# AN ABSTRACT OF THE THESIS OF

Salvador Tello for the degree of Master of Science in Fisheries Science presented on May 19, 1998. Title: Analysis of a Multispecies Fishery: The Commercial Fishery Fleet of Iquitos, Amazon Basin, Peru

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Abstract approved: ______________________________

Peter B. Bayley

In this study an analysis of the commercial fishery of the Loreto Region, with emphasis on the fishery fleet of Iquitos, Amazon Basin, Peru, is presented. There is evidence of a progressive replacement of large species by smaller, more productive and lower value species in the landing of the commercial fishery in the Loreto region. Strong fishing pressure has produced a decrease of large valuable species such as *Brachyplatystoma flavicans* in the commercial landings of the last ten years. No studies have evaluated the association between catch of the fishery fleet and amplitude and duration of the flooding and fishing effort in the Ucayali and Amazon rivers. Hydrological indices were based on the Amazon water stage taken at Iquitos gauge station in the last ten years. Hydrological indices and fishing effort were used as explanatory variables in a multiple linear regression to answer the question whether the factor responsible for the fluctuation in catch per guilds was the intensity of flooding or the severity of the draw-down period while accounting for fishing effort. This analysis was performed with index of the same year and index of the preceding year. The most significant variables were flood index of the same year and number of fishermen-trips. A positive influence of flooding on the omnivore group was evident in the Ucayali (p-value = 0.03) and Amazon (p-value = 0.001) rivers. However, this influence was negative (p-value = 0.03) on the detritivore group in the Ucayali River at high water which is interpreted as being due to reduced feeding places and stranding process. Number of fishermen-trips explains 90% and 96% of the variance of annual catches in the Ucayali and Amazon rivers, respectively. Additionally, six catch prediction models are presented.

# Analysis of a Multispecies Fishery: The Commercial Fishery Fleet of Iquitos, Amazon Basin, Peru

by

Salvador Tello

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Salvador Tello, Author

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# DEDICATION

To my family

To the people from Loreto

**Analysis of a Multispecies Fishery: The Commercial Fishery Fleet of Iquitos, Amazon Basin, Peru**

# 1. INTRODUCTION

## 1.1 Background

Fishing is a very important source of food and income in the Peruvian Amazon. Fish is the main source of animal protein in the local population's diet, and the yearly catch was valued at 80 million dollars in the 1990's.

Two fisheries exist in the Peruvian Amazon: (1) subsistence and local markets, the most important because it gets about 75 % of total catch, and (2) commercial, which comprises 25% of the total catch. About 50 species are exploited by the commercial fishery and more by subsistence fisheries.

Migratory Characiformes and Siluriformes are the most abundant in the catch of the commercial fishery. Species such as boquichico (*Prochilodus nigricans*), gamitana (*Colossoma macropomum*), palometa (*Mylossoma duriventris*), and dorado (*Brachyplatystoma flavicans*), have dominated the catch in the past decade.

The Amazon, like other tropical ecosystems, is very complex. Physical, chemical, and biological attributes are influenced by environmental and geographical factors, which change in a spatial and seasonal fashion. One of the most limiting factors for the management of the Amazon fisheries is the restricted technical and scientific information to promote sustainable use of the fishing resource.

The multispecies characteristic of the Amazon fisheries makes it difficult to design a model to evaluate the association among fish population dynamics, environmental changes and fishing intensity. Unfortunately, no long - term studies of this fishery have been conducted and little is known about the biology of Amazon fish species. Elsewhere, classical stock assessment models of fish population dynamic have been designed to analyze single stock fisheries in temperate ecosystems, but these have not been very successful either (Hilborn and Walters 1992).

### 1.2 Research Approach

For the last forty years fishery biologists have used the results of studies linking physical variables and fish abundance to design mathematical models for predicting standing crop of fish in small streams and fish yield in large rivers. These models consider a large variety of physical variables that could be broadly classified into two groups: (1) drainage basin attributes, and (2) morpho-edaphic and flow characteristics.

Variables on the drainage basin scale are measured from topographic or planimetric maps and are roughly at the scale of the river channel. They include attributes such as drainage basin area, mean basin elevation, total river length, drainage density, floodplain area, stream order and stream gradient. Channel morphometry and flow variables include gauge records, width, depth, mean velocity, wetted perimeter, pool volume, riffle area, surface area, channel volume and gradient. Water temperature and chemical parameters are also considered in this latter group.

In river-floodplain systems there is an association between the drainage basin area of the river, and the catch obtained from it. Basin area and total length of the longest channel of the river are also related just as yield as a function of the main channel (Welcomme 1975, 1976; Bayley 1981b).

Fausch et. al. (1988), reviewed the strengths and weaknesses of 85 models that have been developed since 1970 in the United States, that predict standing crop of stream fish from measurable characteristics of the environment. Unfortunately, these mathematical models are not immediately applicable to tropical, multispecies systems because of the scarce knowledge of parameters required in classical fish population models. Moreover, an understanding of Amazon fish assemblages is complicated by the variety of life histories, species interactions, gear interactions among diverse fisheries and our inability to identify stocks (Gulland 1982; Turner 1985; Bayley and Petrere 1989).

One approach to estimate the yield in a multispecies fishery is by deriving a relation between total catch (as total weight of all species caught, weight of marketable species, or total value) and total effort. Fishing effort could be responsible for year to year or season to season variations of catch. This procedure is attractive because it is simple, effective within the range of conditions encountered and gives results that can be clearly understood by the policy-maker, especially if the fishing effort is expressed in units appropriate for the management program (Gulland 1982; Turner, 1985). This model known as the total biomass Graham-Schaefer model has been applied in the tropics (Welcomme 1975) and it is also applied to the landing of the commercial fishery fleet of Iquitos, Peru, in this study.

The first use of classical models in the Amazon was done by Petrere (1983) using the length-frequency distribution of "gamitana" (*Colossoma macropomum*) and the Beverton and Holt model (Ricker 1975). Later, Bayley and Petrere (1989) applied the Schaeffer model to the landings of "manitoa" (*Brachyplatystoma vaillantii*).

Another approach to evaluating a multispecies fishery is to estimate the predicted catch from a time series of historical catches. This model may include biological, morpho-edaphic, environmental and economic data as predictors, and performs best when catch and stock size are correlated with important environmental influences, such as monsoons or the hydrological cycle (Larkin 1982).

In river-floodplain systems growth, reproduction success, mortality, standing stock, and catch can be hypothesized to relate to the intensity of floods and/or with the severity of the draw-down (low-water) period. Therefore, the water stage as measured at a gauge, may be the easiest procedure for prediction. In addition to simple water stage, different measures of the amplitude and intensity have been used to evaluate the influence of flooding on fish yields in African floodplains. Flooding and floodplain characteristics are of major importance to estimate catches from African floodplain fisheries (University of Michigan 1971; University of Idaho 1971; Dudley 1972; Kapetsky 1974; Muncy 1973, 1977; Welcomme 1975, 1976 and 1979). There is evidence of an association between the annual extent and duration of inundation and fish abundance in the Kafue, Niger, Shire and in the middle Orinoco rivers (Welcomme 1977; Novoa 1989).

The many factors influencing the association between catch (or fish growth) and fluctuation of the flood regime differs between ecosystems. The seasonally of the flood regime is determined by precipitation and by the latitude, and flooding conditions are quite different in river systems located in the northern hemisphere than those in the southern part. Even within the same system, conclusions about the influence of geomorphological and hydrological patterns on fish catch have differed depending on the fish species, method used, or sector of the river sampled (Dudley 1979; Bayley 1981b; Novoa 1989, respectively).

Most of the studies relating to the association between catch and flooding fluctuation has been done in river-floodplain systems different than that of the Amazon basin. Therefore, it is necessary for fishery management in the Peruvian Amazon to answer some questions, such as: Is the extent and duration of the inundation or the draw-down period affecting the catch of the commercial fishery? How does the degree of flooding affect the abundance of commercial fish stocks in the Ucayali and Amazon rivers, both considered the most important basins in the Peruvian Amazon? Is it possible to predict year-to-year variation of catch in those rivers using water level information? These questions will be assessed throughout this study.

It is assumed that when species of fish compete for food or space, or prey on each other, an increase in the abundance of one will be reflected by a decrease in another. These changes in species composition occur not only due to species interactions, but also because of the depression of stocks of large fish species and the inevitable species composition adjustment resulting from a multigear and multispecies fishery supplying different and expanding markets, as well as changes in environmental conditions.

As fishing intensity increases, larger species are replaced by smaller and fast growing species (Regier and Henderson 1973; Marten 1979a; Bayley and Petrere 1989; Novoa 1989; Welcomme 1985; Turner 1977; Lae 1995) that typically produce higher total yields and P/B ratios. Therefore, it is not an easy task to keep the desired diversity and composition of the catches in the Amazon fisheries because of the tendency of the fish population to change due to fishing intensity and variations in the physical environment. In addition, several species are often caught in the same type of gear and we cannot therefore target effort clearly on a species by species basis (Hilborn and Walters 1992). Estimation of fish population parameters of all relevant species is practically impossible in a multispecies fishery. To facilitate the analysis, it is necessary to group a number of species according to shared biological parameters and fishery responses in order to simplify analysis and assist in the prediction of community changes. This procedure is consistent with the Guild Concept described by Austen et. al. 1994 where species associations were used to describe a community change in response to environmental perturbation. The authors suggest that trophic groups respond to environmental changes, including fishing pressure, in a more predictable, robust manner than any individual species. Species that feed on detritus, for instance, could be placed in the same group if their individual sizes and other ecological attributes are considered sufficiently similar.

There is a necessity to develop simple models that reflect the essential properties of multispecies fisheries. These models must be based on ecological approaches that permit the prediction of changes in species composition and/or total yield (Larkin 1982). It is essential, therefore, to define not only criterion for the assessment of the fishery in the Amazon basin, but also to design a model that permits a better understanding of how the fish populations are responding to changes in natural conditions, fishing effort, and indirectly from demographic pressure through market and environmental impacts.

Because of the importance of such predictions for the management of the commercial fishery in the Peruvian Amazon, the following objectives are proposed:

## 1.3 Objectives

- To define and describe the catches in term of groups based on trophic levels. These groups were then used as response variables related to environmental changes and to fishing intensity.
- To determine if changes in species groups from the catch are related to changes in the physical environment and / or fishing intensity.
- To design a model (s) for predicting changes in composition of the landings (catch) of the commercial fishery fleet in Iquitos, Peru.

In summary, the purpose of this research was to analyze the commercial fishery of Iquitos in order to provide information to design a conceptual plan for the appropriate management, development, and conservation of the fishery in the Peruvian Amazon.

# 2 MATERIAL AND METHODS

## 2.1 Study Area

The Amazon River basin comprises 7,000,000 km$^2$ and it is the world's largest rainforest and the place with the highest biodiversity index. This region contains the most intricate and voluminous network of waterways on the planet, providing habitat for at least 2,000 fish species. Due to seasonal changes in the water level, lakes, lagoons, channels and large rivers inundate large extension of the forest during approximately six to nine months each year, producing a dynamic interaction between the land and aquatic environment. This seasonal inundation is considered not only the principal process that produces floodplain in the Amazon system, but is also the main mechanism for seasonal changes in the environment, affecting all aspects of the fish biology, such as their food, migration, growth and breeding process (Lowe McConnell 1975; Goulding 1980; Junk 1984; Junk et al. 1989; Bayley 1991 and 1995).

In the Peruvian Amazon basin, water level can fluctuate 5–12 meters per-year causing the river to form enormous floodplains. During the flood season the main channels and their floodplains are essential for the growth of fish populations. Areas that are periodically inundated by the lateral overflow of rivers or lakes provide excellent nursery grounds for many fish populations.

The study area is located in the Peruvian Amazon basin (Fig 1a), comprising the Loreto region (Fig 1b) which includes the Amazon and Ucayali rivers. Both systems are considered the most important basins in Peru. The Amazon River from its origin to the common boundary with Brazil and Colombia is around 3,000 km long. The most significant sector from a fishing and fish production perspective has a length of 1,300 km from the town of Contamana (Ucayali River) in Peru to Leticia (Amazon River) in Colombia (Foldout map and Fig 1b).

Fig 1a

PERUVIAN AMAZON

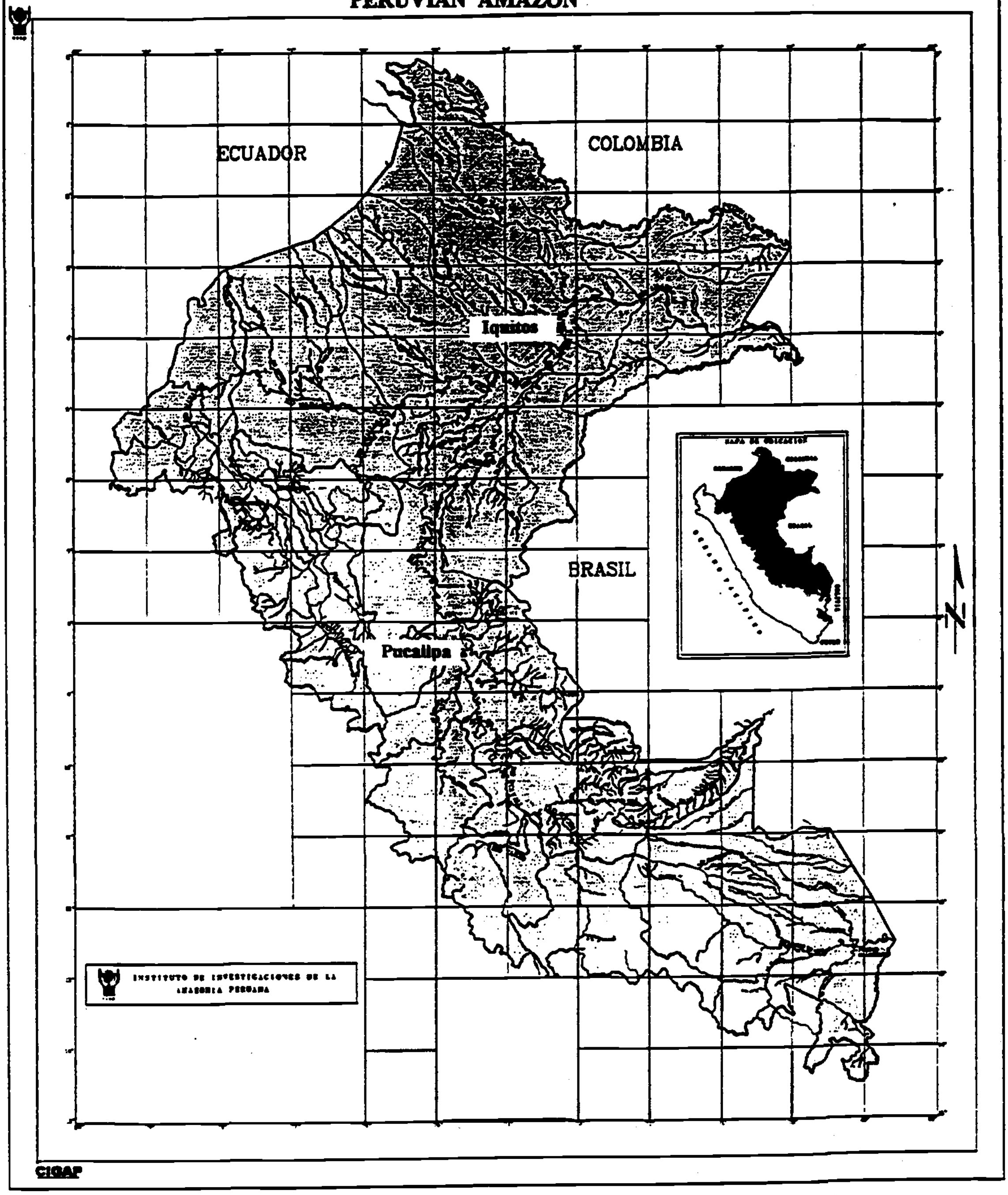
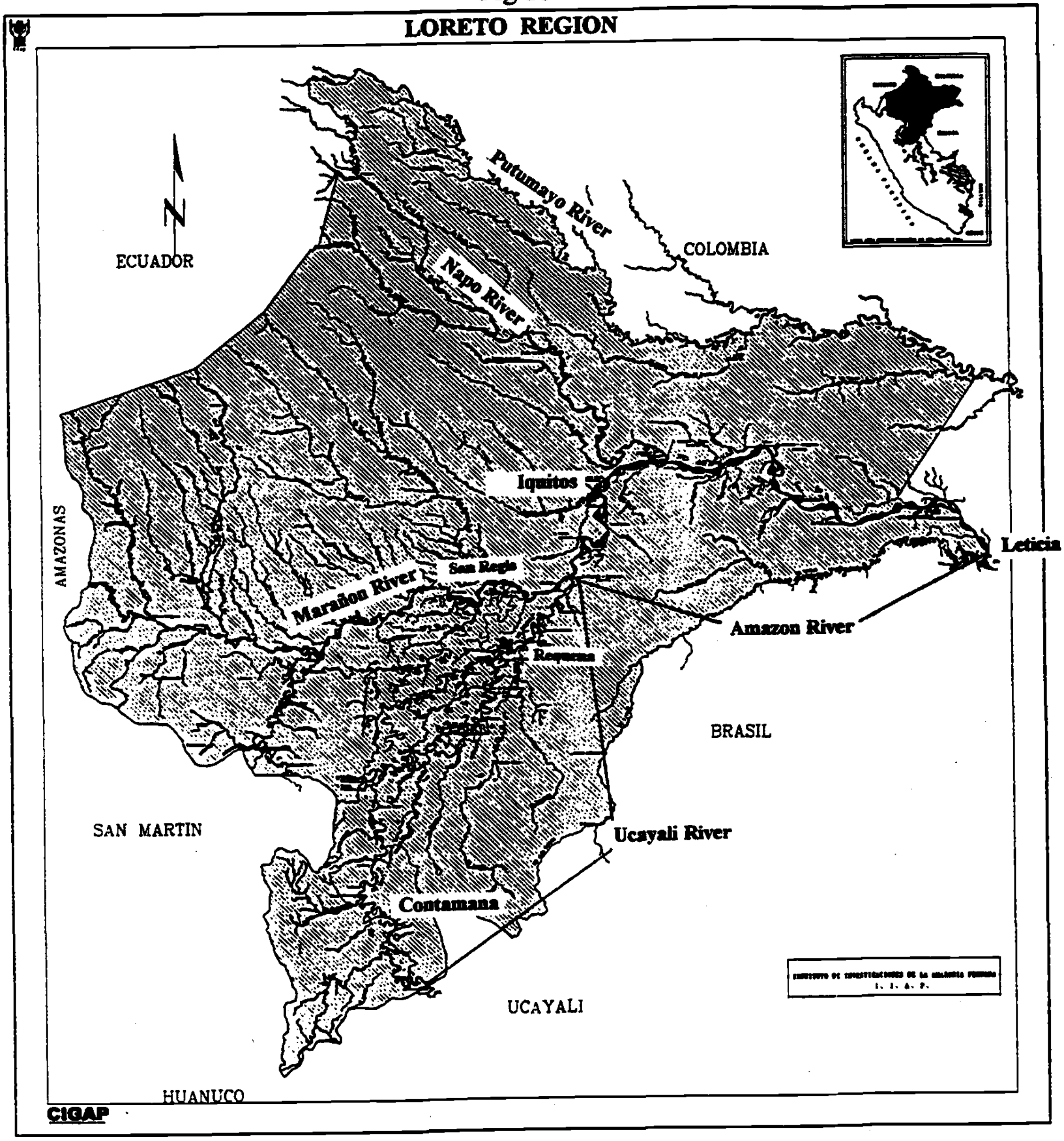


Fig 1b


LORETO REGION
N
ECUADOR
Putumayo River
Napo River
COLOMBIA
Iquitos
AMAZONAS
Leticia
San Regis
Marañon River
Amazon River
Requena
BRASIL
SAN MARTIN
Ucayali River
Contamana
UCAYALI
HUANUCO
CIGAP

This part of the Amazon basin includes numerous tributaries and water bodies with different physical and chemical properties that provide habitat for the abundant and diverse fish populations and result in an important component of the commercial fishery.

The study area is in the humid tropical zone, with average temperatures ranging from 20 to 33 °C and annual precipitation varying from 2,000 to 3,000 mm. A relatively dry season occurs from June to September. Lower temperatures take place between April and June (Table 1 in Appendix A).

According to Fittkau's 1971 (cited by Junk and Furch 1985) hydrochemical and geochemical classification, the Amazon River basin is divided in three basic provinces: (1) the Andean and pre-Andean region (western peripheral region), (2) the archaic shields of Guyana and central Brazil (northern and southern peripheral region), and (3) the central Amazon. The study area is located in the western peripheral region where the rivers contain high sediment loads and high concentrations of mineral salts, with a large percentage of alkali-earth metals and neutral pH. According to Sioli (1967) and Junk and Furch's (1985) water classification, the rivers of the study area (i.e. Ucayali and Amazon) are considered as "white water rivers". This name is given to the muddy water, rich in fine suspended inorganic solids and related to areas with intensive erosion processes like those close to the Andes mountains. In addition, whitewater has relatively high concentrations of total electrolytes and a pH value near 7 (Table 2 in Appendix A). The Ucayali and Amazon rivers are also considered to have extensive floodplains because more than 2.3 % of the basin area is covered by floodplains (Bayley 1981a).

