus have decreased markedly from 15,000 tons/y in 1972 to 800 tons/y in 1996 (Figure 4). Tambaqui is especially important in Amazonas State, where it fetches top market prices. INPA and the University of Amazonas

<sup>669</sup> Araujo-Lima & Goulding, 1997

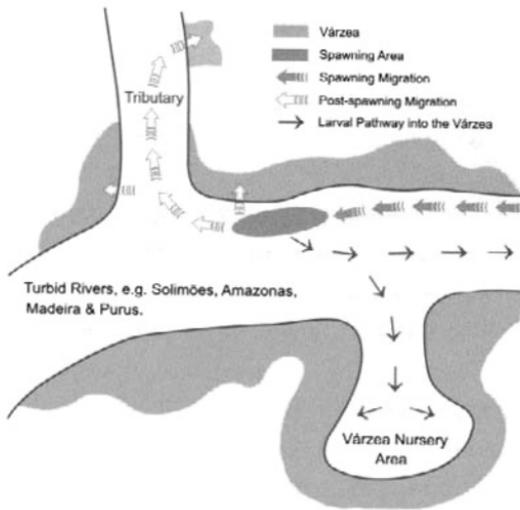
<sup>670</sup> Araujo-Lima & Goulding, 1997

<sup>671</sup> Araujo-Lima & Goulding, 1997; Costa, 1998

<sup>672</sup> Loubens & Panfili, 1997

<sup>673</sup> Costa et al., 1999a, 1990b

<sup>674</sup> Loubens & Panfili, 1997



**FIGURE 5.** Reproductive migration of tambaqui (*Colossoma macropomum*) in the Central Amazon<sup>675</sup>

(FUA) in Manaus have therefore actively monitored its landings. The main market for tambaqui is Manaus; however, the landing sites are now dispersed throughout the city, making data collection difficult. The catches are landed not only by the fishing fleet, but also by other boats hired by middlemen, who sell directly to city supermarkets and restaurants outside the catch area.<sup>676</sup> It is difficult therefore to know if the recent and extremely low reported landings reflect the actual catch.

Despite the problems associated with statistics, there is no doubt that the stock has been overexploited. Using different methods Petrere (1983) and Mérona and Bittencourt (1988) both reached similar conclusions in the early 1980s. Most fish currently landed are juveniles;<sup>677</sup> and although catches were already low in 1985, fishing effort has not been reduced even though CPUE has fallen. Mérona and Bittencourt (1988) tried without success to estimate the MSY for this species.

### *Piaractus brachypomus*

*P. brachypomus* is known as *pirapitinga* in Brazil, as *paco* in Peru or *cachama blanca* in Colombia. It was formerly considered part of the *Colossoma*

<sup>675</sup> Figure extracted from Araujo-Lima & Goulding, 1997

<sup>676</sup> Araujo-Lima & Goulding, 1997

<sup>677</sup> Araujo-Lima & Goulding, 1997

genus. Britski (1977) and Géry (1977) reviewed the species. Pirapitinga is a large herbivore (max. ~80 cm) distributed widely in the Amazon, Tocantins and Araguaia rivers and their main tributaries, including those poor in nutrients. It is also found above the rapids of these tributaries.<sup>678</sup> Pirapitinga occurs in the Orinoco Basin as well.<sup>679</sup>

Very little is known about the larvae. Juveniles are found in the floodplain of nutrient-rich rivers, often between the roots of aquatic macrophytes. Adults live in the flooded forest of the Amazon River and its nutrient-rich tributaries, but are also found in the headwaters of nutrient-poor tributaries.

The migration of the pirapitinga is not well known. Goulding (1979) suggested that it is similar to that of other migratory characins.

**Landings** – Pirapitinga landings in Manaus have varied from 200 tons/y to 2,900 tons/y between 1976 and 1996, but with no clear trend (Figure 4).

### ***Mylossoma* spp. and *Myleus* spp.**

*Mylossoma* are known as pacu, *pacu comum*, *pacu caranha*, *pacu manteiga* or *pacu branco* in Brazil. In Venezuela the fish is called *palometa*. There are actually two species: *Mylossoma duriventre* and *Mylossoma aureum*. Other species, such as *Myleus schomburgki*, *Myleus torquatus* and *Myleus rubripinnis* are occasionally marketed under this name, but in small quantities. *M. schomburgki* is also known as *pacu mula*. The other species are normally referred to as just pacu.

*M. duriventre* (max. 25 cm) and *M. aureum* (max. 20 cm) are omnivores distributed throughout the Amazon Basin, including the Amazon River, its main nutrient-rich tributaries, and the Tocantins and Araguaia rivers. They also occur in the lower reaches of nutrient-poor tributaries. The larvae of *Mylossoma* spp. have been reported drifting in the Amazon River.<sup>680</sup> Juveniles live under the floodplain macrophytes of the Amazon River,<sup>681</sup> while adults live in the flooded forest.<sup>682</sup>

Migration patterns have not been completely worked out, but seem similar to the patterns of other migratory characids like *Brycon* spp. At

<sup>678</sup> Goulding, 1980; Lauzanne et al., 1990

<sup>679</sup> Oliveira & Araujo-Lima, 1998

<sup>680</sup> Nascimento, 1992; Araujo-Lima, 1994; Oliveira & Araujo-Lima, 1998

<sup>681</sup> Sanchez-Botero, 2000

<sup>682</sup> Goulding, 1979

the beginning of the flood season, adults migrate from floodplain lakes to the Amazon and Madeira rivers, where they spawn.<sup>683</sup> The same migration presumably occurs in other nutrient-rich tributaries. Larval fish drifting in the rivers for a few days are carried to the floodplains where they develop. After spawning, adults return to the floodplain and disperse into flooded forests when they become accessible. There they feed until the low water period, whereupon they migrate to nutrient-rich rivers, swimming upstream to the next tributary or floodplain lake.

*Myleus* spp. are common in nutrient-poor tributaries, and less frequent in white water rivers. The movements of *Myleus* spp. have been less studied, but these species seem not to migrate to nutrient-rich water to spawn.<sup>684</sup> Juveniles of *Myleus* spp. have been reported in the floodplains of the Negro River.<sup>685</sup>

**Landings** – Manaus landings averaged 3000 tons/y in the 1994–1996 period. In Tefé (1992–1994) the mean catch was 73 tons/y.<sup>686</sup> During 1997, landings of pacu in three cities (Manacapuru, Itacoatiara and Parintins) totalled 360 tons.<sup>687</sup> Data for Santarém in Pará State from 1993 show landings of 102 tons.<sup>688</sup>

### ***Semaprochilodus* spp.**

*Semaprochilodus* spp. are known as the *jaraqui* in Brazil, and as *yarachi* in Peru and Colombia. Three species occur in the Brazilian Amazon: *Semaprochilodus insignis*, *S. taeniurus* and *S. brama*.<sup>689</sup>

This genus occurs only in the Amazon and Orinoco basins and in some rivers of Guyana.<sup>690</sup> *S. insignis* (max. 36 cm) and *S. taeniurus* (max. 35 cm) are widespread in the basin, occurring in most of its tributaries, but apparently not in the Xingú and Tapajós rivers. *S. brama* (max. 40 cm) occurs only in the Tocantins, Araguaia and Xingú rivers. All three species are detritivores.

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<sup>683</sup> Goulding, 1979

<sup>684</sup> Goulding, 1979, 1980

<sup>685</sup> Araujo-Lima et al., 1986

<sup>686</sup> Barthem, 1999

<sup>687</sup> Bittencourt, 1999

<sup>688</sup> Isaac & Ruffino, 1996

<sup>689</sup> Castro, 1990

<sup>690</sup> Castro, 1990

Recently-hatched larvae of *S. insignis* and *S. taeniurus* have been reported drifting in the Amazon River.<sup>691</sup> Juveniles of *S. insignis* and *S. taeniurus* were found in the floodplains of the Amazon River.<sup>692</sup> Adults and older juveniles of both species live mainly in black and clear water rivers,<sup>693</sup> where they are found in flooded forests, the main channel of the rivers and their tributaries, sandy beaches, floodplain lakes and forest streams. *S. taeniurus* prefers sandy beaches while *S. insignis* prefers streams. Both species are also found, at least temporarily, in white water rivers and floodplain lakes.

*S. taeniurus* and *S. insignis* migrate twice a year.<sup>694</sup> They undertake spawning migrations at the beginning of the flooding season, moving out from nutrient-poor tributaries (black and clear waters) downstream towards turbid-water rivers (white water) to spawn. *S. taeniurus*, in general, starts its migration before *S. insignis*. Spent fish return to the flooded forest of the same poor water tributary, where they feed for three to four months. Dispersal migration occurs in the middle of the floods when the fish descend from nutrient-poor tributaries once more and migrate upstream in nutrient-rich rivers, entering and successively leaving other tributaries until the low water season. When the water level starts to rise again the fish spawn in the mouth of the last nutrient-poor tributary entered. Ribeiro and Petrere (1990) suggest that jaraqui living in the upper reaches of tributaries are older and do not migrate, but they did not propose the age limit for migration. The non-migratory jaraqui are much larger than the migrating fish.

The migration pattern of *S. brama* in the Tocantins River and in the Middle and Upper Araguaia rivers differs from those of the two species described above.<sup>695</sup> These fish migrate upstream from lakes and the main channel at the beginning of the flood. During the migration their gonads mature and they spawn in the floodplains of the headwaters. After spawning they move downstream and spread into the flooded forests. When the water recedes they return to the main channel.

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<sup>691</sup> Nascimento, 1992; Araujo-Lima, 1994

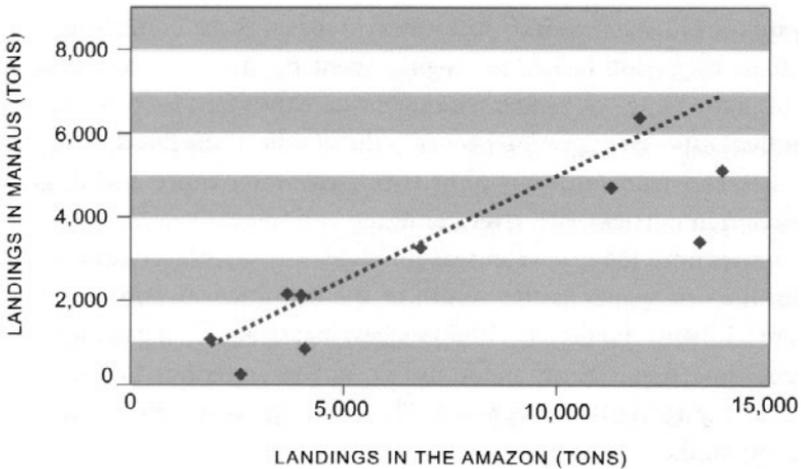
<sup>692</sup> Bayley, 1983; Araujo-Lima & Hardy, 1987; Fernández, 1993

<sup>693</sup> Ribeiro & Petrere, 1990

<sup>694</sup> Goulding, 1980; Ribeiro & Petrere, 1990

<sup>695</sup> Ribeiro et al., 1995

**Landings** – Jaraqui (*S. taeniurus*, *S. insignis*) are the second most-captured fish in the Amazon over the last two decades. Their total catch was difficult to measure due to the fragmentation of the landings over several ports, but was estimated in 1998 as 9,700 tons/y (Figure 4). The maximum landings in Manaus Central Harbour, the largest port of Amazonas State, was approximately 13,000 tons/y in the mid-1980s. If one assumes landings of this harbour represent approximately 50% of the total Amazonian landings (Figure 6), then the maximum catch in this period would be 26,000 tons/y. Landings have been decreasing since then, and in 1996 they had dropped to approximately 7,000 tons/y in Manaus harbour (Figure 4)<sup>696</sup> and 10,247 tons/y in the whole Amazon.<sup>697</sup>



**FIGURE 6.** Landings of representative characids<sup>698</sup> in Manaus relative to the whole Amazon basin<sup>699</sup>

Mérona and Bittencourt (1988) applied the Schaeffer model to jaraqui data and estimated a maximum sustainable yield (MSY) of 11,000 tons/y for an effort of 84.4 fisher/day, a yield reached only in 1985. Their estimation must be considered carefully because it was based on the yield of only part of the fishing fleet.

<sup>696</sup> Batista, 1998

<sup>697</sup> IBAMA, 1997

<sup>698</sup> matrinxã, jaraqui, pacu, curimatã and pirapitinga landings. Each circle represents one species in 1995 or 1996.

<sup>699</sup> The dashed line indicates Manaus landings if it was equal to 50% of basin's landings (Batista 1998; IBAMA 1996, 1997).

Average landings in other cities of Amazonas State were 250 tons/y in Tefé (1991–1994),<sup>700</sup> 500 ton/y in Itacoatiara (1996–1997), and 150 tons/y in Parintins and Manacapuru (1996–1997).<sup>701</sup> In Santarém, Pará State, the landing was 185 tons in 1993.<sup>702</sup>

There were no official fisheries statistics for *S. brama* in the Tocantins River,<sup>703</sup> but Costi et al. (1977) noticed that this species was relatively abundant in the fish assemblage of this river.

### ***Prochilodus* spp.**

Popular names for these detritivore species are *curimatã* in Brazil, *boquichico* in Peru, *sábalo* in Bolivia and *bocachico* in Colombia. Three species occur in the Amazon: *Prochilodus nigricans*, *P. rubrotaeniatus* and a third undescribed *Prochilodus* sp.<sup>704</sup>

Two species have a very restricted distribution: *Prochilodus rubrotaeniatus* occurs only in the headwaters of the Negro, Branco and Trombetas rivers<sup>705</sup> and the undescribed *Prochilodus* sp. has been reported in the headwaters of the Tapajós River. Therefore, most of the landings in the Amazon are probably of *P. nigricans*.

*P. nigricans* (max. 37 cm) is found in the Amazon River and its main tributaries, including the Tocantins River, at altitudes of up to 700 m and in the Brazilian, Peruvian, Colombian and Bolivian Amazon.<sup>706</sup> It does not seem to occur above the middle reaches of black water tributaries. The species' main habitats are the Amazon River, its white water tributaries and their associated floodplain. Newly hatched larvae are found in the Amazon River mainstem,<sup>707</sup> but may drift in other white water tributaries as well. First feeding larvae and more developed stages are found in the adjacent floodplains,<sup>708</sup> where they live among the roots of floating meadows, common in the floodplain during the spawning period.

Juveniles also spend most of their time associated with the herbaceous floodplain vegetation.<sup>709</sup> Adults are found feeding in the floodplains of

<sup>700</sup> Barthem, 1999

<sup>701</sup> Bittencourt, 1999

<sup>702</sup> Ruffino et al., 1998

<sup>703</sup> Ribeiro et al., 1995

<sup>704</sup> Castro, 1990

<sup>705</sup> Castro, 1990; Ferreira, 1993

<sup>706</sup> Loubens & Aquim, 1986

<sup>707</sup> Nascimento, 1992

<sup>708</sup> Bayley, 1983; Fernández, 1993

<sup>709</sup> Fernández, 1993

the Amazon River and its tributaries, especially in the flooded forest or under the herbaceous vegetation,<sup>710</sup> and migrating in the Amazon River and white water tributaries.

This species seems to have at least two migratory patterns. In the Amazon Basin, excluding the Tocantins River, *P. nigricans* adults migrate between successive floodplain lakes during the receding water season (September).<sup>711</sup> The distance they migrate during this period has not been measured. Later, at the beginning of the flooding season, this species leaves the floodplain lake systems to spawn in the mouths of their inlets.<sup>712</sup> The larvae drift in the river up to 15 days,<sup>713</sup> eventually being carried to the floodplain. Juveniles probably recruit to migrating schools at one or two years of age. The same pattern has been reported for the Madeira River.<sup>714</sup>

The migration in the Tocantins River seems to differ from the above pattern.<sup>715</sup> Before the construction of Tucuruí Reservoir, the fish left the floodplain during low water season and moved upstream. At the beginning of the flood season they spawned in an extended upriver region and then migrated downstream to the floodplain. The eggs and larvae were believed to drift passively towards the floodplains.

After the reservoir was constructed the movements remained similar in the Middle and Upper Tocantins rivers. At the beginning of the low water period the fish leave the floodplain and the reservoir and migrate upstream, and apparently schools of fish from the Lower Araguaia River also join this upstream migration. At the confluence of the Tocantins River and its tributary the Araguaia River, the fish seem to swap rivers. The fish of Tocantins River migrate upstream into the Lower Araguaia River and the inverse occurs as well.<sup>716</sup> When the water level starts to rise, schools of fish move to tributaries to spawn in the shallow and recently inundated areas (although spawning also takes place in the river). After spawning fish return to the reservoir or to their original floodplain lakes. Large numbers of young juveniles are found in the reservoir and floodplain lakes, so downriver larval drift must occur.

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<sup>710</sup> Mérona, 1988; Mérona & Bittencourt, 1993

<sup>711</sup> Fernandes, 1997

<sup>712</sup> Schwassman, 1978; Araujo-Lima, 1984; Petry, 1989

<sup>713</sup> Araujo-Lima, 1994; Araujo-Lima & Oliveira, 1998

<sup>714</sup> Goulding, 1980

<sup>715</sup> Carvalho & Mérona, 1986

<sup>716</sup> Ribeiro et al, 1995

**Landings** – In Tefé, landings in 1992, 1993 and 1994 averaged 232 tons/y of curimatã.<sup>717</sup> During 1997 landings in three cities (Manacapuru, Itacoatiara and Parintins) were 434 tons of curimatã.<sup>718</sup> Data for Santarém in Pará State from 1992, 1993 and 1994 revealed landings of 391, 185 and 962 tons of curimatã,<sup>719</sup> with an average CPUE of 6.8 kg/fisher/day. Landings are very high in Manaus reaching over 5,000 tons/y in 1996.<sup>720</sup>

### ***Potamorhina* spp., *Curimata* spp. and related species**

The fish marketed as *branquinha* is made up of many relatively small detritivore species (max. < 25 cm) within several genera. Fish from the genera *Potamorhina* and *Curimata* dominate landings, but *Psectrogaster* and *Curimatella* are also harvested occasionally. Vari<sup>721</sup> has recently reviewed the family and its taxonomy is now better organised.

Three species of *Potamorhina* (*P. latior*, *P. altamazonica* and *P. pristigaster*), six species of *Curimata* (*C. ocellata*, *C. vittata*, *C. kneri*, *C. inornata*, *C. incompta* and *C. cisandina*), two species of *Psectrogaster* (*P. rutiloides* and *P. amazonica*) and at least three species of *Curimatella* (*C. dorsalis*, *C. meyeri* and *C. immaculata*) are found in the Central Amazon and in the headwaters of nutrient-rich rivers.<sup>722</sup> *C. cyprinoides* was found only in the Tocantins and Araguaia rivers and *C. aspera* in the Upper Solimões River.<sup>723</sup>

The larvae of *Potamorhina latior* and *P. altamazonica*, *P. rutiloides*, *P. amazonica* drift in the mainstem of the Amazon River,<sup>724</sup> but not much is known about the larvae of *Curimata* and *Curimatella* spp. Juveniles are found in the floating macrophytes of floodplain lakes, while adults inhabit the flooded forest and the mainstem of the Amazon River.

**Landings** – Branquinha landings seem to be increasing in Manaus; in Acre, where their landings are higher, there are no time-series statistics.

<sup>717</sup> Barthem, 1999

<sup>718</sup> Bittencourt, 1999

<sup>719</sup> Mota & Ruffino, 1997

<sup>720</sup> Batista, 1998

<sup>721</sup> Vari, 1984, 1989a, 1989b, 1992

<sup>722</sup> Goulding, 1979, 1980; Vari, 1984, 1989a, 1989b, 1992; Silvano et al., 2000

<sup>723</sup> Vari, 1989a

<sup>724</sup> Nascimento, 1992; Araujo-Lima, 1991

## IMPACTS ON MIGRATORY SPECIES

### Fisheries

#### Social and economic significance

**A**mazonian freshwater fisheries contribute significantly to Brazilian harvest of aquatic animals: 15% of the Brazilian marine, freshwater and aquaculture production and 54% of all Brazilian freshwater fisheries production in the period of 1993 and 1998.<sup>725</sup>

Fisheries also play an increasingly important role in supplying protein to the Amazonian population. During the mid-seventies the average consumption of fish in Manaus and other cities near the Amazon floodplain was 160 g/person/day (fresh weight),<sup>726</sup> with slightly higher values in the lowlands of Peru.<sup>727</sup> More recent data from rural areas of the Central Amazon has shown that this consumption has increased to 300 to 800 g/person/day.<sup>728</sup> In these areas, where the average per capita income is less than US \$1,400/year, fish is the main protein source and is an important income-generating resource.<sup>729</sup>

In 1985,<sup>730</sup> there were an estimated 14,639 boats dedicated to artisanal fishing in Pará State, employing 79,000 fishermen. Of these boats 5,910 are equipped with an engine, 3,130 sail mostly by wind and 5,590, usually small wooden canoes of 6 to 12 m long, use paddles or a small outboard motor (5–8 hp). Approximately 60% of the boats had a gross storage capacity of less than 5 tons. The total catch of this fishing fleet was 95,000 tons, or 1.2 tons/fisherman/year. There was considerable regional variability: 55% of the artisanal fishermen fished in estuary and coastal waters, whereas the remainder fished in continental waters. Artisanal fishermen made up 17% of the Economically Active Population of the primary sector, with 33% in the Middle Amazon River of Pará; 72% in the Salgado/ Bragantina/ Viseu region and 82% in the microregion of the Marajó Island fields.

