Freshwater fishes of the Amazon River basin: their biodiversity, fisheries, and habitats

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*Stretching more than seven million square kilometers, the Amazon River basin is the largest river basin in the world and discharges about one-sixth of all freshwater from the continents to the oceans of the world. The age of this ecosystem, its position near the equator and the enormous diversity of its aquatic habitats, have produced the most diverse fish fauna on the planet. About 2,500 fish species have already been described and it is estimated that more than 1,000 new species remain to be discovered. Knowledge concerning this multitude of fish species is still insufficient, which makes their management and protection difficult. About 50% of the species are thought to occur in the large rivers and connected floodplains and another 50% in headwater streams. Inland fisheries give rise to 450,000 t of fish each year and thus contribute substantially to the protein supply of local populations. However, despite their economic importance, these fisheries receive little attention from the respective governments. The fisheries are highly selective and several stocks of large species with high market value have been over fished. Fish culture is still in its infancy but its development is expected to provide high-quality species during periods of low supply. Over large areas, aquatic habitats are still in near-natural conditions because of the low densities of resident human populations. Nonetheless, over the last few decades, the pressure on aquatic ecosystems and habitats has steadily increased, mainly due to large-scale destruction of natural vegetation cover by agro-industries in the savanna belt (*cerrado*), small-scale agriculture in the Andean hill slopes, and logging in rain forests. These activities have placed aquatic biodiversity, including fishes, at serious risk. Many headwater species have restricted distributions and are therefore particularly vulnerable to large-scale environmental degradation. Moreover, the construction of large reservoirs for hydroelectric power generation has serious consequences for fish fauna. Currently, about 16.4% of the Amazon River basin is protected, and another 15.2% is under partial protection in indigenous reserves in Brazil. Another 9.1% will be implemented as reserves in the next 10 years in the Brazilian part of the basin. The formulation by the Amazonian countries of a coherent policy that integrates long-term management of the river basin with sustainable management of aquatic and wetland habitats, including their fauna and flora, is urgently needed.*

Keywords: Management, environment, protection

Introduction

The Amazon River basin has an enormous diversity of fish species and thus is of great interest to ichthyologists. With about 2,500 described and probably more than 1,000 not yet described species of fish, the species richness of the basin exceeds that of other large river basins, such

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as the Mekong (1200-1700), Zaire (about 700), Paraná/Paraguay/LaPlata (591), Mississippi (375), Yangtze Kiang (322), Nile (129), Danube (103), and Volga (88) (Water Resources eAtlas, 2006; Quirós et al., 2007). The basin is bordered by the Andes Mountains in the west, the archaic shields of the Guyanas and Central Brazil in the north and south, respectively, and extensive lowland areas in the center leading to the Atlantic Ocean in the east. The large size, equatorial location, and high precipitation of the Amazon River basin likely explain its diversity. Similar paleo-climatic conditions, maintained for millions of years, may have also contributed by reducing extinction rates.

Human impacts in the basin were minor until the middle of the 20th century. However, in the 1950s, development accelerated mainly in the Brazilian part of the basin, which led to extensive road construction to support timber exploitation, mining activities, reservoir construction, and the establishment of agro-industries. The human population of the basin reached approximately 25 million in 2000, about 70% of which was concentrated in urban centers. There is strong and widespread dependence on freshwater fishes as a source of animal protein. Although the population density is still relatively low, transformation of the vegetation cover has begun to affect the extensive network of rivers, floodplains, and other wetlands. 57% of the Brazilian cerrado and 16% of the Amazon rainforest are destroyed (Machado et al., 2004; INPE, 2006). Nonetheless, despite the clear dependency of the human population on this resource, governments have failed to develop strategies and methods for sustainable management of their countries' aquatic ecosystems. Most countries, including Brazil which includes about two-thirds of the Amazon basin, have no detailed inventories or classifications of their water bodies and wetlands. Their protection is therefore generally not considered in the planning of large development projects, which inevitably pose serious risks to the integrity of aquatic ecosystems and the maintenance of aquatic biodiversity. As a consequence, the economic importance of developing sustainable inland fisheries has largely been ignored by Amazon basin nations.

In this review, we summarize current knowledge of Amazonian inland waters and characterize the fish fauna and its evolution. We also describe regional fisheries, analyze the status of fish habitats, and discuss the threats to these ecosystems as well as measures for their protection.