The most productive floodplains in the Peruvian Amazon are located in the study area, in particular those associated with the Ucayali River. The hydrological conditions produce flood pulses responsible for high fish production, and the nutrient levels are excellent in this river system (Hanek 1982; Guerra et al. 1990; Bayley, et al. 1992; Tello 1995). The vital mechanism accountable for the existence, productivity, and interactions of the fish population in river-floodplain systems is the flood pulse (Junk et al. 1989). However, amplitude, frequency, and duration of the flooding regime vary among basins according to gradient, topography, soil types and latitude, and thus productivity and yield patterns of the fishery fluctuate considerably from one place to another.

The Ucayali River possesses peculiar morphological features compared to those of the Amazon River. The Ucayali is the most significant basin of the Pacaya-Samiria Natural Reserve, which is estimated to cover about 21,135 $km^2$ of land between the Ucayali and Marañon rivers. This region lies in the Ucamara Depression east of the Andes, where the topography is extremely flat apart from a small non flooded area along the southwestern boundary. Swamps and floodplains occupy 95 % of the Pacaya basin (Bayley et al. 1992). Taking into consideration active floodplains and swamps, the Ucayali is 30 % greater in extent than the Amazon in the study area. In addition, the Ucayali contains a larger number of oxbows, meander scroll depressions and a greater extent of permanent swamps in the Peruvian Amazon (Table 1).

These water bodies expand and contract according to the annual flood cycle and during the highest floods tend to integrate into a continuous surface of water covering whole floodplains that can even connect the Ucayali and Marañon rivers. When the water goes down, thousands of permanent and semi-permanents standing water bodies are left by the receding flood. Many of them remain isolated from the main channel during long period of time (Lowe-McConnell 1969; Bayley 1982; Junk 1983; Goulding et al. 1988)

Table 1. Morphological features of the rivers from the study area (Bayley 1981a)

| **Basin** | **Channel Length (km)** | | **Max. inundated floodplain ($km^2$)** | | |
|---|---|---|---|---|---|
| | | **Main river area($km^2$)** | **Lakes-channels** | **Active floodplain** | **Swamps** |
| Ucayali | 570 | 469 | 58 | 7,284 | 9,534 |
| Amazon | 566 | 1,195 | 259 | 5,131 | 4,334 |
| TOTAL | 1,336 | 1,664 | 711 | 12,415 | 13,868 |

## 2.2 Data Collection

Information compiled by the Peruvian Ministry of Fisheries, Peruvian Amazon Research Institute (IIAP), National Harbor Enterprise (ENAPU), Sistema Nacional de Hidrografía y Navegación, Pro-Nature and the Fishermen's Association has been used in this research. It was also based on fields studies performed in the harbor and market of Iquitos. This city of 300,00 habitants is located in the Loreto Region and it is considered to be the principal fish marketplace and the most important landing port of the commercial fishery fleet in the Peruvian Amazon. In addition, interviews with fisherman and other people connected with the fishing activity were performed.

The information was divided into two data sets: (1) total landing in the Loreto region and (2) the catch landed by the commercial fishery fleet in Iquitos. In the former case, salted and dried fish were converted to fresh fish weight using the factors 1.8 for salted and 2.5 for dried fish (Hanek 1982). Landings at major cities such as Nauta, Requena, Contamana and Caballo Cocha were included within the Loreto data.

Catch data by weight from the commercial fishery fleet were compiled from logbooks of the fishermen's association. Unfortunately, the data catch collected by the fishermen did not show consistent distinction between species of the same genus, nor between types of gear used in the catch. Therefore, to analyze the nature of fishing exploitation and fish community changes over time, species were grouped according to trophic level and effort characterized by the amount of fishing activity. Data from the fishermen association were cross-checked with a field study done in the Iquitos port (Del Aguila 1995) to test the accuracy of the information available.

Fish caught by the subsistence fisheries of towns, villages and the riverine population disseminated along the rivers of the study area have not been included in the analysis. Because of it was not possible to get information on discards, landing and catch is used synonymously. Likewise, the Ucayali and Amazon rivers are referred to jointly as "the study area" throughout the analysis. A curvimeter was used to measure the distances between Iquitos port and the fishing places located in the study area. Also, raw data from Bayley's (1981) inundated area evaluations using LANDSAT, radar images and aerial photography were used to estimate morphological features of the Ucayali and Amazon rivers.

## 2.3 Water Level and Hydrological Indices

Little is known about the regulatory process of fish population and production in river-floodplain systems. However, it is expected that annual extent and duration of inundation affect abundance of fish stock available for exploitation. The intensity of the flood has been found to determine the magnitude of the stock through differences in recruitment, survival and growth, and also affect access between river channels and water bodies, thus altering catch within the same year (Welcomme 1985). Low water levels are considered to be associated with higher mortality. Therefore, the more severe the draw-down period, the greater the influence of the low water regime on catch in some river floodplain systems (University of Michigan 1971; University of Idaho 1971). Comparisons of catch versus flooding history have been made to test these assumptions (University of Michigan 1971; Kapetsky 1974; Welcomme 1985; Novoa 1989).

If there is evidence that the year-to-year variations in catch is caused by the intensity of flood or the severity of the draw-down period, then it will be possible to predict the effect of the flooding regime on the catch for management purpose, and to demonstrate the importance to maintaining the natural flood cycle.

Because estimates of floodplain area that are inundated during each hydrological cycle were not available, it was necessary to find a different way to plot a flood index against the annual catch of the fishery fleet. Two indices were designed to identify the importance of both components of the hydrological regime (intensity of the flood and draw-down period). These hydrological indices, based on Kapetsky (1974), utilized a plot of the Amazon water stage taken at the Iquitos gauge station during the last 16 years (1980-1996). Values for these indices were estimated as the area either under or above the water level curve using 113 m as reference level. The level adopted estimates the level at which water starts to overflow onto the floodplain (bankfull).

Flood index (FI) is defined as the area over the curve above the 113-m water level adopted (Fig 2). Values for this index for each hydrological cycle were estimated by plotting the mean water level between the maximum and minimum measures taken on each month at the Iquitos gauge station. The area under the water-level curve was calculated by using a planimeter.

FI is a measure of the annual amplitude and duration of the inundation of the floodplain. Catch in a given year was plotted against hydrological index of the same year ($FI_y$), of the previous year ($FI_{y-1}$), and fishing effort and a regression line fitted.

Regression analysis was used to answer the question of whether the factor responsible for the fluctuation in catch was the intensity of flooding or the severity of the draw-down period. In the latter case, catch was used as the response variable and the dry season index (DSI) and fishing effort as explanatory variables. This analysis was performed in the same year ($DSI_y$), and in the previous year ($DSI_{y-1}$).

DSI is the area above the water-level curve under the arbitrary water level adopted. This is a measure of the amplitude and duration of the contraction of the aquatic environment after the floodplain has dried.

In addition to water level data from the Iquitos gauge station (Amazon River), water level data from Pucallpa (Ucayali River), Requena (Ucayali River), San Regis (Marañon River) and Tamshiyacu (Amazon River) gauge stations were used to compare the hydrological regimes. These places are all located within the study area. Water stage at Iquitos gauge station which corresponds to the initial inundation and final retraction of the water from the floodplain, served as the basis for the estimation of the hydrological indices.

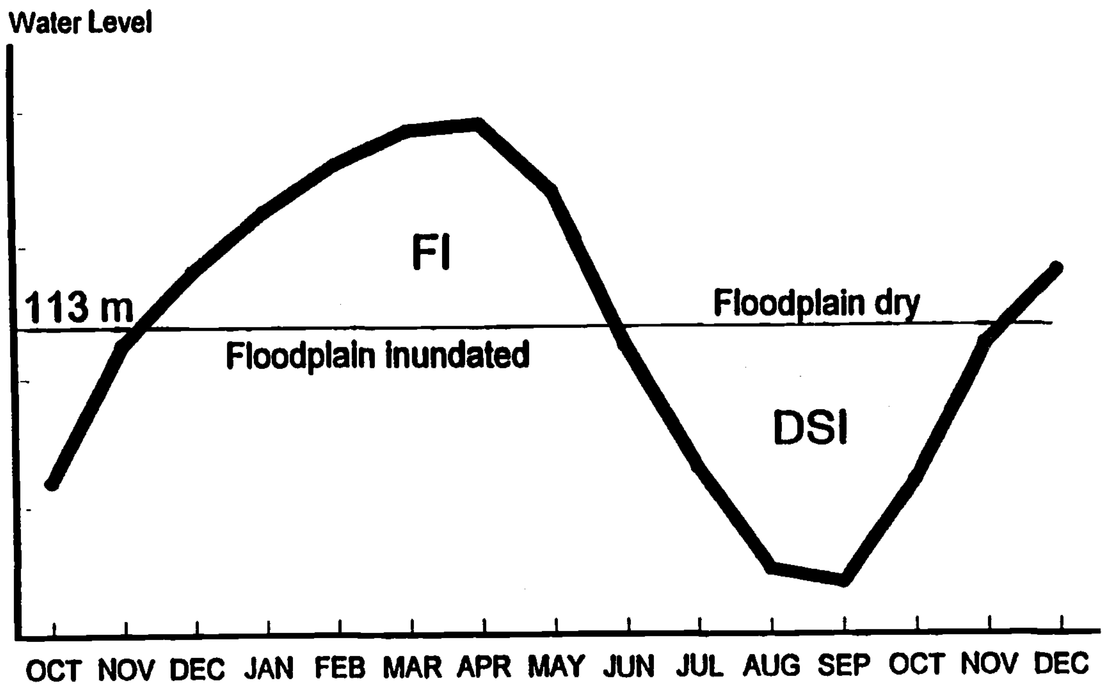


Fig 2 Hydrological indices used to predict annual catch in the study area

## 2.4 Trophic Groups

Despite the variety of food consumed by fish species in the Amazon floodplain, it is possible to classify fish into guilds according to their predominant feeding habits (Welcomme 1979; Austen et.al. 1994). Three trophic groups were delineated from the commercial fishery catch. The division of fish species into these guilds was based on Marlier (1967, 1968), Bayley (1988a) and personal observation. These groups were: (1) primary consumers or detritivores (bottom deposits, mud, detritus, and algae eaters) such as *Prochilodus nigricans*, *Potamorhina spp.* and *Curimata spp.*, (2) secondary consumers or omnivores (insects, mollusks, crustaceans, fruits, seeds, leaves and higher plants eaters) such as *Colossoma macropomum*, *Piaractus brachypomus*, *Brycon spp.*, *Mylossoma spp.*, and *Triportheus spp.*, and (3) tertiary consumers or piscivores comprising big catfish such as *Brachyplatystoma flavicans*, *Brachyplatystoma filamentosum*, *Pseudoplatystoma fasciatum* and *Paulicea lutkeni* .

To facilitate the analysis of change in composition of the catches according to each trophic group and species, plots of catch against the years of the fishery was used. Finally, catch per each group in a given year was used separately as response variable and hydrological indices of the same year, of the previous year and fishing effort as explanatory variables to test the hypothesis stated earlier.

## 2.5 Statistical Analysis

Two data sets from were considered separately in the analysis: (1) monthly landings by guild from May to November to analyze the influence of flooding regime and fishing effort on the Iquitos landings, and (2) annual landings by guild to derive the catch prediction models for the Iquitos fishery fleet. In the former case, seven months were selected in order to avoid overlap (Fig 3) due to time differences between catch (calendar year) and indices (hydrological year). There was a high correlation between FI and A

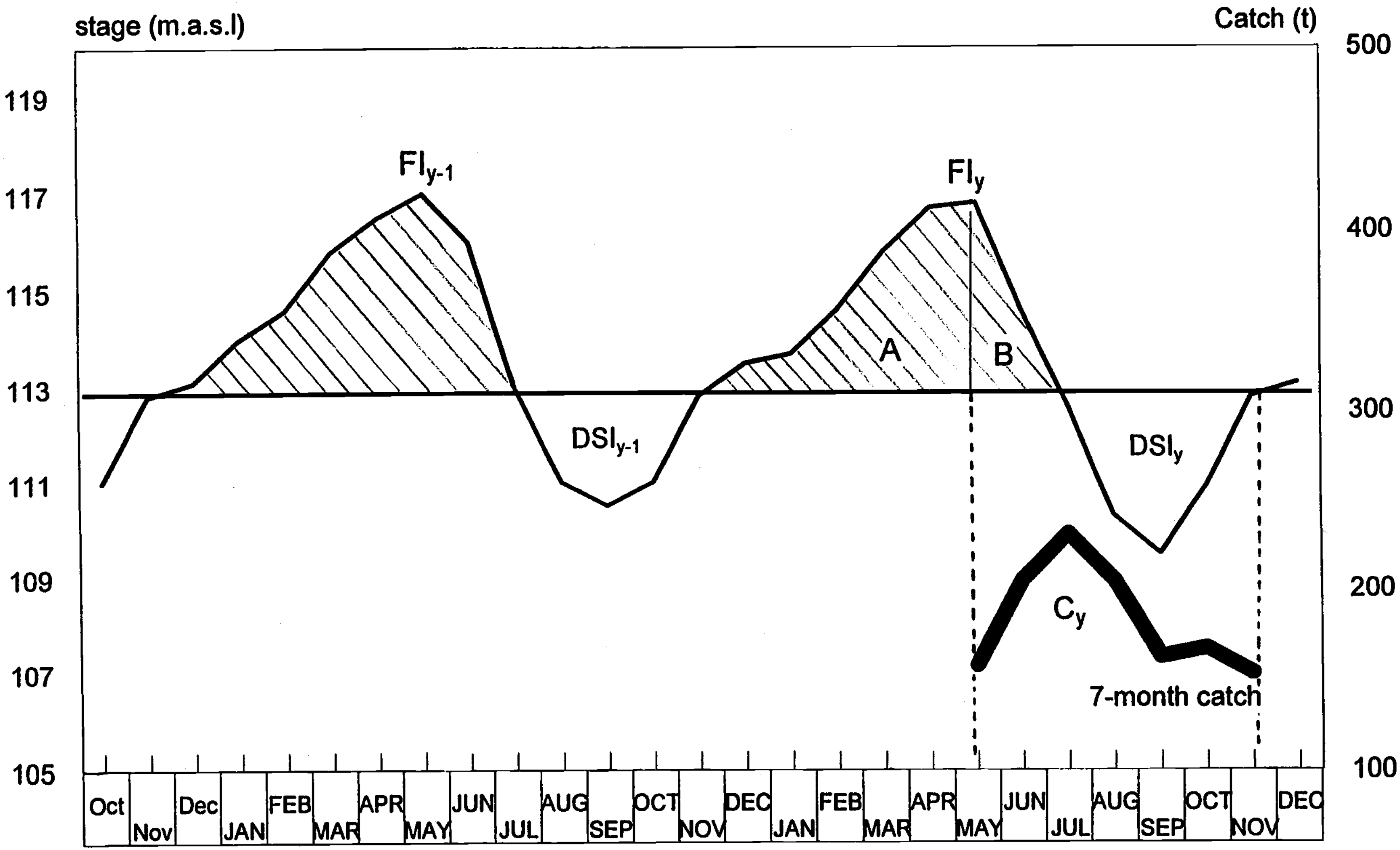


Fig 3 Graph showing the time trend of catch and hydrological indices used for the 7-month catch models

(which is an index of the amplitude and duration of the rising water) and between FI and B (an index of the amplitude and duration of the water retraction before the floodplain has dried completely). It was reasonable, therefore, to use FI for the analysis, which was easier to measure.

Statistical analysis were performed by considering the full model, including all the variables believed to determine the catches:

$$C_y = \beta_0 + \beta_1 (FI_y) + \beta_2 (FI_{y-1}) + \beta_3 (DSI_y) + \beta_4 (DSI_{y-1}) + \beta_5 (E)$$

Where, $C_y$ is the annual catch in year *y* from the rivers of the study area; $FI_y$, and $FI_{y-1}$ are flood indices of year *y* and of the preceding year, respectively ; $DSI_y$ and $DSI_{y-1}$ are dry season indices of year *y* and of the preceding year, respectively (Fig 3); E is the number of fishermen-trips that operated in each river. The log-transforms of all variables in this model were ultimately used.

To test the independence among the explanatory variables a Pearson correlation coefficient analysis was used. Also, a test based on autocorrelation was performed using residuals from the proposed models to determine if serial correlation is present in the response residuals.

To test if the effect that one of the explanatory variable has on the mean response depends on the value of an other, first-order interactions from the regression of catch on the hydrological indices and number of fishermen (full model) were evaluated using each interaction in turn.

The full model was later reduced to a simpler equation by dropping explanatory variables of low significance. Data from the Ucayali and Amazon rivers were analyzed individually to identify any relationship arising from changes not only in temporal fishing patterns but also in flooding fluctuations and nature of terrain flooded. The statistical analyses were performed with the Program SAS.

# 3 RESULTS

## 3.1 Historical Development of the Fishery

Since 1750 many chronicles, books and technical reports have been written about the relationship between man and fish in the Amazon region. The Jesuit missionaries narrated their experiences with natives during the evangelical process such as Manuel Uriarte who lived in a native village located in the Marañon River from 1750 to 1767. In his chronicle "Diario de un Misionero en Maynas" (Monumenta Amazónica 1992), Uriarte narrated how different fish species are captured by fisherman using harpoon, hook, bow-and-arrow and poison. The first reference about the use of gill-nets to catch fish is reported by this missionary.

The knowledge of natural science was increased in the last years of the eighteenth century, and interest in the Amazon region occupied an important place in the scientific world. The most notable contributions during the nineteenth century were the reports of Humboldt and La Condamine (1852). The studies of Spix and Martius (1823 – 1831), Agassiz (1867) and Spruce (1908) were also significant contributions to the knowledge of natural science in the Amazon region . Alfred Wallace (1848 – 1852) was the first naturalist to divide Amazon limnology systematically into three major water types: white water, clear water and black water rivers. His reports included more than 200 drawings of fish from the Negro River, Brazilian Amazon.

The commercial fishery in the study area began in the Ucayali River during the nineteenth century, increasing significantly in the last years as a consequence of the rubber boom in the Peruvian Amazon (Bonilla 1976; Barcia 1986). Although the fish production decreased with the economic crash of rubber plantations years later, fishing continues today to be one of the most important activities of the riverine population.

Fishing technologies and methods of preserving catches have changed radically since the advent of Europeans. Since the arrival of synthetic twine, more efficient harvesting methods such as gillnets and large seines have become widely used by the fishermen. Smith (1985) describes the impact of cultural and ecological change on Amazonian fisheries. Historical aspects of the fisheries were described by Verissimo (1895), Smith (1981), Goulding (1983), Junk (1984a) and Bayley (1981b). Likewise, in the Peruvian Amazon this activity was described by Hanek (1982), Eckman (1985), Bayley and Petrere (1989), Guerra et al. (1990) and Bayley et al. (1992).

### 3.2 Fish Yield in the Peruvian Amazon

Fish yield in the Peruvian Amazon was estimated at 80,000 t year$^{-1}$ (Bayley et al. 1992; Tello 1995). The subsistence fishery comprised about 75% of the total catch landed in the region, whereas the remaining 25% were obtained by the commercial fishery. The catch from the latter fishery is landed mostly in Loreto (75%) and Ucayali (25%), both considered as the most notable regions from a fishing point of view (Fig 4).

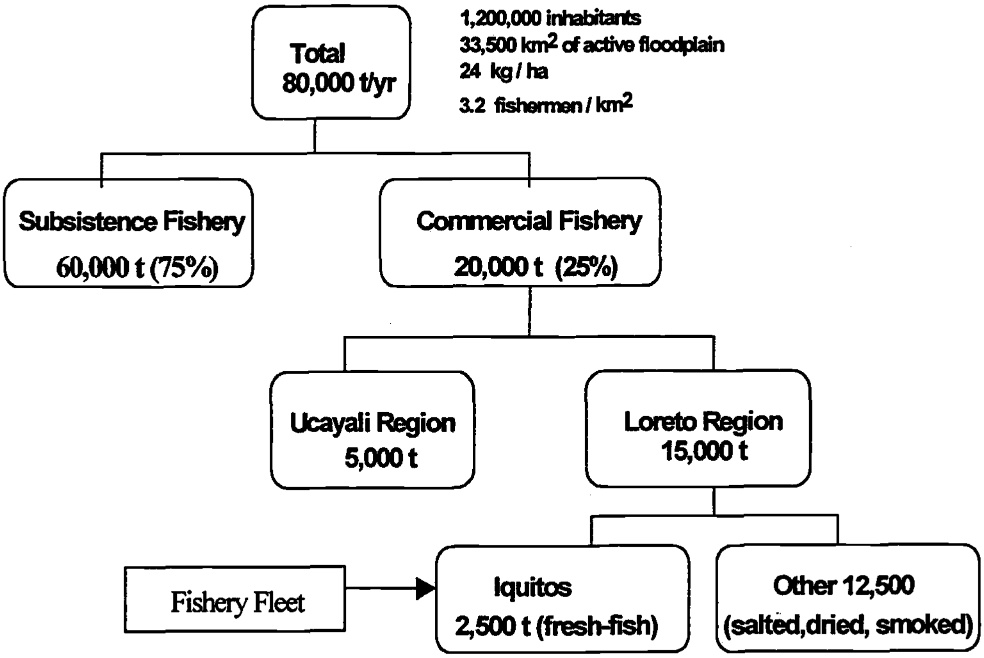


Fig 4 Fish yield in the Peruvian Amazon estimated for 1994 (from Tello 1995)

### 3.3 Loreto Region Landings

Total fish landed in Loreto during 1996 was estimated at 13,200 t (Table 3 in Appendix A). 85 % of this total was landed as fresh, salted and dried by fishermen and boats different than those from the fishery fleet at cities such as Iquitos, Nauta, Requena, Contamana, Caballo Cocha and Puerto Alegría (Foldout map). The remaining 15 % were landed as fresh fish by the fishery fleet only in Iquitos .