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<sup>725</sup> IBAMA, 1999

<sup>726</sup> Shrimpton & Guiliano, 1979; Smith, 1979

<sup>727</sup> Hanek, 1982; Eckman, 1985

<sup>728</sup> Cerdeira et al., 1997; Batista et al., 1998; Ayres et al., 1998; Fabr e & Alonso, 1998

<sup>729</sup> IBGE, 1992

<sup>730</sup> SUDEPE, 1986

A more recent analysis of this type is not available, but extrapolation from these data suggests that fishing in the last decade supported 780,000 people in the Amazon, equivalent to 15% of the total population and 34% of the rural population. This is probably an underestimate, as it is likely that decreasing availability of land for farming over this time has increased substantially the proportion of the population that fishes.

### Species contributing to Amazon fisheries

The principal species in the most recent landings reported by the Brazilian Agency for Environmental Protection (IBAMA; 1996–1998) were piramutaba (*B. vaillanti*), curimatã (*P. nigricans*), jaraqui (*Semaprochilodus* spp.), dourada (*B. flavicans*), matrinchã (*Brycon* spp.), tambaqui (*C. macropomum*), tucunaré (*Cichla* spp.), mapará (*Hypophthalmus* spp.), filhote (*B. filamentosum*), pirapitinga (*P. brachypomus*) and branquinha (*Potamorhina* spp., *Curimata* spp. and related genres) (Table 2). There may be some dispute about catch values or rank of species in this list, as IBAMA's compilation does not always agree with scientific publications, but there is little disagreement about the 24 species most frequently caught. These species have also been listed as the highest catches since the early seventies, although with some change in ranking.<sup>731</sup> The majority of these are migratory species that carry out reproductive migrations in the Amazon River or its nutrient-rich tributaries, and have larvae or juveniles that drift into nursery grounds in the estuary or floodplain. Yield from both habitats is strongly influenced by the high nutrient load coming from the Andean headwaters.

The species composition of catches in the two most productive states (Amazonas and Pará) are quite different from one another (Table 2). Fishers in Amazonas tend to catch more characids, whereas those of Pará concentrate on catfish. The emphasis on catfish is due to market preferences: the people in Amazonas State tend to believe that eating catfish is unhealthy, an opinion not shared by the people of Pará.

The total catch from the Amazon may be as much as three times the values presented by IBAMA (Table 2). For example, the unreported catches of subsistence fisheries in rural areas of Amazonas (including cities with less than 50,000 people) may total approximately 113,000 tons/y, which,

<sup>731</sup> SUDEPE, 1986

if added to the reported landings, would triple the total catch of this state and probably rank it officially among the highest fisheries producers of Brazil.<sup>732</sup>

The composition of subsistence fisheries shows good agreement with the commercial artisanal fisheries near Manaus,<sup>733</sup> Pará,<sup>734</sup> and Acre.<sup>735</sup> The reported catch does not seem, however, to reflect the natural fish abundance in the floodplains. Mérona (1990a and b) found that in the floodplain of Lago do Rei (Amazonas) the fishing fleet caught only 30% of the diversity and less than 75% of the estimated fish biomass of the floodplain. He attributed the mismatch to the great number of unexploited small species that could not be caught with the gear currently in use. A similar mismatch seems to occur in the Middle Amazon River as well. In the floodplain of the Lower Trombetas River, the fish assemblage biomass is dominated by *Plagioscion* spp. (15%), *Hydrolycus scomberoides* (11%), *Hemiodus* spp. (10%), anostomids (8%), *Cichla* sp. (5%) and *Auchenipterichthys longimanus* (4%).<sup>736</sup> Most of these species are relatively unimportant in the landings of Santarém and Parintins, two nearby cities.<sup>737</sup>

### Statistics used in evaluating landings

Fishery statistics have not been continuously collected in the region. There are adequate statistics of the main market in Manaus from INPA's Fisheries Department for the mid-1970s to mid-1980s,<sup>738</sup> but sampling was interrupted from the mid-1980s to the early 1990s. Landings in Manaus are once again being monitored, this time by the University of Amazonas.<sup>739</sup> Landings in Belém and Santarém, the most important cities of Pará State, and Tefé in Amazonas State have also recently begun to be monitored by research groups from the Museu Paraense Emilio Goeldi, Projeto Iara and Mamirauá Institution, respectively.<sup>740</sup> Other cities, such

<sup>732</sup> The unreported catch from the State was calculated by using the average daily fish consumption of 300g/day for a rural population of 1.03 million people.

<sup>733</sup> Batista et al., 1998

<sup>734</sup> Begossi & Braga, 1992

<sup>735</sup> Silvano et al., 2000

<sup>736</sup> Ferreira, 1993

<sup>737</sup> SUDEPE, 1986; Ruffino et al., 1998

<sup>738</sup> Petreire, 1978a, 1978b; Mérona & Bittencourt, 1988

<sup>739</sup> Batista, 1998

<sup>740</sup> Ruffino & Isaac, 1995; Barthem, 1999

TABLE 2. Landings by species group in seven states of Brazilian Amazon in 1998<sup>741</sup>

SPECIES	CATCH (TONS)							
	TOTAL	AM	RO	AC	RR	PA	AP	TO
Piramutaba – <i>B. vaillanti</i>	21,458	5,287	168	0	0	15,626	377	0
Jaraqui – <i>Semaprochilodus</i> spp	9,700	8,845	319	72	5	210	100	149
Curimatã – <i>P. nigricans</i>	9,135	6,542	509	242	7	1,187	405	243
Dourada – <i>B. flavicans</i>	8,254	1,606	231	90	9	5,270	1,048	0
Matrinxã – <i>Brycon</i> spp	4,237	3,328	425	108	5	61	264	46
Filhote – <i>B. filamentosum</i>	3,932	2,743	57	81	19	766	222	44
Pacu – <i>Mylossoma</i> spp	3,599	2,965	138	93	9	238	0	156
Surubim – <i>Pseudoplatystoma</i> spp	3,572	2,624	257	143	6	374	168	0
Mapará – <i>Hypophthalmus</i> spp	3,137	445	6	67	5	2,486	0	128
Tucunaré – <i>Cichla</i> spp	3,043	1,165	621	73	11	953	125	95
Tambaqui – <i>C. macropomum</i>	2,591	1,849	386	92	2	226	36	0
Pirapitinga – <i>P. brachypomus</i>	2,454	2,105	175	73	2	99	0	0
Pescada – <i>Plagioscion</i> spp	1,389	412	17	9	7	917	0	27
Aracu – Anostomidae	1,336	381	157	163	0	482	63	90
Branquinha – Curimatidae	1,192	474	45	557	2	57	0	57
Tamoatã – Callichthyidae	1,155	36	0	0	1	860	258	0
Sardinha – <i>Triportheus</i> spp	1,045	984	45	6	1	9	0	0
Aruanã – <i>Osteoglossum bicirrhosum</i>	553	551	0	1	1	0	0	0
Caraçu – <i>Astronotus</i> spp	471	130	0	10	2	193	136	0
Pirarucu – <i>A. gigas</i>	452	75	32	133	2	43	105	62
Mandi – Pimelodidae	399	0	36	297	0	0	0	66
Apapã – <i>Pellona</i> spp	263	4	9	0	0	250	0	0
Bodó – Loricariidae	259	65	4	32	2	156	0	0
Pirarara – <i>P. hemiliopterus</i>	237	150	84	0	3	0	0	0
Other species	8,218	2,854	216	55	17	3,076	1,780	211
Total	92,100	45,621	3,937	2,397	117	33,567	5,087	1,374

<sup>741</sup> IBAMA, 1999; Species or group in shaded box are migratory and make up 80% of the total catches (see text for references). AM = Amazonas, AC = Acre, RO = Rondônia, RR = Roraima, AP = Amapá, PA = Pará, TO = Tocantins.

as Porto Velho in Rondônia State and Itacoatiara in Amazonas State were sampled for short periods during the 1970s and 1980s<sup>741</sup> and monitoring has now recommenced. Another source of landing statistics, used mainly in Acre and Roraima, are the reports of Fisher Unions (Colônias de Pesca).<sup>743</sup> The recently begun Provarzea project intends to finance the consistent collection of statistics in the most important cities of the Amazon. The cities mentioned above are included in this project.

IBAMA has recently been compiling catch statistics in seven states (Figure 7) of the Brazilian Amazon. This compilation comes from various sources, such as fisher associations and local institutions, including some of those cited above. Fishers and local authorities reported the landings as fish products, which may combine several species of the same genus or related groups, but at other times cover only one taxonomic species. This data presented the same landing values for 1993, 1994 and 1995 for many products, suggesting that they had not been sampled during that period.

### Boats and fishing gear

The harvest of Amazonian migratory fish is complex and depends not only on biological features but also on economic and social issues. Because these species form shoals, they are caught efficiently with seine nets, except



**FIGURE 7.** Brazilian states and principal cities in the Amazon basin<sup>744</sup>

<sup>742</sup> Smith, 1979; Goulding, 1979

<sup>743</sup> Santos, 1986; Boischio, 1992

<sup>744</sup> Adapted from IBGE, 1992

in the estuary where the trawl net is the gear most often used. This gear is expensive, so most fishers employ cheaper and more diverse harvesting techniques. Moreover, fish only form schools seasonally, and seine nets are inefficient during the part of the year when they are dispersed. Therefore, numerous fishing gear types and techniques are used depending on habitat, season and fisher's income. Some examples are the trawl net, beach seine, purse seine, fixed gillnet, drifting gillnet, hook, bait hook and longline.

The basic operational fishing unit is a canoe with two fishermen. This canoe is generally based out of a larger accompanying vessel. Most of the variation in the fishing fleet is in the size of this main fishing boat and the number of fishermen and canoes associated with it.

The "accompanying vessel" fishing boats in the Amazon are most commonly built following old Portuguese tradition, with a low level of specialization for fishing. They are sturdily constructed, and use regional wood and local labour, but are poorly suited to the excessively powerful engines often used, resulting in excessive fuel consumption and fishing costs.<sup>745</sup> Only the largest boats have storage compartments built into the structure of the hull, while the great majority use removable boxes, enabling boat owners to use their boats for other activities such as transport of cargo, cattle and passengers. This way, boat owners can enter or leave the fishery, taking advantage of other opportunities between fishing trips or during periods of low productivity, but the ice boxes used are commonly not well designed for maintaining the quality of the fish catch.

The main feature distinguishing the commercial fisheries of different regions is the gear they use. In Manaus, Itacoatiara, Manacapuru, Tefé and Porto Velho 30–33% of fishers use gillnets and 50–70% use lampara seines (*redinha*)<sup>746</sup>, with the remainder using hooks, while in freshwater fisheries of Santarém and Belém primarily gillnets are used throughout different sizes of boats. Coastal fisheries in Belém also include an industrial trawling fleet.

One reason for the contrast in gear between Manaus and other Solimões cities, on the one hand, and Santarém and Belém, on the other,

<sup>745</sup> Prof. Flávio W. Lara, Federal University of Pará's Technologic Centre

<sup>746</sup> Batista 1998; Projeto Mamirauá; Barthem, 1999

is regulatory. Until recently, purse seines and trawls were prohibited in inland waters of Pará State, where Santarém and Belém are located, while their use is legal upstream in Amazonas State (Manaus and Tefé). However, given the generally low compliance with fishery regulations, it is difficult to believe that the law would be obeyed if there were not other reasons for not using seines. For example, Barthem (pers. comm.) suggests that a combination of different ecological conditions, differences in the behaviour of the main commercial species, and the relatively high cost of purse seines may deter their use in the Lower Amazon. Poor economic conditions would also inhibit investment in this more expensive gear even once they have become legal.

### **Structure of Amazon fisheries**

There have been many attempts to classify fishing effort according to several criteria, such as the people involved, the geographic scope of their operations, and the eventual market:

Furtado (1990 and 1993), noticing the close link between riverside people and fish, classified the fishers as “resident fishers”, “farmer-fishers” and “professional fishers”. The first two categories include people living in the countryside. Resident fishers exploit the flooded forest and sell their catch to the fishing fleet or cargo boats during the flood season. The farmer-fishers, on the other hand, fish mostly for their families with the occasional sale of surplus fish, dividing their time between farming and fishing. Both categories are the extremes of a continuum of time-sharing between farming and fishing. Professional fishers live in the cities and fish full-time, selling their catches in their home ports.

Bayley and Petrere (1989) identified two main types of fishing: “diffuse” and “large-scale commercial”. Diffuse fishing is carried out by inhabitants of rural areas, villages and smaller cities along the river banks and lakes, while commercial fishing occurs near major cities.

Isaac and Barthem (1995) classify the fisheries as “subsistence”, “artisanal” and “industrial”. Subsistence fishing is a traditional activity of rural people in the Amazon and is complementary to other activities. Artisanal fisheries are commercial; the fishers are professionals and work almost exclusively in the fisheries business. The artisanal fisheries, however, may hire fishers from the rural areas on a part-time basis, providing them with ice and equipment. The industrial fishery operates large fishing vessels

and works mostly in the estuary catching piramutaba, prawns and a few other species.

More recently, Barthem (1999) classified fisheries by their level of investment. They described the working regime of the fishers as either “industrial” or “artisanal”, with several subdivisions in the latter.

In this chapter, we have opted to analyze the harvest by its markets, which integrates these other classification systems. In this scheme, we recognize fisheries for “export markets” and fisheries for “regional and local markets”.

**Fisheries for export markets** – Fish exported from the Amazon are mainly catfishes. *B. vaillantii* (piramutaba) is by far the most harvested and is caught in both the industrial and artisanal fisheries. For the state of Amazonas, catfish export averaged 5,000 tons/yr between 1995 and 1998. More than half of this (2,774 tons/yr) was piramutaba, a third (900 tons/yr) was dourada and the remaining was surubim, filhote and a few other species.<sup>747</sup>

The industrial fishery demands high investments and exploits the estuary of the Amazon River throughout the year. The fishing fleet is composed of approximately 60 Brazilian boats, with some foreign investment from Japan. This fleet has exported piramutaba since 1971.<sup>748</sup> The main buyers are the United States, Holland, Germany, Japan, and Nigeria. Nigeria buys smaller fish than the other countries. Fishing is typically carried out by two trawlers of 20–100 metric tons towing a 45 m-wide trawl net between them at a depth of 40 m, generally in low salinity waters.<sup>749</sup> The minimum allowed mesh size for this net is 10 cm. Fish as small as 1 kg (~50 cm in length) are retained, but occasionally 80% of the catch is smaller and is discarded.

Artisanal fishers harvesting piramutaba in the Amazon River estuary and river (states of Amazonas and Pará) sell their catch to fish-packing plants. They use mostly longlines and gillnets, which can be as long as 400 m. Hooks are baited preferably with *Hypophthalmus* spp. in the river; but *Semaprochilodus* and *Brycon* may also be used. Longlines may reach up to 200 m, with the mainline attached to a tree or a buoy. Landings of

<sup>747</sup> Rezende, 1998

<sup>748</sup> Dias Neto & Mesquita, 1988

<sup>749</sup> Barthem & Goulding, 1997

piramutaba are highest between March and July (high-water period) and, along the Amazon River, between August and October (low water period).<sup>750</sup>

In term of fisheries for other catfish species in Amazonas State and western Pará State, fishers use long nets and drifting gillnets to catch dourada, surubim, filhote and mapará. Professional and artisanal fishers sell the fish either directly to cargo boats or to fish-packing plants. These packing plants also maintain small fishing fleets that buy fish from the subsistence fishers. Landings are exported to southern states of Brazil and abroad.

Dourada, filhote, and surubim are caught in the river during their migration, though most of the dourada and filhote caught are immature.<sup>751</sup> The catches are greater during the low water period in the Solimões and Amazon rivers near Manaus and Santarém, respectively<sup>752</sup> and in the Madeira River near Porto Velho.<sup>753</sup> Catfishes are also exported to Colombia from Tabatinga, a border town.<sup>754</sup> Landings in other cities in the Middle Solimões River are negligible.<sup>755</sup>

In Rondônia, dourada is caught in the river and in the rapids.<sup>756</sup> Fishers working the rapids use hooks similar to those used with tuna, and they also cast nets. This gear is highly efficient because the fish concentrate in pools just below the waterfalls, waiting for opportunities to swim over the rapids. To reach these pools the fishers stand on platforms.

Unlike the catfishes described above, mapará is caught with gillnets in floodplain lakes at high water. Landings are greater in Pará State, from where fish-packing plants export filets of these species. Mapará represented 19% of the 1993 landings.<sup>757</sup> These species are considered an alternative catch when other valuable fish are unavailable.<sup>758</sup>

**Fisheries for regional and local markets** – Most catfish (including dourada, surubim, filhote and mapará) are not popular fare in the local markets of Amazonas State, but are highly appreciated in Rondônia, Acre and Pará states.

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<sup>750</sup> Barthem & Goulding, 1997

<sup>751</sup> Rezende, 1998

<sup>752</sup> Zuanon, 1990; Rezende, 1998; Proj. Iara, unpublished data; Batista, 1998; Cerdeira et al., 2000

<sup>753</sup> Goulding, 1979; Boischio, 1992

<sup>754</sup> unpublished data

<sup>755</sup> Barthem, 1999

<sup>756</sup> Goulding, 1979

<sup>757</sup> Ruffino et al., 1998

<sup>758</sup> Cerdeira et al., 2000

The catfish *dourada*, *mapará* and *surubim* are thus also harvested in the estuary for regional and local markets. In Pará and Amapá, *dourada* is harvested in the estuary by small boats<sup>759</sup> using gillnets and baited longlines. Gillnets may be as long as 3,000 m and they drift as far as 20 km with the tide. Longlines in the estuary are shorter than 65 m, and are baited with *Gobioides* spp. and shrimp. Other gear such as the beach seine and hooks are occasionally used.

Further upriver, *mapará* is consumed in Pará State, especially in its eastern region, and the Tocantins River supports an important *mapará* fishery for local consumption. *Mapará* is of limited importance to the markets of Amazonas State.<sup>760</sup> The harvest from small cities such as Tefé and Alvarães is negligible,<sup>761</sup> but the species is consumed. *Surubim*, caught primarily with gillnets in floodplain lakes, is probably the most important migratory catfish for the markets of Amazonas State.<sup>762</sup>

The characids *jaraqui*, *tambaqui*, *curimatã*, *pacú*, *matrinxã*, *pirapitinga* and *branquinha* are consumed only locally and regionally, and mostly in the Western Amazon. These species are very important in the main cities of Amazonas State, where they total more than 80% of all landings. Each fish has peculiarities in its harvesting technique, but in general they are caught with seine nets during migration and with gillnets when dispersed in the flooded forest. Some specific examples are:

*Jaraqui* is caught with beach seines for nine months of the year.<sup>763</sup> It migrates actively to spawn or to disperse and, during those times (May, June, December and January) the fisheries rely mostly on seine nets (~80% of total catch). *Matrinxã* follows the same pattern (Figure 8).

*Curimatã* is caught mainly with gillnets and cast nets by subsistence fishers.<sup>764</sup> Professional fishers from Manaus who normally use gillnets rely heavily on seine nets during low water dispersion migration. In the late 1970s, fishing during the spawning season seemed more intense than it is now. This may not, however, reflect actual fishing trends, since fisheries have been legally closed during the spawning season since the 1990s, and fishers are likely to not have reported landings during the closures.

<sup>759</sup> Barthem & Goulding, 1997

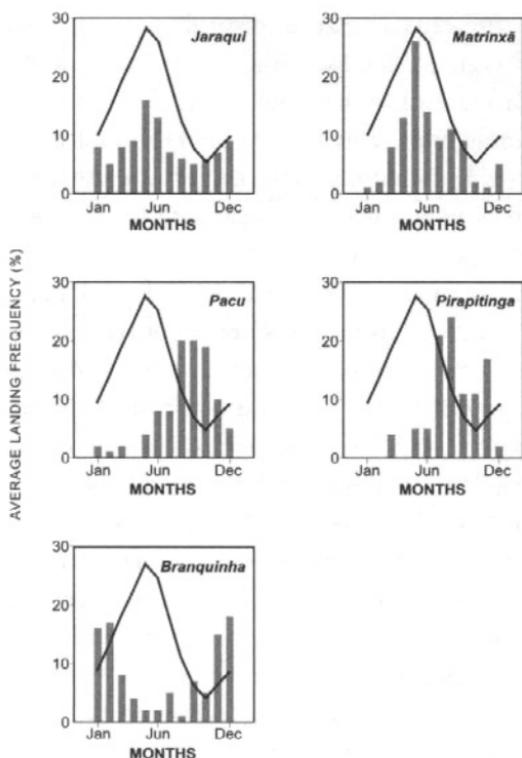
<sup>760</sup> Batista et al., 1998; Queiroz, 1999

<sup>761</sup> Barthem, 1999

<sup>762</sup> Batista et al., 1998; Queiroz, 1999; Barthem, 1999

<sup>763</sup> Ribeiro & Petrele, 1990

<sup>764</sup> Batista et al., 1998



**FIGURE 8.** Monthly landings frequencies of representative characids in Manaus for the years of 1994–1996 (bar graph), including relationship to relative water levels (line graph)<sup>765</sup>

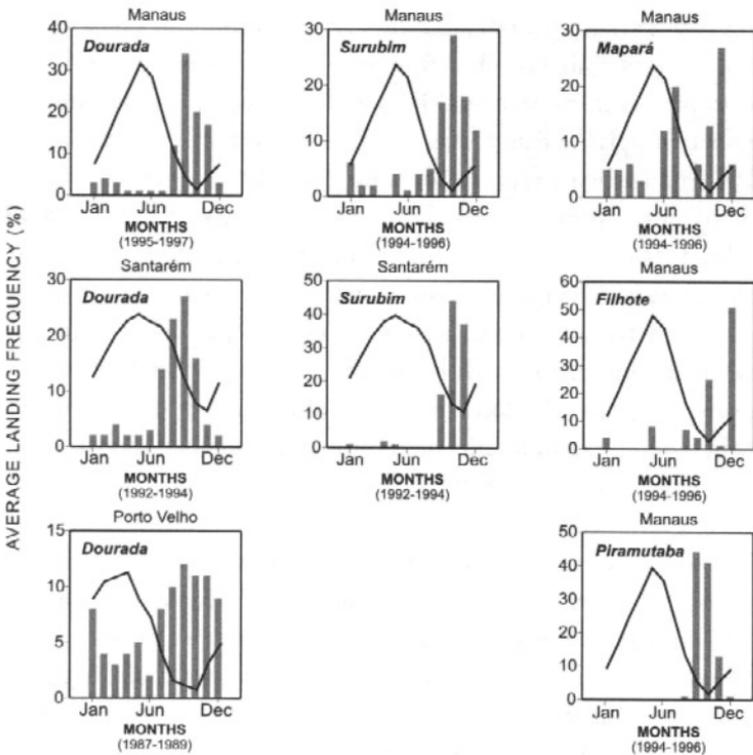
Fisheries supplying the Santarém market exploit mostly gillnet captures in floodplain lakes and rivers of the Middle Amazon River.<sup>766</sup> Pacu and pirapitinga follow a similar trend to curimatã (Figure 8).