Population and physical characteristics

The Amazon River basin covers an area of about 7,351,000 km^2 in tropical South America, from 4°N to 18°S and from 42° to 79°W. About 4,982,000 km^2 (67.79%) are in Brazil, 956,751 km^2 in Peru (13.02%), 824,000 km^2 in Bolivia (11.20%), 406,000 km^2 in Colombia (5.52%), 123,000 km^2 in Ecuador (1.67%), 53,000 km^2 in Venezuela (0.72%), and 5,370 km^2 in Guyana (0.08%) (CABS/CI, 2000). In 2000**,** approximately 25 million people lived in the Amazon basin. Of the 21 million people in the Brazilian section, 68% lived in urban areas, and the proportion has been increasing (Becker, 1995; IBGE, 2002) (Figure 1).

More than one million square kilometers of the central basin are less than 100 m above sea level. The Amazon River flows at about 5°S parallel to the equator and annually transports $6{,}300 \times 10^9$ m^3 of water and $1{,}150 \times 10^6$ t of sediments to the Atlantic Ocean (Milliman and Meade, 1983; Meade, 1994). The mean slope over the 3,000 km from Iquitos to the mouth of the river is only about 2–3 cm km^{-1}, but high discharge rates can result in current velocities up to 3 m s^{-1}.

The climate in the central basin is hot and humid, with a mean annual temperature of 26.6°C (Ribeiro and Adis, 1984). The mean annual precipitation in the central basin is about 2,500 mm yr^{-1} and increases to about 5,000 mm yr^{-1} in the Andes foothills. In the archaic shields, comprising the northern (Guyanas) and southern (Central Brazil) uplands of the central basin, precipitation decreases to 1,000–1,500 mm yr^{-1} and the difference between the dry and the rainy season becomes more pronounced (Salati and Marques, 1984). The vegetation of the central basin, the Andes foothills, and parts of the archaic shields consists of different types of rain forest. Decreasing precipitation and a 4 to 6 month dry period on the plateaus of the shields result in the replacement of forest by different types of savanna vegetation (*cerrado*).

The Amazon River and its large tributaries exhibit predictable monomodal flood pulses in response to dry and rainy seasons. The annual flood amplitude can reach 15 m. Maximum discharge in the southern tributaries is about 3 months earlier than in the northern tributaries, so that the mean flood amplitude of the main stem is buffered to about 10 m near Manaus and 6 m near Santarém (Irion et al., 1997). Floods become more related to

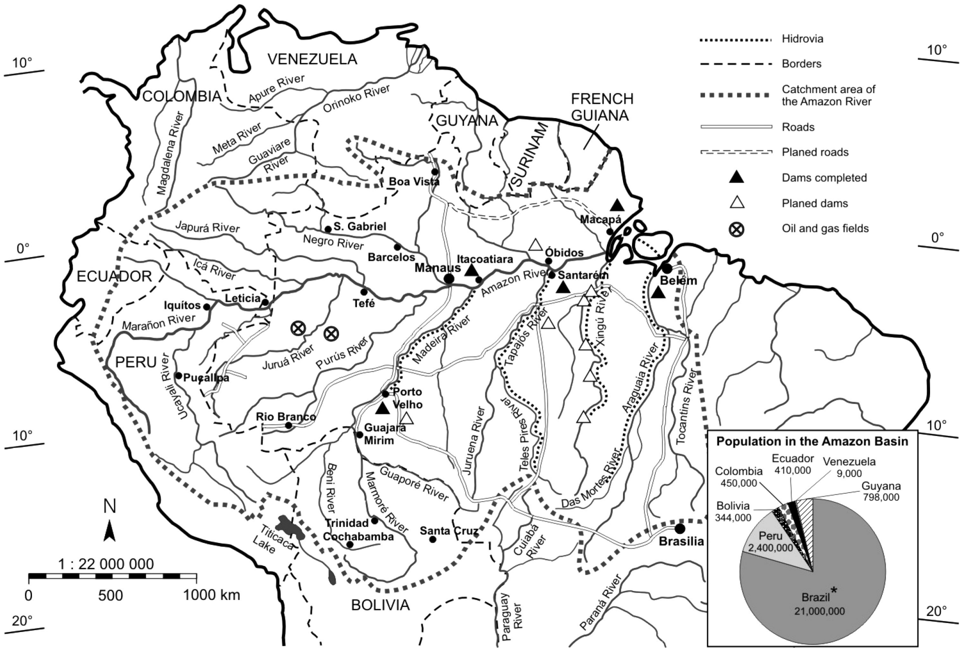

Figure 1. Human population and major development projects in the Amazon River basin (Fearnside 1989), and population numbers (CADMA 1992, *data for Brazil from 2005).

individual rain events with decreasing river order. The base flow of small streams that are not associated with large wetlands is increased during the rainy season, with pronounced short floods due to heavy rain storms.