The catch is transported from the fishing place to the cities mostly by mean of passenger ships. A small part is consumed locally and the remainder is transported to Iquitos. From this city, a large proportion of the catch is exported to places such as Tarapoto and Yurimaguas where the fish is not abundant and therefore very valuable.

It was estimated that there are about 45 species exploited by the commercial fishery in the Peruvian Amazon (Tello 1995) and many more by subsistence-local market-fisheries. Migratory Characoids dominated the catch in Loreto and comprised 83.5% of the total landed in 1996, whereas Siluriforms (mostly large catfish) accounted for 7%. *Prochilodus nigricans*, was the most abundant species during 1996 (32% of total landings), followed by *Potamorhina spp.*, and *Curimata spp.* which accounted for 20 and 10% of the landings, respectively. These latter three species are the dominant detritivorous fish groups in the Peruvian Amazon landings.

The Ucayali is considered the most productive basin because 57% of the fish landed in Loreto in the last 15 years were caught in this river, 11% in the Amazon, 10% in the Marañon and 22% in other rivers (Barthem et al. 1995). 39 % of the fish landed in the Loreto Region during 1996 were caught in the Ucayali, 18% in the Marañon, 9% in the Amazon and 34% in other rivers (Table 4 in Appendix A). Details on the fishery fleet as well as the analysis of species composition of the landings are presented in a later section.

## 3.4 Fishery Fleet of Iquitos

An average of 2,200 t fresh fish is landed by the commercial fishery in Iquitos each year. The nutritional demands of the urban population is supplied in great part by this fishery because the low price allows people of restricted economical resources to obtain inexpensive and high quality protein. Fish is cheaper than beef, chicken or pork.

Fishing boats are usually registered in the Fishermen Association, and the following analyses are based on landing of these boats compiled in the logbooks. An intense calibration program was performed during one year to assess the accuracy of official statistics compared with those of the association of fishermen (Del Aguila 1995). The results showed that information from logbooks (fishermen) are the best approximation to the catch landed by the commercial fishery fleet in Iquitos (Fig 1 in Appendix B).

An average of 75 fishing boats operated each year in the study area. The number of trips depends on the season (Table 2). If we consider that one boat spent six more days preparing for the next trip, then 12 is the estimate average number of trips per year.

Table 2. Average number of days spent in the river by a fishing unit during a trip according to the season estimated for 1994 (Del Aguila 1995)

| Season | Traveling | Fishing | Selling | Total |
|---|---|---|---|---|
| Wet season | 14 | 7 | 7 | 28 |
| Dry season | 8 | 4 | 7 | 19 |
| Average | 11 | 6 | 7 | 24 |

### 3.4.1 Characteristic of the Fishing Boats

The fishing units were divided into large, medium and small boats according to their size, capacity, number of ice blocks, number of fishermen and number of gears (Figures 2, 3 and 4 in Appendix B). Seven percent of the fleet comprised "large" boats which had mean length: 22 m (20 - 30 m); width: 5 m (4 - 6 m); isothermal box capacity: 17 t (15-20 t); number of ice blocks: 750 (>750); number of fishermen: 12 (10-15); and eight different gears (6 - 10). Likewise, 26% of the fishing units comprised "medium" boats which had length: 17.5 m (15 - 20 m); width: 3.5 m (2.5 - 5 m); isothermal box capacity: 12.5 (10 - 15 t); number of ice blocks: 625 (500-750); number fishermen: 9 (8 - 10); and five different gears (4 - 6). Finally, the most numerous group (67% of the fleet) comprised "small" boats. These were boats 13 m long (8 - 17 m); width: 3 m (1.5 - 4 m); box capacity: 6 t (2 - 10 t); number of ice blocks: 300 (100 - 500); number of fishermen: 6 (4 - 8); and a mean number of three different gears (2 - 4).

Number of days per fishing trip depends on the vessel size and number of ice blocks, but is usually no longer than 30 days. A typical fishing unit is well equipped to travel long distances following the up-stream fish migrations that can cover 600 km of river. None of the boats used sophisticated devices for fish detecting, such as echo sounders.

The main fishing gear employed was the round haul seine of diverse length (90 - 180 m), high (25 - 35 m) and stretched mesh size (1.5 - 2 inches). However, beach seine and gill-net were used depending of the season and the species targeted. The fish is stored forming layers between ice in special designed wood boxes of several sizes and capacities.

### 3.4.2 Fishery Fleet Landings

A total of 40 species was exploited for the fishery fleet in the last nine years. However, many more are captured because several species of the same genus are frequently registered by just one common name. For instance, two species of the genus *Triportheus* (*T. elongatus* and *T. angulatus*) are usually registered by the fishermen under the common name of "sardina" (for more details see Checklist in Appendix C).

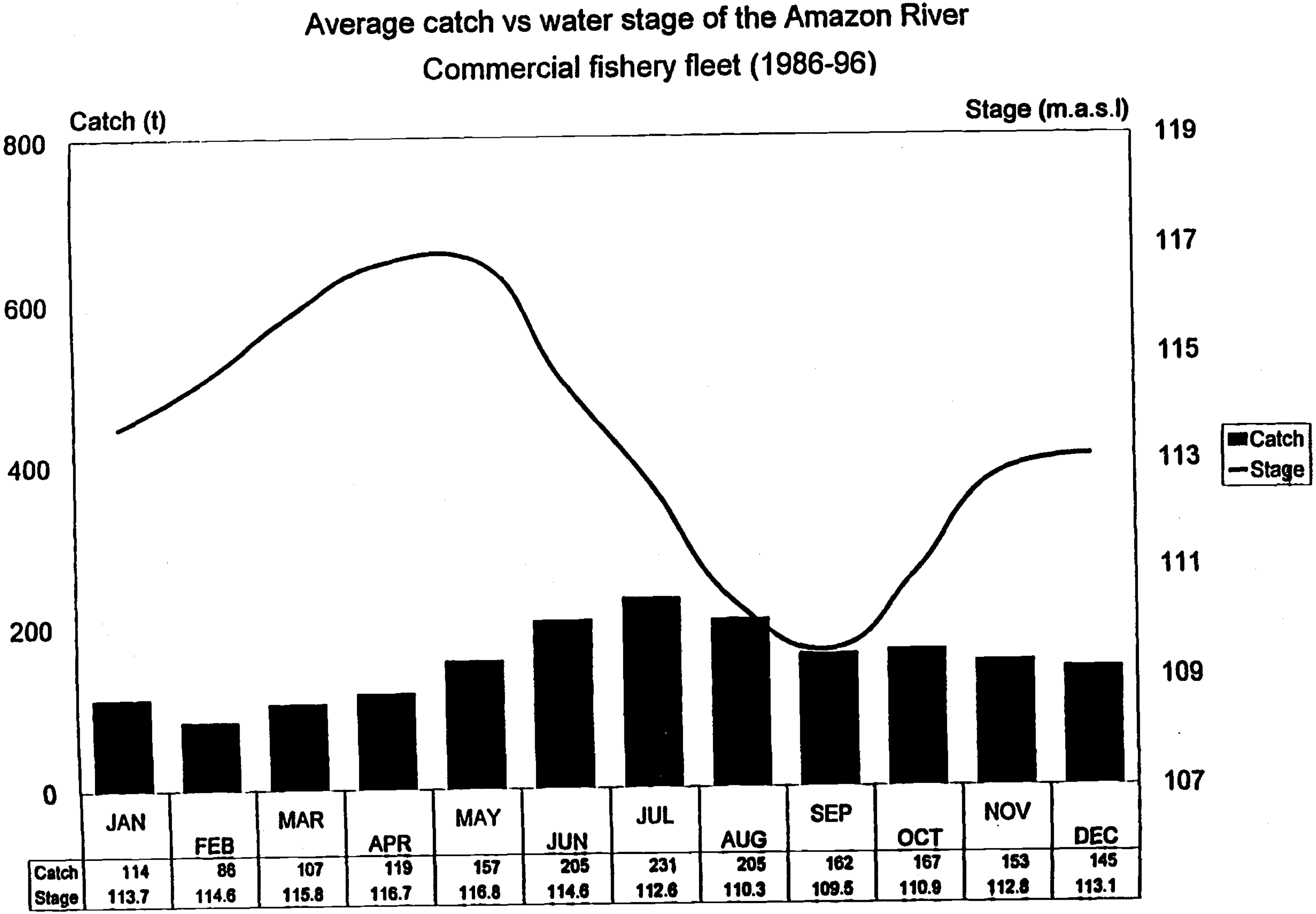
A nine-year time series of landings have been recorded for the commercial fishery fleet (Table 3). Years 1989 and 1990 were absent from the archives of the Fishermen Association. An average annual commercial catch of 2,200 t fresh fish was landed only in Iquitos in the last decade. From this amount, 58.5% were caught in the Ucayali River, 26% in the Amazon River, 6.3% in the Marañon River and 9.2% in other rivers (Tables 5, 6 and 7 in Appendix A). Three (*Potamorhina spp.*, *Curimata spp.*, and *Prochilodus nigricans*) of the 40 species exploited by the fishery fleet represented 62% of the total landings in 1996.

Table 3 Annual fresh fish (t) caught by the commercial fishery fleet and landed in Iquitos

| Year | Ucayali | Amazon | Marañon | Other* | Total |
|---|---|---|---|---|---|
| 86 | 2191 | 264 | 129 | 172 | 2756 |
| 87 | 1067 | 1015 | 56 | 144 | 2282 |
| 88 | 1172 | 207 | 350 | 330 | 2059 |
| 91 | 1165 | 673 | 80 | 262 | 2180 |
| 92 | 1429 | 329 | 115 | 325 | 2198 |
| 93 | 1210 | 1009 | 92 | 139 | 2450 |
| 94 | 634 | 906 | 230 | 137 | 1907 |
| 95 | 1216 | 520 | 134 | 102 | 1972 |
| 96 | 1508 | 235 | 62 | 170 | 1975 |

*Napo, Putumayo, Tapiche, Tigre, Curaray, Manati and Chambira rivers

A plot of the means of monthly catches against stage of the Amazon River for a nine-year period shows the seasonal pattern of the fishery in the study area (Fig 5).



| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Catch | 114 | 88 | 107 | 119 | 157 | 205 | 231 | 205 | 162 | 167 | 153 | 145 |
| Stage | 113.7 | 114.6 | 115.8 | 116.7 | 116.8 | 114.6 | 112.6 | 110.3 | 109.5 | 110.9 | 112.8 | 113.1 |

Fig 5 Graph showing seasonal trends of the fishing in the study area

During the rising water there is a massive migration of species into the floodplain. Terrestrial and aquatic sources of detritus, plant material, fruits, seeds, and invertebrates provides abundant food for fish. Fish remain in the floodplain eating and accumulating fat for almost seven months as an strategy to survive during the period of low food (Bayley 1989).

Water levels in the study area begin to recede in May, and fish leave the floodplain forming large schools during this time. The riverine inhabitants and professional fishermen obtain the greatest catches and highest revenues during this migration period. Commercial fishermen usually anchor their boats in the tributary or connecting channel mouths and keep a sharp vigilance for the upstream migration. They follow and exploit the schools until the fish reach another tributary upstream. It was estimated (from Fig 5) that 35% of the total fish landed by the fishery fleet in Iquitos were caught during the recession of floodwaters (May-September). There is also a smaller peak of abundance during September - December when most of Characoids descend out of the varzea lakes (lakes influenced by the turbid "white water" rivers), channels and tributaries to the main river to migrate upstream and spawn in the turbid water.

### 3.4.3 Fishing Effort

The most reliable, accurate and simple measures of fishing effort were derived from the number of fishermen-trips per river per year and the number of trips per river per year. The number of days was not considered due to variability not associated with fishing activity. If the time spent searching or in transit changes frequently, days on the river will always be a biased estimator of fishing effort (Gulland 1964b; Murphy and Willis 1996). As has been indicated, it was not possible to get information about catch per type of gear used. Therefore, number of fishermen-trip and number of trips were used irrespective of the gear employed.

### 3.4.4. Catch and Fishing Effort

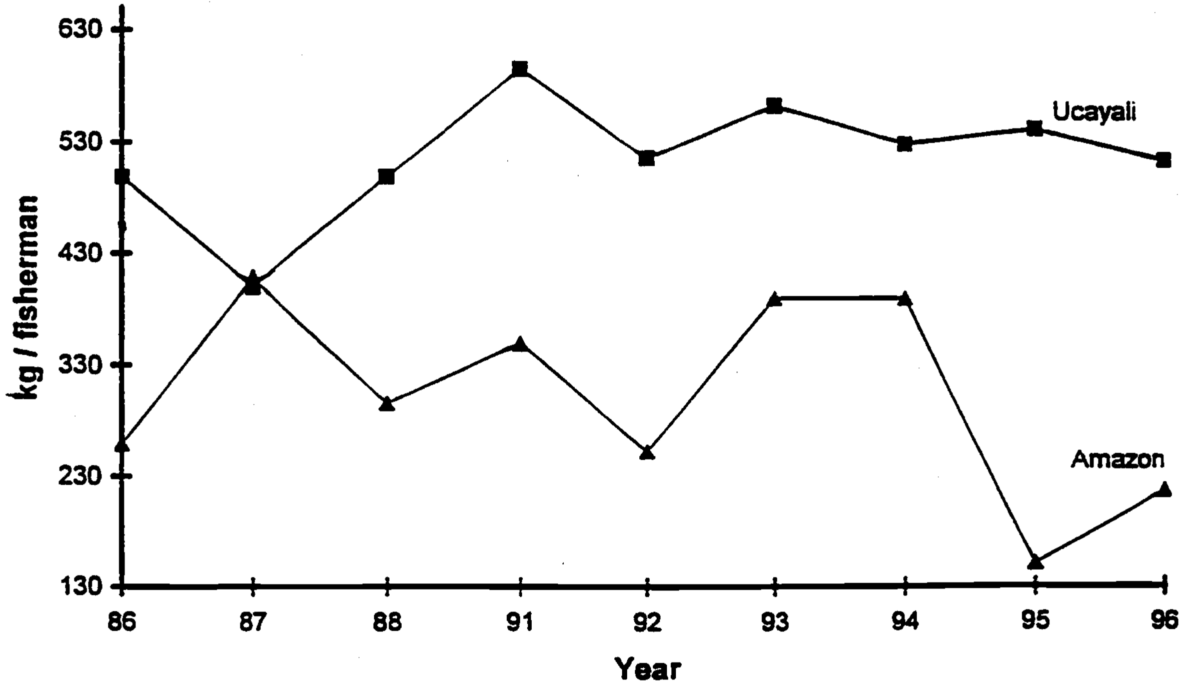
Fishing effort data from Table 8 in Appendix A was used to estimate annual catch rate (CPUE) for the commercial fishery fleet (Table 9 in Appendix A). Catch per unit effort in the study area varied from 454 kg fishermen-trip$^{-1}$ in 1986 to 433 in 1996. The CPUE related to number of fishing trips varied from 3.97 t trip$^{-1}$ in 1986 to 2.94 in 1996. There was some fluctuation in the indices of abundance during those years, perhaps due to variations in the flooding regime and/or fishing intensity.

A peculiar fish behavior was observed during 1995 when an unusually large upstream migration of big catfish *Brachyplatystoma vaillanti* and Characiforms took place in the Amazon river near Iquitos. Because of cost per-day for moving large boats for short trips, the fishermen used their smaller, faster auxiliary boats for fishing. Consequently, number of fishermen-trip and number of trips increased significantly (50% and 110%, respectively), as compared to 1994. The annual catch rate, therefore, appears to decrease during 1995. That year was eliminated from the analysis presented in later sections because of the abrupt change in type and quantity of fishing effort.

The average annual catch rate, excluding 1995 in the Amazon, increased slightly in the Ucayali and decreased in the Amazon during the years considered in the analysis (Fig 6). The Ucayali River showed the highest index of abundance as rate of CPUE. This river is considered the most productive river-floodplain system in the Peruvian Amazon (Hanek 1982; Bayley et al. 1992).

Because of it is risky in a multispecies fishery to apply standard model relating catch and effort designed for analysis of fisheries based on single species (Welcomme 1985), the following analysis of the commercial fishery fleet, component of the fishery, must be considered exploratory.

An analysis of the relationship between yield (kg ha$^{-1}$) and fishing intensity (number of fishermen per square kilometer) was attempted for the study area using the Graham-Schaefer model (Equation 13.16 in Ricker 1975). The relationship was:



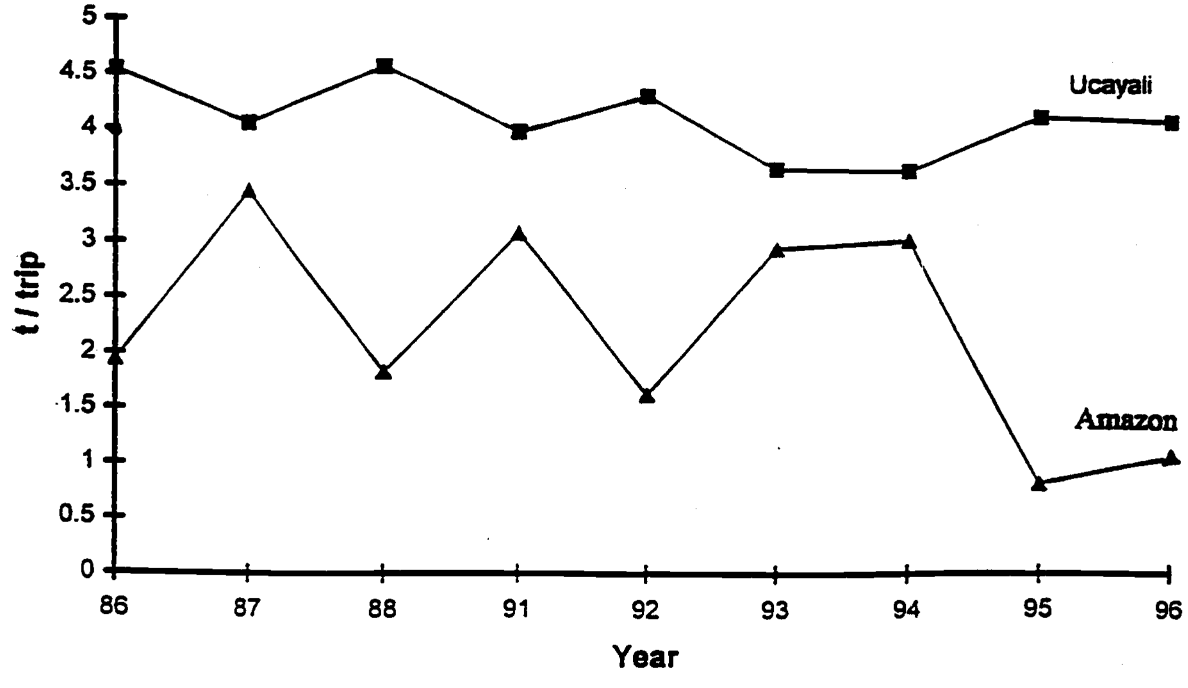


Fig 6 Annual catch rates (CPUE) of the Iquitos fishery fleet

Yield (kg $ha^{-1}$) = $-0.4328 + 7.3185\,(E) - 4.5879\,(E)^2$

from which:

optimum level of fishing effort (Ricker 1975) = $a\,(2b)^{-1} = 0.8$ fishermen $km^{-2}$

and,

MSY (Eq. 13.19 in Ricker 1975) = $a^2\,(4b)^{-1} = 2.9$ kg $ha^{-1}$

Where:

E = fishing intensity (fishermen $km^{-2}$)

a = coefficient of E

b = coefficient of $E^2$

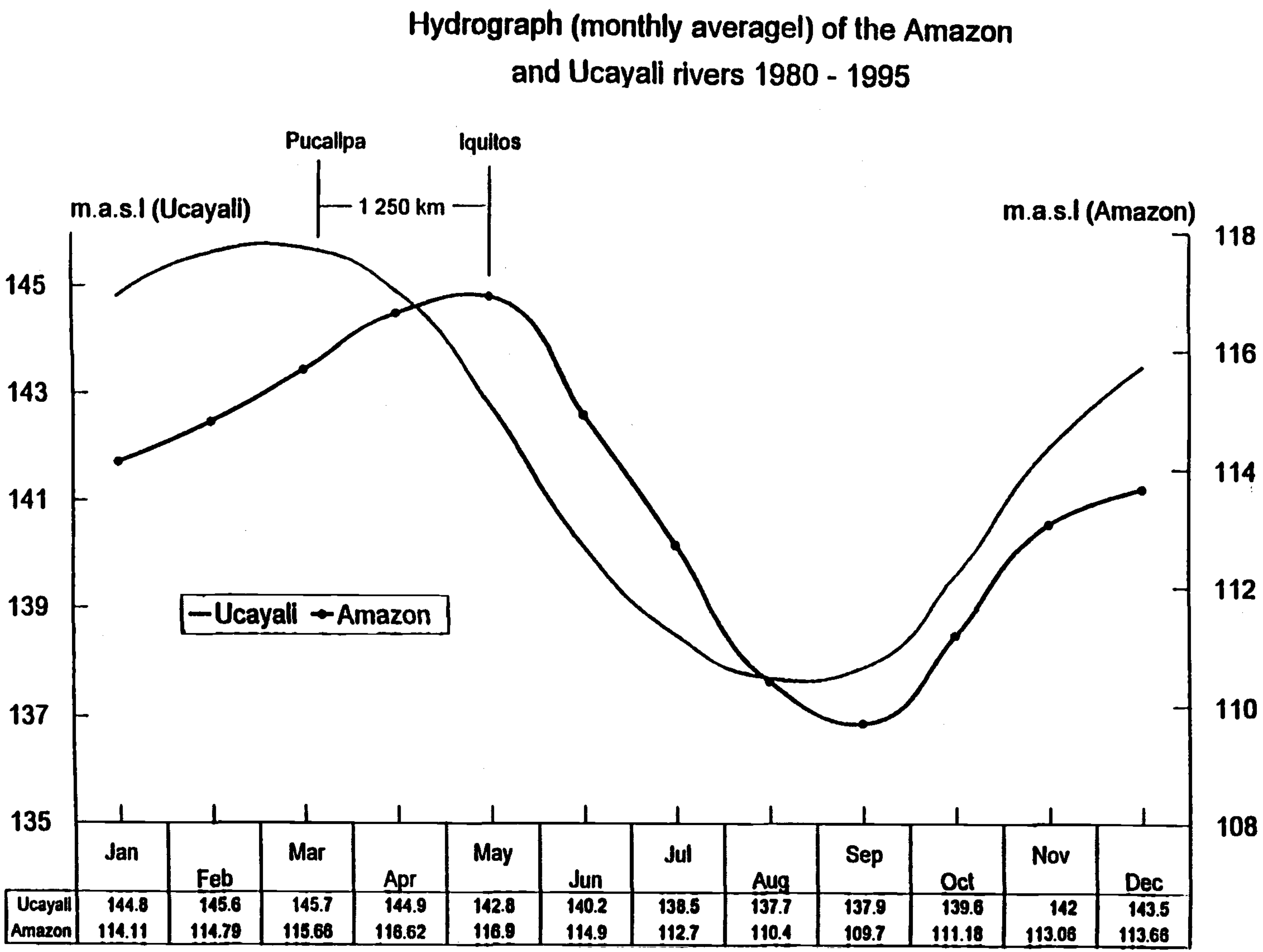
According to this relationship, the total yield of the commercial fishery fleet in the study area seems to increase with increasing the number of fishermen up to a density of about 0.8 commercial fishermen per square kilometer, after which the total yield may decline with increased exploitation. This seems a low intensity compared with Welcomme (1985) and Bayley and Petrere (1989), but the commercial fishermen are only a small proportion of the total number, which includes mostly part-time fishermen (subsistence and local market fishery) Table 10 in Appendix A show the data from which CPUE was derived.