Tambaqui was also harvested with seine nets in the past.<sup>767</sup> In the late 1970s there was little difference between landings in the flood and dry seasons, though catches peak in the early dry season. Currently, however, the harvest is highly skewed towards the low water period and fisheries are based on the floodplain (Figure 9). The floodplain fisheries rely mostly on 2–3 kg juveniles, the fishery of which is very intensive during the low water period. Subsistence fishers are now also catching the young fish

<sup>765</sup> Adapted from Batista, 1998; line graphs indicate relative water levels

<sup>766</sup> Mota & Ruffino, 1997

<sup>767</sup> Petrere, 1978b; Mérona & Bittencourt, 1988



**FIGURE 9.** Monthly landings frequencies of representative catfish in Manaus (1976–1978; 1994–1996) and Porto Velho (1987–1989) (bar graph), including relationship to relative water levels (line graph)<sup>768</sup>

that are hiding under the macrophytes during the low water period in lakes isolated from the river. This fishery is very aggressive and a common source of conflict in riverside communities.

Branquinha fisheries follow an inverse pattern to that of other species, being harvested mostly during the beginning of the flood or during spawning (Figure 8). This pattern is a response to the low availability of other species on the market at this time, which leads to higher seasonal prices and turns branquinha into a profitable catch.

**Santarém case study: co-existing fishing strategies**—Almeida et al. (2001) indicates that, despite considerable technological homogeneity, the Santarém fleet is composed of two distinct groups of boats with different

<sup>768</sup> Data from Petrere, 1985b; Boischio, 1992; Batista, 1998; line graphs indicate relative water levels

fishing and marketing strategies. The largest number of boats comprise an informal fleet of independent fishing boats that supply the local market, while an incipient more formal fleet is composed of a small number of large boats supplying fish-processing factories for the export market.

The smaller boats tend to be more generalist in their construction, with a low correlation between fish holding capacity and boat size, while larger boats tend to be more specialized with a relatively high correlation between size and ice capacity. Larger boats tend to have motorized canoes contracted by fishermen and a large area of net per fisher, whereas the smaller boats tend to use family labour, short-term partnerships, and lower technology. Incomes also tend to be higher in large boats, for both owners and fishers, although in smaller boats non-monetary benefits from family relationships may be important.

Fishing strategies of the two groups of boats also differ. Smaller boats are limited by fuel and ice capacity and tend to make a larger number of shorter trips. These thus concentrate fishing effort in areas near Santarém, often the same areas year after year. Larger boats fish larger and more variable total areas and consequently place less pressure on any one fishing ground.

The fishing pattern for both groups is markedly seasonal, though the two patterns of activity are quite different. Trip frequency for smaller boats peaks in the low water season from August through October, but the pattern is more complicated for the larger boats. Those in the 4–8 ton category have a bimodal pattern with peaks in April–May and July–August, whereas the largest boats have a peak of activity in April–May and are absent from the region in the low water season.

Marketing strategies of the two groups also differ. Smaller boats supply the local domestic market with characins and cichlids, while larger boats supply processing plants with catfish for export to other parts of Brazil. Furthermore, while the smaller boats supply exclusively the Santarém market, larger boats operate on a regional scale, monitoring prices in several markets and choosing the most advantageous ones to land their catch. These boats are only seasonally present in the Santarém market, operating elsewhere during the rest of the year.

The large boats are clearly beginning to dominate fishing in the area. Boats over 15 tons represent only 11% of the total fishing fleet, but bring in 42% of the total catch. These larger boats are also more productive in terms of conventional measures of fisheries productivity (CPUE).

However, net profitability, including consideration of capital investment, is actually higher for small boats.

In actual fact, there is relatively little competition between the two fishing groups as they exploit different species for different markets. While large boats may bring in 42% of the annual catch, virtually their entire catch goes to the fish-processing plants, while almost the entire catch of smaller boats is landed in the domestic market. The large boats probably do not enter the domestic market because it cannot presently absorb the volume of fish they must produce.

### Unsustainable fisheries impacts

Amazonian fisheries have significant impact on stocks, but two trends are particularly unsustainable: juvenile bycatch and/or targeting juveniles for fishing and unregulated increasing fishing pressures.

In terms of impacts on juveniles, the fishing industry in the estuary causes considerable mortality of piramutaba juveniles due to the small mesh size of the nets,<sup>769</sup> and while the legal size for dourada is 60 cm in Pará and Amapá states,<sup>770</sup> a large part of the catch in these states is fish smaller than this limit.<sup>771</sup> In the case of tambaqui, taking fish shorter than 50 cm is prohibited, but juveniles as small as 20 cm can easily be found in fish markets in Manaus.<sup>772</sup> The heavy fishing pressure on juveniles is considered to be responsible for the decline of both tambaqui and piramutaba, the two most obvious cases.

Increased fishing pressure is brought about by both increased effort (more fishing days and number of fishers per day) and a marked improvement in fishing technology. Before the 1960s, fishers relied on traditional bow and arrow, harpoon, hooks, and seine nets.<sup>773</sup> Longer seines and gillnets, made of improved material, have since become available and more affordable, and today fishers can catch fish in any habitat and during most of the year. The number of fishers has also increased. Most people living in the floodplain fish for food<sup>774</sup> or as a secondary activity. Unreported catches, as indicated by the large number of small Styrofoam

<sup>769</sup> Barthem & Goulding, 1997

<sup>770</sup> Isaac et al., 1998

<sup>771</sup> Barthem & Goulding, 1997

<sup>772</sup> Araujo-Lima & Goulding, 1997

<sup>773</sup> Petreire, 1990

<sup>774</sup> Furtado, 1993

iceboxes full of fish on river banks, is equal to or greater than the reported one. The floodplain fishery is especially intense during the end of low water and the beginning of the rising water season. In this period many lakes became shallow and are still isolated from the main river making fish populations especially vulnerable to fishers. The techniques employed by these fishers are destroying habitats and are leading to considerable conflicts in the rural communities.

As an example of both increased fishing and impact on juveniles, in the mid-1970s the tambaqui (*C. macropomum*) was exploited mostly with seine nets during its migration in the river.<sup>775</sup> However, by the mid-1980s the flooded forest was being intensively exploited with gillnets and uncontrolled tambaqui landings increased substantially, including a substantial catch of juvenile fish.<sup>776</sup> The fish is currently considered very overexploited.

Government strategies for reducing the unsustainable impacts on fisheries stocks include regulatory prohibitions, but other less conventional measures for better fisheries management have also been proposed, and will be discussed in the section on strategies for mitigation.

## Non-fisheries Impacts

The impact of development on the Amazon fish fauna is still poorly understood. The Amazon Basin has a fish diversity of approximately 2,500 species<sup>777</sup> and the basic biology of most fish fauna is still unknown. Research effort has been concentrated on those species of commercial importance, which total less than 250.<sup>778</sup>

The principal recognized non-fisheries impacts on migratory fish populations are the mercury pollution of rivers and habitat destruction (including the building of dams and reservoirs). Tin mining, which is also very active in the Amazon, causes both deforestation and pollution.

### Mercury pollution

Many authors have recently reported Mercury pollution in the Madeira, Tapajós and Negro rivers.<sup>779</sup> Mercury is relatively cheap and therefore has

<sup>775</sup> Petrere, 1978a, 1978b

<sup>776</sup> Mérona & Bittencourt, 1988

<sup>777</sup> Araujo-Lima & Goulding, 1997

<sup>778</sup> Petrere, 1978a, 1978b, Ferreira et al., 1998

<sup>779</sup> Pfeifer & Lacerda, 1990; Palheta & Taylor, 1995; Akagi et al., 1995; Barbosa et al., 1995; Boischio & Henshel, 1996; Silva-Forsberg et al., 1999

been intensively used by wildcat miners to chemically amalgamate gold. The process produces vaporous mercury or slurry, which is released directly into the rivers or precipitated with rain. Since mercury is used almost 1:1 in proportion to the gold produced, it is estimated that more than a thousand tons have been released in the Amazon in the past two decades.<sup>780</sup> There is no formal control or enforcement against mercury pollution in rivers or fish markets.

Mercury reaches the fish through the foodchain, after being converted into methyl-mercury in sediments, a process accelerated by the high concentrations of organic acids found in Amazonian waters.<sup>781</sup> Methyl-mercury is sequestered in lipids. The biomagnification of mercury by the foodchain causes top predators to have high bodily concentrations of this metal.

The toxic effect of methyl-mercury in fish is well documented. It can kill the adult fish at high concentrations (> 40 mg/l) and the embryo at relatively low concentrations (3 mg/l); methyl-mercury also has an adverse effect on larval development and teratogenic and neurotoxic effects on young and adults.<sup>782</sup> In Amazonian rivers contaminated with mercury, detritivorous and omnivorous fish such as curimatã, pacu and matrinxã have relatively low bodily accumulation of this heavy metal.<sup>783</sup> On the other hand, high concentrations of mercury have been reported for piscivores, including filhote, dourada and other catfishes. *Cichla* of the Tapajós River and *Hoplias*, a top predator from the Madeira River, had especially high values.<sup>784</sup> The latter was also reported to have a high frequency of nuclear alterations associated with mercury pollution. Since most large catfishes are top predators, they are especially sensitive to biomagnification. The half-life of mercury in fish muscle is two years.<sup>785</sup>

The effects of mercury are not limited to the fish themselves. Analysis of mercury concentrations in the hair of people living in fishing villages along the Tapajós River revealed a dangerous level of methyl-mercury.<sup>786</sup> A risk assessment analysis of people living in riverside villages on the Madeira River indicated a high hazard of neurobehavioral effects, and

<sup>780</sup> Palheta & Taylor, 1995; Barbosa et al., 1995

<sup>781</sup> Silva-Forsberg et al., 1999

<sup>782</sup> Bleau et al., 1996

<sup>783</sup> Boichio & Henshel, 1996

<sup>784</sup> Pfeiffer & Lacerda, 1990; Akagi et al., 1995; Porto, personal communication

<sup>785</sup> Eysink et al., 1988

<sup>786</sup> Akagi et al., 1995

young children are ingesting doses that have been correlated with neurological damage from mercury poisoning elsewhere.<sup>787</sup> Nervous system dysfunction was also found in riverside communities on the Tapajós River, where people with a high mercury concentration in the hair performed badly in neurofunctional tests.<sup>788</sup>

Central Amazonian people avoid eating large catfishes and are probably contaminated by eating non-migratory predators such as *Cichla* and *Osteoglossum*. Migratory catfishes such as dourada and filhote are prone to high mercury concentrations and these fisheries may be exporting contaminated fish to the south of the country. This however remains to be tested. Piramutaba does not migrate into the Tapajós and Madeira rivers and has less chance of being heavily loaded with methyl-mercury.

### Deforestation and reservoirs

Deforestation and reservoirs are important examples of habitat modification in the Amazon Basin that may affect migratory fish populations. Deforestation has been intensive in the flooded forest of the Amazonian floodplain, where there are many species of tree used by the timber industry. Clearing trees is also the first step in agriculture and tin mining. Since many fish rely on the forest for food and shelter,<sup>789</sup> it would be surprising if the deforestation of the flooded forest did not affect fish diversity. Algalivorous species might increase in density, because deforestation increases algal production, which may benefit these fish.<sup>790</sup> However, this impact has not been studied.

Habitat destruction caused by construction of reservoirs is a further reason for concern in the region. As mentioned above, only a few hydropower plants have been built in the Amazon Basin, but the basin has tremendous hydroelectric potential and it is believed that it is only a matter of time before the electric sector begins to invest.<sup>791</sup> The impact of damming on fish fauna has been addressed in Tucuruí (Pará) and Samuel (Rondônia),<sup>792</sup> but studies on the other large dams (Paredão, Balbina, Coaracy Nunes and Curuá-úna) are incomplete, lacking pre- and/or post-

<sup>787</sup> Boischio & Henshel, 1996

<sup>788</sup> Lebel et al., 1998

<sup>789</sup> Goulding, 1980

<sup>790</sup> Ribeiro & Petreire, 1990

<sup>791</sup> Fearnside, 1995

<sup>792</sup> Carvalho & Mérona, 1986; Mérona et al., 1987; Leite, 1993; Ribeiro et al., 1995; Santos 1995

filling evaluations. Therefore, most predictions must be based on these two case studies or on studies in other basins. Leite (1993) and Santos (1995) noted a reduction in species richness and catch per unit of effort after the closures at Tucuruí and Samuel, both in the reservoir area and below the dams. Migratory species were not found below the Tucuruí Dam. These authors also reported an increase in the abundance of piscivorous fish and a decrease in frugivorous and detritivorous species. These detritivorous and frugivorous fish, which disappeared from the reservoir area after the filling phase, were still abundant in the upper reaches of the basin.

Leite (1993), studying the fish community in Tucuruí until 1988, argued that its composition was still very unstable three years after the closure. Ribeiro et al. (1995) later confirmed this observation. The impact on the migratory fish seemed to be greater than on other species. Ribeiro et al. (1995) reported that in the early 1990s the fisheries situation had improved and catches in the reservoir had increased to pre-filling levels, but migratory species were not abundant in the landings. Downriver from the dam the fisheries did not show the same recovery, probably due to recruitment failure. The authors, however, did not believe that the situation had stabilised, and commented that catches, especially in the reservoir, may drop in the following years, when most of the submerged organic matter will have decomposed.

Because the large migratory catfish migrate long distances along the basin, it was suggested by Barthem et al. (1991), that hydroelectric dams could impede fish migration. The dourada and filhote are suspected to be the species most susceptible to the dam barriers, because they migrate into the nutrient-poor rivers, where most reservoirs are planned.<sup>793</sup> Migration of piramutaba on the other hand is restricted to the Amazon River.<sup>794</sup> However, from the data available<sup>795</sup> the effects of dams are not yet clear. Leite (1993) reported equally low densities of dourada before and after the closure of Tucuruí Dam, and Santos (1995) found no dourada in the Jamari River before or after the Samuel Reservoir was closed.

Other fish, such as jaraqui, mapará, pacu, matrinxã and curimatã are expected to be affected by reservoirs, which may interrupt their migratory routes upstream, especially in the nutrient-poor tributaries of the Madeira

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<sup>793</sup> Fearnside, 1995

<sup>794</sup> Barthem & Goulding, 1997

<sup>795</sup> Leite, 1993; Santos 1995

River.<sup>796</sup> However, the impoundment of the Tocantins River seems to have improved the jaraqui fisheries in this system, where catch increased by 40%.<sup>797</sup> Ribeiro et al. (1995) attributed this change to an increase in algae production in the reservoir, which they hypothesized would be beneficial for this species. The building of dams in some of the tributaries of the Amazon River was also suggested as a potential impact on the population of curimatã (*P. nigricans*). Carvalho and Mérona (1986) studied the potential effect of the Tucuruí hydroelectric plant on the upriver migration of curimatã and suggested that the dam would block the migration upstream and disturb the stock. However, their prediction was not borne out. This species was one of the most abundant in upriver fish assemblages five years after the closure,<sup>798</sup> although its abundance in the lower part of the river appeared to have declined.

A similar effect seems to have occurred with mapará. The abundance of *H. edentatus* and *H. marginatus* increased after the filling phase of Samuel Reservoir<sup>799</sup> and Tucuruí Reservoir<sup>800</sup> respectively. However, in the Lower Tocantins River, where the harvest was already low before the reservoir was built, landings of locally caught mapará dropped dramatically.<sup>801</sup>

In conclusion, building reservoirs seems to impact species differently; some seem to be negatively affected while others respond positively to habitat change. However, a common trend observed is the general reduction of fish diversity and the abundance of frugivorous species.

Despite these concerns few proposals have been put forward to mitigate the impact of reservoirs on fish migration beyond the creation of hatcheries, which have been built in most reservoirs to stock them with native species. In cases where hatchery programs have been set up, there has been little follow-up on stock densities and the efficacy of the program.

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<sup>796</sup> Santos, 1995

<sup>797</sup> Ribeiro et al., 1995

<sup>798</sup> Braga, 1990; Ribeiro et al., 1995

<sup>799</sup> Santos, 1995

<sup>800</sup> Leite, 1993

<sup>801</sup> Ribeiro et al., 1995

## MANAGEMENT AND MITIGATION

### Legal and Management Instruments

#### Legislation

**B**razilian laws that apply to all fishing activities are the legal frameworks on which regulations to protect migratory species are built. Fishing activities must comply with Decree-law 221/67 and Law 7679/88, which are country-wide. The first law defines fisheries and the properties of the aquatic biota. It acknowledges only three categories of fishing activities: commercial, sport and scientific, and postulates that all aquatic organisms living in Brazilian waters, including lakes, reservoirs, bays, rivers, gulfs, etc are in the public domain for all people in these three categories. This law also prohibits fishing with explosives and poisons. Law 7679/88 limits fishing in inland and marine waters during spawning.

There are no specific regulations for inland fisheries. Local ordinances are applied regionally and by states. Examples of these regulations were Ordinance 466/72 and 1534/89, which regulate mesh size of some gear, gear type and impose size limits.

In addition to difficulties of enforcement (regulations are only lightly enforced in most areas), the above laws are intrinsically flawed.<sup>802</sup> For example, they ignore subsistence fishers, who make up an important part of the fishing effort, and the limitation of 7 cm minimum mesh size for gillnets is of doubtful effect. This mesh size is effective in reducing the catch of immature curimatã and jaraqui, but not tambaqui, whose stocks are under greater pressure.

### Technical Instruments

#### Stocking of reservoirs

Stocking reservoirs with hatchery-produced larvae and juveniles is a standard mitigating procedure in Brazil. However, there are few accounts of the effectiveness of this procedure in rejuvenating natural populations.

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<sup>802</sup> Isaac et al., 1993; Barthem et al., 1997; Ruffino 1999

Moreover, there is a tendency to stock the reservoirs not with the impacted species, but with species that have an economic or social appeal, including exotic species. The gap between the native and exotic populations is aggravated in the Amazon by the lack of technology to produce most of the local species.

The Amazon's hydroelectric power plants include hatcheries supported by local governments. The Aquaculture Plant of Balbina, in the Uatumã River, has been producing juveniles of *Tilapia* and tambaqui for several years, which are sold to local fish farmers.<sup>803</sup> Although larval tambaqui have been released occasionally in the reservoir, the effect has not been measured. Tambaqui was not abundant in the upper reaches of the Uatumã River before the damming, and because it has to migrate downriver to the Amazon River to spawn, its production in the reservoir would probably not be sustainable.

### **Stocking of floodplains**

Another mitigation strategy being tested is stocking floodplains with hatchery-raised fish. Stocking lakes and streams is common practice in Europe, Asia and North America, but has not been tested in the Amazon. A pilot experiment, presently being carried out in floodplain lakes of the Lower Solimões River by Araujo-Lima and a team from INPA, is designed to test whether stocking is viable in systems as full of predators as the Amazon, and also to determine whether the stocked fish range throughout the interconnected floodplain lakes network. This will help to determine if stocking can be used as a local management alternative conducted by ranchers and lake-communities. The project is also considering the genetic implications of stocking.

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<sup>803</sup> Araujo-Lima & Goulding, 1997

## The Conventional Centralised Model for Brazilian Fisheries Management

Brazilian fisheries management is based on three assumptions:

- Water resources are public domain and should be accessible to any citizen;
- User groups are not capable of managing the resource without the supervision and control of the state; and
- The maximum sustainable yield of each resource can be estimated through scientific methods.

These assumptions are now being questioned.