Habitat characterization

The Amazon Basin is part of a very old depression that already existed on the Gondwana continent and then opened to the west. When South America separated from Africa, about 110 million years before present (BP), the basin was already closed in the west by the Early Andes, except for an opening to the Pacific (Maranon Portal or Guayaquil Gap) that probably closed during the late Cretaceous period (73 Ma). Rivers drained to the west into a depression along the eastern border of the Early Andes that opened to the Caribbean Sea. With the uplift of the Andes, the pre-Andean depression was subjected to marine ingressions of differing extent in the late Cretaceous (83–67 Ma), early Tertiary (61–60 Ma), and late Tertiary (11.8–10 Ma) periods, as indicated by marine sediments. After cessation of these marine transgressions, the depression was covered by rivers, lakes, and extended wetlands. Large freshwater lakes were formed in the Tertiary period (Lago Pozo in the middle Eocene to early Oligocene, 43–30 Ma; and Lago Pebas in the late Tertiary, 20–11.8 Ma) and were filled with sediments of riverine origin from both the Andes and the shields of Central Brazil and the Guyanas. In the late Miocene (8 Ma), the connection to the Caribbean Sea was closed by the Vaupes Arch, the Amazon River opened its way to the Atlantic Ocean, and the modern Amazon drainage system incised large valleys and floodplains in the soft sediments (Lundberg et al., 1998).

Classical lakes occur mostly in the endorheic Titicaca basin, which is separated from the Amazon drainage area, and in Andean valleys. There are a few small lakes also in the periphery of the basin. In contrast to East Africa, where large and deep lakes exist, Amazonia is characterized by rivers, and its lack of closed river basins has profoundly influenced evolution of the fish fauna. Classic fish habitats are found in the fluvial parts of the basin and are determined by river discharge, gradient, and geology. These fluvial habitats include water falls and rapids along the borders of the shields and in the Andes. They are associated with specific rheophilic fishes, plants, and invertebrates, and can also interrupt the upstream migration of fishes and other fauna. Of utmost importance to the biological production and diversity of fishes are different types of wetlands, such as floodplains formed by the rivers and streams

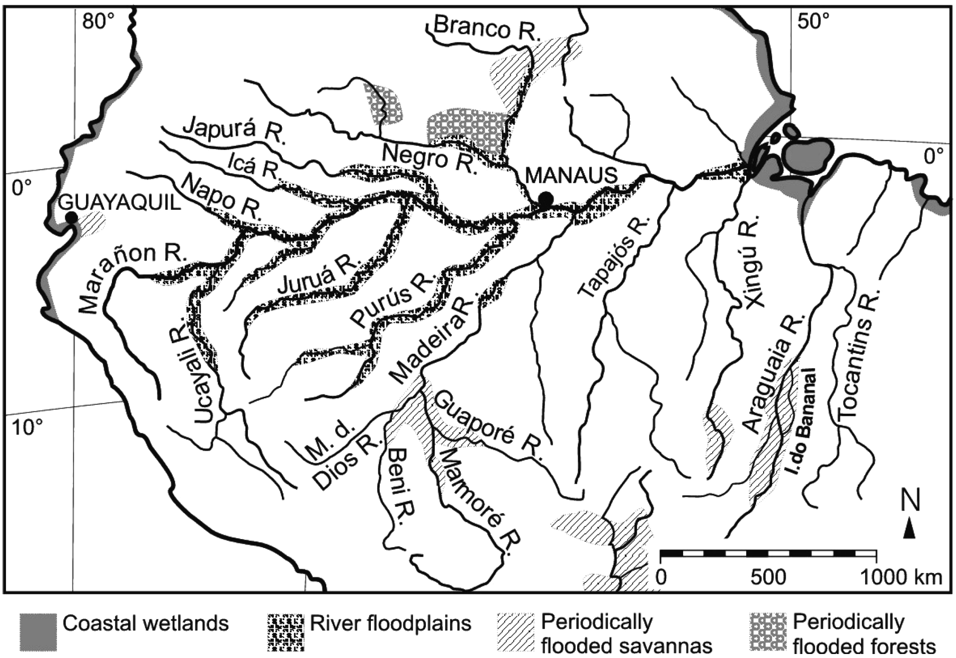

Figure 2. The distribution of large wetlands in the Amazon River basin (Junk, 1993).

in the dominant low-gradient regions, wetlands in paleo-floodplains near the Andes, and wetlands that occupy interfluvial depressions (Figure 2).