### 3.5 Water Stage and Hydrological Indices

Monthly stage measurements from gauge stations located in the Ucayali (Pucallpa and Requena) , Marañon (San Regis) and Amazon (Iquitos and Tamshiyacu) rivers were examined to determine the water stage to be used for estimating the hydrological indices. There was a strong association between the levels of the Amazon River in Iquitos and the other sectors analyzed, when the Amazon water stage was used as response and water stage from the other sectors as explanatory variables ($R^2 = 0.86$). A weak association was found between the water stages at Pucallpa and Iquitos ($R^2 = 0.42$, Fig 5a in Appendix B). This may be due to the greater distance between these stations. An average 16-year time series of stage measurements taken at Iquitos and Pucallpa were used to plot the variation of water height against time to estimate the difference in amplitude (the total difference in level between maximum and minimum discharge), and duration (the time taken by the flood curve to pass from one water stage to the next). The flood curves had unimodal wave forms, with similar flood regime and amplitude (Fig 7). However, the curves displayed dissimilar duration features that may in part be attributed to differences in river morphology and extent of the floodplain. The flood crest takes around two months to move from Pucallpa to Iquitos located 1,250 km downstream. In addition, there were many missing days in the Pucallpa data series.

Elsewhere, Requena and San Regis stations are closer either to Iquitos (190 and 250 km upstream, respectively) or to the confluence Ucayali-Marañon (40 and 150 km upstream, respectively). In contrast with Pucallpa, there was an association between levels of the Amazon in Iquitos and levels of the Ucayali in Requena ($R^2 = 0.59$) and Marañon in San Regis ($R^2 = 0.52$). Details are shown in Figures 5b, 5c and 5d in Appendix B.

Bayley (1992) found a high association of the Pacaya River level with the Iquitos gauge (R = 0.93). This river is located in the Pacaya-Samiria Natural Reserve which is currently estimated to cover 2,130,000 ha (21,300 $km^2$) of land between the Ucayali and Marañon rivers as far their junction. Differences between the Pacaya and Amazon hydrograph is caused by the moderating effect of swamp and floodplains which occupy 95 % of the Pacaya basin compared with 12 % estimated for the Peruvian Amazon (Bayley 1981a). Fig 6 in Appendix B shows a clear association between levels of the Amazon and Pacaya rivers. Unfortunately, Requena and San Regis stations were closed after four years of operation. However, Iquitos and Pucallpa gauge stations continue to be used for daily measurements of the water stage. Because of the limiting factors for using water stage from Pucallpa, Requena, and San Regis stations, the Amazon River was considered an adequate predictor of relative area flooded in the study area and its water stage (Fig 7 in Appendix B) was used to estimate the hydrological indices (Table 4).



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ucayali | 144.8 | 145.6 | 145.7 | 144.9 | 142.8 | 140.2 | 138.5 | 137.7 | 137.9 | 139.6 | 142 | 143.5 |
| Amazon | 114.11 | 114.79 | 115.68 | 116.62 | 116.9 | 114.9 | 112.7 | 110.4 | 109.7 | 111.18 | 113.06 | 113.66 |

Fig 7 Time taken for the flood wave to traverse the distance between Pucallpa and Iquitos

Table 4. Hydrological indices estimated from the Amazon River levels (Iquitos gauge)

| | INDEX* | |
|---|---|---|
| Year | FI | DSI |
| 84 | 2063 | 538 |
| 85 | 425 | 863 |
| 86 | 1363 | 494 |
| 87 | 2163 | 831 |
| 88 | 1213 | 1744 |
| 89 | 1906 | 1044 |
| 90 | 1025 | 731 |
| 91 | 1456 | 1700 |
| 92 | 450 | 694 |
| 93 | 1881 | 275 |
| 94 | 2488 | 594 |
| 95 | 875 | 1475 |
| 96 | 1125 | 1019 |

* FI = flood index
DSI = dry season index

## 3.6 Changes in Composition of the Landings

### 3.6.1 Loreto Region Landings

In the past 15 years, there has been a progressive replacement of large species by smaller, but more productive species. The fishery in Loreto (Fig 1b) is sustained mostly by detritivores that constituted 65% of total landing during 1996. The maximum landing of detritivores occurred in 1987 (8,855 t), decreased by 20% and 50% during 1988 and 1989, respectively (Fig 8a). Despite some variation there was a positive trend in the landings of detritivores in Loreto. *Prochilodus nigricans* was the most significant commercial species.

Omnivore also increased until 1991 (2,148 t). Subsequently, the landings dropped by 50% probably due to fishing intensity. Landings of this group decreased during the last five years (Fig 8b).

The maximum landings of piscivores occurred during 1988 and decreased in the latter years (Fig 8b). This group has been intensely exploited since 1980 in the Peruvian Amazon because of two factors: (1) introduction of large deepwater drifting gillnets and (2) opening of the international market. The catfish fishery is practiced for specialized fishermen groups. A small part of the landings is consumed in Iquitos whereas a large proportion is exported to Colombia, North America, and Europe. *B. flavicans* and *P. fasciatum* are considered the most valuable catfish in the international market. Yields of both species have dramatically decreased in the study area in the last eight years (Fig 8c). Mean catch length of *B. flavicans* has decreased to the point where the fishery fleet is harvesting mostly immature individuals (Tello et al. 1995) and may seriously affect the recruitment and regeneration of this valuable species.

In the case of piscivores, it was impossible to get reliable information of catch per rivers and fishing effort from the large catfish fishery because this activity is performed by a particular group of fishermen without any relationship with the fishery fleet described in this study. In addition, species of this group are caught in rivers different than those of the study area, where the Amazon water level fluctuation might not exert influence because they flow from different origins. Therefore, it was not possible to do an analysis about the influence of water level fluctuation on the piscivore landings.

Change in species composition of the landings has occurred in the omnivore group. A progressive reduction of larger species (i.e. *Colossoma macropomum* and *Brycon spp.*) and the corresponding increase of high yield, smaller, cheaper and fast growing species such as *Mylossoma spp.* and *Triportheus spp.* has occurred in the regional landings likely due to fishing intensity (Fig 9a and 9b). There is strong fishing

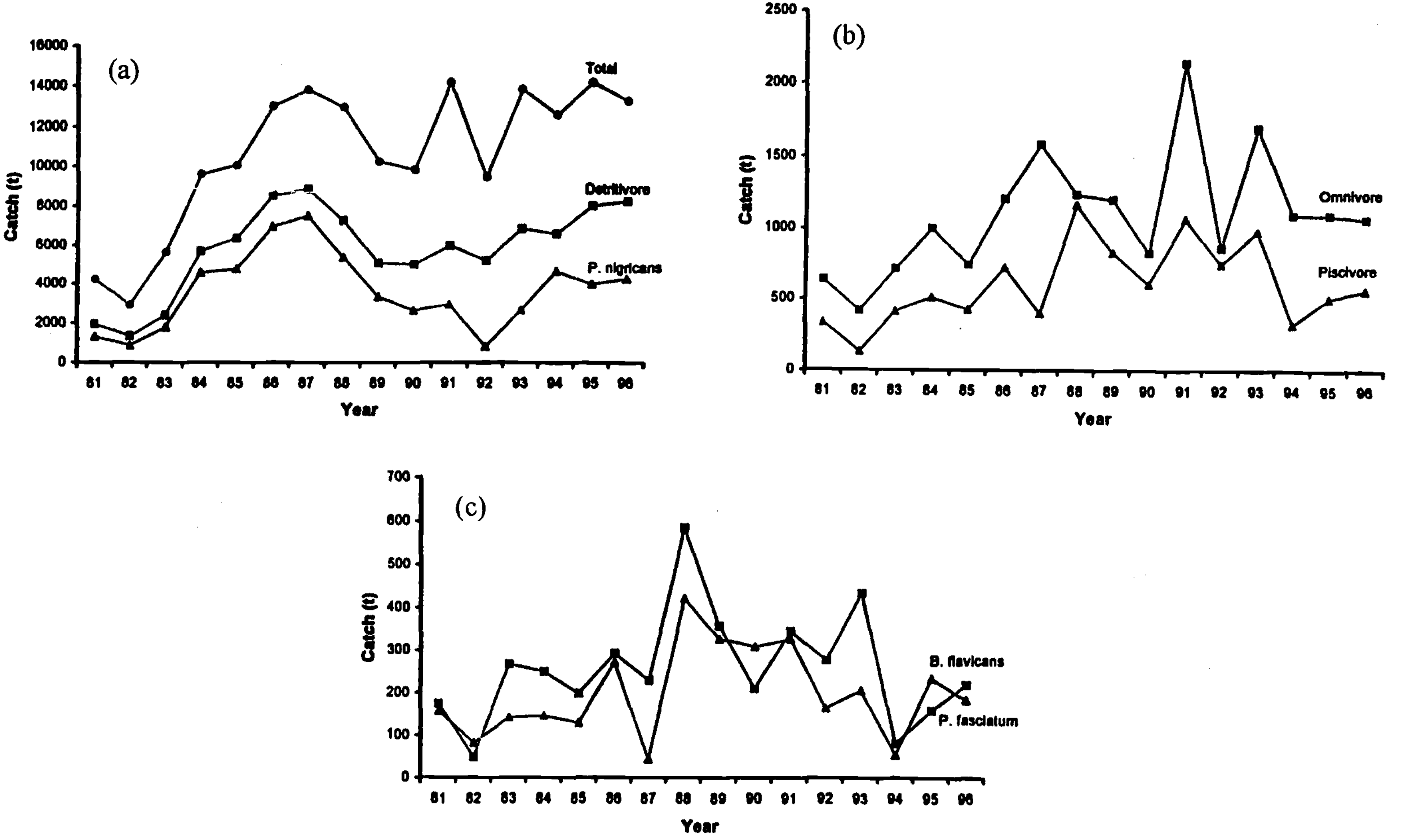


Fig 8 Time trend in the regional landings

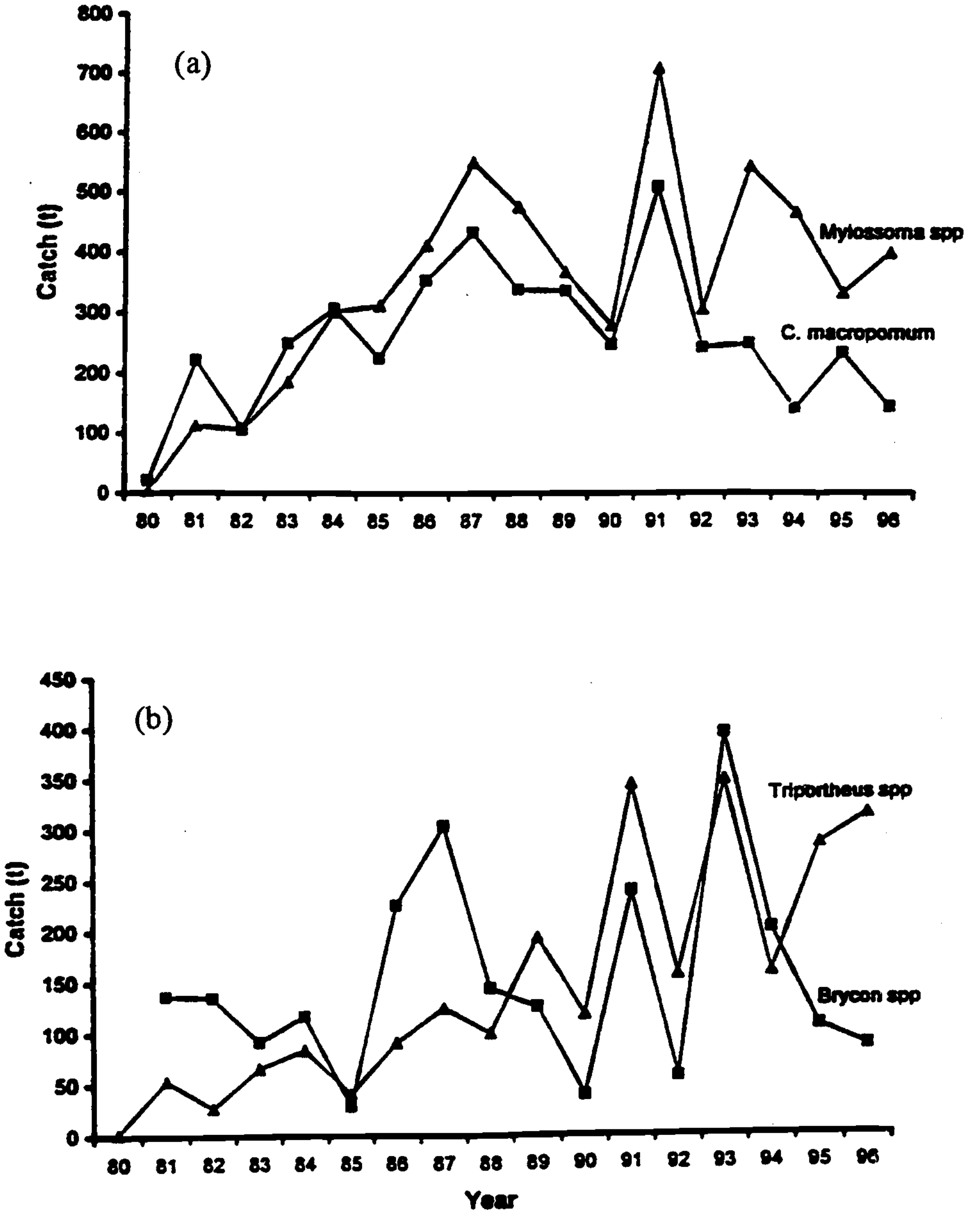


Fig 9 Time trend in the regional landings

pressure on the former species because of high market demand due to their flesh quality and larger size.

### 3.6.2 Fishery Fleet Landings in Iquitos

Small differences in species composition of the trophic groups were found between regional and local landings. In the regional landings there was a positive trend in landings of the detritivore group, controlled mostly by an increase in the landings of *Prochilodus nigricans*. This pattern was not apparent in the study area where the landing of this species has decreased in the last four years likely due to an intense fishing pressure nearby the big cities such as Iquitos, Requena and Contamana (Fig 10a). Regional landings did not show this feature because the fish came not only from the Amazon and Ucayali rivers but also from other rivers far away from the big cities.

A progressive reduction of larger species such as *P. nigricans* and the increases of smaller, low-value species such as *Potamorhina spp.* was observed in the landing of detritivores (Fig 10c).

## 3.7 Catch, Water Stage and Fishing Effort (Iquitos Fishery Fleet)

### 3.7.1 Full Model (7-month fishery response)

To analyze the influence of flooding regime and fishing effort on the catch fluctuations, catch per guild from May to November was used (see Fig 3). During those months the fish are more vulnerable to the fishing gears because they are migrating or confined in the main river channels and lakes.

A preliminary examination of the matrix of scatter plots and residual plots indicated some skewed distributions and trends in the relationship between the response and the explanatory variables in the full model. After a logarithmic transformation of the

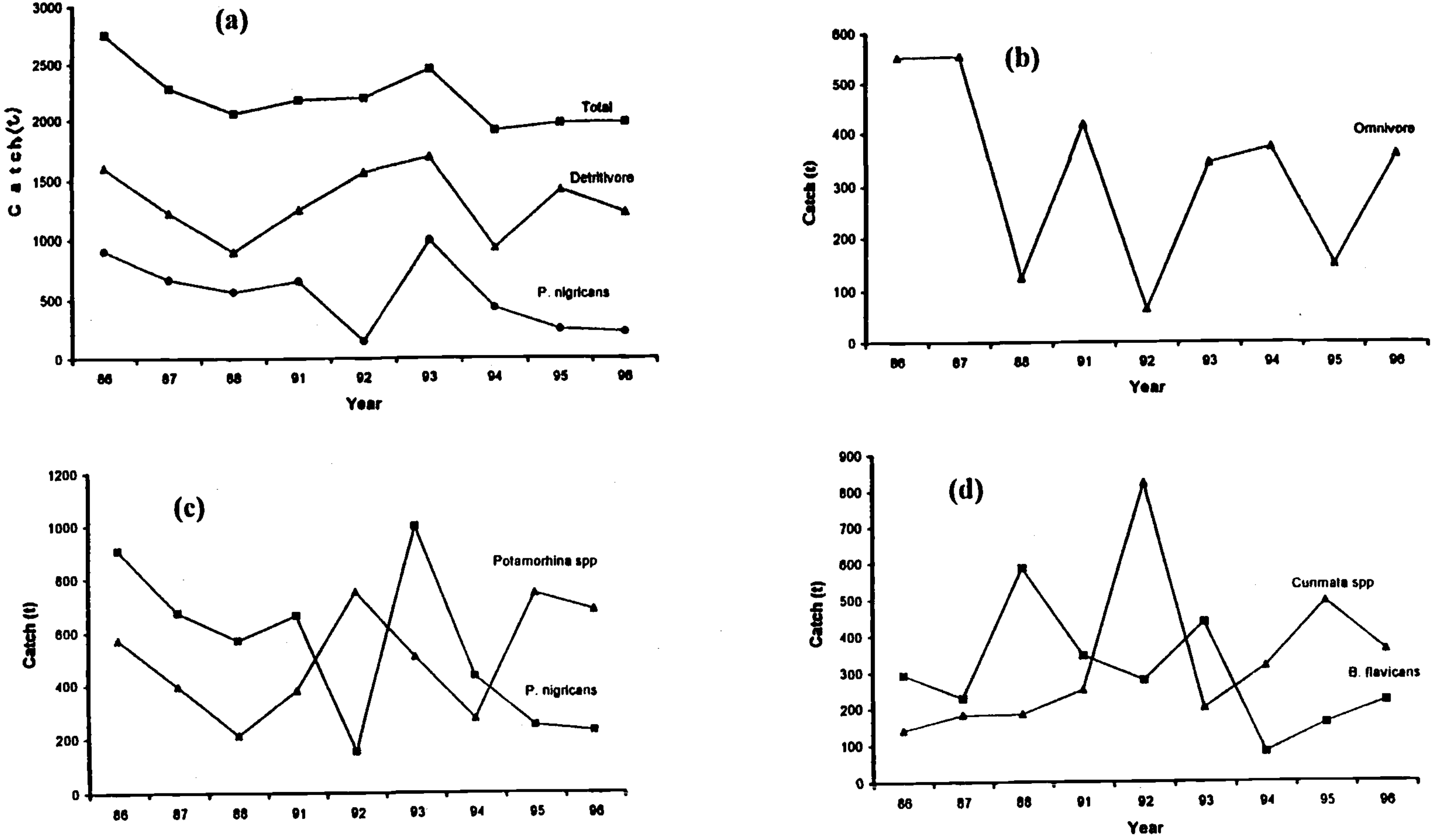


Fig 10 Time trend in the Iquitos landings (fishery fleet)

response and explanatory variables, none of the graphical methods showed any trend or asymmetric distribution.