First, the government has been unable to regulate regional fisheries, which have *de facto* been transformed into “open access”, or uncontrolled fisheries. Second, most government agencies assume that fishers are unable to protect the resource from excessive exploitation. However, many floodplain communities, with their strong social control and low number of inhabitants, are capable of community management; mutual monitoring (one of the basic conditions for the success of the initiatives) would be fairly easy in such communities.

A third issue is the complexity of Amazon fisheries. Fisheries science and the classic methods for estimating optimal or sustainable yield are marked by uncertainty and reflect the variability of natural and social phenomena. The sources of uncertainty are not always predictable and in many cases constitute “surprises” in models. Sophisticated and data-intensive methods developed to improve fisheries management are common for well-developed temperate fisheries systems. Unfortunately, the management of Amazonian fisheries cannot wait for the development of such complex models, especially when one considers the long time series of data needed.

Conventional fishery management strategies concentrate on the fish stock and its capacity to recover from catch removal. However, the preservation of floodplain habitat is an important factor in the maintenance of fish abundance. The extreme sensitivity of freshwater

fishes to habitat modification<sup>804</sup> is especially acute for Amazonian floodplain fisheries, in which the slow rise and fall of water levels have enabled many species to take advantage of conditions during each phase of the cycle. The floodplains provide food for fish growth and habitats for refuge. In the development of a new management perspective, the environment, the fish and the fishers should be considered as a unit, whose integration is vital for the maintenance of the resource.

## Management

Regulation and management have largely effected the mitigation of fishery impacts on Brazilian fish stocks. The most common regulations are:

- Regulating fishing gear, both for efficiency and size;
- Establishing closures;
- Limiting entry; and
- Establishing quotas.<sup>805</sup>

The first two measures are used intensively in the regulation of Amazonian fisheries, while fishing licenses have only been used to a lesser degree to regulate freshwater fisheries. Quotas and boat licenses are applied only to the industrial piramutaba fishery in the estuary.

### Prohibition of fisheries

Isaac et al. (1993) presented a detailed discussion on the effectiveness of laws on the management of fisheries in Brazil, and concluded that the complete prohibition of fisheries during the spawning migration does not seem to be a practical management measure.<sup>806</sup> Allowing the same stock to be fished a few months before spawning, when they form migrating shoals for dispersion during low and receding water, loses the advantage of protecting the females just before spawning.

A further complication is the definition of fish stocks. So far there has been little information on what constitutes a stock. Nevertheless, the

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<sup>804</sup> Welcomme, 1985

<sup>805</sup> Welcomme, 1985; Ross, 1997

<sup>806</sup> Isaac et al., 1993

stock definition (and assessment) are important for developing conventional management strategies, particularly when the resource is exploited by more than one country, as are the piramutaba and dourada.<sup>807</sup>

### **Fishery reserves**

Fishery reserves have for some time been considered for the Amazon Basin. Bayley and Petrere (1989) suggested that controlling fisheries in remote areas of the Amazon could be a viable management option in the region and would protect overexploited species. Ribeiro and Petrere (1990) suggested that the establishment of controlled areas, periodically closed for two consecutive years and opened for one year, could reduce fishing pressure on jaraqui, and Petrere (1990) suggested that controlled reserves could be an effective way to manage migratory species.

Rural communities have also proposed fishery reserves. Due to the limited presence of the state, communities living around floodplain lakes have started to develop and enforce their own local fishing regulations. In the 1970s these regulations aimed to reduce the activity of fishing boats from Manaus and other cities.<sup>808</sup> Local residents regulated the use of specific gear, such as seines and gillnets, and the entrance of motorboats with ice chests. During the late 1970s conflicts between fishers and local communities often made the news in Manaus. Nowadays, to avoid conflicts, a person will often have to ask for the permission of community leaders to fish commercially, scientifically or for sport, and commonly permission is denied.

Conflicts also developed within communities and between community members and ranchers. Within the community, some resident-fishers moved towards a “professional” reliance on fisheries because the value of agricultural products from floodplains dropped; fish stocks in common floodplain lakes then also started to decline.<sup>809</sup> Riverside communities see the impact of ranchers, who alter the landscape when they introduce cattle, as detrimental to fish production.<sup>810</sup>

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<sup>807</sup> Ruffino, 1999

<sup>808</sup> Petrere, 1990

<sup>809</sup> Câmara & McGrath, 1995; Furtado, 1998

<sup>810</sup> Furtado, 1998

## Community-based management

Community regulations have evolved into complex fishing “accords” as a result of the concern of riverside communities with their livelihood. Such agreements have apparently developed to protect the fishing rights of community members and seem not to be motivated by environmental considerations.<sup>811</sup> The agreements are forged in meetings, occasionally attended by the fishers associations, and are based on community needs. Nowadays, such fishing accords are common along the Amazon floodplain. Câmara and McGrath (1995) registered 65 lakes in the mid-Amazon River region whose use is regulated by such accords. In a 50 km section of the Lower Solimões River at least 4 floodplains lakes are so managed.

Sustainable community-based management of a common fisheries resource has been the aim of recent projects in the Middle Amazon and Solimões rivers.<sup>812</sup> Despite institutional and methodological differences, these projects have been evaluating how riverside populations exploit the fishery, and how they organise and relate with their neighbours.

The floodplain lakes of Mamirauá Sustainable Development Reserve have been categorised for different uses or scales of exploitation.<sup>813</sup> Preliminary evaluations indicated that tambaqui catches were higher in protected (unfished) than in exploited lakes, suggesting that part of the stock was finding refuge in the protected areas.<sup>814</sup> Landings from the Reserve in Tefé, the nearest city, also dropped from 18% to 9% of the total landings in four years, indicating a reduction in exploitation by the fishing fleet. In Middle Amazon River, bigger catches and higher income per fishing time were reported in lakes managed by fishing accords.<sup>815</sup> However, it is not yet clear if lake-management is a sustainable activity. Câmara and McGrath (1995) found that people on the island of Ituqui needed an area larger than the lake they lived on to make their annual catches sustainable.

These studies suggest that community-based management can be a promising alternative for Amazonian fisheries, at least in some areas. To succeed, however, relations between stakeholders will have to improve, and in some cases residents may have to reduce their consumption of the

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<sup>811</sup> Ruffino, 1999

<sup>812</sup> McGrath et al., 1994; Ayres et al., 1998

<sup>813</sup> Ayres et al., 1998

<sup>814</sup> Costa, 1998

<sup>815</sup> McGrath et al., 1994

resources. The advantages of this management strategy for conservation of fish diversity are not clear, since the communities seem in some cases to be depleting the fish stocks of "their" lakes. Additional attention to conservation will have to be included in plans, perhaps through environmental education. Isaac et al. (1998) further discussed this new approach to fisheries management.

An additional advantage of community management is that the state plays a limited role in enforcement. Regionally, IBAMA is implementing fishing accords. In the Lower Solimões River, for example, these accords are agreed upon in community meetings and submitted to IBAMA. The Agency then sends staff to train residents for assuring compliance. Community members approach any transgressor and encourage compliance. If abuse persists, IBAMA agents are called in. The same system is also being used in the Mamirauá Reserve.<sup>816</sup>

Regulating Amazonian fisheries is a difficult task. However, there is consensus in the region that no management policy can be successful without the participation of those who use the resource. Lack of user-group participation in planning and monitoring has been a major factor in the lack of compliance with existing regulations. Community management initiatives are to a large extent a response to the community's lack of participation in the formal process. Through these fishing accords civil society is developing an alternative to the conventional management model and at the same time regulating fishing activity to address community management objectives.

Community-based management of Amazon fisheries poses several important questions. Are restrictions on gear, season, etc. sufficient to manage the resources efficiently? Is it necessary to restrict effort by limiting the number of fishers? If yes, what should the other fishers do?

This leads to other important questions: how does one evaluate the success of such lake management systems, and how does one predict the effects of regulatory measures on both natural and social environments? Much additional information is needed before this kind of trade-off can be satisfactorily assessed.

Another challenge is the monitoring and evaluation of community management systems. Community-level data for monitoring lake-fisheries are virtually non-existent. Collecting data is another traditional

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<sup>816</sup> Ayres et al., 1998

responsibility of the federal government in which community participation is urgently needed to ensure user-group involvement in all stages of management.

A fourth question is the efficacy of the lake reserve model for the management of fish stocks. Many commercially important species, though little studied, have complex migratory cycles and use a variety of environments over the course of their lives, some of which would be protected by lake reserves and others not. It seems evident that it will be necessary to manage migratory species from a macro (regional) perspective, while community management will be most effective on a smaller geographic scale. Other kinds of policy and technical measures will be needed to adequately protect large migratory species.

A final issue is the capacity of communities to enforce management rules. Enforcement is typically easiest when infractions involve fishers from outside the community, and far more complicated for controlling the community itself. Lack of unity and consensus keeps rules from gaining maximum support among the community members. Despite these concerns, community-based management seems to be a promising development.

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

Most authors now agree that Amazon fisheries should be managed at the species or species group level.<sup>817</sup> Barthem et al. (1997) argued that piramutaba, which undergoes extensive migrations and is mostly exploited by a small fishing fleet based in the estuary, is suitable for conventional regulations based on mesh size and limitation of fishing effort. Barthem and Goulding (1997) recommended increasing the minimum mesh size of the estuary fishing fleet to 12 cm in order to reduce the impact on juveniles and consequently the fishing pressure on the stock. Barthem et al. (1997) think that the pressure of the artisanal fisheries on piramutaba is negligible. The dourada, which is also exploited in the estuary, could also be managed this way, but the authors refrained from proposing any specific strategy.

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<sup>817</sup> Isaac et al., 1993; Barthem et al., 1997

Fisheries management of tambaqui, curimatã, jaraqui, matrinxã and pacu must employ a different strategy. Restricting the fisheries of these species during the migration period is difficult to enforce. However, their young live in the floodplain, and limiting fisheries in the floodplain could be an effective management tool.<sup>818</sup> Barthem et al. (1997) also recommend the creation of floodplain reserves to manage these species. These reserves would also protect adults when they are not migrating, creating temporary refuges for the shoals.

IBAMA, the official regulatory agency for Amazon fisheries, seems receptive to suggestions from the scientific community. Recently it proposed watershed-specific regulations as part of the Program of Inland Fisheries and Management of River Basins.<sup>819</sup> This Program groups the regulations by river basin and therefore allows decentralised and more flexible decisions. Ordinance 07/96 allows regional IBAMA headquarters to propose fishing regulations such as closures (Table 3). Ordinance 08/96 proposes size-limit regulations for four Amazonian fish. The Agency has also published the procedures for the establishment of participatory community management.<sup>820</sup> Riverside communities have used this type of informal management on "fishing accords" for some time and IBAMA's recognition is a step closer towards its legalisation.

**TABLE 3.** Types of fishing regulations applied by IBAMA in the Amazon Basin

TYPE OF REGULATION	EXAMPLES
Minimum legal size limit	Applied to tambaqui, pirarucu ( <i>Arapaima gigas</i> ) and surubim (55, 150 and 180 cm, respectively).
Prohibition of gear	Do not allow towing gillnets, or use them associated with noise in shallow floodplain lakes (batição); Do not fish with explosives or poison.
Area closure	Prohibition of fishing within 200 m of river confluences and using gear that close more than 1/3 of the area, to protect migration routes.
Spawning season closure	The closure period is determined by local IBAMA agencies according to species.

<sup>818</sup> Barthem et al., 1997

<sup>819</sup> Fisher et al., 1992

<sup>820</sup> IBAMA, 1997

Further research on impacts of habitat destruction on fish stocks is needed before proper recommendations can be presented. Although it sounds obvious that the destruction of floodplain vegetation will affect fish assemblages, experience drawn from the reservoir studies mentioned above suggests that the expected impacts do not always occur. Experimental studies are needed to establish causal relationships between habitat modification and fisheries. These types of studies have been initiated but still have a way to go before objective conclusions can be drawn.

The long-term biological survey of closed reservoirs should become part of the agendas of local scientific institutions. Research in these reservoirs may follow the usual descriptive approach, but more attention should be directed to hypothesis testing using existing baseline information on the impacts of reservoirs on riverine stocks.

Mercury pollution in rivers should be controlled immediately. One possible way to do so would be to restrict the selling of the metal to large mining companies, which have trained personnel and are theoretically easier to monitor. Controlled sales are applied to chemical reagents used to process cocaine, such as chloroform and acetone, and could be applied to mercury as well. However, to assume that IBAMA or local environmental agencies would have the capacity to control the use of mercury by wildcat miners would be naïve. IBAMA has neither the equipment nor the personnel to do so, and other agencies would need to become involved.

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MIGRATORY FISHES OF THE  
**Colombian Amazon**

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## CHARACTERISTICS OF THE BASIN

### Geography, Geology, Climate and Habitat

The Colombian Amazon includes 5.6% of the total area of the Amazon Basin (Figures 1 and 2), and represents 420,000 km<sup>2</sup> or 31% of Colombian territory (Figure 2). Although the Amazon (Solimões) River mainstem borders Colombian territory for only 120 km, six major tributaries to the north (Table 1), including the Caquetá River (Japura in Brazil) and the Putumayo River (Iza in Brazil) are important Colombian rivers in which migratory fish species are believed to spawn.

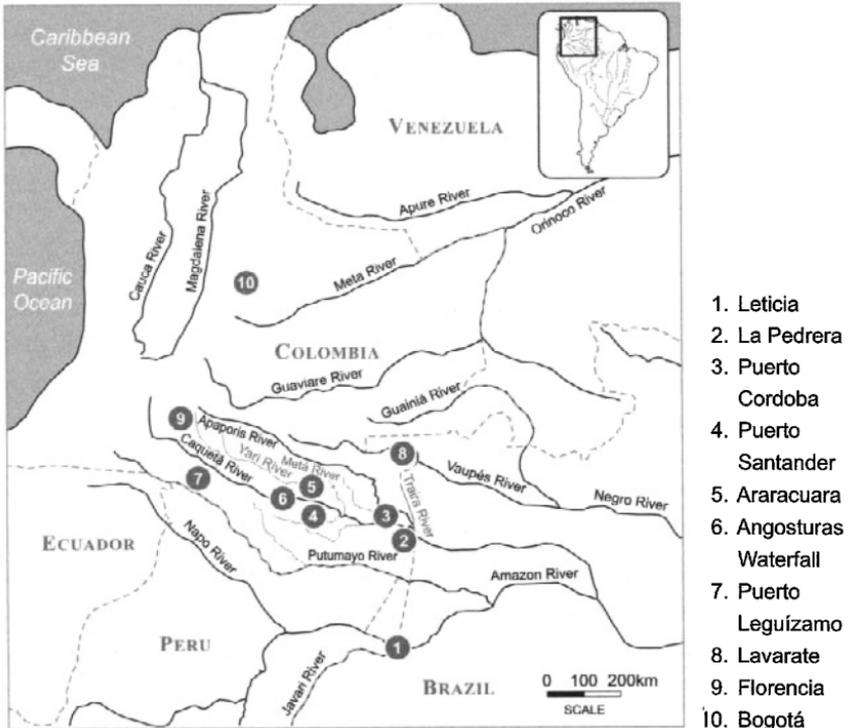


FIGURE 1. Map of Colombian Amazon basin

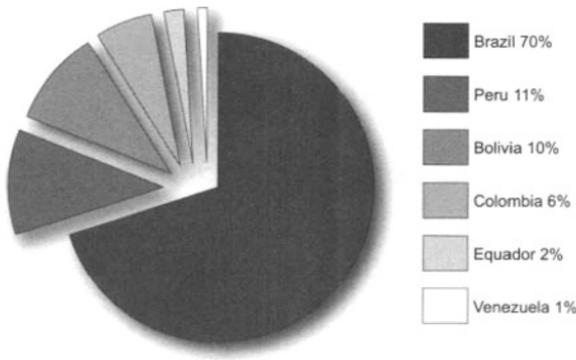


FIGURE 2. Distribution of Amazon basin territory, by country<sup>821</sup>

TABLE 1. Main river systems in the Colombian Amazon Basin<sup>822</sup>

RIVER	ORIGIN	NAME IN BRAZIL	TOTAL LENGTH (KM)	LENGTH IN COLOMBIAN TERRITORY (KM)
Amazon	Andes	Amazon	6,771	120
Caquetá	Andes	Japura	2,200	1,200
Putumayo	Andes	Iza	1,800	1,548
Apaporis	Guyana shield	Apaporis	1,020	1,020
Vaupes	Guyana shield	Vaupes	1,000	677
Guainia	Guyana shield	Negro	2,000	642

The present-day river systems have resulted from the processes associated with the uplift of the Andes during the Miocene (23 to 5 million years ago). Amazonian rivers began to run from west to east with this uplifting, and resulting large Neogene lakes and the erosion of long torturous waterways are believed to have created the rivers and drainage patterns of today.<sup>823</sup>

The northern Colombian Amazon now drains out of a western prolongation of the Guyana Shield, which divides the Amazon and Orinoco basins. The shield here consists of a Precambrian rocky base and outcrops, covered by thin sandy soil. The outcrops are vegetated with a distinctive *caatinga* community, while the remainder is covered by a

<sup>821</sup> TCA, 1995

<sup>822</sup> TCA, 1995; IGAC, 1999

<sup>823</sup> Frailey et al., 1988

mature rain forest ecosystem.<sup>824</sup> The water draining from this area is variably acidic and poor in nutrients.

To the east and northeast, on the other hand, the Amazon drains out of the Andean highlands of over 4,000 m in elevation, with large amounts of water captured in fragile and unique ecosystems, such as the Paramos (misty mountains). On their way down, torrents erode soils rich in nutrients that are deposited on the large sedimentary floodplains, giving rise to the productive *varzeas* (flooded forests) of the Central Amazon valley of Brazil and some parts of the Putamayo and Solimões rivers in Colombia.

Productivity of the river and its floodplains is thus highly influenced by which drainage system is providing the water. In general, the mineral content of the waters and productivity in Columbia increases from north to south.<sup>825</sup>

The climate of the region is greatly influenced by the Inter-tropical Convergence Zone. Rainfall averages 2,500 mm/year in the lowlands and 4,500 mm/y in the Andean foothills (Table 2). These high levels of precipitation fall in a long and continuous rainy period between March and September in the north and a bimodal rain pattern to the south of the equator, with peaks in March and October.<sup>826</sup>

Average temperature in the Colombian Amazon ranges from 24–29°C and varies little with latitude. Diurnal fluctuation can, however, exceed 10°C. Relative humidity always exceeds 75%, solar brightness is less than 5 h/day, potential evapo-transpiration is 1,447 mm/y and the rainfall exceeds drainage capacity throughout the year, resulting in a constant excess of water in the soil. The wind intensity is low and diminishes through the day.<sup>827</sup>

**TABLE 2.** Climatic characteristics in different parts of the Colombian Amazon<sup>828</sup>

LOCATION	RAINFALL (MM)	ALTITUDE (M)	AVERAGE TEMPERATURE (°C)	RAINY DAYS / YEAR
Leticia	2,836	100	26.4	204
Araracuara	3,059	232	26	225
Florencia	8,800	244	24.9	247
Lavarate	3,496	100	—	254

<sup>824</sup> IGAC, 1999

<sup>825</sup> Duque, 1995

<sup>826</sup> PRORADAM, 1979

<sup>827</sup> PRORADAM, 1979

<sup>828</sup> PRORADAM, 1979

## MIGRATORY SPECIES AND MIGRATION PATTERNS

Most of the South American fish fauna seems to have had a common ancestral origin in the Amazon Basin.<sup>829</sup> Estimates of fish diversity for the entire basin range between 2,000 and 3,000 species.<sup>830</sup> However, only 241<sup>831</sup> of the 500 expected to be present in Colombia<sup>832</sup> have been reported so far; of these, 69 can be considered migratory species in this region.<sup>833</sup>

### Order Clupeiformes

#### *Pellona* spp.

This genus of freshwater herring is widely distributed in South American rivers, including the *sardina* and *lacha* in Spanish, the *sardinha*, *apapa*, and *apapa-branca* in Portuguese, and *pellona* or *shad* in English. In the Caquetá River, these fish migrate upriver for several hundred kilometers to spawn; traditional knowledge indicates fish also migrate into the river from Brazil. The fish can be as large as 73 cm (*Pellona flavipinis*),<sup>834</sup> though most are smaller. They are pelagic and omnivorous, feeding on plankton and other items in the water column and surface. They are of relatively minor importance to fisheries, but are captured in artisanal and subsistence fisheries for local consumption. No fisheries data for this group are available. Species found in the Caquetá River are *Rhinosardinia amazonica*, *Pellona castelnaeana*, and *P. flavipinis*.

### Order Characiformes

#### *Brycon* spp.

The *Brycon* genus is quite diverse in South America, with several species in all areas contributing to sport and artisanal fisheries, as well as being

<sup>829</sup> MinAmbiente, 1997

<sup>830</sup> TCA, 1995; Goulding et al, 1988

<sup>831</sup> Alvarez-León et al., in preparation

<sup>832</sup> MinAmbiente, 1997

<sup>833</sup> primarily based on information from the Coqueta River: Baptiste-Ballera, 1998; Rodríguez-Fernández, 1991, 1999; traditional knowledge of Trujillo (2000, pers. comm.) as well as information in: Nova et al., 1982; Taphorn, 1992; Froese & Pauly, 2001.