The water quality of rivers corresponds to the bio-geochemical conditions of their catchment areas (Sioli, 1984). Rivers with catchment areas that include the Andes, e.g., the Amazon, Purus, Juruá, Japurá (partially), and Madeira Rivers, transport large volumes of dissolved and suspended matter that give the water a turbid, loamy color (whitewater rivers, Sioli, 1984). Conductivity is high (60–100 μS cm^{-1} in central regions) relative to other tributaries and the water has a near neutral pH (6.5–7.0). The water is rich in dissolved alkali-earth metals and carbonate. The fertility of the sediments is the result of the presence of clay minerals illite and montmorillonite, which have a high ion-exchange capacity. Rivers draining large podsol areas are low in suspended matter, but of a brownish-reddish color because of the large amounts of dissolved humic substances (blackwaters). These waters are acidic (pH 4–5) and their conductivity is low (5–20 μS cm^{-1}) due to the limited content of dissolved minerals. Dissolved alkali metals dominate the cations whereas the carbonate content is very low. Clearwater rivers drain the archaic shields of central Brazil and the Guyanas. The green-tinted water is transparent because of the low levels of dissolved and suspended material. The pH of these rivers is slightly acidic, between 5 and 6; conductivity varies between 20 and 30 μS cm^{-1} and is mostly accounted for by alkali metals but a low carbonate content. The Tapajos River is representative of this group. Small clearwater streams can be very electrolyte poor (2.5–7.5 μS cm^{-1}) (Wantzen, 2003). However this is not a categorical classification since there are many transitional waters due to natural or human influences. Accelerated soil erosion in agricultural areas often increases sediment load and the turbidity of blackwater and clearwater rivers, but the mineral content of these "pseudo-whitewaters" changes little.

In response to the substantial fluctuations in discharge, most Amazonian lowland streams and rivers have developed extensive floodplains. Embedded in these floodplains are shallow floodplain lakes that number in the thousands. During low-water periods, the lakes are isolated but they become progressively connected with each other and with the river as the water level rises. Lakes in floodplains with sufficient rainfall remain connected with the river throughout the year. Water of different chemical composition, such as rain water, ground water, water from tributaries, and water from the parent rivers, in combination with the complex geomorphologies of the floodplains lead to complex mixing patterns affecting productivity, biogeochemical cycles, and vegetation cover, and increase habitat diversity for fishes in the transition zone (perirheic zone; Mertes, 1997). The mouths of blackwater and clearwater tributaries are often partly blocked by sediments of the whitewater rivers and form sizable ria lakes. Large interfluvial areas become periodically flooded during the rainy season because of limited drainage. In depressions, broad shallow lakes may form that persist for several years but dry out during periods of extreme drought. At the foothills of the Andes, extensive paleo-floodplains exist together with former oxbow lakes that have been transformed to swamp forests. About 20–25% of the entire Amazon basin is periodically waterlogged or flooded and thus exhibits wetland characteristics, such as anoxic soils, wetland vegetation, and limited drainage. By contrast, the active floodplains fringing rivers with large flood amplitudes are relatively well-drained and their waters are only locally or periodically anoxic.

Floodplains in the rain forest are covered with a flood-adapted species-rich forest that tolerates a mean annual inundation as long as eight months and a water depth of up to 10 m (Wittmann et al., 2002). Lower-lying and disturbed areas are covered by herbaceous vegetation during the low-water season, whereas communities of free-floating and rooted emergent aquatic macrophytes develop during the rising-water season. Submersed macrophytes are rare because of insufficient light. Similarly, in blackwater rivers, aquatic macrophytes are rare or absent because of low nutrient levels and/or low pH values. In savanna areas, the floodplains are covered by savanna vegetation, with flood-tolerant forest surrounding permanent water bodies. Drought- and fire-tolerant shrubs and trees are found on higher-lying areas, where flood stress is less pronounced. These shallow-water floodplains have abundant and species-rich communities of submersed, emergent, and free-floating aquatic macrophytes (Junk and Piedade, 1997).

A preliminary classification of the Amazonian wetlands according to their hydrology, the physical and chemical characteristics of the water and sediments, and the vegetation cover is given in Junk and Piedade (2005).