The correlation matrix between the logarithm of explanatory variables of the full model is given in Table 5. None of the correlation coefficients were highly significant (p-value > 0.01) and only $DSI_{y-1}$ with $FI_y$ and with EU were significant (p-value < 0.05). When tests were performed by replacing in each reduced model the explanatory variables ($FI_y$ and EU) by $DSI_{y-1}$ in turn, the $DSI_{y-1}$ coefficient becomes insignificant compared with the dropped variables, which remained significant throughout the tests.

Table 5. Pearson correlation coefficients (df = 8) for explanatory variables

| | $FI_y$ | $FI_{y-1}$ | $DSI_y$ | $DSI_{y-1}$ |
|---|---|---|---|---|
| $FI_y$ | 1 | | | |
| $FI_{y-1}$ | -0.212 | 1 | | |
| $DSI_y$ | -0.268 | 0.668 | 1 | |
| $DSI_{y-1}$ | -0.781* | -0.262 | 0.097 | 1 |
| EU | -0.445 | -0.408 | 0.138 | 0.709* |
| EA | 0.246 | 0.075 | -0.241 | -0.504 |

Where:

$FI_y$ = flood index of the same year

$FI_{y-1}$ = flood index of the preceding year

$DSI_y$ = dry index of the same year

$DSI_{y-1}$ = dry index of the preceding year

EU = number of fishermen-trips in the Ucayali River

EA = number of fishermen-trips in the Amazon River

The estimates were done in logarithmic scale for both rivers.

* = p-value < 0.05

Similarly, Table 6 shows the first order interaction estimates (p-values) from the regression of catch per guild on all hydrological indices and number of fishermen in the full model. Note that most interactions did not present significant values ($p\text{-value} > 0.05$). However, in the omnivore group the interaction of number of fishermen-trips with flood index of the preceding year ($FI_{y-1}$) and dry index of the same year ($DSI_y$) show slight significance ($p\text{-value} < 0.05$, Table 6). When tests were performed by replacing in each reduced model the explanatory variables $FI_y$ and E by $FI_{y-1}$ and $DSI_y$ in turn, these latter variables become insignificant compared with the replaced variables, which remained highly significant throughout the tests. Even if the interaction is considered significant (it would not be if the tests were considered multiple and Bonferroni corrections were applied) there is no ecological explanation and it could have been caused by chance due to the smallness of the sample.

To confirm the suspected lack of influence of the draw-down period, a regression of catch per guild on dry index of the same year ($DSI_y$), of the preceding year ($DSI_{y-1}$), and number of fishermen-trips (E) was performed for the Ucayali and Amazon rivers separately. None of the dry indices were significant ($p\text{-value} > 0.1$) after accounting for number of fishermen.

The regression parameter estimates (full model), standard error and p-values from the regression of 7-months-catch per guild on hydrological indices and number of fishermen-trips are shown in Table7.

Table 6. All first order interactions (p-value) from the regression of catch on all hydrological indices and number of fishermen-trips (the analysis was performed in log scale and using each interaction in turn in the full model)

| | $FI_y$ X E | $FI_{Y-1}$ X E | $DSI_Y$ X E | $DSI_{Y-1}$ X E | $FI_Y$ X $FI_{Y-1}$ | $FI_Y$ X $DSI_Y$ | $FI_{Y-1}$ X $DSI_Y$ | $FI_{Y-1}$ X $DSI_{Y-1}$ | $DSI_Y$ X $DSI_{Y-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| **Omnivores** | | | | | | | | | |
| Ucayali River | 0.2 | 0.07 | 0.02 | 0.1 | 0.2 | 0.1 | 0.7 | 0.07 | 0.3 |
| Amazon River | 0.7 | 0.02 | 0.01 | 0.4 | 0.3 | 0.5 | 0.4 | 0.3 | 0.9 |
| **Detritivores** | | | | | | | | | |
| Ucayali River | 0.3 | 0.2 | 0.1 | 0.2 | 0.1 | 0.3 | 0.1 | 0.2 | 0.9 |
| Amazon River | 0.4 | 0.06 | 0.2 | 0.2 | 0.4 | 0.9 | 0.6 | 0.09 | 0.7 |

Table 7. Parameter estimates (full model), standard error and p-values from the regression of catch per guild (May to November) on hydrological indices and number of fishermen-trips

| | Constant | $\ln(FI_y)$ | $\ln(FI_{y-1})$ | $\ln(DSI_y)$ | $\ln(DSI_{y-1})$ | Ln(E) |
|---|---|---|---|---|---|---|
| **Omnivores** | | | | | | |
| Ucayali River | | | | | | |
| Value | -6.983 | 1.043 | -0.541 | 0.419 | 0.372 | 0.398 |
| s.e. | 15.26 | 0.93 | 0.78 | 0.58 | 0.93 | 0.49 |
| p-value | | 0.3 | 0.5 | 0.5 | 0.7 | 0.4 |
| Amazon River | | | | | | |
| Value | -22.828 | 2.264 | -0.429 | 0.561 | 0.302 | 1.131 |
| s.e. | 18.94 | 1.03 | 0.7 | 0.52 | 1.13 | 0.43 |
| p-value | | 0.1 | 0.5 | 0.3 | 0.8 | 0.08 |
| **Detritivores** | | | | | | |
| Ucayali River | | | | | | |
| Value | 4.706 | -0.448 | -0.158 | 0.041 | -0.179 | 0.932 |
| s.e. | 4.12 | 0.24 | 0.21 | 0.16 | 0.25 | 0.13 |
| p-value | | 0.1 | 0.5 | 0.8 | 0.5 | 0.006 |
| Amazon River | | | | | | |
| Value | 3.571 | -0.0004 | -0.093 | -0.043 | -0.4092 | 0.769 |
| s.e. | 18.79 | 1.03 | 0.69 | 0.52 | 1.12 | 0.43 |
| p-value | | 0.9 | 0.9 | 0.9 | 0.7 | 0.1 |

### 3.7.2 Reduced Models (7-month fishery response)

After doing a stepwise procedure in which each least significant explanatory variable was dropped in turn, the remaining significant ($p$-value $< 0.05$) variables were flood index of the same year ($FI_y$) and number of fishermen-trips (E) (Table 8). The non-significant $FI_y$ coefficient for detritivores in the Amazon was shown just for comparison. Plots of the standardized residuals versus the predicted values of the 7-month reduced models are shown in Fig 8 in Appendix B

Table 8 Parameter estimates (reduced models), standard errors (s.e) and p-values from the regression of 7-month (May-November) catch per-guild on flood index of the same year and number of fishermen-trips

| | Constant | Ln ($FI_y$) | ln(E) |
|---|---|---|---|
| **Omnivores** | | | |
| Ucayali River | | | |
| Value | -8.532 | 1.014 | 0.846 |
| s.e | 3.83 | 0.35 | 0.26 |
| p-value | | 0.03 | 0.01 |
| Amazon River | | | |
| Value | -16.523 | 2.022 | 0.877 |
| s.e. | 3.03 | 0.37 | 0.31 |
| p-value | | 0.001 | 0.03 |
| **Detritivores** | | | |
| Ucayali River | | | |
| Value | 1.083 | -0.254 | 0.960 |
| s.e. | 0.99 | 0.09 | 0.06 |
| p-value | | 0.03 | 0.0001 |
| Amazon River | | | |
| Value | -3.363 | 0.342 | 0.885 |
| s.e. | 2.42 | 0.29 | 0.25 |
| p-value | | 0.3 | 0.001 |

The results showed that flood index of the same year and fishing effort had a positive association with omnivore catch in the Ucayali and Amazon rivers. A doubling of $FI_y$ would be associated with a change in catch of 2-fold (95% CI: 1.0 to 3.7) for the Ucayali and 4-fold (95% CI: 2.1 to 7.6) for the Amazon. Similarly, a doubling of the number of fishermen-trips would be associated with a change in omnivores catch of 1.8-fold (95% CI: 1.1 to 2.8) for the Ucayali and 1.8-fold for the Amazon (95% CI: 1.0 to 3.1).

In contrast, flood index of the same year had a negative association with detritivores catch in the Ucayali River, but no detectable association in the Amazon. A doubling of the flood index of the same year would be associated with a change in catch (a 20% reduction) of 0.8-fold (95% CI: 0.7 to 1.0) for the Ucayali. Fishing effort had a positive association with detritivores catch in the Ucayali and Amazon rivers. A doubling of the number of fishermen-trips would be associated with a change in catch of 1.9-fold (95% CI: 1.7 to 2.2) for the Ucayali and 1.8-fold (95% CI: 1.2 to 2.9) for the Amazon.

A test based on autocorrelation was performed on model residuals to determine if serial correlation (lack of independence) is present in the models (Table 9). No correlations were significant (p-value > 0.05).

Table 9. Serial autocorrelation (lag = 1) of residuals from the proposed models

| Model | Correlation Coefficient | p-value |
|---|---|---|
| $Ln(C_y) = 1.0837 - 0.2540 \ln(FI_y) + 0.9598 \ln(E)$ | -0.52 | 0.2 |
| $Ln(C_y) = -8.5318 + 1.0140 \ln(FI_y) + 0.8458 \ln(E)$ | -0.46 | 0.2 |
| $Ln(C_y) = -3.3630 + 0.3423 \ln(FI_y) + 0.8849 \ln(E)$ | 0.39 | 0.3 |
| $Ln(C_y) = -16.5235 + 2.0215 \ln(FI_y) + 0.8770 \ln(E)$ | 0.02 | 0.9 |

### 3.7.3 CPUE and Hydrological Indices

To answer the question if an index of biomass is associated with water fluctuation in the study area, an analytical method was used. It consisted of plotting the flood index of the same year ($FI_y$) against catch per unit effort (kilograms per fisherman-trip) through May to November for each guild (Table 10 below; Figures 9 and 10 in Appendix B). Because none of the ln(E) coefficients were different than unity in the 7-month models (Table 8), the following analysis is a natural extension of those models. The results found in this section reinforce those of the reduced models, but with generally greater significance.

Table 10 Parameter estimates, standard errors and p-values from the regression of CPUE per guild (May to November) on flood index of the same year

| | Constant | $Ln(FI_y)$ | Change in CPUE* (95% CI) |
|---|---|---|---|
| **Omnivores** | | | |
| Ucayali River | | | |
| Value | -3.4460 | 1.1126 | 2.1 |
| s.e. | 2.21 | 0.30 | (1.3 – 3.6) |
| p-value | | 0.008 | |
| Amazon River | | | |
| Value | -10.1752 | 1.9780 | 3.9 |
| s.e | 2.44 | 0.34 | (2.2 – 6.9) |
| p-value | | 0.006 | |
| **Detritivores** | | | |
| Ucayali River | | | |
| Value | 7.5277 | -0.2298 | 0.8 |
| s.e. | 0.56 | 0.07 | (0.7 – 0.9) |
| p-value | | 0.02 | |
| Amazon River | | | |
| Value | 2.9704 | 0.3084 | |
| s.e. | 1.96 | 0.27 | |
| p-value | | 0.3 | |

* x-fold change in median catch with 2-fold increase in $FI_y$

## 3.8 Prediction of Future Catch

Because estimates of future annual catch is one of the main objectives of the fishery policy makers, the annual catch (January – December) per guild was used in order to derive the predictive models. Procedures similar to those of the 7-months models were used for the prediction models. In this case, after doing a stepwise procedure in which each least significant explanatory variable was dropped in turn, the remaining significant ($p$-value $< 0.05$) variables were $FI_y$, $FI_{y-1}$ and E. Observed catch (12 months) per guild was compared against predicted catch to assess the validity of the models. Two data sets were used in the analyses in order to provide different options for catch prediction according to the available information: (1) wet indices and fishing effort and (2) fishing effort only.

Tables 11 and 12 in Appendix A show the comparison of the observed versus the predicted catches derived from the reduced models (Equations 1 – 6 in Table 11 overleaf). Analysis carried out on data using hydrological indices and number of fishermen or number of fishermen alone estimated differences within ± 10 % of the observed catch. Scatter plots of the 12-month catch per guild versus fishing effort (number of fishermen-trips) are shown in Fig 11 in Appendix B.

Table 11. Prediction models (reduced) based on 12-month catch (January – December)

| | Constant | $Ln(FI_y)$ | $Ln(FI_{y-1})$ | Ln(E) |
|---|---|---|---|---|
| **Omnivores** | | | | |
| Ucayali River | | | | |
| Equation 1 | -15.088 | 1.026 | | 1.640 |
| s.e. | 4.40 | 0.27 | | 0.41 |
| p-value | | 0.01 | | 0.007 |
| Amazon River | | | | |
| Equation 2 | -16.087 | 1.609 | | 1.210 |
| s.e. | 3.46 | 0.48 | | 0.52 |
| p-value | | 0.02 | | 0.06 |
| Equation 3 | -11.512 | | | 2.171 |
| s.e. | 5.25 | | | 0.71 |
| p-value | | | | 0.02 |
| **Detritivores** | | | | |
| Ucayali River | | | | |
| Equation 4 | 8.066 | -0.384 | -0.214 | 0.386 |
| s.e. | 1.80 | 0.8 | 0.07 | 0.13 |
| p-value | | 0.004 | 0.02 | 0.03 |
| Equation 5 | 0.499 | | | 0.811 |
| s.e. | 1.46 | | | 0.19 |
| p-value | | | | 0.003 |
| Amazon River | | | | |
| Equation 6 | -3.553 | | | 1.263 |
| s.e. | 1.53 | | | 0.21 |
| p-value | | | | 0.001 |

# 4 DISCUSSION AND CONCLUSIONS

## 4.1 Flooding Regime and Fish Abundance

### 4.1.1 Trophic Groups

There is no doubt about the benefit of the flood pulse on aquatic production in river-floodplain systems. During the flood season lakes, main channels and their floodplains are essential for the survival of fish populations. Areas that are periodically inundated by the lateral overflow of rivers and lakes provide excellent nursery grounds for fishes (Junk et al. 1989; Bayley 1991 and 1995). Most of the commercial fish species from the Peruvian Amazon spawn at the beginning or during the period of the flood season due to the rising floodwater permit to spread eggs and larvae over the varzea habitat, in particular in littoral habitats. Growth rates are high for larvae and alevines because the food is abundant in the inundated forest (Lowe McConnell 1975; Bayley and Petrere 1989).

The positive influence of flooding on the omnivore group was evident in the Ucayali and Amazon rivers. The rising water provides access to larger feeding and dispersion areas. During this season, fruit, seeds and arthropods are abundant in the inundated forest and those are the main elements of the diet of *C. macropomum*, *P. brachypomus*, *Brycon spp.*, *Mylossoma spp.* and *Tryportheus spp.* (Goulding 1980). Bayley (1988) found that seasonal effects on growth were highly significant for omnivores in the Brazilian Amazon. He observed that higher growth rates in omnivores were associated with periods of increased rates of flooding during the season, which could be related with increased availability of food as more ground is inundated. The positive influence of flooding could be also attributed to the greater number of lagoons becoming connected with the rivers as flood amplitude increases and thus improving opportunities for migration of fish denied access in previous years (Bayley 1973; Welcomme 1985; Novoa 1989).

However, a negative association of $FI_y$ with detritivore catch and CPUE was found in the Ucayali, but not in the Amazon. Factors such as deoxygenation and feeding opportunities are probably the main determinants of population size and consequently of production and yield of detritivores in the Ucayali River. The annual water-level variation results in periodical changes between terrestrial and aquatic phases. When the water level rises, the terrestrial herbaceous vegetation dies and decomposes while simultaneously, aquatic and semi-aquatic plants develop in huge quantities. This process produces large amount of organic detritus as well as locally strong reductions of dissolved oxygen, frequently accompanied by the production of hydrogen sulfide. These conditions are mostly influenced by the amplitude and duration of flooding, floodplain extent, geomorphology, and high production of vegetation (Welcomme 1979; Junk 1984; Junk et al. 1989).

Small fish accompanied by piscivores and other large fish species follow the moving littoral as the water level rises, feeding in the recently inundated area (Bayley 1988). However, locally this colonization can be limited by low dissolved oxygen and presence of hydrogen sulfide. Therefore, many species tend to congregate near the surface, increasing the risk of predation by birds. As inundation increases, stratification results in a larger volume of hypolimnetic water with low dissolved oxygen and high biological oxygen demand. This process affects detritivores more because they feed mostly on bottom deposits and that is where the more severe conditions occur. The Ucayali has a flatter floodplain compared with that of the Amazon River in the study area. The topography of the Ucayali floodplain results in less littoral zone at higher water levels combined with poor edaphic conditions toward the "aguajal" (swamps) region. In contrast, the Amazon has limited swamps in its floodplain and more littoral zones are evident at higher water levels.

Large areas of swamps more distant from the Ucayali River remain isolated from rivers during several months, or even years. These acid waters (pH as low as 4.0) with high concentration of humic and fulvic acids are connected to the floodwater during very high flooding event. Studies in the Achafalaya River in Louisiana, USA, showed that extensive areas of that river basin consists of flooded backwater and swamps throughout which oxygen values are chronically low (Matthews 1998).

Therefore, stagnant water from backwater and swamps may easily kill fish. Periodic mortality, typically at high water, appears to be normal events in tropical river-floodplains. It has been reported from many systems such as Rupununi savana (Lowe-McConnell 1964), Kafue (Michigan and Idaho universities 1971 and Kapetsky 1974), Zambezi (Roberts 1972), Gambia (1974), Apure (Welcomme 1979), Negro (Junk et al. 1983), Ucayali-Pacaya (Azabache 1990) and Pacaya-Samiria (personal observation).

Duration of flooding appears to be critical for the fish population in the floodplain that is gradually inundated by the lateral overflow of rivers and lakes. This process is two times longer than the water retraction phase in the central Amazon River (see Fig 8, Junk et al. 1983 and Bayley 1988a). Therefore, rapid recession of floodwaters increases the danger of fish being isolated in permanent or semi permanent stranded water. Most fish abandon the floodplain during the recession of the floodwater, but a proportion of the community often less migratory species remain in the stranded waters. The majority of these fish die as a consequence of desiccation and predation. Annual losses of fish trapped in these isolated water bodies can be significant in river-floodplain systems (Welcomme 1979; Lowe McConnell 1987).

Species of the detritivore group, however, show an impressive response following over-fishing or natural depletion in bad years. This is the case of *P. nigricans* landings that are returning rapidly to the high levels reached in 1986 despite intense fishing pressure. The mean catch length of *P. nigricans* was fairly constant during the past years (from 26 cm in 1991 to 25.5 cm in 1996) which means that growth-overfishing was probably not occurring. The mean catch length is above the first maturity median length estimated by Garcia et al (1995) for this species in the study area.

The Ucayali and Amazon rivers display different morphological characteristics. Although the length of both river reaches is almost the same, the Amazon contains a narrower active floodplain (9 $km^2$ of floodplain per km of channel length) than the Ucayali (13 $km^2$ $km^{-1}$ of channel length), despite being downstream. Consequently, permanent and temporal water bodies are much less abundant in the Amazon than in the

Ucayali. This may in part explain why there was no significant evidence of an association between detritivore catch in the Amazon and flood index of the same year. Petrere (1983), reported that morphological variables such as channel length and floodplain area did not significantly increase the accuracy of the predicted catches in the Brazilian Amazon. Bayley (1988a) in the Brazilian Amazon found no evidence of seasonal growth and density-dependent effects on young detritivores.

Although there was strong evidence of an association between catch and hydrological indices and fishing effort in the study area, defining a dominant causal relationship is not possible due to the observational nature of the study. Inferences to other geographic areas and different fisheries would not be appropriate using these parameters.

### 4.1.2 Changes in Species Composition

Larger species are progressively being replaced by high yield, smaller and low-value species in the Loreto region landings due to decreased yield of larger species with fishing intensity and change in gears. This selective process tends to be due to a preference by both fishermen and consumers for larger species and the lower capacity of these species to support high levels of fishing mortality (Welcomme 1985). As fishing increases and these larger species become over-exploited, they are progressively displaced in terms of biomass by small and short-lived species. This is likely due to short lived species adapts better to fishing intensity because they have higher P/B ratios. In general, small species tend to have higher natural mortality and growth rates, both factors suggest a higher turnover. In addition, smaller species have higher biomass because they occupy a lower level in the food chain. Large species are less productive per unit of biomass than smaller ones (Regier and Henderson 1973; Turner 1985; Lowe McConnell 1987; Lae 1994).

Changes in species composition have occurred in many river-floodplain systems. Novoa (1989) observed a reduction of mean size and proportion of catfish catch in the

Orinoco River. Likewise, Bayley and Petrere (1989) found evidence of large species such as *A. gigas* and *C. macropomum* have progressively disappeared from the catch in the Manaus fishery, Brazil.

Exploitation of piscivores may result in increased production of prey species in some river-floodplain systems, and may partly explain increase of total yield. This trend of species replacement was observed in Lake Victoria and the Nile River caused by reduction in predator abundance through fishing. Large species were replaced by a sequence of smaller size and more productive fish species (Marten 1979a; Lae 1995). Similar patterns were observed in Malawi and Tanganyika lakes (Turner 1977).

Despite the evidence of growth over-fishing in some catfish species, only future observations will determine whether those declines are merely fluctuations or will result in the commercial extinction of some fish population in the Peruvian Amazon.