<sup>834</sup> Froese & Pauly, 2001

aquaculture candidates.<sup>835</sup> Colouration is striking, and several of the smaller species contribute to the aquarium trade as various kinds of tetras.<sup>836</sup> The larger species are voracious piscivores as larvae,<sup>837</sup> but omnivores with a preference for fruits and seeds as adults. Most are strong swimmers, and species important in the Colombian fishery carry out reproductive migrations of several hundred kilometers in large schools. Fishing is most pronounced during these migrations, contributing to fisheries for both local consumption and export, though catches appear to be decreasing (see discussion of fisheries). Species encountered in the Caquetá River are *Brycon cephalus*, *Brycon breviceauda*, *Brycon melanopterus*, and *Brycon pesu*, known primarily as *sábalo* in Spanish. *B. cephalus* is widespread in the Amazon<sup>838</sup> and is the principal species in commercial fisheries. The other species are more restricted in range, with *B. melanopterus* possibly being non-migratory in parts of its range.<sup>839</sup> *B. pesu* is of interest to the aquarium trade.<sup>840</sup>

### ***Curimatella* and *Curimata* spp.**

These fish, known as *branquinha* in Brazil, are detritivorous species that are about half the size of *Prochilodus* and *Semaprochilodus* (max. ~20 cm). These species migrate upriver to spawn, probably in the order of 100–200 km. Fisheries on these species is for local consumption, and no specific catch statistics for Colombia are available. Species encountered in the Caquetá River include *Curimatella alburna*, *Curimata cyprinoides*, *Curimata amazonica*, *Curimata planirostris*, *Curimata rutiloides*, *Curimata simulata*, and *Curimata vittata*. Of these, *C. vittata* is also of interest to the aquarium trade.<sup>841</sup>

### ***Colossoma* and *Piaractus* spp.**

The *gamitana* (*Colossoma macropomum*), known as *tambaqui* in Portuguese, is of particular importance to the sport and commercial fishery in many parts of the Amazon, both for local consumption and for

<sup>835</sup> see Chapters 2, 3, 4 & 5

<sup>836</sup> Froese & Pauly, 2001; CEMIG, 2000

<sup>837</sup> see Chapter 4

<sup>838</sup> see Chapter 6

<sup>839</sup> see Chapter 6

<sup>840</sup> Froese & Pauly, 2001

<sup>841</sup> Froese & Pauly, 2001

export. This is a large omnivorous fish (up to 20 kg or more), with a preference for seeds and nuts. Beyond its regional importance as a food and sport fish, it is particularly known for its role in maintaining flooded forest ecosystems,<sup>842</sup> resistance to low oxygen conditions,<sup>843</sup> and aquaculture.<sup>844</sup> Reproductive migrations in Colombia extend for several hundred kilometers. Contribution to the Colombian fishery is significant, but relatively low.

The related *gamitana rosa* (*Piaractus brachypomus*), known as *pirapitinga* in Portuguese (synonymous with *Colossoma brachypomum*, *Colossoma bidens* and *Piaractus bidens*), is of less importance to export fisheries in Colombia, but is caught for local consumption. It is similar to *C. macropomum*, including in migratory habit, but is smaller and less well studied.

### ***Leporinus* spp.**

The *Leporinus* species are known as *boga* and *omima* in Spanish, *piau*, *piapara* and variations in Portuguese. These are omnivorous species of the distinctive Anostomidae, or headstander, family. A variety is present in the Amazon Basin, with several of the larger species also present and important to fisheries in other basins of South America,<sup>845</sup> including several of importance to the aquarium industry.<sup>846</sup> In Colombian rivers, they appear to migrate several hundreds of kilometers to spawn, generally followed by a variety of catfish. The fish are generally omnivorous, limited in their diet by a characteristically small mouth. Size of the species that contribute to the fishery varies from 20 to 40 cm. The species are of importance to fisheries for local consumption, but specific catch statistics in Colombia are not available. Of the *Leporinus* spp. *L. agassizi*, *L. brunneus*, *L. fasciatus*, *L. friederici*, *L. trifasciatus*, *L. granti*, *L. moralesi*, *L. niceforoi*, *L. obtusidens*, and *L. subniger* have been reported for the Caquetá River fishery; of these *L. subniger* is distinctive to Colombia<sup>847</sup> and *L. fasciatus* and *L. granti* are of interest to the aquarium trade.<sup>848</sup>

<sup>842</sup> Araujo-Lima & Goulding, 1998; Goulding, 1980

<sup>843</sup> Saint-Paul, 1984

<sup>844</sup> Lovshin, 1995

<sup>845</sup> see Chapters 2, 3, 4 & 5

<sup>846</sup> CEMIG, 2000

<sup>847</sup> Froese & Pauly, 2001

<sup>848</sup> Froese & Pauly, 2001

### ***Mylossoma* and *Myleus* spp.**

Species of these genera include the *palometa*, *garopita*, and *garopa* in Spanish, and *pacu* in Portuguese. They are relatively small discoid fish (12–25 cm), omnivorous in nature, that migrate a few hundred kilometers for reproduction. Three species are recorded in the fishery of the Caquetá River: *Mylossoma aureum*, *Mylossoma duriventre* (= *duriventris*), and *Myleus schomburgki*. These fish are of importance to the fishery for local consumption; the latter two are also of interest to the aquarium trade.

### ***Rhaphiodon vulpinus* and *Hydrolicus* spp.**

These fish, known as *machete* and *payara* in Spanish and *peixe-cachorro* in Portuguese, are distinctive carnivorous schooling fish in the Cynodontidae family, characterized by an elongated body and pronounced, protruding canine teeth. In Colombia, *Rhaphiodon* migrates several hundred kilometers for reproduction. The *Hydrolicus* spp. (*H. pectoralis* and *H. scomberoides* in the Caquetá River) probably migrate shorter distance. The species contribute to the fisheries for local consumption, but no catch statistics are available. *H. scomberoides* is also of interest to the aquarium trade.<sup>849</sup>

### ***Salminus* spp.**

The *Salminus* species, *dorado* or *salmón* in Spanish and *dourado* in Portuguese, are medium-sized carnivorous migratory fish particularly appreciated by sport fishermen throughout their range in South America, as well as by commercial fisheries where numbers are adequate. *Salminus affinis*, *Salminus hilarii* and *Salminus maxillosus* are present in the Caquetá River and contribute to fisheries for local consumption, but no catch statistics are available. Reproductive migrations appear to extend several hundred kilometers, though the extent of migration by *S. affinis* is not known.

### ***Schizodon fasciatum***

*Schizodon* spp. occur widely in South American rivers, often under the name of *piava* or *ximboré*. These are herbivorous relatives of the *Leporinus* spp., long-distance migrators, quite numerous, and important

<sup>849</sup> Froese & Pauly, 2001

components of the food chain. In general, they do not constitute a significant fishery, but *Schizodon fasciatum* (*lisa* in Spanish and *acurupintado* in Portuguese) is fished in Colombia for local consumption. No catch statistics on this fish are available.

### ***Semaprochilodus* and *Prochilodus* spp.**

*Semaprochilodus* spp. and *Prochilodus* spp., known in Spanish as *yaraquí* and *bocachico* respectively (*jaraquí* and *curimatã* in Portuguese), migrate upriver several hundred kilometers during high water to spawn. These fish form part of the important detritivorous fish group of South American rivers discussed more fully in the previous chapters. They grow up to about 40 cm and contribute to fisheries for local consumption in Colombia. No specific data on their capture in Colombia are available. Species reported for the Caquetá River are *Semaprochilodus amazonensis* (= *insignis*), *Sema-prochilodus brama*, *Semaprochilodus theraponura* (= *insignis*), *Prochilodus nigricans*, and *Prochilodus rubrotaeniatus*. *P. nigricans*, and *S. insignis* are considered widespread in the Amazon, and are reported to migrate long distances, while *S. brama* and *P. rubrotaeniatus* are more restricted in distribution.<sup>850</sup> *P. rubrotaeniatus* is possibly restricted to headwater regions of only a few rivers,<sup>851</sup> living in pairs,<sup>852</sup> and may have more restricted migratory behaviour.

### ***Serrasalmus* spp.**

The piranhas, including *piraña* in Spanish and *pirambeba*, palometa or *piranha* in Portuguese (piranha are considered as *Pygocentrus* spp., a subset of the *Serrasalmus*-like species, by some authors<sup>853</sup>). These fish contribute to fisheries for local consumption in Colombia, though catch statistics are not available. Although some countries restrict trade for fear of introductions into local waterways, several species have entered the aquarium market.<sup>854</sup> The piranhas are carnivorous and omnivorous fish, fairly small in size. *Serrasalmus* (*Pygocentrus*) *nattereri*, *Serrasalmus rhombeus*, *Serrasalmus spilopleura*, and *Serrasalmus striolatus* have been

<sup>850</sup> see Chapter 6

<sup>851</sup> see Chapter 6

<sup>852</sup> Froese & Pauly, 2001

<sup>853</sup> Britski et al., 1999

<sup>854</sup> Froese & Pauly, 2001

reported from the Caquetá River. Seasonal movements of less than 100 km by these fish have been reported for this region, but these are probably not strictly for reproduction.

### ***Triportheus* spp.**

*Triportheus albus*, *Triportheus angulatus*, and *Triportheus elongatus* have been found in the Caquetá River. These fish are small pelagic fish (11–22 cm), primarily insectivorous in nature.<sup>855</sup> Like the *Pellona* spp., these are known as sardinha in Spanish and sardina in Portuguese, but are of the same genus as the hatchetfish in English. Migrations of 100 km or less have been reported, but it is not clear if these are for reproductive purposes. They contribute in a minor way to the Colombian fisheries for bait, subsistence and local consumption.

## Order Siluriformes: Pimelodidae

### ***Brachyplatystoma* spp.**

The *Brachyplatystoma* catfish, including, in Spanish, the various *zúngaros*, and the *pirabutón*, are the mainstay of the commercial export fishery in Colombia. *Brachyplatystoma filamentosum*, *Brachyplatystoma flavicans*, *Brachyplatystoma vaillanti*, *Brachyplatystoma juruensis*, and *Brachyplatystoma rouseauxi* are present in the region, with the first three the best known and the most important to the fishery. *B. juruensis* is also of interest to the aquarium trade.<sup>856</sup> Reproductive migrations of these species may extend to over 1,000 km.<sup>857</sup> These fish are more extensively described in the following section and in Chapter 6.

### ***Pseudoplatystoma* spp.**

The *pintadillo rayado* and *pintadillo tigre*, *Pseudoplatystoma fasciatum* and *Pseudoplatystoma tigrinum* respectively, described in previous chapters, are large carnivorous catfish. *P. fasciatum* is of principal importance to the Colombian export fishery. These fish migrate between 300–500 km in Colombian rivers, but it is not clear if these are purely for reproductive purposes.

<sup>855</sup> Britski et al., 1999

<sup>856</sup> Froese & Pauly, 2001

<sup>857</sup> Barthem & Goulding, 1997

### Other migratory Pimelodids

Other migratory catfish of the Pimelodidae family also contribute significantly to the fishery in Colombia. They are carnivorous and appear to migrate several hundreds of kilometers to spawn; most are also described in the previous chapters and in the following sections. The species reported for the Caquetá River that are the most important to fisheries are *Leiarius marmoratus*, *Sorubim lima*, *Sorubimichtys planiceps*, *Brachyplatystoma platynema*, *Paulicea luetkeni*, and *Phractocephalus hemiliopterus*. *Pimelodus blochii*, *Pimelodus pictus*, *Pirirampus pirinampu*, *Platynemataichthys notatus* and *Calophysus macropterus* are also present, but are of less significance to the commercial fishery. *P. pictus*, *P. pirinampu*, *C. macropterus*, and *P. hemiliopterus* are also of interest to aquarists.

### Order Siluriformes: other families

#### *Hypophthalmus* and *Ageneiosus* spp.

*Hypophthalmus edentatus* and *Ageneiosus brevifilis* are medium-sized catfish of the Caquetá River (50–60 cm in length) that belong to the Pimelodidae<sup>858</sup> and Auchenipteridae families, respectively. Both are found in various South American rivers, but reproductive migration does not appear to occur in all locations. *H. edentatus*, known as the *mapará* in Spanish and Portuguese and the highwaterman catfish in English, refers to at least three species: *H. edentatus*, *H. marginatus* and *H. fimbriatus*. They are distinctive in that they are filter-feeding planktivorous catfish and appear to be migratory in the Colombia and Tocantins rivers,<sup>859</sup> travelling relatively short distances, but not migratory in the Itaipu Reservoir, where it has been introduced.<sup>860</sup>

*A. brevifilis*, known in Spanish as the *bagre paisano* or *bocon* and in Portuguese as the *mandubo* or *bocado*, are distinctive in that they lack the barbels so common in catfish. The fish are nevertheless carnivorous, as are most other catfish, feeding on other fish and crustaceans.<sup>861</sup> Short migrations for reproductive purposes appear to occur in Colombia, but are not described for other basins.

<sup>858</sup> Britski et al., 1999

<sup>859</sup> see Chapter 6

<sup>860</sup> A. Agostinho, pers. com.

<sup>861</sup> Froese & Pauly, 2001

## Order Perciformes

### *Plagioscion squamosissimus*

The *pescada*, known in Portuguese as the *pescada do piau*, in Spanish as the *curvina* or *curvinata* and in English as silver croaker or South American silver croaker, is an euryhaline fish<sup>862</sup> that has invaded many reservoirs of Brazil, contributing significantly to commercial and sport fisheries.<sup>863</sup> The fish is an aggressive carnivore, with a preference for eating other fish, and makes more use of open water than many other native migratory species. It thus does very well in the reservoirs where it has been introduced, often to the detriment of other species. It is a member of the drum family (Sciaenidae) and one of the few representatives of the perches in South American freshwater.

The *pescada* is native to the Colombian Amazon Basin, and contributes to commercial fisheries for local markets. While not considered migratory in most other parts of its range, including other parts of the Amazon,<sup>864</sup> it appears to carry out migrations of several hundred kilometers in Colombian rivers twice a year.

## Principal Fishery Species

Of all the migratory species, large catfish of the Pimelodidae family such as dorado (*B. flavicans*), *lechero* (*B. filamentosum*), pirabutón (*B. vaillanti*), and pintadillo (*P. fasciatum*) dominate studies and data collections. *B. vaillanti* and *B. flavicans* are two of the most important migratory catfish species in commercial fisheries of the Amazon Basin, representing (together with *B. filamentosum*, *P. fasciatum*, and *S. lima*) more than 90% of the total fish landings.<sup>865</sup> Barthem and Goulding (1997) reviewed their migratory patterns and the geographical distribution of life stages and size classes. These authors hypothesize that spawning occurs only in the Upper Amazon, including the Colombian portions of the Caquetá, Putumayo and Amazon rivers, while larval and juvenile rearing occurs only 1,800 km downstream near the estuary (see also Chapter 6).

<sup>862</sup> Froese & Pauly, 2001

<sup>863</sup> see Chapters 2 & 5

<sup>864</sup> Ribeiro, 1983

<sup>865</sup> INPA, 1993,1994,1995,1996,1998

## Migratory Patterns in Colombia

The high costs and limited success of tagging experiments have hindered fish ecologists in answering many questions about temporal and spatial dynamics in the large geographical area of the Amazon Basin. In Colombia, most of the information on migratory species comes from the Caquetá River system, where experimental studies on biology and fisheries have been carried out over the last two decades (Table 3).<sup>866</sup> Fisheries statistics have provided additional information, especially for large commercial catfish species, and the traditional knowledge of indigenous communities has proved helpful in understanding migration, behaviour and habitat use of fish communities.<sup>867</sup>

Migratory movements vary from small local displacements of a few kilometers to hundreds or even thousands of kilometers up or down main channels of large rivers.<sup>868</sup> It is presently believed that migration patterns vary greatly among species groups and that migration can be for spawning, feeding or population dispersion.<sup>869</sup> During these movements, which are not fully understood for most species, individuals migrate between lotic and lentic systems of white, clear and black waters, taking advantage of the different conditions created by the flood pulse that allows seasonal use of a variety of habitats.

Traditional knowledge of fishermen at the confluence of the Caquetá and Meta rivers,<sup>870</sup> suggests the following sequence of migrations:

Migrations start as waters rise, with small fish species (< 5 cm, collectively known as sardina) the first to show concerted movement. These move upriver along the banks of the Caquetá and in the flooded vegetation along its margin (the varzea) for about two months, in visible schools. The *Pellona* spp. (freshwater herring; also known as sardina) and the *Hydrolicus* spp. (carnivorous characids) are the next to be seen, but only in the river channel and in the largest tributaries, and for a shorter period of time. The *Pimelodus* spp., *Sorubim* spp., and *Pseudoplatystoma* spp.

<sup>866</sup> Arboleda-Ochoa, 1989; Baptiste-Ballera, 1988; Agudelo-Córdoba, 1994; Hernandez et al, 1994; Gómez-León, 1996; Muñoz-Sosa, 1996; Rodríguez-Fernandez, 1991, 1999

<sup>867</sup> Rodríguez-Fernandez, 1991; Prada-Pedreiros, 1989; Hernández et al., 1994; Rodríguez-Fernandez, 1999

<sup>868</sup> Barthem & Goulding, 1997; Junk et al., 1997

<sup>869</sup> Junk et al., 1997

<sup>870</sup> L. Trujillo, pers. comm.

catfish are seen next, followed by most of the remaining characids (*Prochilodus*, *Semaprochilodus*, *Colossoma*, *Piaractus*, and *Brycon* spp.). The longer-range migrating catfish appear to pursue this latter group, including the *Brachyplatystoma* spp. and *P. luetkeni*. The catfish *L. marmoratus* and the *Tripottheus* spp. sardina are then seen later, still within the high water period. Other catfish move upstream during the

TABLE 3. Seasonal movements of fish in the Middle Caquetá River Basin<sup>871</sup>

SPECIES	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
<i>Pellona castelnaeana</i>				X	X	X	X			
<i>Prochilodus nigricans</i>					X		X			
<i>Piaractus brachypomus</i>	X			X	X	X				
<i>Colossoma macropomum</i>	X			X						
<i>Brycon</i> spp.					X	X	X	X		
<i>Hydrolicus scomberoides</i>					X	X				
<i>Tripottheus albus</i>				X	X	X	X	X		
<i>Tripottheus angulatus</i>				X	X	X	X	X		
<i>Rhaphiodon vulpinus</i>				X	X	X	X	X	X	X
<i>Allophysus macropterus</i>							X	X	X	X
<i>Ageneiosus brevifilis</i>			X							
<i>Brachyplatystoma filamentosum</i>	X	X	X		X					
<i>Brachyplatystoma flavicans</i>	X			X	X				X	X
<i>Brachyplatystoma vaillanti</i>						X	X			
<i>Brachyplatystoma platynema</i>							X	X		
<i>Merodontotus tigrinus</i>				X						
<i>Paulicea luetkeni</i>		X	X	X						
<i>Pimelodus</i> sp.						X				
<i>Platynemateichthys notatus</i>					X	X	X			
<i>Pharctocephalus hemiliopterus</i>					X		X	X		
<i>Pseudoplatystoma fasciatum</i>							X	X		
<i>Pseudoplatystoma tigrinum</i>							X	X		
<i>Sorubimichtys planiceps</i>							X			
<i>Plagioscion squamasissimus</i>						X	X	X		
<i>Cichla ocellaris</i>								X		

<sup>871</sup> Arboleda-Ochoa, 1989. No observations were made July and August. Observations made near Araracuara.

low water period, including *P. pirinampu*, *C. macropterus*, *H. edentatus*, *B. vaillanti*, and *Plathynematchthys notatus*. No downstream migrating schools are observed, though mature fish of a variety of migratory characids and catfish are at times seen moving down tributary streams in a less concerted fashion.

Although there are differences in habitat use between species and size-classes, research generally supports this traditional knowledge and provides complementary information. Most Characids have been reported to leave floodplains and start upriver spawning migrations in the river as the water levels begin to rise. For the Caquetá, Rodríguez-Fernández (1991) reports that large groups of *Prochilodus* spp., *Curimata* spp., *Brycon* spp., *Hydrolycus scomberoides*, *P. castelnaeana*, *C. macropomum* and some species from the family *Anastomidae* move upstream in the main channel, and are easily detected by local fishermen, especially in rapids. These movements are referred to as *subienda*, occurring primarily during the high-water season from June-September. Fish in the Lower Caquetá River appear to come from Brazilian waters, though it is not clear if these migrate the whole distance along the river or if a number of populations are migrating coincidentally. Peak concentrations of migratory fish occur sequentially in the Lower Caquetá River at Puerto Cordoba (100 km from the Brazilian border), at the confluence with the Metá River (250 km upstream), the waterfalls of Araracuara (500 km from the border), and then the waterfalls of Angosturas (a further 50 km upstream) (Figure 1).<sup>872</sup> The fish arrive at Araracuara already at the end of the highwater season, and Baptiste-Ballera (1988), reported that during the *subienda*, individuals of *Schizodon* spp., *Prochilodus* spp., and *Rhaphiodon* spp. migrated through the large rapids while *Brycon breviceauda* spawned before ascending. Spawning of most fish occurs in the mainstem channel of the Caqueta River.