Fish species diversity

The extent of fish species diversity in Amazonia has yet to be determined because many habitats have not been adequately sampled. Recent samples in the main channels of the Amazon and Negro Rivers revealed several new species (Fernandes et al., 2004; Thomé-Souza and Chao, 2004), and a new fish family that was identified in specimens sampled in the vicinity of Manaus is currently being described (Petry, 2003). To date, 4,475 fish species are recognized in the *Check List of the Freshwater Fishes of South and Central America* (Reis et al., 2003), about 2,500 of which are from Amazonia. Another 1,550 yet to be described species have been projected, implying a total of about 6,025 species in neotropical freshwaters (Reis et al., 2003), while Schäfer (1998) estimated over 8,000 species. About two-thirds of the species occur in the Amazon basin. By comparison, about 1,050 North American species, 360 European species, and 500 species from Australia-New Guinea have been described. The fish faunas of Africa and tropical Asia are incompletely known and may reach more than 3,000 species each (Lundberg et al., 2000).

It is estimated that about half of the Amazonian species occur in large rivers and their floodplains, with the remainder in small tributaries, where endemism is very high because of geographic isolation (Menezes, 1996). In the 1,200-km-long reach of the lower Negro River, Goulding et al. (1988) collected more than 450 fish species and estimated that it contains a total of more than 700 species. Bayley (1983) reported more than 226 fish species in Lago Camaleão, a floodplain lake on an island in the Amazon River near Manaus with a surface area of about 2 km^2 during periods of high water.

About 85% of the Amazonian fish fauna belong to the Ostariophysi, 43% are Characiformes, 39% Siluriformes, 6% Cichlidae, and 3% Gymnotiformes (Lowe-McConnell, 1987). There is a corresponding diversity in morphology, food and feeding habits, as well as reproduction strategies among species and higher taxa. Strongly oscillating water levels force the fishes to vacate preferred habitats and thus to small- or large-scale spawning and feeding migrations. Large catfishes, such as *Brachyplatystoma vailantii* (*piramutaba*) and *B. flavicans* (*dourada*), migrate long distances between their juvenile feeding grounds in the Amazon estuary and their spawning grounds in the headwaters of Colombia, Bolivia, and Peru (Barthem and Goulding, 1997). When the water levels are high, many floodplain fish species rely on organic matter produced *in situ*. Food items of terrestrial origin, such as fruit and insects of the floodplain forest, make up a considerable portion of their diets, as shown by stomach-content analyses and stable-isotope studies (Goulding, 1980; Soares et al., 1986; Oliveira, Martinelli, et al., 2006, Oliveira, Soares, et al., 2006).

Most species living periodically or permanently in floodplains have developed multiple adaptations to low oxygen concentrations (Val et al., 1996; Junk et al., 1997). In addition, low light conditions may have contributed to the unique morphological, neurological, and electrosensory adaptations of the endemic Gymnotiformes.

In a recent preliminary approach, ichthyologists of The Nature Conservancy and World Wildlife Fund subdivided the Amazon River basin into 13 eco-regions according to catchments or parts of catchments of major tributaries (Petry, 2003); however, the number of eco-regions will certainly increase when the sub-basins are better sampled.

Fishery yield and potential

The potential of the inland food fishery of the Amazon basin has been estimated at about 900,000 t yr^{-1} based on comparisons with other tropical river-floodplain fisheries (Bayley and Petrere, 1989). In 1980, the total basin yield was around 199,000 t yr^{-1}, as determined by human population and per capita consumption data. Bayley (1998) estimated that the total yield in 1991 was 425,000 t yr^{-1} based on the human population reported in that year. Much of the the increase from 1980 to 1991 was due to higher estimates of per capita fish consumption for rural floodplain communities, i.e., 370 g d^{-1} (Cerdeira et al., 1997) and 400–800 g d^{-1} (Batista et al., 1998; Fabré and Alonso, 1998), which were not available during the first study. These high values contrast with the 11–39 g d^{-1} (Bayley and Petrere, 1989) estimated for populations distant from floodplains.