## 4.2 Catch, Fishing Effort and Catch Prediction

It was concluded that the number of fishermen-trips in the prediction models explains 90% and 96 % of the annual catches in the Ucayali and Amazon rivers, respectively. Petrere (1986) found that the number of fishermen-trips accounts for 95.5 % of the variance in the catch for Solimoes and Amazon rivers, almost the same value found in the Peruvian Amazon.

In contrast, the fishing effort of 0.3 fishermen $km^2$ and the yield of 1.4 kg $ha^{-1}$ estimated in this study for the fishery fleet of Iquitos, Peru, in 1996 was lower than the values estimated by Petrere for the fishery fleet of Manaus, Brazil, in 1978 (0.72 and 1.74, respectively).

There is no doubt that the extent and duration of the inundation affects biomass of fish stock available for exploitation but depends on trophic groups. This is supported by the results presented in 3.7.3 and 3.8.

Many efforts have been made to predict catches in future years from information on flood regime and fishing effort in other river-floodplain systems, using models similar to those described in this study (University of Michigan 1970; Dudley 1972; Welcomme 1975; Muncy 1977). Predicted values should be consistently better than ± 10 % of the observed catch to use with accuracy for the purpose for which such estimates have been designed, such as regulation of the number of fishermen, number of trips, fishing costs and anticipating supplies of fish to the market (Welcomme 1975).

The catch prediction models presented in this study were based on 9-years of data. The accuracy of the predictions would improve as an increasing number of years is added to the models

The regression analysis equations (Equations 1 – 6 in Table 10) are the only available procedures for predicting fish yield in the study area, considering our lack of knowledge of the biological mechanisms. The application of these models could be a useful tool for immediate but prudent use (Petrere 1983).

### 4.3 Status of the Fishery

The idea that high or moderate yield fisheries can probably sustain their yield under current exploitation is in part supported by this study. The total commercial yield at similar levels of effort displayed by the fishery fleet in the study area remained fairly constant even with changes in species composition. This makes sense because multispecies yields do not reflect the changes of species composition even as yield increases (Welcomme and Henderson 1976; Bayley 1981a and 1992).

Bayley (1988a) estimated a maximum multispecies yield of 150 kg $ha^{-1}$ $yr^{-1}$ based on maximum floodplain area and corrected for fishing effort of the subsistence fishery (as number of fishermen) in tropical river floodplains fisheries which corresponds to a fishermen density of about 18 individuals per square kilometer of floodplain. Using these values, Bayley et al. (1992) estimated that total yield per active floodplain in the Peruvian Amazon in 1981 was 18.3 kg $ha^{-1}$ (2.4 fishermen $km^{-2}$). Assuming a human population increase of 3.1 % $yr^{-1}$, a similar per capita consumption and a similar proportion exported from the area, the authors estimated that the yield in 1991 would be about 80,000 t (24.1

kg $ka^{-1}$ $yr^{-1}$ and 3.2 fishermen $km^{-2}$) and in 2001 would be about 109,000 t (32.7 kg $ha^{-1}$ $yr^{-1}$ and 4.3 fishermen $km^{-2}$). Likewise, Welcomme's (1979) statement "while stocks of individual species may be over-fished, well-documented examples of over-fishing at the community level in rivers are very rare and when recorded are often due to environmental variables (human intervention)" is still valid for the Peruvian Amazon. Therefore, despite some evidence of growth over-fishing in some large catfish species, I agree with Bayley (1992) when he write "the Peruvian Amazon fisheries are capable of providing adequate protein supplies for some time in the future, assuming that the hydrological system and water quality are maintained".

Unfortunately, the Amazon system has been suffering an intense exploitation of many other natural resources. The mineral (gold, petroleum) and timber clearing of floodplain forest eliminates an important source of food and breeding places for the fish population. Deforestation rates have increased in Loreto to a point which 54,712 ha of forest is cut every year (150 ha $day^{-1}$). Environmental changes produced by chemical products spilled into the tributaries of the Amazon River, as a consequence of the cocaine process, will cause severe damage not only to the aquatic community but also to the human population. It was estimated that million tons of kerosene (57), sulfuric acid (32), acetone (5.4) and toluene (5.4) were released to the Huallaga River, one of the largest tributaries of the Amazon, during 1996.

### 4.4 Recommendation for Future Research

Studies from river-floodplain fisheries in other systems provide valuable information to increase our understanding of the fish populations and fisheries in the Amazon. However, it is necessary to perform the following specific ecological studies in order to know until what level that information could be used to assess the fishery in the Amazon basin.

Studies on migration patterns and mortality rates under various water level conditions over additional years would be useful for fishery management in the Amazon system. Special studies are needed to examine specific hypothesis that considering influence of the hydrological cycle on the fish population. It would be very valuable to follow exceptional floods to assess the time scale and mechanisms of flood effects on fishes.

In addition, it is important to direct efforts to testing and refining the models designed in this study in the light of forthcoming data for prudent use under future fishing or environmental conditions.

Elsewhere, the improvement of products of the fishery and their transport from the fishing places to the markets is another factor to be considered to avoid unnecessary losses.

Finally, none of the recommendations previously indicated could be applied if there is not a systematic monitoring of the fisheries in the Amazon that would include commercial and subsistence catch an effort by major species groups. It is of vital necessity the institution of a standardized long-term system of data collection not only in the Peruvian sector but also in the Colombian and Brazilian Amazon due to these countries harvesting a common fishery resource such as the migratory large catfish.

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# APPENDICES

# APPENDIX A

## (Tables)

Table 1. Climatic data from the study area ( from Bayley et al. 1992)

| Station | Geogra. Coord. | N° of years | Annual Precip(mm) | Min. Temp(°C) | Mean temp(°C) | Max temp(°C) | Climate Type |
|---|---|---|---|---|---|---|---|
| Tamshiyacu | 03°20'<br>72°57' | 19 | 2 990 | 20.1 | 25.7 | 31.7 | Hyper-humid |
| Requena | 05°05'<br>73°32' | 12 | 2217 | 20.8 | 26.5 | 32.1 | Humid |
| Juancito | 06°02'<br>74°52' | 19 | 2024 | 21 | 26.0 | 31.8 | Humid |
| Muyuy | 03°54'<br>73°13' | 8 | 2 297 | 20.5 | 26.7 | 33.1 | Humid |
| Yurimaguas | 05°52'<br>76°07' | 34 | 2 112 | 20.4 | 26.5 | 32.5 | Humid |

Table 2. Physical and chemical characteristics from rivers of the study area (from Azabache 1992)

| Parameter | Ucayali river | Amazon river | Marañon river |
|---|---|---|---|
| Water temperature (°C) | 24.5 - 32.0 | 24.0 - 32.0 | 22.5 - 27.5 |
| Dissolved oxygen ($mgl^{-1}$) | 3.3 - 7.5 | 2.4 - 7.2 | 2.8 - 6.9 |
| PH | 6.4 - 9.1 | 6.0 - 8.4 | 5.4 - 7.5 |
| Conductivity ($\mu mhoscm^{-1}$) | 194.0 - 378.8 | 103.5 - 209.6 | 102 - 169.9 |
| Transparency (cm) | 4 - 32 | 7.5 – 41 | 5 - 30 |
| Calcium hardness ($mgl^{-1}$) | 56 - 102 | 40 – 90 | 26 - 62 |
| Magnesium hardness ($mgl^{-1}$) | 18 - 78 | 6 – 30 | 4 - 24 |
| Total hardness ($mgl^{-1}$) | 90 - 138 | 50 – 110 | 26 - 80 |
| Alkalinity ($mgl^{-1}$) | 88 - 142 | 55 – 100 | 42 - 98 |
| Suspended solids ($mgl^{-1}$) | 100 - 1 500 | 100 - 1 500 | 100 - 900 |

Table 3 Total fish (t)* per species landed in the Loreto Region

| SPECIES\YEAR | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anodus spp.* | 49 | 90 | 128 | 124 | 175 | 267 | 252 | 309 | 237 | 470 | 560 | 492 | 424 | 322 | 157 | 351 | 179 |
| *Arapaima gigas* | 33 | 220 | 308 | 560 | 548 | 387 | 408 | 440 | 543 | 393 | 191 | 289 | 146 | 226 | 183 | 210 | 197 |
| *Astronotus ocellatus* | 1 | 25 | 33 | 117 | 100 | 77 | 89 | 93 | 127 | 141 | 263 | 279 | 101 | 243 | 126 | 219 | 154 |
| *Brachyplatystoma flavicans* |  | 174 | 48 | 267 | 249 | 198 | 293 | 229 | 585 | 358 | 210 | 346 | 278 | 436 | 81 | 159 | 220 |
| *Brachyplatystoma filamentosum* |  |  |  |  |  |  |  |  | 22 | 72 | 25 | 181 | 149 | 85 | 12 | 102 | 103 |
| *Brycon spp.* |  | 137 | 135 | 92 | 117 | 29 | 226 | 304 | 144 | 126 | 39 | 239 | 57 | 394 | 202 | 107 | 87 |
| *Colossoma macropomum* | 21 | 221 | 108 | 249 | 307 | 225 | 353 | 432 | 338 | 336 | 247 | 508 | 241 | 248 | 141 | 233 | 144 |
| *Cichla monoculus* | 1 | 19 | 20 | 142 | 131 | 154 | 95 | 98 | 165 | 160 | 202 | 238 | 114 | 133 | 95 | 157 | 91 |
| *Curimata spp.* | 148 | 180 | 163 | 200 | 335 | 481 | 438 | 308 | 690 | 760 | 997 | 1299 | 1557 | 1381 | 597 | 1401 | 1335 |
| *Hoplias malabaricus* |  | 17 | 20 | 115 | 107 | 159 | 58 | 120 | 156 | 131 | 287 | 341 | 153 | 165 | 616 | 560 | 549 |
| *Hypophthalmus spp.* | 61 | 115 | 78 | 119 | 186 | 357 | 296 | 367 | 374 | 279 | 451 | 538 | 272 | 495 | 678 | 731 | 501 |
| *Mylossoma spp.* | 4 | 112 | 106 | 185 | 301 | 312 | 411 | 550 | 475 | 367 | 279 | 707 | 305 | 542 | 465 | 332 | 398 |
| *Osteoglossum bicirrhosum* | 3 | 42 | 49 | 149 | 182 | 156 | 213 | 162 | 234 | 175 | 179 | 284 | 152 | 173 | 98 | 307 | 119 |
| *Oxydoras niger* |  | 20 | 20 | 43 | 31 | 25 | 54 | 74 | 66 | 84 | 183 | 272 | 83 | 104 | 6 | 80 | 39 |
| *Paulicea lutkeni* |  |  |  |  | 114 | 95 | 156 | 124 | 138 | 73 | 61 | 216 | 153 | 256 | 173 | 8 | 57 |
| *Potamorhina spp.* | 253 | 458 | 307 | 413 | 797 | 1138 | 1153 | 1058 | 1195 | 972 | 1376 | 1726 | 2823 | 2821 | 1355 | 2530 | 2620 |
| *Piaractus brachypomus* | 5 | 110 | 37 | 117 | 188 | 133 | 125 | 174 | 183 | 178 | 148 | 350 | 104 | 172 | 130 | 141 | 125 |
| *Plagioscion auratus* | 3 | 90 | 46 | 134 | 179 | 136 | 152 | 232 | 335 | 230 | 416 | 377 | 245 | 319 | 160 | 258 | 188 |
| *Prochilodus nigricans* | 109 | 1308 | 857 | 1768 | 4557 | 4759 | 6941 | 7489 | 5363 | 3316 | 2632 | 2947 | 805 | 2643 | 4636 | 3963 | 4270 |
| *Pseudoplatystoma fasciatum* |  | 157 | 81 | 142 | 146 | 129 | 272 | 44 | 422 | 327 | 309 | 327 | 165 | 206 | 53 | 234 | 184 |
| *Pterygoplichthys multiradiatus* | 45 | 124 | 82 | 172 | 157 | 335 | 131 | 119 | 302 | 228 | 294 | 354 | 172 | 313 | 67 | 121 | 195 |
| *Rhanphiodon vulpinus* |  |  |  |  |  |  |  |  |  |  |  |  |  | 159 | 24 | 110 | 98 |
| *Schizodon fasciatus* | 48 | 74 |  | 180 | 342 | 210 | 176 | 288 | 177 | 785 | 112 | 388 | 85 | 287 | 287 | 215 | 144 |
| *Semaprochilodus spp.* |  |  |  |  |  |  |  |  |  |  | 9 | 119 | 151 |  | 101 | 43 | 77 |
| *Serrasalmus spp.* |  |  |  |  | 2 | 4 | 1 | 2 |  |  | 2 | 161 | 148 | 231 | 16 | 40 | 23 |
| *Triportheus spp.* | 2 | 54 | 27 | 66 | 84 | 41 | 91 | 125 | 100 | 194 | 118 | 344 | 157 | 348 | 160 | 285 | 314 |
| Other | 1466 | 486 | 243 | 275 | 256 | 245 | 614 | 635 | 546 | 73 | 224 | 841 | 414 | 1117 | 1942 | 1248 | 828 |
| TOTAL | 2252 | 4233 | 2896 | 5629 | 9591 | 10052 | 12998 | 13776 | 12917 | 10228 | 9814 | 14163 | 9454 | 13819 | 12561 | 14145 | 13239 |

*salted and dried fish converted to fresh by 1.8 and 2.5, respectively

Table 4. Total fish landed in the Loreto region during 1996 by location and product.

| Basin | Fresh fish | Salted fish | Dried fish | Total* |
|---|---|---|---|---|
| Ucayali | 2 244 | 467 | 837 | 5 178 |
| Amazon | 695 | 34 | 152 | 1 136 |
| Marañon | 554 | 262 | 569 | 2 449 |
| Other | 1 387 | 315 | 1 010 | 4 476 |
| Total | 4 880 | 1078 | 2 568 | 13 239 |

* salted and dried fish converted to fresh weight by 1.8 and 2.5, respectively

Table 5. Annual fresh fish (t) caught by the fishery fleet in the Ucayali River

| **Species** | **86** | **87** | **88** | **91** | **92** | **93** | **94** | **95** | **96** |
|---|---|---|---|---|---|---|---|---|---|
| *P. nigricans* | 828 | 256 | 485 | 437 | 110 | 541 | 100 | 131 | 197 |
| *Potamorhina spp.* | 516 | 322 | 162 | 267 | 643 | 276 | 221 | 565 | 622 |
| *Brycon spp.* | 109 | 19 | 12 | 18 | 2 | 30 | 16 | 1 | 7 |
| *Mylossoma spp.* | 292 | 92 | 64 | 133 | 20 | 72 | 50 | 32 | 158 |
| *Curimata spp.* | 102 | 129 | 105 | 135 | 506 | 105 | 160 | 323 | 277 |
| *Triportheus spp.* | 52 | 39 | 23 | 59 | 33 | 77 | 24 | 42 | 114 |
| *Hypophthalmus spp.* | 21 | 24 | 9 | 7 | 20 | 15 | 13 | 23 | 30 |
| *S. fasciatus* | 67 | 5 | 68 | 43 | 12 | 24 | 31 | 19 | 29 |
| *C. macropomum* | 22 | 31 | 11 | 3 |  | 2 |  | 1 |  |
| *P. auratus* | 61 | 51 | 41 | 32 | 31 | 13 | 13 | 26 | 28 |
| *P. brachypomus* | 8 | 11 | 1 | 1 | 1 | 7 | 4 |  | 6 |
| Other | 113 | 42 | 191 | 30 | 51 | 48 | 2 | 53 | 40 |
| **TOTAL** | 2191 | 1067 | 1172 | 1165 | 1429 | 1210 | 634 | 1216 | 1503 |

Table 6. Annual fresh fish (t) caught by fishery fleet in the Amazon River

| **Species** | **86** | **87** | **88** | **91** | **92** | **93** | **94** | **95** | **96** |
|---|---|---|---|---|---|---|---|---|---|
| *P. nigricans* | 78 | 416 | 83 | 224 | 42 | 451 | 332 | 117 | 29 |
| *Potamorhina spp.* | 55 | 72 | 49 | 112 | 106 | 229 | 52 | 177 | 57 |
| *Brycon spp.* | 44 | 102 | 2 | 20 | 1 | 25 | 97 | 1 | 1 |
| *Mylossoma spp.* | 24 | 209 | 9 | 132 | 2 | 60 | 134 | 21 | 21 |
| *Curimata spp.* | 24 | 29 | 18 | 76 | 159 | 87 | 64 | 107 | 40 |
| *Triportheus spp.* | 1 | 45 | 2 | 42 | 2 | 65 | 40 | 53 | 51 |
| *Hypophthalmus spp.* | 1 | 8 | 3 | 3 | 5 | 13 | 3 | 18 | 2 |
| *S. fasciatus* | 1 | 87 | 12 | 39 | 2 | 20 | 134 | 9 | 7 |
| *C. macropomum* |  | 6 | 1 | 3 | 4 | 1 | 3 |  |  |
| *P. auratus* |  |  | 3 | 3 | 3 | 11 | 6 | 4 | 2 |
| *P. brachypomus* |  | 1 |  | 5 |  | 4 | 3 |  |  |
| Other | 31 | 40 | 25 | 14 | 3 | 43 | 38 | 13 | 25 |
| **Total** | 264 | 1015 | 207 | 673 | 329 | 1009 | 906 | 520 | 235 |

Table 7. Annual fresh fish (t) caught by the commercial fishery fleet in the Marañon and other rivers

| **Species** | **86** | **87** | **88** | **91** | **92** | **93** | **94** | **95** | **96** |
|---|---|---|---|---|---|---|---|---|---|
| *P. nigricans* | 114 | 48 | 281 | 128 | 34 | 103 | 58 | 25 | 30 |
| *Potamorhina spp.* | 69 | 60 | 94 | 78 | 196 | 52 | 128 | 109 | 95 |
| *Brycon spp.* | 15 |  | 6 | 5 |  | 6 | 9 |  | 1 |
| *Mylossoma spp.* | 39 | 17 | 37 | 39 | 6 | 13 | 29 | 6 | 24 |
| *Curimata spp.* | 14 | 24 | 61 | 40 | 156 | 9 | 92 | 63 | 43 |
| *Triportheus spp.* | 7 | 7 | 13 | 17 | 10 | 15 | 14 | 8 | 18 |
| *Hypophthalmus spp.* | 3 | 4 | 5 | 2 | 6 | 2 | 7 | 4 | 30 |
| *S. fasciatus* | 9 | 10 | 39 | 12 | 3 | 4 | 17 | 4 | 4 |
| *C. macropomum* | 3 | 5 | 6 | 1 |  |  |  |  |  |
| *P. auratus* | 8 | 9 | 24 | 9 | 9 | 2 | 7 | 5 | 4 |
| *P. brachypomus* | 1 | 2 |  |  |  | 1 | 2 |  | 1 |
| Other | 17 | 10 | 114 | 11 | 22 | 24 | 14 | 12 | 7 |
| Total | 301 | 200 | 680 | 342 | 440 | 231 | 367 | 236 | 232 |

Table 8. Annual fishing effort from the commercial fishery fleet

| | 86 | 87 | 88 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|
| **Loreto Region** | | | | | | | | | |
| N° fishermen-trip | 6263 | 5563 | 4125 | 4668 | 5149 | 5282 | 4207 | 6535 | 4768 |
| N° trips | 725 | 603 | 525 | 589 | 650 | 743 | 567 | 1060 | 689 |
| **Study Area** | | | | | | | | | |
| N° fishermen-trip | 5409 | 5157 | 3054 | 3891 | 4079 | 4749 | 3534 | 5700 | 4024 |
| N° trips | 618 | 557 | 369 | 510 | 532 | 672 | 474 | 929 | 592 |
| **Ucayali River** | | | | | | | | | |
| N° fishermen-trip | 4391 | 2672 | 2353 | 1961 | 2772 | 2154 | 1202 | 2251 | 2943 |
| N° trips | 482 | 263 | 256 | 292 | 331 | 330 | 174 | 295 | 369 |
| **Amazon River** | | | | | | | | | |
| N° fishermen-trip | 1018 | 2485 | 701 | 1930 | 1307 | 2595 | 2332 | 3449* | 1081 |
| N° trips | 136 | 294 | 113 | 218 | 201 | 342 | 300 | 634* | 223 |

* these values were not considered in the analysis due to high values(see text for details)

Table 9. Annual catch rates (CPUE) from the commercial fishery fleet

| | 86 | 87 | 88 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|
| Loreto Region | | | | | | | | | |
| kg fisherman$^{-1}$-trip | 440 | 410 | 499 | 467 | 427 | 464 | 453 | 301 | 414 |
| t trip$^{-1}$ | 3.80 | 3.78 | 3.92 | 3.70 | 3.38 | 3.30 | 3.36 | 1.86 | 2.87 |
| Study Area | | | | | | | | | |
| kg fisherman$^{-1}$-trip | 454 | 404 | 452 | 472 | 431 | 467 | 436 | 305 | 433 |
| t trip$^{-1}$ | 3.97 | 3.73 | 3.74 | 3.60 | 3.30 | 3.30 | 3.25 | 1.87 | 2.94 |
| Ucayali River | | | | | | | | | |
| kg fisherman$^{-1}$-trip | 499 | 399 | 498 | 594 | 515 | 561 | 527 | 540 | 512 |
| t trip$^{-1}$ | 4.54 | 4.05 | 4.57 | 3.98 | 4.31 | 3.66 | 3.64 | 4.12 | 4.08 |
| Amazon River | | | | | | | | | |
| kg fisherman$^{-1}$-trip | 259 | 408 | 295 | 349 | 252 | 389 | 389 | 151 | 217 |
| t trip$^{-1}$ | 1.94 | 3.45 | 1.83 | 3.08 | 1.63 | 2.95 | 3.02 | 0.82 | 1.05 |