Spent fish appear to enter the floodplains after spawning, though some may also forage in the *varzea* during the *subienda* and return to the river mainstem to spawn in October. Baptiste-Ballera (1988) reported the seasonal entry of *Brycon*, *Semaprochilodus*, *Prochilodus*, *Myleus*, *Colossoma*, *Leporinus* and *Pseudoplatystoma* spp. into floodplains of the Caquetá and

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<sup>872</sup> Arboleda-Ochoa, 1989, Rodríguez-Fernandez, 1999

Yari rivers to feed, and similar events have been proposed for other rivers such as the Amazon,<sup>873</sup> Cahuinari,<sup>874</sup> and Igara Parana.<sup>875</sup>

As the water levels drop, movement from the flooded forest areas back to main channels of rivers and large streams commonly begins.<sup>876</sup> The fish may then move upstream again, as suggested by the concentration of fish at the Araracuara Falls: peak fish concentrations at this location only occurs in December-January, whereas 100 km downstream this peak occurs before September.<sup>877</sup> Baptiste-Ballera (1988) observed upriver migratory movements of this kind in the Caquetá River between October and March for *Rhaphiodon* spp., *Schizodon* spp., *Prochilodus* spp., *Hypophthalmus* spp., *Platynemathichthys* spp., *M. duriventre*, *Triportheus* spp., and Pimelodid catfish and found evidence of a permanent presence of *Brycon* spp. and *Leporinus* spp. in the headwaters of some tributaries. There is little evidence of concerted downstream movements in the Caquetá during high water comparable to those reported as part of the dispersion migration in the Madeira.<sup>878</sup>

Migrations of some catfish species cover great distances. Barthem and Goulding (1997) described the migratory patterns of *B. flavicans* and *B. vaillanti*, the long distance migratory patterns most frequently observed. Based mainly on fisheries data and the biology of these species in the Middle Caquetá River Basin, these authors propose the existence of exclusive nursery habitats in the delta of the Amazon River and spawning grounds more than 3,000 km upriver in Colombia.<sup>879</sup> *B. filamentosum*, the largest of the commercial species (max. known size 280 cm) in Colombia, provides most of the data on seasonal movements of this group of fish in Colombian waters. Rodríguez-Fernández (1999) has suggested that migration in the Middle Caquetá River Basin peaks in September-January, as water is receding and captures are the greatest.

Although less studied, some contrasting migratory trends along the main river channel have been proposed for catfish species such as

<sup>873</sup> Jimenez-Segura, 1994

<sup>874</sup> Walshburguer et al., 1990

<sup>875</sup> Santamaria, 1995

<sup>876</sup> Junk et al., 1997

<sup>877</sup> L. Trujillo, pers. comm.

<sup>878</sup> Barthem & Goulding, 1997

<sup>879</sup> Arboleda-Ochoa, 1989; Rodríguez-Fernandez, 1991; Muñoz-Sosa, 1996

*P. fasciatum* and *P. hemioliopterus*.<sup>880</sup> According to Rodríguez-Fernández (1991), few *P. hemioliopterus* are caught during the period of the lowest water levels in February and when high water levels stabilise after April, but many are caught when the water levels are rising in the intervening period of March to April. This suggests that the species migrates in the main river channel only as the water level is rising. *P. fasciatum*, on the other hand, is caught primarily between January and April, suggesting a more prolonged migratory and/or resident period in the river channel.

## Relationship Between Habitat and Fish Distribution

The relationship between habitat and distribution of fish species is still poorly understood for the Colombian Amazon, as it is for most of the basin. Although migratory movements have been reported in several studies,<sup>881</sup> little attention is paid to the absence of fish species in places that appear to enjoy the same habitat and water quality as others that are densely occupied, or to the presence of large quantities of fish in habitats with little food and poor water quality. Descriptions of transient occupation of habitats, such as floodplains and lakes, are frequently reported.<sup>882</sup> In order to understand the distribution of organisms, Pulliam (1996) proposed several notions: (1) suitable habitats are often unoccupied, (2) density is a misleading indicator of habitat quality, (3) organisms are often found in unsuitable habitats, and (4) for some populations, the majority of individuals occur in “sink” habitats. Hanski et al. (1996) defines sink habitats as the continuous area of space within which a local population lives where the growth rate, at low density and in absence of immigration, is negative. These challenging ideas will have implications for fish ecologists in the design of management and conservation strategies.

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<sup>880</sup> Rodríguez-Fernandez, 1991

<sup>881</sup> Baptiste-Ballera, 1988

<sup>882</sup> Goulding et al., 1988; Baptiste-Ballera, 1988; mcsSaint-Paul et al., 2000; Silvano et al., 2000

## IMPACTS ON MIGRATORY SPECIES

### Fisheries Impacts

#### Commercial fisheries

While there are no detailed descriptions of the development of commercial fisheries in the Colombian Amazon, present-day fisheries appear to have evolved out of artisanal fisheries conducted by indigenous communities. Most of the fishing is still carried out by indigenous people, and continues to reflect traditional fisheries knowledge and subsistence economies. Along the Caquetá River Basin, members of at least 10 different ethnic groups carry out commercial fishing activities.<sup>883</sup> From their relations with the colonists, indigenous people have been incorporating economic-dependent expectations into their life style; however, fishing activities are still managed with shamanistic and cosmological considerations, according to the spatial and temporal habitat symbolism.<sup>884</sup>

The growth and consolidation of these fisheries for export from the region has been closely linked to improved transport to major cities in the Colombian interior. Nevertheless, most fish were marketed as dried products until the introduction of freezer plants in the 1970s<sup>885</sup>. Currently, the fishermen sell their catch to large freezer plants, from where it is flown by charter aircraft to Bogotá (Figure 3). According to available statistics, all of this commercial catch is migratory species.

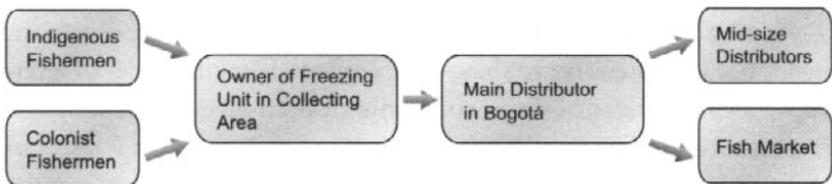


FIGURE 3. Fisheries marketing structure in the Caquetá River

<sup>883</sup> Rodríguez-Fernandez, 1999

<sup>884</sup> Rodríguez-Fernandez, 1991

Fishing is now the most important income-generating activity and the main source of protein in the Colombian Amazon Basin. It has become fundamental for local and regional economies that previously relied on extractive activities such as rubber-tapping, fur-trading, and gold mining. Fishing is also of great social significance, particularly at the local level, as it is one of the few legal income-generating activities that the largely indigenous populations can pursue in the area. However, income inequities are significant. For example, only a few colonists, that control the fishing industry through paternal agreements with the indigenous fishermen, own all the freezer plants. Fishers' income represents 15% or less of the overall profit in this system.

The demographic evolution of fishing communities in the Colombian Amazon Basin has been little studied, but studies on main rivers like the Caquetá<sup>886</sup> and the Amazon<sup>887</sup> show the existence of a highly dispersed rural population in small and medium-sized villages like Araracuara, Puerto Santander, La Pedrera, and Leticia, with freezing units and airport infrastructure.

### Collection of fisheries data

The study of fisheries and the implementation of a data-collecting system in the Colombian Amazon is very recent. In 1979 the Institute of Natural Resources Renovation and Environment (INDERENA), began monitoring commercial catches in some of the main landing centres (Table 4), a task that was assumed in 1992 by the newly created National Institute for Fisheries and Aquaculture (INPA).

Several studies conducted by universities, NGOs and research institutions in the last decade have complemented the knowledge of several aspects of fisheries biology and ecological trends of commercially important migratory species like *B. filamentosum*, *B. flavicans*, *P. fasciatum* and *P. tigrinum*, *P. luetkeni*, *P. hemiliopterus*, *Brachyplatystoma platynema*, *P. nigricans*, and *Brycon* spp.<sup>888</sup>

<sup>885</sup> Rodríguez-Fernandez, 1999

<sup>886</sup> Arboleda-Ochoa, 1989; Rodríguez-Fernandez, 1991, 1999

<sup>887</sup> Prada-Pederos, 1989

<sup>888</sup> Arboleda-Ochoa, 1989; Baptiste-Ballera, 1988; Agudelo-Córdoba, 1994; Celis-Perdomo, 1994; Gómez-León, 1996; Muñoz-Sosa, 1996; Rodríguez-Fernandez, 1991, 1999

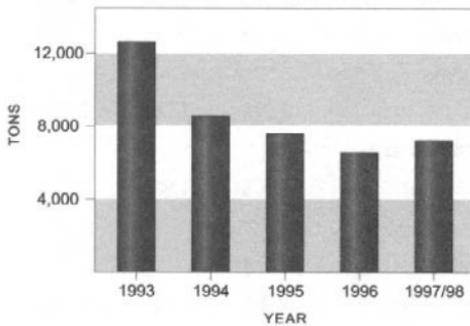
**TABLE 4.** Main fisheries landing centres in Colombia<sup>889</sup>

COLLECTING CENTRE	RIVER SYSTEM	MINIMUM CATCH RECORDED (TONS)	MAXIMUM CATCH RECORDED (TONS)	AVERAGE CATCH (TONS/YEAR)
Leticia	Amazon	2,087	13,456	5,531
Puerto Asis	Putumayo	—	—	64
Puerto Leguizamo	Putumayo	—	—	185
La Pedrera	Coquet	112	299	230
Araracuara	Coquet	18	112	80

### Summary of landings

Official information available for the Colombian Basin (subsistence catch not included) suggests irregular catch patterns ranging between 5,000 to 10,000 tons a year for the entire basin (Figure 4), with exceptional peak catches like those of 1993, which exceeded 13,500 tons.<sup>890</sup> Most of the species included in the statistics are migratory catfish, dominated by large species like *B. filamentosum*, *B. flavicans* and *P. fasciatum*. Only a small proportion is migratory fish species of the Characidae family, like *Brycon* sp., *C. macropomum* and *P. nigricans* (Table 5).<sup>891</sup>

Fisheries of migratory species exhibit marked seasonal and annual variation. High catches are reported during the low water period, with a

**FIGURE 4.** Annual catch of migratory fish species in the Colombian Amazon basin<sup>892</sup>

<sup>889</sup> Arboleda-Ochoa, 1989; Rodríguez-Fernández, 1991,1999; CAP, 1993; INPA, 1993, 1994, 1995, 1996, 1998; Anzola-Potes, 1995, TCA, 1995; Espitia, 1996, Agudelo-Cordoba, 1999; Fabre & Alonso, 1999

<sup>890</sup> Anzola-Potes, 1995

<sup>891</sup> INPA, 1993, 1994, 1997, 1998

<sup>892</sup> INPA, 1993, 1994, 1995, 1996, 1998

considerable decrease during the period of rising water and flooding of the forest.<sup>893</sup> Seasonal movements are not simultaneous for main migratory species and some trends for sequential displacement in the main river channel have been detected for large catfish.<sup>894</sup>

The Amazon port of Leticia is, despite the tiny fraction of Colombian territory traversed by the mainstem of the river, the main marketing centre in the Colombian portion of the Amazon Basin (Table 4). This is due mainly to the contribution of Brazilian captures (more than 80% of the market). In 1992, 88% of the total volume of the Colombian freshwater fisheries was actually caught in Brazil.<sup>895</sup> The fish market of Leticia handles 95% of the Colombian Basin total and has evolved from handling 2,500 kg in 1980 to nearly 9,000 for 1997, with an installed storage capacity of 800 tons and 50 to 60 fish merchants.<sup>896</sup>

TABLE 5. Catch of principal migratory fish species in the Colombian Amazon<sup>897</sup>

SPECIES	CATCH (TONS)				
	1993	1994	1995	1996	1998
<i>Paulicea luetkeni</i>	*	21	66	*	*
<i>Pseudoplatystoma fasciatum</i>	2,404	243	1,500	1,236	1,436
<i>Brachyplatystoma platynema</i>	*	0.1	61	4	908
<i>Prochilodus reticulatus</i>	95	302	316	26	644
<i>Piaractus brachypomus</i> ,	4	*	0.2	3	3
<i>Colossoma macropomum</i>					
<i>Sorubim lima</i>	2,274	1,742	1,887	1,652	305
<i>Phractocephalus hemiliopterus</i>	*	9	3	*	*
<i>Brachyplatystoma flavicans</i>	4,804	1,986	2,057	1,811	2,154
<i>Sorubimichthys planiceps</i>	*	*	*	*	0.3
<i>Brachyplatystoma vaillanti</i>	4	*	190	633	467
<i>Brachyplatystoma filamentosum</i>	965	1,145	1,099	82	85
<i>Brycon</i> spp.	260	128	0.4	22	92
<i>Leiarius marmoratus</i>	*	*	*	5	7
Dried fish from different species	1,259	2,509	*	811	845
Total Basin	15,627.1	9,689.4	9,826.1	7,719.0	8,880.0

<sup>893</sup> Muñoz-Sosa, 1996

<sup>894</sup> Rodríguez-Fernandez, 1999

<sup>895</sup> TCA, 1995

<sup>896</sup> Agudelo-Córodoba, 1999

<sup>897</sup> \* = Information is not available

Second in importance to the Amazon River are the fisheries in the region of the Middle Caquetá River (Table 6), with catches sold through small fishing towns such as Araracuara, Puerto Santander and La Pedrera. Almost the whole catch reported in the statistics are of migratory species (Figure 5), and according to the study of Rodríguez-Fernández (1999), in the catch from 1992–1994 a few large catfish species predominate (Figure 6). Unlike Leticia, where better and cheaper transport possibilities exist, the marketing of characid fish species in the Caquetá Basin is negligible. However, these species may be very important to subsistence fishermen and, if comparable to Brazil and Peru, this catch may be substantial.<sup>898</sup>

TABLE 6. Total commercial catch in the three main Colombian river systems<sup>899</sup>

RIVER SYSTEM	1994		1995		1996		1997	
	TONS	%	TONS	%	TONS	%	TONS	%
Amazon River	2,275	90%	5,293	92%	5,618	93%	8,752	96%
Putumayo River	130	5%	250	4%	116	2%	118	1%
Caquetá River	126	5%	230	4%	314	3%	305	3%
Total	2,531		5,773		6,048		9,175	

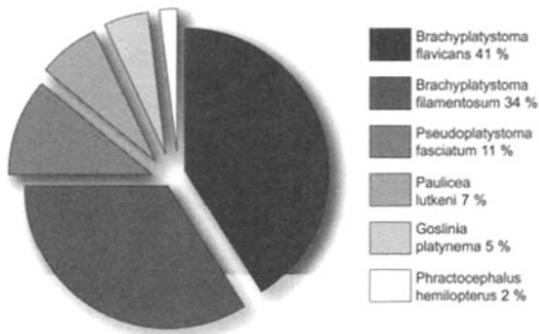


FIGURE 5. Composition of migratory fish catch in the Middle Caquetá River<sup>900</sup>

<sup>898</sup> Bayley & Petrere, 1989

<sup>899</sup> Agudelo-Córdoba, 1999

<sup>900</sup> Rodríguez-Fernández, 1999

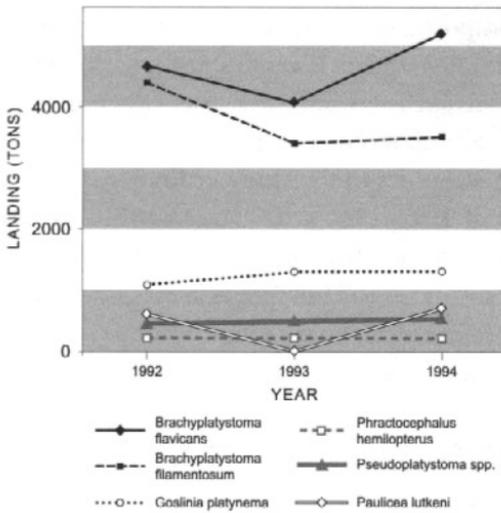


FIGURE 6. Changes in the catch of principal migratory fish species in the Middle Caquetá River basin 1992–1994<sup>901</sup>

## Fishing gear

Colombian fishermen, reflecting a combination of traditional and modern methods, use a variety of fishing gear (Table 7). The trend in fisheries in the last decade shows a decrease of the capture per unit effort for all of the main fishing gear types and especially for stationary and drift nets.<sup>902</sup> Timing and effort put into fishing varies over the year with changes in availability of migratory fish and with the fishing methods used. Drift nets are the most time-consuming and profitable gear in regions like the Lower Caquetá River where fishermen work average sessions of 12 hours during the night.<sup>903</sup> Harpooners work exclusively in large rapids like Araracuara and La Pedrera on the Caquetá River (also at night), but since they have to share the few appropriate spaces, their sessions are limited to 6 hours a day.

Another commonly used technique is “hook-hanging” or “hanging-line” which is practised throughout the year, but more by occasional or part-time fishermen, and during the daytime. In this procedure, the fisherman uses a 60–80 m polyester rope tied to a strong tree branch and

<sup>901</sup> Rodríguez-Fernandez, 1999

<sup>902</sup> Rodríguez-Fernandez, 1999

<sup>903</sup> Rodríguez-Fernandez, 1991

TABLE 7. Main fishing gear types used in the Colombian Amazon<sup>904</sup>

NAME			BASIN	DESCRIPTION	TARGET	FISHING LOCATION
SPANISH	PORTUGUESE	ENGLISH				
Atrarraya	Tarrafa	Castnet	Amazon Orinoco	Circular net, with lead at the edges	Small and medium catfish and scaled fish	River channels and lakes free of submerged branches and other tangling obstacles
Agallera	Malhadeira	Gillnet	Amazon	Passive fishing. Average length=24 m, mesh size=18 cm	Medium and large catfish	Main channel
Arpón	Arpão	Harpoon	Amazon	Long wooden stick with a metal point tied to a short rope	Large catfish	Rapids
Líneas de mano	Linha de mão	baited handline	Amazon	Line, with a hook and weight	Scaled fish Small to medium catfish	Flooded forest, streams, river
Espinel Calandrio	Curumim ou espinhel	Longline with one or several baited hooks	Amazon	Long line suspended by a buoy or wood float forming a floating line with several equidistant hanging hooks. Length and number of hooks can vary from 20 m and 16 hooks to 60 m and 50 hooks	Medium to large catfish	Main channel

<sup>904</sup> Adapted from Prada-Pedreiros, 1989

TABLE 7. *continued*

NAME			BASIN	DESCRIPTION	TARGET	FISHING LOCATION
SPANISH	PORTUGUESE	ENGLISH				
Colgadera		Hanging line		The simplest device, easy to guard and operate. Suspended from a tree branch over fast river currents of the river channel with rocky or clay bottoms.	According to the hook and bait can be used for large catfishes	Shore of river main channel
Boya o ancla, guaral, rendal o ramero	Poita estiradeira	Longline with one or several hooks baited	Amazon	A line, with a hook and weight suspended by a buoy	Medium and large catfish	Main channel
Zagalla	Zagaia	Trident	Amazon	Wooden stick with a trident metal point	Scaled fish, small catfish	Surface, night fishing
Flecha	Flecha ou flechão	Arrow with or without bow	Amazon	Wooden stick with a single metal point that separates from the stick. Used with or without a bow from canoes	Scaled fish, small catfish	Surface fishing
Chinchorro	Arrastadeira	Beach seine	Prohibited in Colombian Amazon	Net suspended from buoys and weighted with lead to sink it to the bottom; operated from a beach to encircle fish.	All	Beaches

**TABLE 7. *concluded***

NAME			BASIN	DESCRIPTION	TARGET	FISHING LOCATION
SPANISH	PORTUGUESE	ENGLISH				
Hondera	Redinha	Purse seine	Amazon	Net suspended from floating devices (styrofoam or plastic); lead weights sink it to the bottom. Requires crew of at least two people in the boat. Length varies from 20 to 150 m.	Large catfish	Main channel
Malla rodada	Malhadeira à deriva	Drift gillnet	Amazon	Net suspended from floating devices like styrofoam or plastic. Mesh size varies from 18 cm to more than 20 cm and allowed to drift with current.	Large catfish	Main channel

anchored to the bottom by a stone. A baited hook is hung from the rope at about 3 m from the bottom. This technique is not very time consuming and requires only the monitoring of hooks for bait replacement or collection of the catch.

### Overexploitation

Barthem et al. (1991) describe several different forms of fish over-exploitation related to growth, recruitment and ecological factors that are likely to occur in the Amazon Basin. However, analysis of the official statistics shows short-term decreases and instabilities in the volume of captures reported for the Caquetá and Amazon rivers.<sup>905</sup> Data available from studies in the collecting centres of the 5 principal subsystems of the Colombian Amazon are insufficient to construct useful models for any of the migratory fish species.

An estimated total potential catch of 5,000–10,000 tons/y has been proposed for the Colombian Amazon,<sup>906</sup> corresponding to 2.5–5% of the annual yield for the whole basin.<sup>907</sup> The existing information and the limited data series are, however, insufficient for drawing conclusions about exploitation levels and maximum sustainable yields, especially when 80% of the catch in the Colombian market may be from Brazilian waters. Since most of the information used to infer migratory patterns comes from fisheries that are highly selective and that depend on seasonal effort, special emphasis should be placed on research designed to take account of these characteristics.

Overfishing of sexually mature individuals is the most direct threat to migratory species. Unfortunately, information on the proportion of individuals caught in relation to the total spawning population is not available. Data analysed by Muñoz-Sosa (1996) for the Caquetá River suggest that some populations are being over-harvested, based on the calculation of a negative instantaneous growth coefficient ( $r=0.2167$ ).