Of the total yield in 1991, estimated proportions from Brazil, Peru, Columbia, and Bolivia were 79, 20, 0.8, and 0.7%, respectively. The various fisheries can be divided into subsistence/local market and commercial components, but fishermen often supply both from the same artisanal activity when buyers for high-value species are available. Fisheries primarily for subsistence and the local market are found along all major rivers and the yield comprises a significant part of the total calorific diet of the inhabitants, in addition to satisfying animal protein requirements at low cost (Bayley and Petrere, 1989; Barthem et al., 1995; Batista et al., 2000). Although per capita consumption in cities is lower than in rural floodplains, the proportion and magnitude of the yield consumed in riverine cities are significant, and are increasing. The three largest cities on the Amazon River in Brazil, Manaus, Santarem, and Belém, accounted for 25% of the total Brazilian Amazon yield in 1991, which was consumed by 25% of the 10.0 million people censused in the Brazilian Amazon (Bayley, 1998; half of Belém's consumption was presumed to be of marine origin and thus discounted). By contrast, Brazilian subsistence and local market fisheries, defined as districts containing urban populations of less than 50,000, accounted for 71% of the total Brazilian Amazon yield. This proportion was dominated by those districts containing várzea (whitewater floodplain), which accounted for 61% of the total Brazilian Amazon yield, consumed, in turn, by only 18% of the human population (Bayley, 1998). Of the estimated 1991 yield of 80,000 t from the Peruvian Amazon, 75% was for subsistence and local markets (Bayley, 1998).

The total export of food fish from the basin in 1991 was roughly 20,000 t (Bayley, 1998). This export was dominated by piramutaba (*Brachyplatystoma vaillantii*) from the industrial, export-oriented, large catfish fisheries initiated in Belém in 1972. Exports from this fishery and from the shrimp fishery have accounted for about 50 and 15%, respectively, of the combined commercial yield from Belém in recent years (Barthem, 2004). The catfish fishery yield decreased from 28,486 t in 1977 to 10,000 t in 1993, while the export value of piramutaba decreased from 13 million US$ in 1980 to about 3 million US$ in 1994 (Barthem and Goulding, 1997), pointing to overexploitation of these stocks (Barthem and Petrere, 1995). From the mean 34,000 t of fish that were landed in Belém in 1994 and 1995, about 28% were sold at the local fish market (Ver-O-Peso) and 72% at the ports of the fishing industries (Barthem, 2004).

Knowledge of fish yield by taxon and fishing effort are essential for understanding the effects of exploitation and year-to-year hydrological changes on the yields of important taxa and the economics of the various fisheries. However, except for the Belém-based industrial fishery, sufficiently long-term data are lacking. The collection of such data from rural centers in the floodplains, which dominate the total fishery yield, while difficult and costly, is feasible. However, even data collection from Manaus, the most concentrated fish market in the region (Mérona and Bittencourt, 1988; Batista, 1998; Soares and

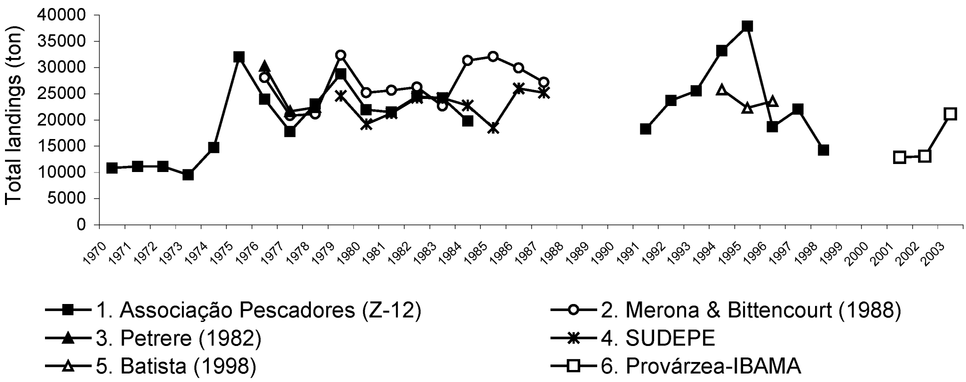

Figure 3. Total landings at Manaus markets from 1970 to 1998. Data from Association of Fishermen Z-12: Adolpho Lisboa Market (1970–1984) and Panair Market (1991–1998). [Data from Mérona & Bittencourt (1988): Adolpho Lisboa Market (1976–1987). Data from Petrere Jr. (1982, 1985): Adolpho Lisboa Market (1976–1978). Data from SUDEPE (1984, 1986, 1987): Adolpho Lisboa Market (1979–1987). Data from Batista (1998): Panair Market (1994–1996). Data from Ruffino et al. (2002, 2005): Manaus Modern Market (2001 and 2002) and Manaus Balsa de desembarque de pescado Modern Market (2003).]

Junk, 2000), has suffered from long periods of missing information (Figure 3). A high-level data collection system for yield by fish taxon and fishing effort was established by Petrere Jr. (Petrere Jr., 1978 a, b), but it collapsed after a few years when the scientist in charge left Manaus. Since the mid-1990s, collection of landing statistics in major cities has resumed. The data showed that about 120,000 t of fish were recently landed in major cities (Batista et al., 2004).