Table 10. CPUE, number of fishermen per active floodplain area and yield in the Ucayali and Amazon rivers (commercial fishery fleet)

| Year | N°fishermen km$^{-2}$ | Kg per fisherman | Yield (k ha$^{-1}$) |
|---|---|---|---|
| 1986 | 0.44 | 454 | 1.98 |
| 1987 | 0.42 | 404 | 1.68 |
| 1988 | 0.25 | 452 | 1.11 |
| 1991 | 0.31 | 472 | 1.48 |
| 1992 | 0.33 | 431 | 1.42 |
| 1993 | 0.38 | 467 | 1.79 |
| 1994 | 0.28 | 436 | 1.24 |
| 1995 | 0.46 | 305 | 1.40 |
| 1996 | 0.32 | 433 | 1.40 |

Table 11. Predicted catch (t) using guilds group as response variable and flood indices and number of fishermen-trips as explanatory variables.

| | 86 | 87 | 88 | 91 | 92 | 93 | 94 | 95 | 96 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ucayali River** | | | | | | | | | | |
| **Detritivore** | | | | | | | | | | |
| Observed | 1446 | 707 | 752 | 839 | 1259 | 922 | 481 | 1019 | 1096 | 8521 |
| Predicted(1) | 1389 | 748 | 806 | 821 | 1367 | 921 | 486 | 871 | 1098 | 8507 |
| Differ.(%)* | -3.9 | +5.8 | +7.2 | -2.1 | +8.6 | -0.1 | +1.0 | -14.5 | +0.1 | -0.2 |
| **Omnivore** | | | | | | | | | | |
| Observed | 483 | 192 | 111 | 214 | 56 | 188 | 94 | 76 | 285 | 1699 |
| Predicted(2) | 436 | 310 | 139 | 124 | 65 | 188 | 96 | 92 | 185 | 1635 |
| Differ.(%)* | -9.7 | +61.4 | +25.2 | -42.0 | +16.0 | 0 | +2.1 | +21 | -35.0 | -3.8 |
| **Amazon River** | | | | | | | | | | |
| **Omnivore** | | | | | | | | | | |
| Observed | 69 | 363 | 14 | 202 | 9 | 155 | 277 | | 73 | 1162 |
| Predicted(3) | 50 | 308 | 26 | 120 | 11 | 259 | 357 | | 39 | 1170 |
| Differ.(%)* | -27.5 | -15.1 | +85.7 | -40.6 | +22.2 | +67.0 | +28.8 | | -46.6 | -0.7 |

* Difference (%): {(predicted / observed) – 1}100

Table 12. Predicted catch (t) using catch per-guild as response variable and number of fishermen-trips as explanatory variable.

| | 86 | 87 | 88 | 91 | 92 | 93 | 94 | 95 | 96 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ucayali River** | | | | | | | | | | |
| **Detritivore** | | | | | | | | | | |
| Observed | 1446 | 707 | 752 | 839 | 1259 | 922 | 481 | 1019 | 1096 | 8521 |
| Predicted(1) | 1478 | 988 | 891 | 769 | 1018 | 830 | 517 | 860 | 1069 | 8420 |
| Differ.(%)* | +2.2 | +39.7 | +18.5 | -8.3 | -19.1 | -9.9 | +7.5 | -15.6 | -2.5 | -1.2 |
| **Amazon River** | | | | | | | | | | |
| **Detritivore** | | | | | | | | | | |
| Observed | 157 | 517 | 150 | 412 | 307 | 767 | 448 | | 126 | 2884 |
| Predicted(2) | 180 | 557 | 113 | 405 | 247 | 588 | 514 | | 195 | 2799 |
| Differ.(%)* | +14.6 | +7.7 | -24.6 | -1.7 | -19.5 | -23.3 | +14.7 | | +54.7 | -2.3 |
| **Omnivore** | | | | | | | | | | |
| Observed | 69 | 363 | 14 | 202 | 9 | 155 | 277 | | 73 | 1162 |
| Predicted(3) | 34 | 236 | 15 | 136 | 58 | 259 | 206 | | 39 | 983 |
| Differ.(%)* | -50.7 | -35.0 | +7.1 | -32.7 | >200 | +67.0 | +74.3 | | -46.6 | -15.4 |

* Difference (%): {(predicted / observed) – 1}100

# APPENDIX B

## (Figures)

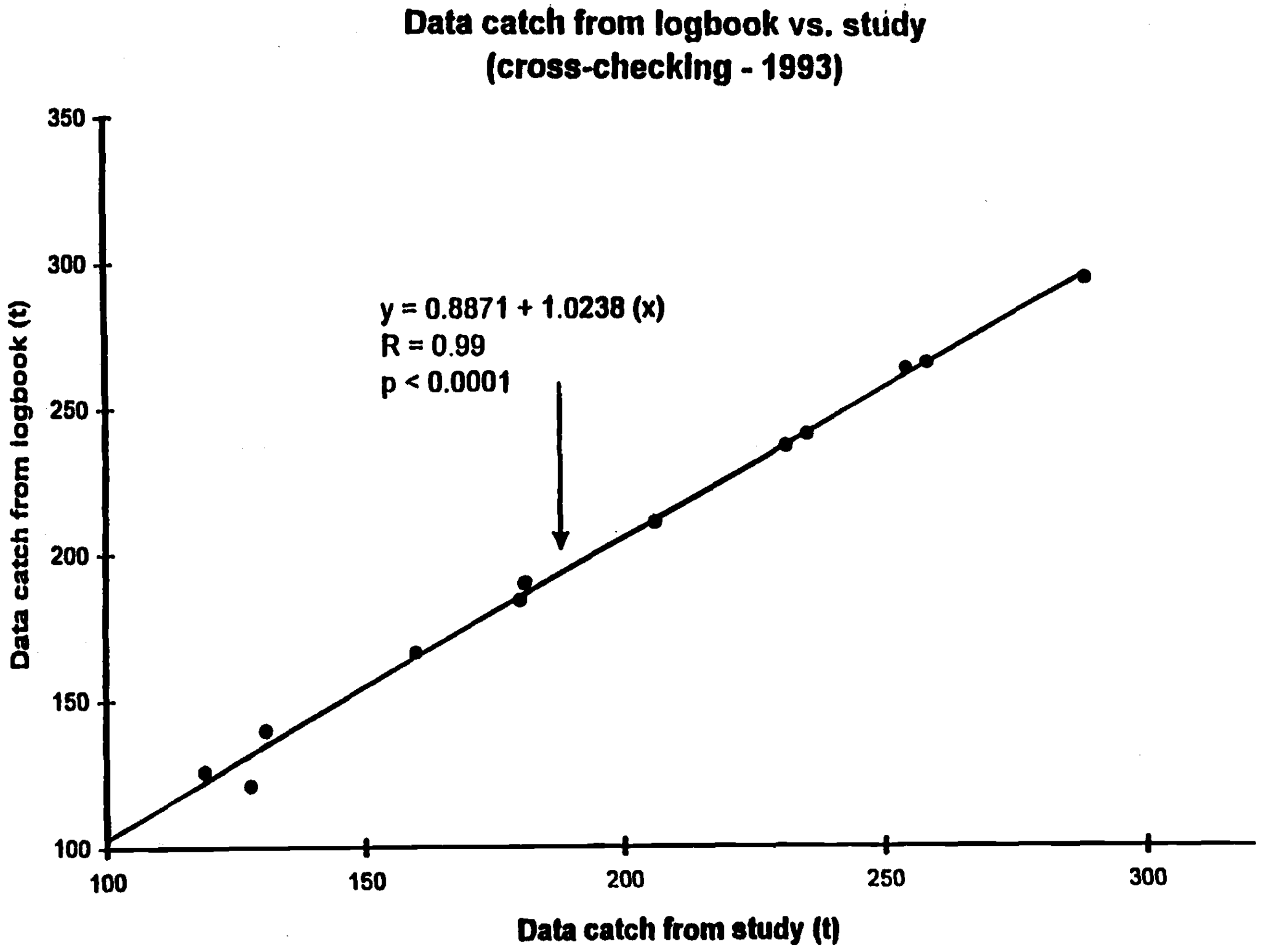


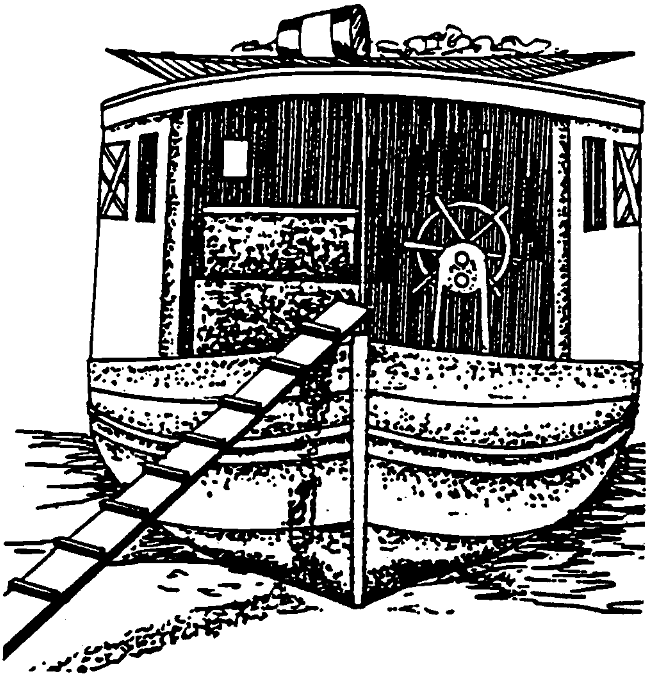
**Fig 1** Scatterplot of data catch from logbooks versus data catch from Del Aguila (1995), with estimated linear regression model

Fig 2 Large Boat

| | |
|---|---|
| Length | : 20 - 30 m |
| Ice box capacity | : 15 - 20 t |
| N° ice bars | : > 750 |
| N° fishermen | : 10 - 15 |
| N° gears | : 6 - 10 |

Fig 3 Medium Boat

Length : 15 – 20 m
Ice box capacity : 10 -15 t
N° ice bars : 500 - 750
N° fishermen : 8 - 10
N° gears : 4 - 6



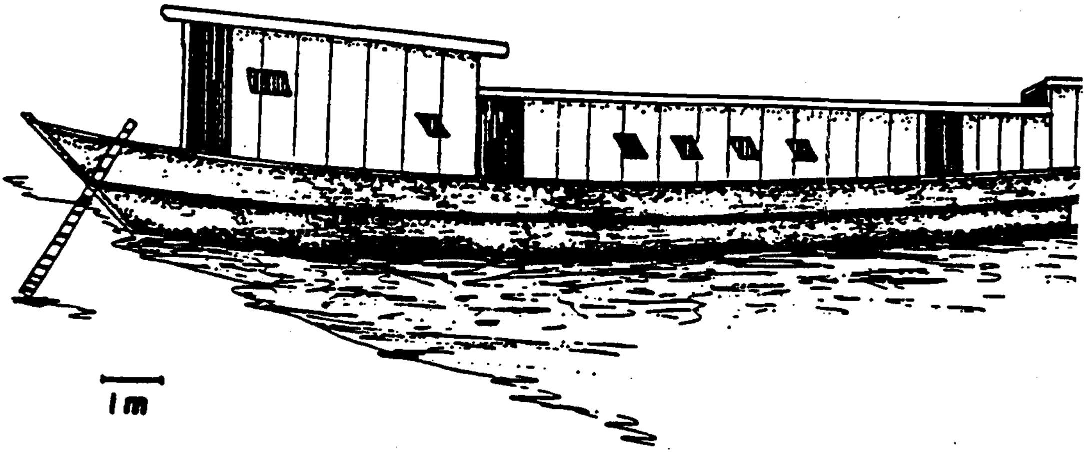


Fig 4 Small boat

| | |
|---|---|
| Length | : 8 – 17 m |
| Ice box capacity | : 2 - 10 t |
| N° ice bars | : 100 - 500 |
| N° fishermen | : 4 - 8 |
| N° gears | : 2 - 4 |

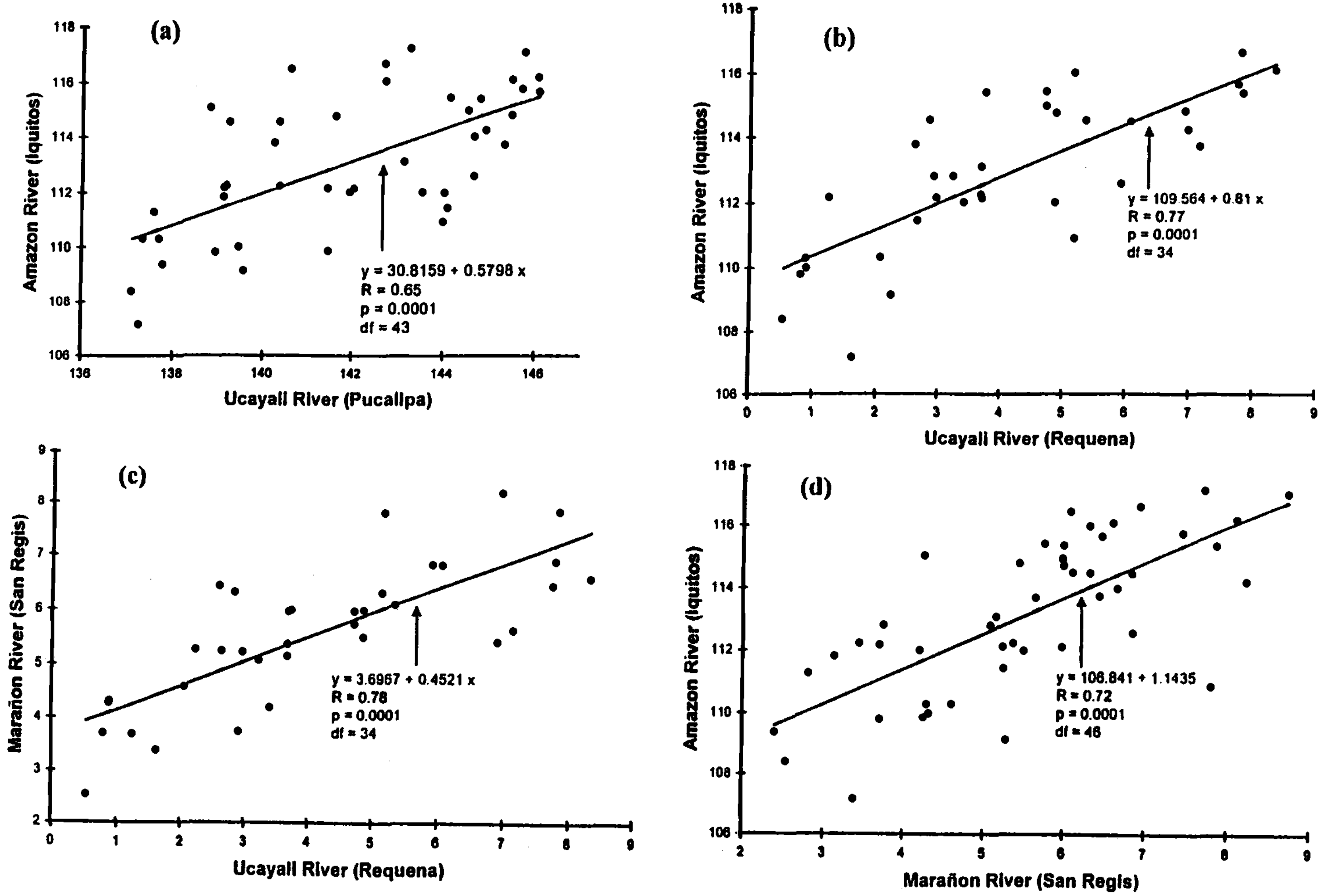


Fig 5 Scatterplot of Amazon's water stage (Iquitos gauge) versus water stage of the Ucayali and Marañon rivers

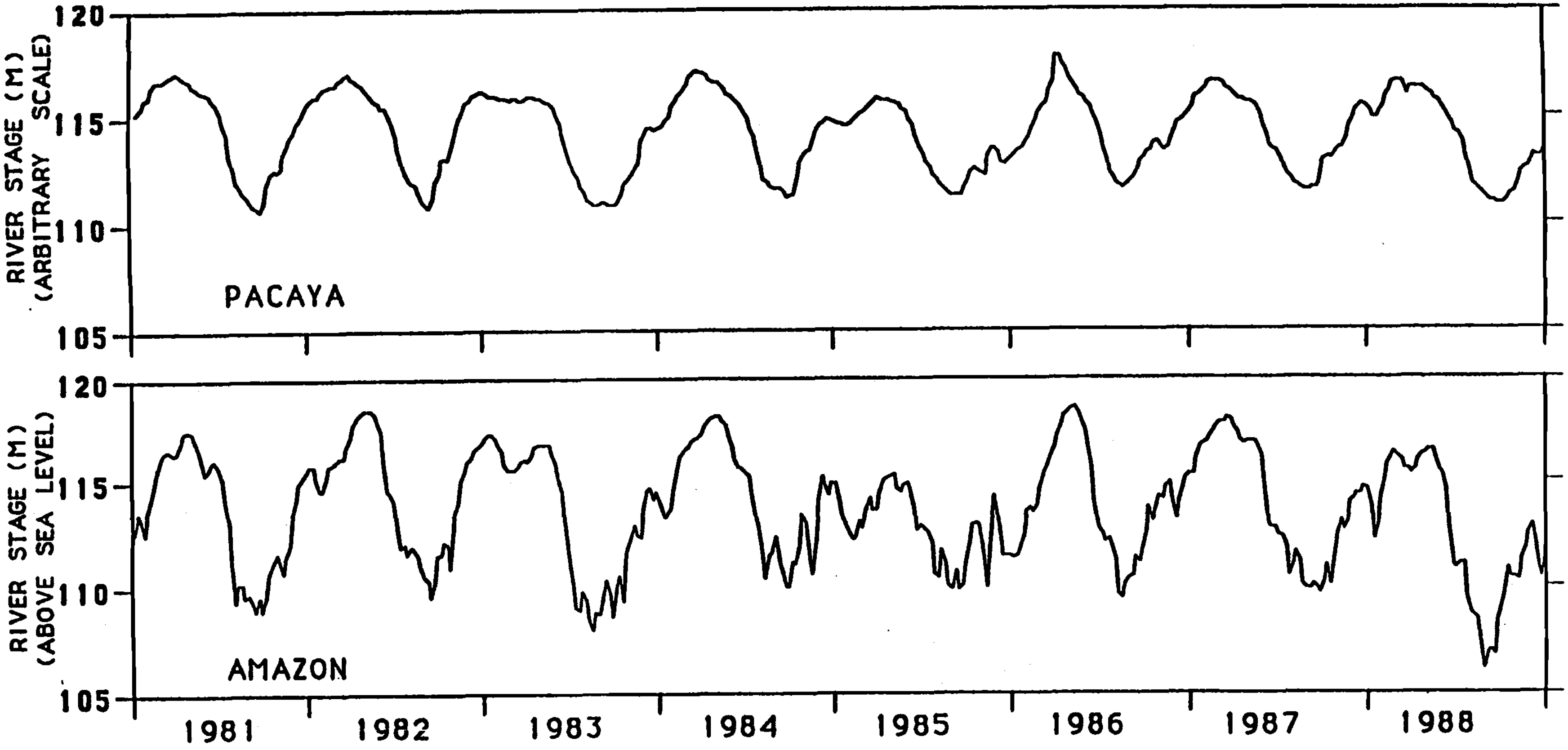


Fig 6 Hydrograph of the Pacaya and Amazon rivers
(from Bayley et al. 1992)