A decade ago Barthem et al. (1991) noted that since populations of large catfish are not yet over-exploited in the Amazon and habitat health is still good, we may be experiencing our last chance to improve our knowledge of tropical species and to guarantee their management and

<sup>905</sup> Agudelo-Córodoba, 1999

<sup>906</sup> Min. Ambiente, 1997

<sup>907</sup> Bayley & Petrere, 1989

the conservation of evolutionarily viable populations. This advice is likely still valid, though for how long we do not know.

## Other Impacts

### Development

Although there are no large infrastructure projects underway in the Colombian Amazon Basin, some proposals for construction of hydroelectric dams or navigation corridors have been put forward.<sup>908</sup> Based on past experience and keeping in mind the precautionary approach, special attention will be needed to avoid threats like those facing migratory fish in other parts of the Amazon.<sup>909</sup>

*Brachyplatystoma* spp., with its high spatial and temporal dependence on environmental conditions, may be highly vulnerable to habitat loss or degradation. Since larval stages of most fish species are highly susceptible to sediment increase and chemical pollutants, and mature (reproductive) individuals are the targets of commercial fisheries, threats to either sexually mature or larval life stages will have important consequences on population demographics throughout the basin.

Habitat of the Colombian Amazon appears to be relatively healthy. However, several economic activities, including gold mining and illegal agriculture, should be monitored carefully. A rapidly growing fleet of Colombian and Brazilian balsas (dredging units) supported by anti-government forces are exploiting gold in the main channel, beaches and river banks of the Caquetá River near Araracuara, where spawning grounds of dourada and piramutaba are thought to exist. Gold extraction is also reported for the Guainiá River (Negro River), the Putumayo River and the Traira River on the frontier of Colombia and Brazil.<sup>910</sup> These activities are not only destroying valuable spawning habitat of fish and turtles, but are also likely contributing substantial mercury pollution to the area.

Planting of illegal crops in rainforest lands is increasing in the headwaters of large important tributaries like the Caquetá and Putumayo. Riparian vegetation is being destroyed and soils are becoming destabilised,

<sup>908</sup> CIFSA, 1995

<sup>909</sup> Barthem et al., 1991

<sup>910</sup> TCA, 1995

affecting the water flows and quality, and local people are being displaced by the associated violence. The main threat to fish, however, is the increasing use of large quantities of herbicides like glyphosphate (Roundup) to eradicate illegal crops. Roundup is prohibited in many countries because of high environmental toxicity and is likely to have dramatic effects in an aquatic environment.

Much of the Colombian fishery for migratory species relies on fish that come from Brazil, so that Brazilian programs for assuring the health of migratory stocks are important. In this regard, a program to prevent ecological degradation of the Amazon estuary has yet to be enforced. While information regarding the magnitude of tidal forest logging is insufficient, the threat is already clear.<sup>911</sup>

## MANAGEMENT AND MITIGATION

### Management

**S**ustainable use and conservation of migratory fish diversity is a goal that is proving to be extremely difficult to achieve, even with management systems that are supported by high-quality information. Unfortunately, data on occurrence and management of fish in Colombia are hugely deficient. Nevertheless, some research and management agencies within the National Environmental System (SINA) are attempting to set out general guidelines for conservation and sustainable use.

Groups involved in fish conservation and management at different levels include indigenous organisations, fishing interests, scientists from universities, research institutes and national or international NGOs, and government management institutions (Table 8). What co-operation exists is still, however, more the result of the efforts of independent individuals, rather than of organized inter-institutional activities.

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<sup>911</sup> Barthem & Goulding, 1997

**TABLE 8.** Principal institutions working on fish-related issues in the Colombian Amazon

INSTITUTION	TOPICS OF INTEREST
<b>Universities</b>	
Universidad Nacional	Ecology, taxonomy
Universidad Jorge Tadeo Lozano	Ecology, Management
<b>Non Governmental Organizations</b>	
Fundación Puerto Rastrojo	Biodiversity, conservation
Fundación Tropenbos Colombia	Fisheries Management, traditional knowledge
Fundación Omacha	Ecology
<b>Governmental Research Institute</b>	
Instituto Amazonico de Investigaciones Cientificas	Biodiversity, Fisheries, Ecology, Aquaculture
<b>Management Institutes</b>	
INPA	Fisheries and aquaculture management
Corpoamazonia	Fisheries and aquaculture management
<b>Indigenous Organizations</b>	Fisheries management, conservation

## Legislation for Protection of Migratory Fish Species

Fisheries in Colombia are regulated under Agreements 015/INDERENA/1987 and 075/INDERENA/1989. The General Statute of Fisheries (Law 13 of 1990, Decree 2256 of 1991) prohibits:

- The exploitation of resources protected by natural reserve areas or closed seasons.
- The use of illegal fishing methods including toxic materials.
- The drying, dyking or damming of rivers, streams, lakes or lagoons and any other water bodies, without the permission of the relevant authority.
- The dumping of materials or pollutants in water ecosystems that interfere with the life cycles of aquatic organisms and/or navigation.
- The fishing, processing and marketing of individuals of less than the minimum size.

Limitations on catch, fishing effort and storage quotas have not been imposed; their effectiveness would be expected to be limited. It is clear

**TABLE 9.** Size restrictions for fishing nets in the Colombian Amazon<sup>912</sup>

	AMAZON RIVER		CAQUETÁ RIVER	
	DRIFTING NET	STATIONARY NET	DRIFTING NET	STATIONARY NET
Maximum Length	150–200 m	40 m	150 m	40 m
Maximum Height	60 nets	6 m	8 m	6 m
Minimum Mesh Size	20 cm	9 cm	10 cm	9 cm

that a more effective system of information and management is required. Lack of financial resources and institutional capacity has limited the development of participatory strategies. In the Colombian Amazon, closed seasons, restrictions on fishing gear and minimum fish sizes for capture have all been used:

- Fishing activities in all lakes and streams in natural and indigenous reserves are restricted to subsistence purposes.
- Net sizes are restricted (Table 9).
- Drift nets are prohibited between December and April.
- Beach seines are prohibited in the Caquetá River.
- The use of nets is prohibited in the rapids of Araracuara and Cordoba in the Caquetá River.
- There is a minimum capture size for some species (Table 10).

## Colombian National Biodiversity Policy

By way of enforcing the mandate of the CBD, adopted by Colombia in Law 165 of 1994, the Ministry of Environment began a National Inventory of Biodiversity in 1997. This project analysed the threats to biodiversity and set down guidelines for the establishment of a National Policy of Biodiversity based on the knowledge, conservation and sustainable use of its components. Unfortunately, no particular reference is made to fish species in the Inventory.

The 1995 Colombian report to TCA (International Treaty on Amazon Co-operation) proposed fisheries conservation in four main areas:

- 1) To preserve catch diversity in highly fished zones, maintain maximum catches in zones of low pressure, establish areas for the

<sup>912</sup> Agreements 015/87 & 075/87

development of commercial fisheries, and aim for maximum sustainable yields.

- 2) To improve the organisational framework and promote participatory management schemes through the establishment of a network of fishing communities and other receptive groups.
- 3) To promote the development of fisheries through capacity building and technical assistance.
- 4) To implement an information network to improve the exchange of statistics, co-ordinate activities, harmonise management measures at national and international levels, harmonise technology transfer programs, and encourage research co-operation.

**TABLE 10.** Minimum capture size allowed for some migratory fish species in the Colombian Amazon<sup>913</sup>

SCIENTIFIC NAME	MINIMUM SIZE (CM)
<i>Brachyplatystoma filamentosum</i>	110
<i>Brachyplatystoma flavicans</i>	85
<i>Brachyplatystoma juruense</i>	50
<i>Brachyplatystoma vaillanti</i>	40
<i>Paulicea luetkeni</i>	80
<i>Brachyplatystoma platynema</i>	70
<i>Phractocephalus hemiliopterus</i>	70
<i>Pseudoplatystoma</i> spp.	80
<i>Pinirampus pinirampu</i>	40
<i>Leiarius marmoratus</i>	40
<i>Callophysus macropterus</i>	32
<i>Ageneiosus brevifilis</i>	35
<i>Hydrolycus scomberoides</i>	55
<i>Mylossoma duriventre</i>	24
<i>Brycon</i> spp.	35
<i>Sorubimichthys planiceps</i>	95
<i>Prochilodus mariae</i>	27
<i>Piaractus brachypomus</i>	51
<i>Colossoma macropomum</i>	60
<i>Semaprochilodus</i> spp.	15

<sup>913</sup> Agreements 015/87 & 075/87; Valderrama-Barco, 1986

In order to meet the above guidelines, regulatory actions have been proposed. However, restrictions on fish size, gear type and closed seasons are usually unenforceable and may even hinder the gathering of information needed for management.

## Aquaculture

Some technical, social and cultural constraints need to be removed before fish culture takes hold in the Colombian Amazon.<sup>914</sup> Although migratory fish species have been gaining acceptance by consumers at the national level and are receiving more attention from marketers, the Amazon region has yet to become fully involved in this process. Experimental culture of native migratory species such as *C. macropomum*, *P. brachypomus*, *Brycon* spp., and *P. nigricans* have been achieved, yet economic feasibility of culture in the Amazon Basin remains low due to high transport and feed costs.<sup>915</sup> Other promising species for aquaculture like *Pseudoplatystoma* spp., *S. lima* and *L. marmoratus* have come under scrutiny, but more knowledge of their biology is required to overcome limiting factors in their culture (such as cannibalism, spermiation in captivity, and the acceptance of economically viable diets).

No particular policy and management system exists in Colombia to assess and control the risk and uncertainty imposed by the introduction of non-native species and the release of cultured migratory species outside their natural habitats. Stocking migratory species like *Prochilodus* spp., *P. brachypomus* and *P. fasciatum* has been reported for all of the most important basins in Colombia, including the Amazon.<sup>916</sup> Both government and the private sector, without any attendant monitoring of results have carried out these stocking programs.

## Reserves and Protected Areas

Reserves established for lakes and small streams represent only a limited portion of the important or threatened migratory fish habitats and are of little use in protecting the most vulnerable commercial catfish species.

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<sup>914</sup> TCA, 1995

<sup>915</sup> TCA, 1995; SINCHI et al., 1996

<sup>916</sup> L. Trujillo, pers. comm.

Since most of these species depend on seasonal flooding of the forest as their main source of food and shelter, the forests themselves should be included in reserves as the main habitat to be protected throughout the basin.

## Data Collecting System

Data on Colombian Amazon fisheries are mostly based on the total catch recorded by INPA at freezer packing plants and ports. The data are, however, likely biased by the vested interest in under-reporting catches. These data are of some use in analysing resource dynamics related to production, but are insufficient to establish the potential exploitation level of the resource. Studies on spatial and temporal dynamics of migratory fish species should be integrated with data on exploitation to clarify the impact of intensive fishing, such as the fishing for *Brachyplatystoma* spp. in torrents and rapids of the Caquetá River – something that is not yet possible.<sup>917</sup>

Information gathered on Colombian fisheries occasionally includes data on lengths and weights, minimum maturing size and reproductive periods, but most available statistics present only the monthly and yearly captures and a brief comment on the three most important species (*B. vaillanti*, *B. flavicans*, and *Pseudoplatystoma* spp.) Studies like those of Rodríguez-Fernández (1991, 1999) in the Middle Caquetá River Basin, carried out in collaboration with local indigenous communities, have been fundamental in obtaining a preliminary picture of migratory fish exploitation and in understanding the socio-economic and cultural framework surrounding the fisheries.

## RECOMMENDATIONS FOR CONSERVATION AND RESEARCH

Colombian Amazon fisheries are threatened by agriculture and anti-drug activities in Colombia, but are also affected by development in the Brazilian Amazon, which makes their sustainable management a transboundary issue. Fisheries management and mitigation of hazards are greatly hampered not only by lack of knowledge of the various species

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<sup>917</sup> Rodríguez-Fernández, 1999

but also by lack of co-operation between the two countries. Since fish recognise no geographic frontiers an international and integrated approach to management and conservation is required. A standardised information system for transboundary fisheries is an old and frequently recognised need<sup>918</sup> yet to be fulfilled. Co-operative research, information gathering and cross-boundary planning (e.g. Brazil-Colombia) are hardly in evidence,<sup>919</sup> yet co-ordinated efforts at fisheries data collection and management should be adopted by countries sharing the Amazon Basin, particularly Brazil and Colombia in the case of *Brachyplatystoma spp.* This will be a difficult task, considering the huge area, and will need a community of interests made up of federal officials, scientists, local fishermen and business people.<sup>920</sup>

The multiplicity of agencies and institutions involved in the Amazon Basin at the national, state and local levels creates a challenge for catchment-based management and decision-making. In Colombia, national institutions like INPA make decisions centrally and local agents have little influence on these governing institutions. Yet the state is unable to co-ordinate activities on the scale required for areas as large as the Amazon Basin. A more inclusive data collection system is also needed, to monitor the evolution of fishing units, local income from fishing and changes in lifestyle of indigenous groups as economic expectations are increasing and alternatives for employment are decreasing.

The research required to understand the biological and ecological aspects of all the migratory fish species of the Amazon Basin is complex and time-consuming, yet it is a prerequisite for sustainable management. At the very least, it is vital to begin research on life histories of the most threatened species and to identify and define more precisely the particular habitats involved in the spawning and growth of early life history stages. Since a good deal of the basic infrastructure as well as the actual and potential human capacity for research and monitoring lies within universities and NGOs, scientists are suited to an important role in understanding what is probably the most complex aquatic ecosystem on Earth. Scientists must address several key issues in migratory fish biology. Identification and management of spawning areas, migratory routes, movement patterns and distribution mechanisms are key needs along the road to achieving sustainable fisheries. Special efforts should be made

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<sup>918</sup> Bayley, 1981; Bayley & Petrere, 1989; TCA, 1995; Barthem & Goulding, 1997

<sup>919</sup> TCA, 1995

<sup>920</sup> as mentioned by Barthem & Goulding, 1997

to construct preliminary models of habitat use for the most important commercial migratory species. Such models will allow scientists to identify information needs and assess threats at the species, ecosystem, and population or community levels.

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APPENDIX

**Summary of Principal  
South American Migratory Fish**

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TABLE 1. Authority and common names of principal South American migratory fishes discussed in this volume

ORDER FAMILY SPECIES	AUTHORITY *	COMMON NAME		
		PORTUGUESE	SPANISH	ENGLISH
Characiformes (characins)				
Characidae				
<i>Brycon cephalus</i>	Günther, 1869	matrinxã	sábalo	
<i>Brycon lundii</i>	Günther, 1864	matrinchá		
<i>Brycon microlepis</i>	Perugia, 1897	piraputanga, pera	sabaleta	
<i>Brycon orbignyana</i>	Valenciennes, 1849	piracanjuba, bracanjuba	pirapitá, salmón criollo	
<i>Brycon</i> spp.	—	jatuarana	sábalo, sabaleta	tetra (various)
<i>Colossoma macropomum</i>	Cuvier, 1816	tambaqui	gamitana, pacu, cachama, cachama negra	tambaqui
<i>Mylossoma and Myleus</i> spp.	—	pacu, pacu comun, pacu manteiga, pacu caranha, pacu mula	palometa, garopita, garopa	pacu
<i>Piaractus brachypomus</i>	Cuvier, 1818	pirapitinga	paco, cachama blanco, gamitana rosa	red pacu
<i>Piaractus mesopotamicus</i>	Holmberg, 1891	pacu caranha	pacú	pacu
<i>Salminus affinis</i>	Steindachner, 1880	dourado	sábalo macho	dorado
<i>Salminus brasiliensis</i>	Cuvier, 1816	dourado		dorado

TABLE 1. *continued*

ORDER FAMILY SPECIES	AUTHORITY *	COMMON NAME		
		PORTUGUESE	SPANISH	ENGLISH
<i>Salminus hilarii</i>	Valenciennes, 1850	tabarana	lagartijo, salmón	dorado
<i>Salminus maxillosus</i>	Valenciennes, 1849	dourado	dorado	dorado
<i>Serrasalmus</i> & <i>Pygocentrus</i> spp.	—	pirambeba, piranha, palometa	piraña	piranha
<i>Triportheus</i> spp.	—	sardinha	sardina	hatchetfish
Cynodontidae				
<i>Hydrolicus</i> spp.	—	peixe cachorro, pirandirá	payara, chambira	payara
<i>Rhaphiodon vulpinus</i>	Spix & Agassiz, 1829	dourado-cachorro, facão, peixe-cachorro	pira-yaguá, machete, perro	biara
Anostomidae (headstanders)				
<i>Leporinus</i> spp.	—		boga	
<i>Leporinus elongatus</i>	Valenciennes, 1849	piapara, piau-verdadeiro	omima	
<i>Leporinus friderici</i>	Bloch, 1794	araçu cabeça gorda, piaú cabeça-gorda		threespot leporinus
<i>Leporinus macrocephalus</i>	Garavello & Britski, 1988	piapara, piavuçu		
<i>Leporinus obtusidens</i>	Valenciennes, 1847	piava, piapara, piavaçu	boga, boga común	
<i>Schizodon borellii</i>	Boulenger, 1900	ximboré	piava	

TABLE 1. continued

ORDER	FAMILY		AUTHORITY *		COMMON NAME		
	SPECIES			PORTUGUESE	SPANISH	ENGLISH	
	<i>Schizodon fasciatum</i>	Spix & Agassiz, 1829		acurupintado	lisa		
	<i>Schizodon nasutus</i>	Kner, 1858		taguara, voga			
	Curimatidae						
	<i>Potamorhina, Curimatella &amp; Curimata</i> spp.	—		branquinha	Llorón		
	Prochilodontidae						
	<i>Prochilodus affinis</i>	Lütken, 1875		curimatá-pioa			
	<i>Prochilodus lineatus / platensis</i>	Valenciennes, 1847 / Holmberg, 1891		curimatá, grumatão	sábalo	curimbata, tarpon	prochilodus
	<i>Prochilodus margravii / argenteus</i>	Walbaum, 1792 / Agassiz, 1829		curimatá-pacu, bambá			
	<i>Prochilodus nigricans / reticulatus</i>	Spix & Agassiz, 1829 / Valenciennes, 1850		curimatã	boquichico, bocachico, sábalo	black prochilodus	
	<i>Prochilodus rubrotaeniatus</i>	Jardine & Schomburgk, 1841		bocachicos	boquichicos		
	<i>Prochilodus scrofa</i>	Steindachner, 1881		curimatá		curimbata	
	<i>Semaprochilodus</i> spp.	—		jaraqui	yaraquí, yahuarachi, sapuara	flagtail prochilodus	

TABLE 1. *continued*

ORDER FAMILY SPECIES	AUTHORITY *	COMMON NAME		
		PORTUGUESE	SPANISH	ENGLISH
Clupeiformes (herrings)				
Clupeidae (herrings, shads, sardines, menhadens)				
<i>Pellona</i> spp.	–	sardinha, apapa, apapa branca	sardina, lacha sardinata	yellowfin river pellona, amazon pellona, shad
Perciformes (perch-like)				
Scianidae (drums or croakers)				
<i>Plagioscion squamosissimus</i>	Heckel, 1840	pescada branca, pescada-de-piauí	curvina, curvinata	South American silver croaker
Siluriformes (catfishes)				
Auchenipteridae (driftwood catfishes)				
<i>Ageneiosus brevifilis</i>	Valenciennes, 1840	bocado, doncellé, fidalgo mandube	bocón	manduba
Pimelodidae (long-whiskered catfishes)				
<i>Brachyplatystoma filamentosum</i>	Lichtenstein, 1819	piraíba, filhote	zúngaro salton, pirahiba, valeyton, lechero	kumakuma, lau-lau
<i>Brachyplatystoma flavicans</i>	Castelnau, 1855	dourada	zúngaro dorado, plateado, dorado	gilded catfish

TABLE 1. *continued*

ORDER FAMILY SPECIES	AUTHORITY *	COMMON NAME		
		PORTUGUESE	SPANISH	ENGLISH
<i>Brachyplatystoma juruense</i>	Boulenger, 1898		bragre listado, zúngaro, zúngaro alianza, siete babas	zebra catfish
<i>Brachyplatystoma platynema</i>	Boulenger 1898	babão	baboso, flemoso, saliboro	slobbering catfish
<i>Brachyplatystoma rousseauxii</i>	Castelnau, 1855			
<i>Brachyplatystoma vaillantii</i>	Valenciennes, 1840	piramutaba, pira-botão, mulher ingrata	pirabutón, manitoa, pirabuton-blanco pobre	lalau catfish, piramutaba
<i>Calophysus macropterus</i>	Lichtenstein, 1819		mota, mota moteada, bagre, simí	zamuraito, pirate catfish, callophysus catfish
<i>Conorhynchus conirostris</i>	Valenciennes, 1840	pirá		
<i>Hemisorubim platyrhynchos</i>	Valenciennes, 1840	jurupoca, liro, bico de pato	maduro, toa	porthole shovelnose catfish
<i>Hypophthalmus</i> spp.	–	mapará, mapará bico de pena	maparate, mapará	highwaterman catfish
<i>Leiarius mamoratus</i>	Gill, 1870	jandiá, jundiá	yaque, barbudo	marbled pim
<i>Paulicea luetkeni</i>	Steindachner, 1877	jaú	manguruyú, amarillo, chontaduro, pejenegro, bagesapo, pejenegro, pacamú	black manguruyu, jau

TABLE 1. *continued*

ORDER FAMILY SPECIES	AUTHORITY *	PORTUGUESE		SPANISH	COMMON NAME
					ENGLISH
<i>Phractocephalus hemiliopterus</i>	Bloch & Schneider, 1801	pirarara		cajaro, guacamayo, músico, pirarara	red-tail catfish
<i>Pimelodus blochii</i>	Valenciennes, 1840	mandi		brage cogotúo	bloch's catfish
<i>Pimelodus maculatus</i>	Lacépède, 1803	mandi-amarelo, pintado	bagre amarillo, mandi-í, picalón		
<i>Pimelodus pictus</i>	Steindachner, 1876			cunchi, cunshi	pictus cat
<i>Pinirampus pirinampu</i>	Spix and Agassiz, 1829	barbado, patí, mandi-alumínio		mota, barba-chata, patí, barbiplancho	flat-whiskered catfish
<i>Platynemichthys notatus</i>	Jardine, 1841			coroatá	striped catfish
<i>Pseudoplatystoma coruscans</i>	Spix & Agassiz, 1829	pintado, surubim		surubí	Spotted sorubim
<i>Pseudoplatystoma fasciatum</i>	Linnaeus, 1766	surubim, cacharra	surubí atigrado, pintadillo rayado, bagre rayado		Tiger shovel-nose catfish, barred sorubim
<i>Pseudoplatystoma tigrinum</i>	Valenciennes, 1840	caparari, cabezona, pirambucu, surubim tigre		tigre zúngaro, pintadillo tigre	Tiger sorubim
<i>Sorubim lima</i>	Bloch & Schneider, 1801	jurupecem, bico de pato	cachorro, cuchara/o, paletón		shovelnose catfish
<i>Sorubimichthys planiceps</i>	Spix & Agassiz, 1829	peixe lenha	paletón, pejeleño		firewood catfish
<i>Steindachneridion scripta</i>	Miranda-Ribeiro, 1918	surubi	bagre cabezón		

TABLE 1. *concluded*

ORDER FAMILY SPECIES	AUTHORITY *	COMMON NAME		
		PORTUGUESE	SPANISH	ENGLISH
Doradidae (thorny catfishes)				
<i>Pterodoras granulosus</i>	Valenciennes, 1821	armado, abotoado	armado	granulated catfish
Heptapteridae				
<i>Rhamdia quelen</i>	Quoy & Gaimard, 1824	jundiá	bagre sapo, guabina	silver catfish
Loricariidae (armoured catfishes)				
<i>Rhinelepis aspera</i>	Spix & Agassiz, 1829	casculo, casculo-preto		armoured catfish

\* as given in FishBase: Froese, R., and D. Pauly (Eds.). 2002. FishBase. World Wide Web electronic publication. [www.fishbase.org](http://www.fishbase.org), 20Aug2002.