About 200 fish species are used for human consumption, but only about 6–12 species comprise more than 80% of the landings in the large cities along the Amazon River (Barthem and Fabré, 2004). Consequently, several species show signs of overfishing, such as piramutaba (*Brachyplatystoma vaillantii*) (Barthem and Petrere, 1996), tambaqui (*Colossoma macropomum*) (Isaac and Ruffino, 1996), jaraqui (*Semaprochilodus* spp.) (Batista, 2000), and pirarucu (*Arapaima gigas*) (Queiroz, 2000). Fishery statistics in Manaus have indicated a relatively stable number of landings over the last few years. The increase recorded in 2003 was probably the result of centralization of the landings in a new market (Figure 3). Tambaqui, formerly one of the most important species sold at the Manaus market, is no longer among the ten most important species by weight. Instead, this list now includes jaraqui, curimatá (*Prochilodus nigricans*), and, recently, pacu (*Mylossoma* spp.) (Figure 4).

The species composition of the catch varies considerably according to region, fishery, and market conditions. The most important species of the Amazon River basin are: in Belem, at the mouth of the Amazon, catfishes (*Brachyplatystoma rousseauxii*, piramutaba, and several species of the family Doradidae, about 58%); in Santarem, on the lower Amazon, catfishes (*Brachyplatystoma rousseauxii*, mapará (*Hypophthalmus* spp.) and *Pseudoplatystoma* spp., about 50%); in the middle and upper Amazon, in Manaus and Tefé, curimatá and jaraqui (45 and 38%, respectively); in the upper Amazon, at Iquitos and Pucalpa, curimatá and branquinhas (curimatids; 55 and 45%, respectively) (Batista et al., 2004); and, near the Andes, at the Caquetá River in Colombia, the large migrating catfishes (more than 90%) (Barthem and Fabré, 2004; Muñoz-Sosa, 1999). These proportions are derived from commercial yields that are either sold in urban centers or exported and therefore do not reflect the higher species diversity of fishes caught for subsistence or local markets (e.g., Smith, 1981; Barthem and Fabré, 2004), as described below.

Fisheries management

This section addresses management in the traditional fisheries sense of managing fishermen's activities. Amazonian fishermen have profound knowledge of the types of fishes and their environments, and use at least 15 types of fishing gear, including bow and arrow, harpoon, hooks, and different types of nets, depending on the species to be captured and its habitats (Batista et al., 2004). The large fish fences and fish traps that are commonly used in Asian inland fisheries are prohibited by law.

As a result of the increased human population in the basin and its concentration in urban centers, commercial fisheries and the supply of markets in