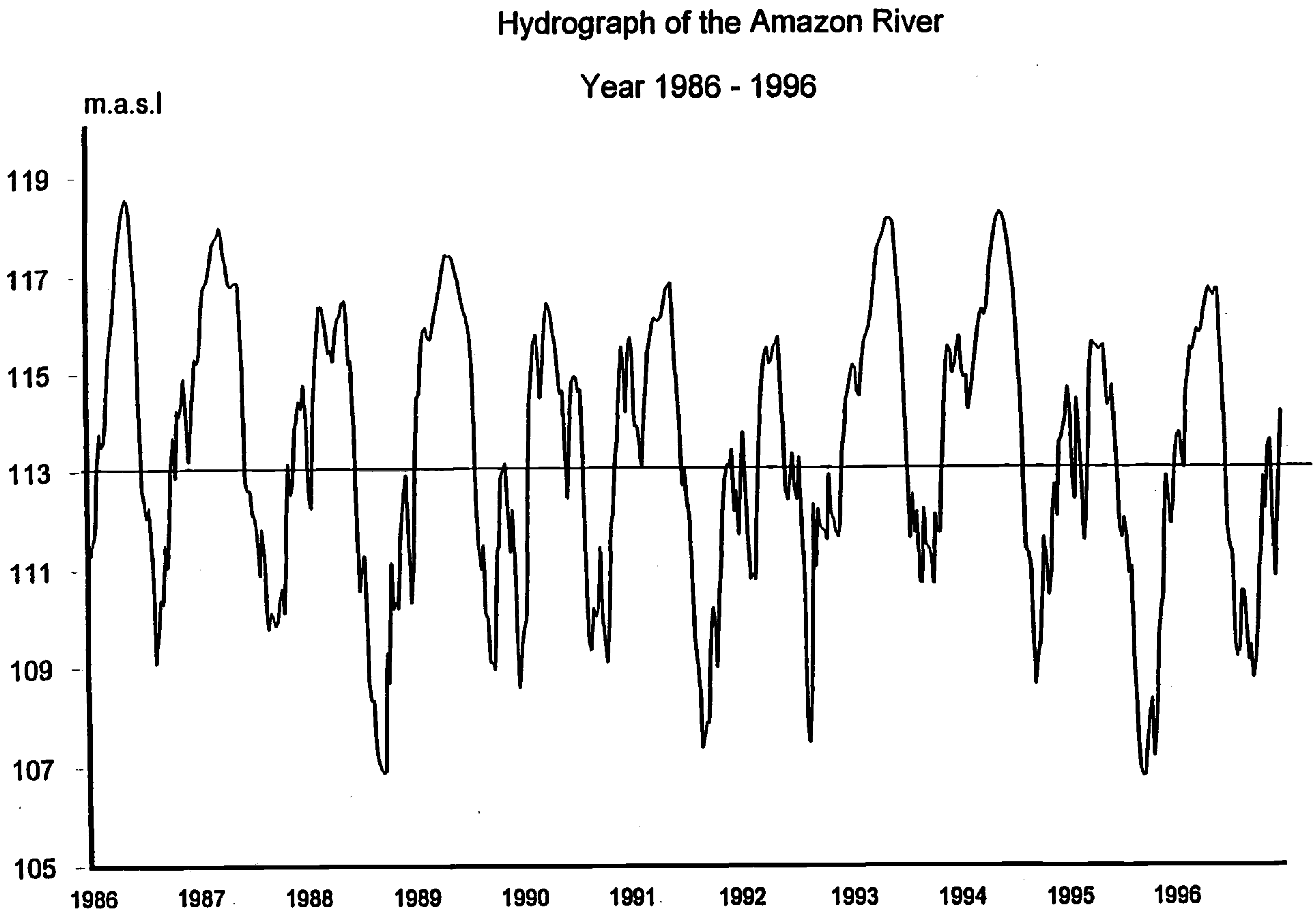


Fig 7 Water stage of the Amazon used to estimate hydrological indices

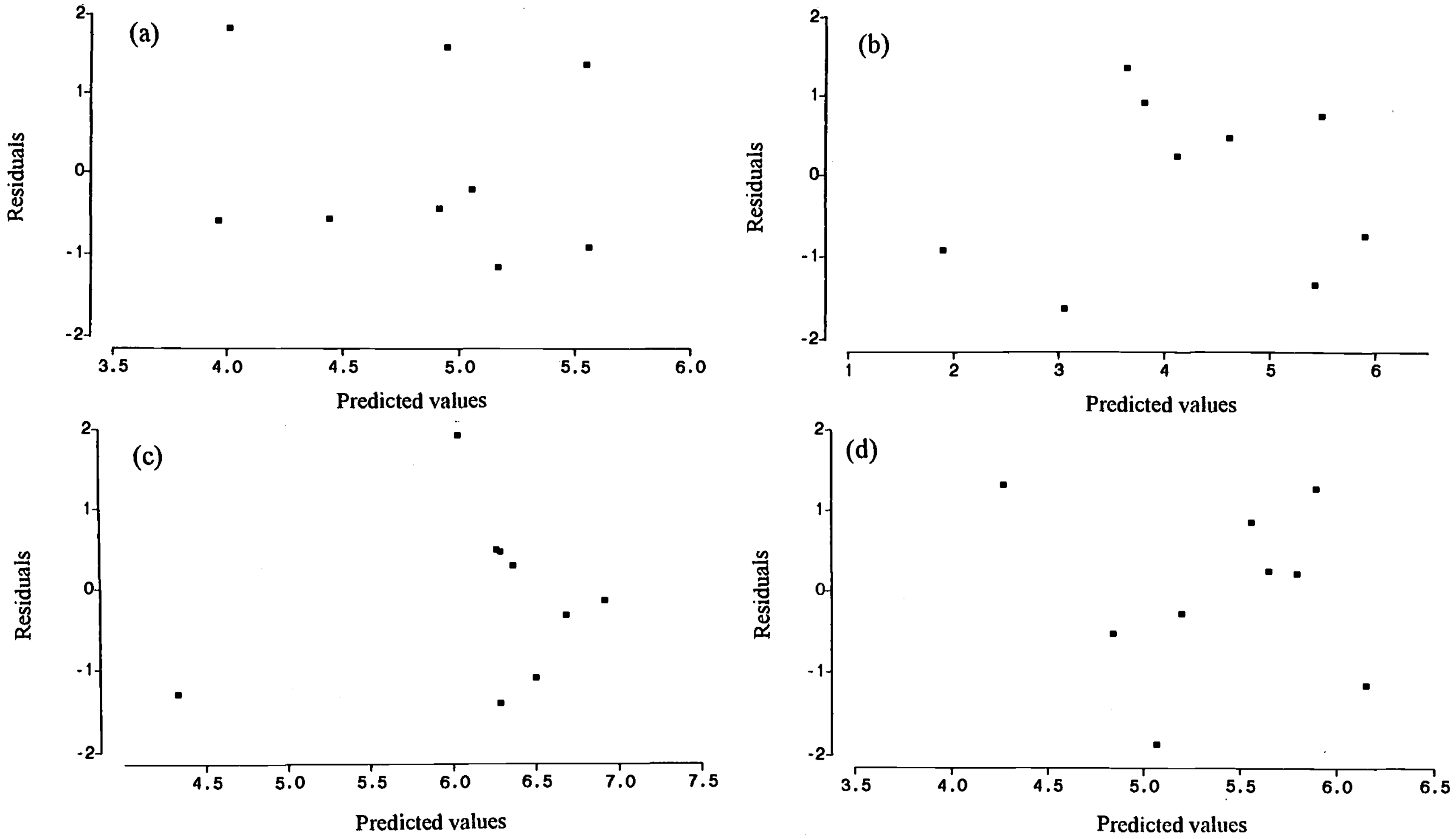


Fig 8 Plot of the residuals versus predicted values from the 7-month reduced models (a) omnivores, Ucayali, (b) omnivores, Amazon, (c) detritivores, Ucayali, (d) detritivores, Amazon

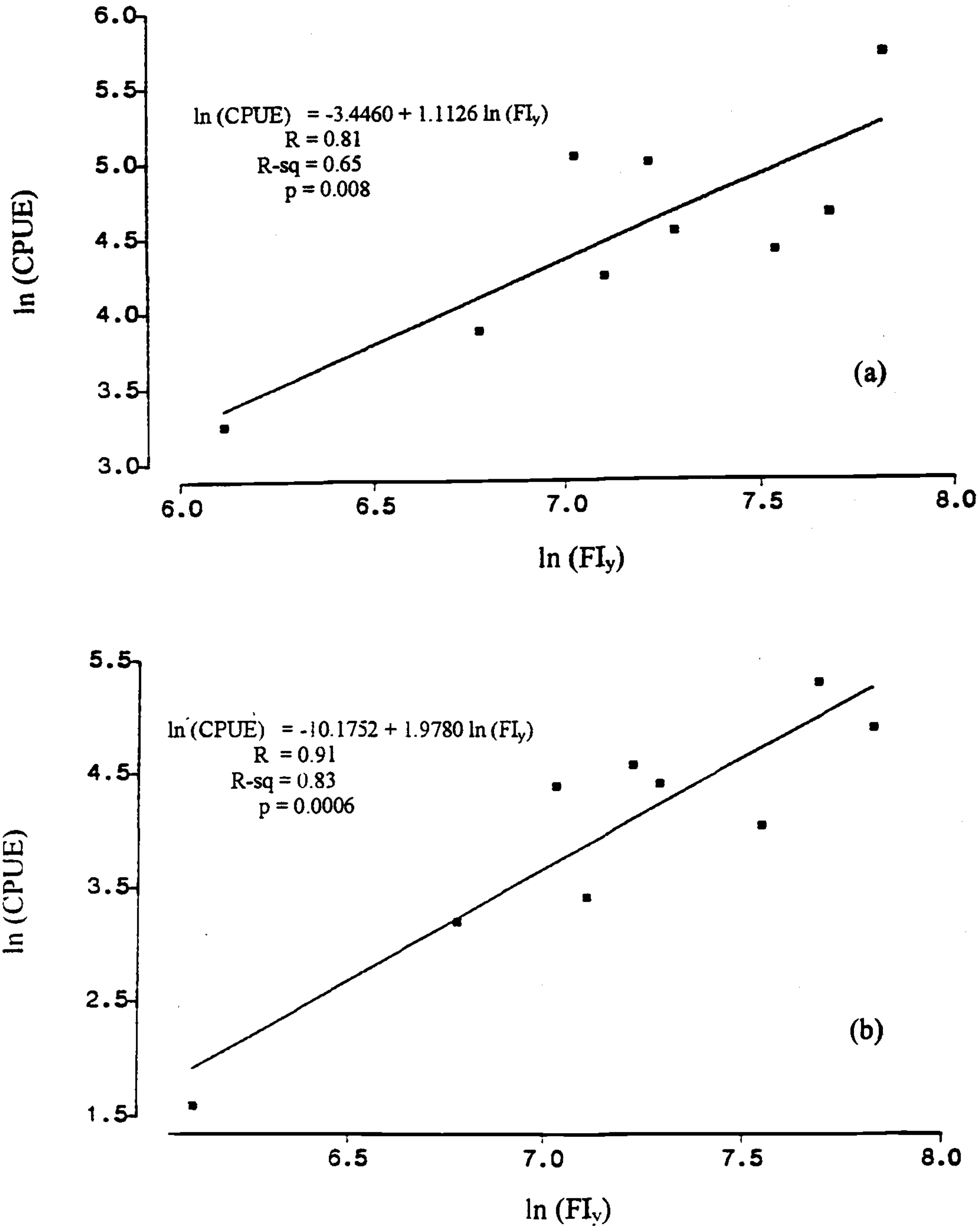


Fig 9 log-log scatterplots of 7-month CPUE for omnivores versus flood index of the same year with estimate linear regression, (a) Ucayali, (b) Amazon

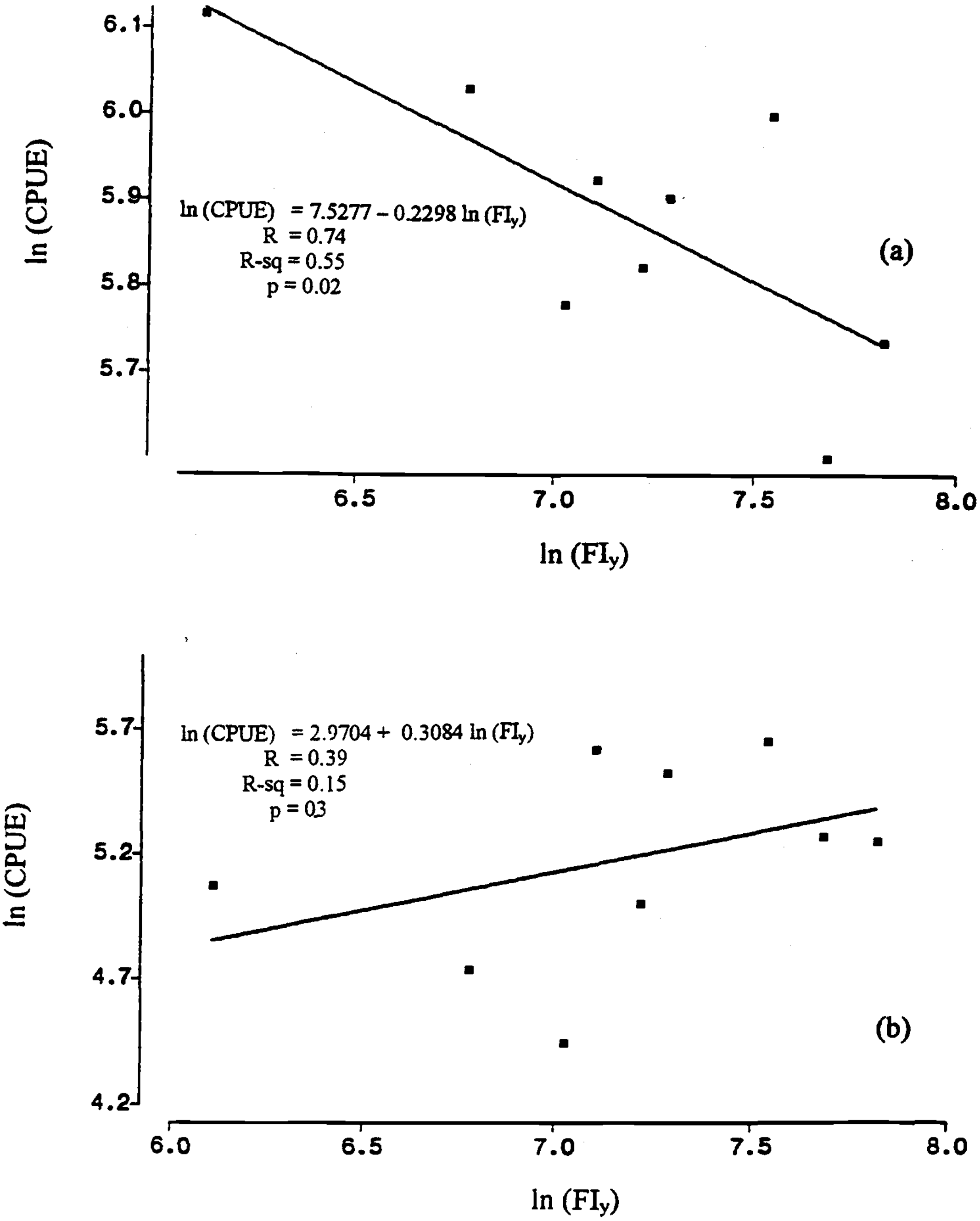


Fig 10 log-log scatterplots of 7-month CPUE for detritivores versus flood index of the same year with estimate linear regression, (a) Ucayali, (b) Amazon

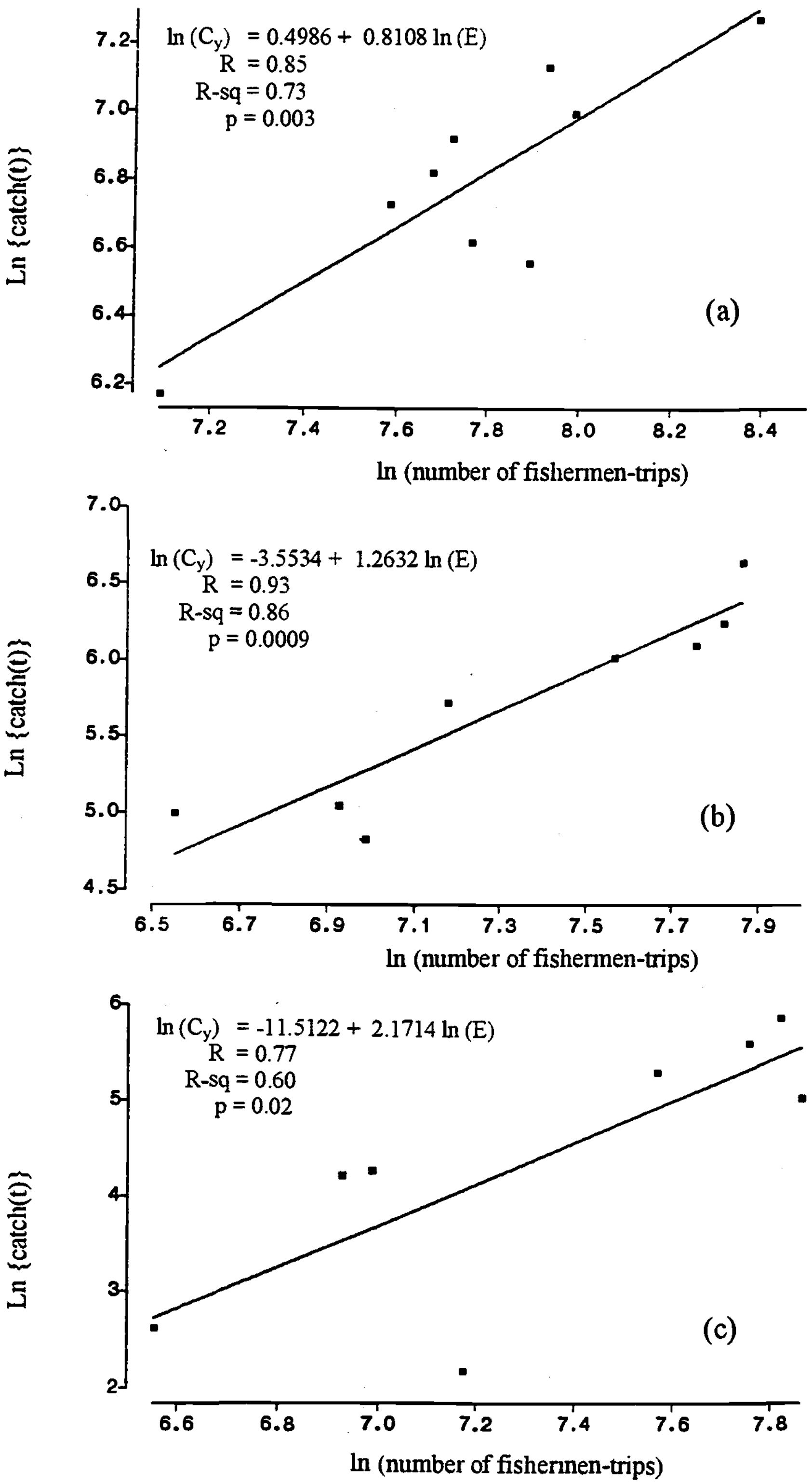


Fig 11 log-log scatterplots of 12-month catch per-guild versus fishing effort with estimate linear regression, (a) detritivores, Ucayali, (b) detritivores, Amazon, (c) omnivores, Amazon

# APPENDIX C

## (Checklist of Fish Species)

# CHECKLIST OF FISH SPECIES

| Local Name | Family | Order | Species |
|---|---|---|---|
| Arahuana | Osteoglossidae | Osteoglossiformes | Osteoglossum bicirrhosum |
| Paiche | Arapaimidae | Osteoglossiformes | Arapaima gigas |
| Zorro | Characidae | Characiformes | Acestrorhynchus falcirrostris |
| Zorro | Characidae | Characiformes | Acestrorhynchus sp. |
| Sabalo cola roja | Characidae | Characiformes | Brycon erythropterum |
| Sabalo clola negra | Characidae | Characiformes | Brycon melanopterus |
| Palometa | Characidae | Characiformes | Mylossoma duriventris |
| Palometa | Characidae | Characiformes | Mylossoma spp. |
| Gamitana | Characidae | Characiformes | Colossoma macropomum |
| Paco | Characidae | Characiformes | Piaractus brachypomus |
| Piraña | Characidae | Characiformes | Serrassalmus nattereri |
| Piraña | Characidae | Characiformes | Serrasalmus spp. |
| Sardina larga | Characidae | Characiformes | Triportheus elongatus |
| Sardina ancha | Characidae | Characiformes | Triportheus angulatus |
| Huapeta | Cynodontidae | Characiformes | Hydrolicus scomberoides |
| Chambira | Hemiodontidae | Characiformes | Raphiodon vulpinus |
| Yulilla | Hemiodontidae | Characiformes | Hemiodus sp. |
| Yulilla | Hemiodontidae | Characiformes | Anodus sp. |
| Boquichico | Prochilodontidae | Characiformes | Prochilodus nigricans |
| Yaraqui | Prochilodontidae | Characiformes | Semaprochilodus sp. |
| Ractacara | Curimatidae | Characiformes | Curimata rutiloides |
| Ractacara | Curimatidae | Characiformes | Curimata sp |
| Chio-chio | Curimatidae | Characiformes | Psectrogaster sp. |
| Llambina | Curimatidae | Characiformes | Potamorhina altamazonica |
| Yahuarachi | Curimatidae | Characiformes | Potamorhina latior |
| Lisa | Anostomidae | Characiformes | Schizodon fasciatus |
| Lisa | Anostomidae | Characiformes | Leporinus trifasciatus |
| Salton | Pimelodidae | Siluriformes | Brachyplatystoma filamentosum |
| Dorado | Pimelodidae | Siluriformes | Brachyplatystoma flavicans |
| Manitoa | Pimelodidae | Siluriformes | Brachyplatystoma vaillanti |
| Cunchi | Pimelodidae | Siluriformes | Pimelodella spp. |
| Doncella | Pimelodidae | Siluriformes | Pseudoplatystoma fasciatum |
| Tigre zungaro | Pimelodidae | Siluriformes | Pseudoplatystoma tigrinum |
| Cunchi-mama | Pimelodidae | Siluriformes | Paulicea lutkeni |
| Shiripira | Pimelodidae | Siluriformes | Sorubim lima |
| Tabla barba | Pimelodidae | Siluriformes | Goslynea platynema |
| Maparate | Hypophthalmidae | Siluriformes | Hypophthalmus edentatus |
| Maparate | Hypophthalmidae | Siluriformes | Hypophthalmus emarginatus |
| Carachama | Loricariidae | Siluriformes | Pterigoplichthys multiradiatus |
| Corvina | Sciaenidae | Perciformes | Plagioscion spp. |