TABLE 2. Status and use of principal South American migratory fishes discussed in this volume

ORDER	PRESENT IN BASIN								
	FAMILY SPECIES	UPPER URUGUAY	LOWER URUGUAY	SÃO FRANCISCO	UPPER PARAGUAY	UPPER PARANÁ	PARANÁ/ PARAGUAY	BRAZILIAN AMAZON	COLOMBIAN AMAZON
Characiformes (characins)									
Characidae									
<i>Brycon cephalus</i>								a, s	a
<i>Brycon lundii</i>			t, s, a						
<i>Brycon microlepis</i>					a, s				
<i>Brycon orbignyanus</i>	e	t				t, s	t, s		
<i>Brycon</i> spp.								a	a
<i>Colossoma macropomum</i>			a, x, q			q (hybrid?)		a+, o	a
<i>Mylossoma</i> and <i>Myleus</i> spp.								a	a
<i>Piaractus brachypomus</i>								a	a
<i>Piaractus mesopotamicus</i>					a, s, o	t, q, s	t, a		
<i>Salminus affinis</i>									a
<i>Salminus brasiliensis</i>			s, a						
<i>Salminus hilarii</i>						t			a
<i>Salminus maxilloso</i>	s	s			s	t, s, a	s, a		a
<i>Serrasalmus</i> & <i>Pygocentrus</i> spp.							a**		a(**?)

TABLE 2. continued

ORDER	FAMILY SPECIES	PRESENT IN BASIN							
		UPPER URUGUAY	LOWER URUGUAY	SÃO FRANCISCO	UPPER PARAGUAY	UPPER PARANÁ	PARANÁ/ PARAGUAY	BRAZILIAN AMAZON	COLOMBIAN AMAZON
	<i>Triportheus</i> spp.					x, q			a
	Cynodontidae								
	<i>Hydrolicus</i> spp.								a
	<i>Rhaphiodon vulpinus</i>					a			a
	Anostomidae (headstanders)								
	<i>Leporinus</i> spp.								a
	<i>Leporinus elongatus</i>			s, a, q		a, q, s			
	<i>Leporinus friderici</i>								
	<i>Leporinus macrocephalus</i>				a, s	x, q**			
	<i>Leporinus obtusidens</i>	a, t	s, c		a, s	a, s	a, s		
	<i>Schizodon borellii</i>								
	<i>Schizodon fasciatum</i>								a
	<i>Schizodon nasutus</i>								
	Curimatidae								
	<i>Potamorhina, Curimatella &amp; Curimata</i> spp.							a	a
	Prochilodontidae								
	<i>Prochilodus affinis</i>			a, s					

TABLE 2. *continued*

ORDER FAMILY SPECIES	PRESENT IN BASIN							
	UPPER URUGUAY	LOWER URUGUAY	SÃO FRANCISCO	UPPER PARAGUAY	UPPER PARANÁ	PARANÁ/ PARAGUAY	BRAZILIAN AMAZON	COLOMBIAN AMAZON
<i>Prochilodus lineatus / platensis</i>	a	c, a		a, s	a, q	a, c		
<i>Prochilodus margravii / argenteus</i>			a, s					
<i>Prochilodus nigricans / reticulatus</i>							a	a
<i>Prochilodus rubrotaeniatus</i>								a
<i>Prochilodus scrofa</i>					a, q			
<i>Semaprochilodus</i> spp.							a	a
Clupeiformes (herrings)								
Clupeidae (herrings, shads, sardines, menhadens)								
<i>Pellona</i> spp.								a
Perciformes (perch-likes)								
Scianidae (drums or croakers)								
<i>Plagioscion squamosissimus</i>			x, q, a**	x	x, q, a**		P. spp.	a(**?)
Siluriformes (catfishes)								
Auchenipteridae (driftwood catfishes)								
<i>Ageneiosus brevifilis</i>								a
Pimelodidae (long-whiskered catfishes)								
<i>Brachyplatystoma filamentosum</i>							i, a+	a+
<i>Brachyplatystoma flavicans</i>							i, a+	a+

TABLE 2. continued

ORDER	FAMILY SPECIES	PRESENT IN BASIN							
		UPPER URUGUAY	LOWER URUGUAY	SÃO FRANCISCO	UPPER PARAGUAY	UPPER PARANÁ	PARANÁ/ PARAGUAY	BRAZILIAN AMAZON	COLOMBIAN AMAZON
	<i>Brachyplatystoma juruense</i>								a
	<i>Brachyplatystoma platynema</i>								a+
	<i>Brachyplatystoma rousseauxii</i>								a
	<i>Brachyplatystoma vaillantii</i>							i, a+, o	a
	<i>Calophysus macropterus</i>								a
	<i>Conorhynchus conirostris</i>			t, a					
	<i>Hemisorubim platyrhynchos</i>				a, s	a, s	a, s		
	<i>Hypophthalmus</i> spp.					x, a**		a+	a
	<i>Leiarius mamoratus</i>								a
	<i>Paulicea luetkeni</i>	e			t, a, s	t, a, s	e?, t, s		a+
	<i>Phractocephalus hemiliopterus</i>								a+
	<i>Pimelodus blochii</i>								a
	<i>Pimelodus maculatus</i>	a	a	a, s**		a, s	a, s		
	<i>Pimelodus pictus</i>								a
	<i>Pinirampus pirinampu</i>					a			a

TABLE 2. *concluded*

ORDER FAMILY SPECIES	PRESENT IN BASIN							
	UPPER URUGUAY	LOWER URUGUAY	SÃO FRANCISCO	UPPER PARAGUAY	UPPER PARANÁ	PARANÁ/ PARAGUAY	BRAZILIAN AMAZON	COLOMBIAN AMAZON
<i>Platynemichthys notatus</i>								a
<i>Pseudoplatystoma corruscans</i>	e	a+	a, s, t	a, s, o	s, q, a	t, a, s	a	
<i>Pseudoplatystoma fasciatum</i>	e	a+		a, s, o		t, a, s	a+	a+
<i>Pseudoplatystoma tigrinum</i>							a, o	a
<i>Sorubim lima</i>				a, s	a**	a, s		a
<i>Sorubimichthys planiceps</i>								a
<i>Steindachneridion scripta</i>	a	a+			t			
Doradidae (thorny catfishes)								
<i>Pterodoras granulosus</i>		a+			a, s, x			
Heptapteridae								
<i>Rhamdia quelen</i>	a	a			a**			
Loricariidae (armoured catfishes)								
<i>Rhinelepis aspera</i>					a, t			
Total # migratory species mentioned by Author	7	12	12	16	26	15	17	41

a = artisanal; a+ = large scale with artisanal technology; i = industrial; s = sport; q = aquaculture

x = introduced to this basin; e = extinct; t = threatened; o = overexploited; \*\* = may not be migratory in this basin

# B

APPENDIX

## **Migratory Fish Species in North America, Europe, Asia and Africa**

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NORTH AMERICA<sup>921</sup>

The best-known and most wide ranging of the North American migratory fish are **salmon**. Salmon are found on both coasts, Pacific and Atlantic. Speciation has been much further evolved in the Pacific, where at least six species are found naturally. All Pacific salmon belong to the single genus *Onchorhynchus*, while the Atlantic salmon is a single species, *Salmo salar*. All species migrate from salt water to spawn in freshwater rivers, burying their eggs in gravel. The salmon species are the mainstays of commercial and sport fisheries, and many populations are augmented by hatcheries. Natural predation and changes in habitat caused by poor forestry practices, dams, and water diversions can all cause high mortality in the early life stages.

Another migratory salmonid species is the **charr**, found in cold freshwater of the Northern Hemisphere and Arctic seas. Where the water body has an outlet to the ocean the charr is migratory, feeding in the arctic seas and returning to rivers to spawn. Arctic cisco feed and migrate in summer along the Arctic Refuge coast, spawning and over-wintering in Canada's Mackenzie River. After hatching, the finger-length juveniles migrate west along the Refuge coast, returning each year to the Mackenzie.

Other species of migratory fish on the West Coast of North America include the **American shad** (*Alosa sapidissima*, introduced), **eulachon (smelt)** (*Thaleichthys pacificus*), **green sturgeon** (*Acipenser medirostris*), **white sturgeon** (*A. transmontanus*) and **Pacific lamprey** (*Lampetra tridentata*). Like the salmon, the **American shad** returns to its freshwater natal areas to spawn in estuaries, streams, and rivers in the spring and early summer. As with South American migratory species, the fertilized eggs float downstream and hatch in 3 to 10 days. Migrating downstream, most juveniles reach the open ocean before winter, normally spending 3 to 4 years at sea before returning to spawn. They range along the Pacific coast from California to Alaska.

<sup>921</sup> Pacific species from [http://www.psmfc.org/habitat/edu\\_anad\\_table.html](http://www.psmfc.org/habitat/edu_anad_table.html); Eastern species from <http://www.chesapeakebay.net/info/fish1.cfm>

Smelt range from Northern California to the eastern Bering Sea and the Pribilof Islands. Young larval eulachon in estuaries and near shore ocean areas are sensitive to marine pollution and toxic runoff from agriculture and urbanization. Droughts and pollution may postpone the smelt's entering freshwater to spawn until conditions are right.

**Green sturgeon** (also known as Sakhalin sturgeon or sterlyad sturgeon) grow slowly and mature late. Apparently they spawn every 4 to 11 years. In the ocean they are highly migratory, spending most of their life in salt water. In North America, green sturgeon are found from Ensenada, Mexico, to Southeast Alaska. Like the white sturgeon, green sturgeon prefer to spawn in lower reaches of large, swift rivers, broadcasting directly into the water column where the fertilized eggs sink to the bottom and attach to substrate. **White sturgeon** (also known as Pacific sturgeon, Oregon sturgeon, Columbia sturgeon, and Sacramento sturgeon) are the largest freshwater fish in North America. They can weigh over 1,500 pounds, grow to 20 feet in length, and live over 100 years. In North America they range from Ensenada, Mexico to Cook Inlet, Alaska. Dams have harmed white sturgeon by landlocking populations and destroying spawning grounds. White sturgeon do not normally use fish ladders, so bypass mitigation measures tend to fail.

The **Pacific Lampreys** (also known as Pacific sea-lamprey, three toothed lamprey, tridentate lamprey, and sea lamprey) range from Baja California to the Bering Sea in Alaska and Asia. Born in freshwater streams, they migrate to the ocean and return to freshwater to spawn. Since the larval form lives as a filter feeder in mud, its habitat can be washed away by dam releases or harmed by pollution.

On the East Coast of North America, anadromous fish species include **alewife**, **striped bass**, **shortnose sturgeon**, and naturally occurring **American shad**. The only catadromous species in the Chesapeake Bay ecosystem is the **American eel** (*Anguilla rostrata*), which spawns in the Sargasso Sea. Anadromous fish, such as the **American shad** and the **blueback herring**, travel from the high salinity waters of the lower Bay or Atlantic Ocean to spawn in the Bay watershed's freshwater rivers and streams.

**Atlantic sturgeon** (*Acipenser oxyrhynchus*) are found from Quebec to the Gulf of Mexico and swim through the Chesapeake Bay in April and May on their way into tributaries, where they spawn and where the young feed. Overfishing, pollution and dam construction have reduced the

population. North American **catfish**, of the family Ictaluridae, are freshwater species that commonly range into estuarine waters.

## EUROPE

The major migratory fish of Europe is the **Atlantic salmon** (*S. salar*). Wild populations of the salmon have vanished from at least 309 rivers in Germany, Switzerland, the Netherlands, Belgium, the Czech Republic and Slovakia, and are about to disappear from Estonia, Portugal, and Poland. Norway, Iceland, Ireland, and Scotland have among them almost 90% of the known healthy populations. The other significant migratory species is **shad**. Many species, such as the **European twaite shad**, *A. fallax*, are migratory and spawn in rivers after migrating from the sea.

Dams have strongly affected many European migratory species. On the Danube River in Austria, developed for hydroelectric power since 1954, only two free flowing areas remained by 1989. Lower down the river, the Bucharest Convention of 1958 (signed by Romania, Yugoslavia, Bulgaria and Russia) regulates fishing for migratory species. The species protected are **beluga** (*Huso huso*), **Russian sturgeon** (*Acipenser guldenstaedti*), **sevryuga** (*Acipenser stellatus*), **sterlet** (*Acipenser ruthenus*), **carp** (*Cyprinus carpio*), **pike-perch** (*Lucioperca sandra*), **bream** (*Abramis brama*), **herring** (*Caspialosa pontica*), **crayfish** (*Astacus leptodactylus*), and **mussel** (*Unio pictorum*). The Zanchi project at the Steccaia Dam on the Ombrone River is Italy's first fishway, designed to allow the upstream spawning migration of **shad** (*Alosa fallax nilotica*). **Sturgeon** (*Acipenser sturio*) also once were found in the lower river, but are now very rare throughout the Tyrrhenian Sea. Other fish that migrate from the sea include **eel** (*Anguilla anguilla*), **mullet** (*Mugil* spp., *Liza* spp.), **lamprey** (*Petromyzon marinus*), and **bass** (*Morone*, *Labrax*). In France, dams on the Rhône have reduced access to spawning grounds of **shad** (*Alosa alosa*), **sturgeon** (*A. sturio*) and **lamprey** (*P. marinus*). In Poland, the Jeziorsko Dam on the Warta River dammed in 1986 has aided in the disappearance of the anadromous *Vimba vimba*.<sup>922</sup> In Russia, where dams block **sturgeon** spawning migrations, fish-lifts have been installed, and models have been developed to calculate their

<sup>922</sup> Penczak et al., 1998

effectiveness.<sup>923</sup> In Sweden, two thirds of large-sized stocks of brown trout, *Salmo trutta*, have become extinct in Lake Vanern due to migratory obstructions.<sup>924</sup>

## MEKONG AND OTHER ASIAN RIVERS

There are about 1,200 fish species in the Mekong system.<sup>925</sup> As in South America, many species migrate upriver to spawn at the onset of high waters, which then carry larvae and juveniles into the floodplain nurseries.<sup>926</sup> The Mekong fisheries are partly based on migrating fish, such as the *dai* (bag net) fisheries in Cambodia<sup>927</sup> and the Khone Falls fishery in the Lao PDR.<sup>928</sup> The larval drift itself is also exploited, as in the Mekong delta in Viet Nam, where millions of *Pangasianodon hypophthalmus* larvae are caught every year to be stocked in ponds and cages.<sup>929</sup>

Since the 1950s nearly six thousand dams, reservoirs and irrigation schemes have been built in the Mekong system. Only one dam has gone across the Mekong mainstem and another is being built (both in Yunnan Province, China). The dams have reduced peak floods during filling stage, fragmented aquatic habitats and blocked fish spawning and nursery areas to migratory species. Mekong giant catfish is an endangered species found only in the Mekong River and its tributaries. In breeding season, it migrates upstream and into the Mekong tributaries to spawn before travelling back to Ton Le Sap in Cambodia and the wetlands in the lower Mekong.

In China's East River, a tributary of the Pearl River, Chinese shad (*Macrura reevesii* Richardson) had virtually disappeared by 1970, their migrations blocked by dams.<sup>930</sup> On the Qiantang River, dammed by the Fuchunjiang, Huanzhen and Xianjiang dams, *M. reevesii* has vanished, and the number of species in the Xianjiang Reservoir fell from 107 to 66–83 because the Xianjiang Dam blocked migrations.<sup>931</sup> In the Yangtze

<sup>923</sup> Poddubny & Galat, 1995; Gertsev & Gertseva, 1999

<sup>924</sup> Ros, 1981

<sup>925</sup> Thuock et al., in prep

<sup>926</sup> Poulsen & Valbo-Jørgensen, 2000

<sup>927</sup> Lieng et al., 1995

<sup>928</sup> Baird, 1998; Singanouvong et al., 1996a, 1996b

<sup>929</sup> Poulsen & Valbo-Jørgensen, 2000

<sup>930</sup> Liao et al., 1989

<sup>931</sup> Zhong & Power, 1996

River *M. reevesii* is also rare. Reservoirs and dams have also stopped the migration of other fishes, shrimps and crabs. Downstream of the Gezhouba Dam on the Yangtze (Changjiang), *Acipenser sinensis* migrations have been affected; hatcheries breed and release this species and *Myxocyprinus asiaticus* into the river.<sup>932</sup> The Three Gorges Project, begun in 1994, will become the largest hydropower station in the world. Silver carp, *Hypophthalmichthys molitrix*, bighead carp, *Aristichthys nobilis*, and black carp, *Mylopharyngodon piceus* are found in the river. The dam may disturb distinct genetic stocks of these species.<sup>933</sup>

In Malaysia, on the Perak River, the Chenderoh Dam has blocked the migration of *Probarbus jullieni* (Cyprinidae), contributing to a decline in their numbers.<sup>934</sup> Dams on the Ganges of India have nearly eliminated the anadromous *Hilsa ilisha* (Clupeidae) in the riverine stretches.<sup>935</sup>

## AFRICA

*Labeo altivelis*, also known as the rednose labeo, migrate from October to December and spawn between January and March. The species is intensely fished, partly for its caviar. *Clarias gariepinus*, a commercially important predatory catfish, moves upriver during the rainy season to lay eggs on vegetation in flooded areas; the Yellow Fish (*Barbus marquensis*) also migrates upstream to spawn during the rainy season.<sup>936</sup> In South Africa, dams have prevented or disrupted the migrations of several vulnerable and rare species.<sup>937</sup> In Lake Kariba on the Zambezi River several species such as the cyprinid *Distichodus mossambicus*, which moves upriver to breed have disappeared from the reservoir because of the lacustrine conditions.

In Mali, along the Central Delta of the Niger River, there are about 130 to 140 species adapted to seasonal and interannual variations in water flow. The Markala Dam built in 1943 and the Selengue Dam built in 1984 do not affect reproduction of many fishes, as spawning areas are located

<sup>932</sup> Zhong & Power, 1996

<sup>933</sup> Zhong & Power, 1996; Lu et al., 1997

<sup>934</sup> Dudgeon, 1992

<sup>935</sup> Jhingran & Ghosh, 1978; Natarajan, 1989; Dudgeon, 1992, 1995

<sup>936</sup> Sugunan, 1997

<sup>937</sup> Skelton, 1987

downstream. Species such as *Gymnarchus niloticus*, *Polypterus senegalus* and *Gnathonemus niger*, whose reproduction is linked to the floodplain, and *Citharinus citharus* and *Clarotes laticeps*, which use the floodplain, have suffered reductions since their upward migrations are disrupted. Flows through the Selengue Dam during the dry season may aid spawning. As well, lateral movements between the floodplain and the main channel are important for many species.<sup>938</sup>

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<sup>938</sup> Lăc, 1995

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