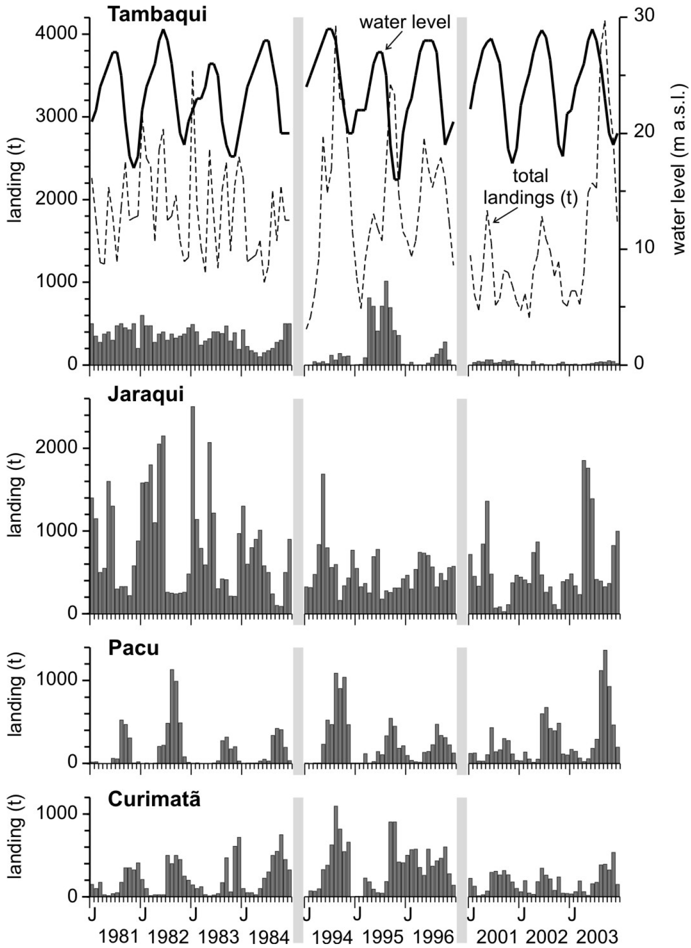

Figure 4. Total monthly landings and monthly landings of tambaqui (*Colossoma macropomum*), jaraqui (*Semaprochilodus insignis, S. taeniurus*), pacu (*Mylossoma* spp.), and curimatã (*Prochilodus nigricans*) at Manaus market in relation to the water level. [Data: Association of Fishermen Z-12 and banco de dados do Projeto do Convênio INPA/CNPq/ORSTOM from 1981–1984. Batista (1998) from 1994 to 1996, Ruffino et al. (2002, 2005, 2006) from 2001 to 2003.]

riverine cities and urban centers connected by the new highways have become of increasing importance. At the same time, the protein and caloric needs of rural and small town populations, especially in floodplain areas, must be guaranteed.

Commercial fishing in the state of Amazonas, Brazil, is carried out by the Association of Fishermen, with the branch in Manaus (Z-12) being the most important. It was founded in 1967 and is affiliated with the harbor authorities. In the 1970s, governmental programs, such as the Plan for Assistance to Artisan Fishery (PESCARD) and the Plan for Fishery Development (PDP), led to rapid growth of the Amazonas fishery. Since then, the number of registered fishermen has increased to 26,870 (according to the Special Secretary of Aquaculture and Fishery of Amazonas State, SEAP-AM). About 45,000 people are involved in activities directly or indirectly linked with this fishery (Ribeiro et al., 1999).

The perspective of professional, city-based fishermen differs from that of fishermen in riverine communities due to the different economic circumstances (Bayley and Petrere, 1989). The former supply high-volume markets and have sufficient capital to profitably exploit fish communities at lower catch per effort values; this increases the yield at the cost of stock size but without necessarily overexploiting stocks. By contrast, most locally based fishermen are part-time and are accustomed to benefiting from high catch per effort to supply fish for their families and for local markets. Many local fishermen, some of them full-time, gain additional cash income from the sale of high-value species to the owners of fishing vessels and vessels that transport goods and passengers to the cities (Barthem et al., 1995; Batista et al., 2000). The growing number of fishing vessels together with the population increases in cities and rural areas has inevitably led to conflicts between professional fishermen and fishermen in riverine communities.

The traditional, centralized approach to the management of fishery resources by the Brazilian government has been inadequate to deal with these conflicts, which have been exacerbated by the limited numbers of fishery biologists with sufficient understanding of population dynamics and economics of fisheries. Local communities have attempted to control access to the fish stocks in their lakes by regulating fishing (*acordos de pesca*) or prohibiting access to some lakes (*reserva de lagos*) (Batista et al., 2004). These efforts have been supported by the Brazilian Environmental Organization IBAMA and led in the early 1990s to experiments with different forms of decentralized participative administration.

One approach has been to elaborate agreements between local communities and state governments to restrict fishing rights in certain lakes or rivers for the benefit of the local population, but to allow professional fishermen to use other lakes for commercial fishery (Fisher et al., 1992; IBAMA, 1994, 1997; McGrath et al., 1994; Ruffino, 1996; Isaac et al., 1998). This type of administration encourages the local population to manage resources in their lakes in a sustainable manner and to invest in the protection of the floodplain forest that provides fruit as food for several valuable fish species. However, it fails to adequately manage migratory species that move among lakes and rivers under the jurisdiction of different management systems or not subject to any form of management.

Another approach has been the establishment by local governments of Reserves for Sustainable Development, such as of the one in Mamirauá, near Tefé, at the confluence of the Amazon and Japurá rivers. The local population has exclusive rights to exploit the natural resources within the reserve, e.g., fish and timber and non-timber products of the area, according to management plans under the supervision of IBAMA. Positive results have been shown for the sustainable management of pirarucu (*Arapaima gigas*). This large osteoglossid piscivore reaches a length of 1.5 m at maturity and has been heavily overfished for several decades in much of the basin. A management plan developed with the technical assistance of scientists and controlled by the local communities has led to substantial local recovery of stocks during the last decade and an increase in catch for the local population (Viana et al., 2003). An extension of this approach to other, feasible areas will make an important contribution to environmental protection because the local population is included in the management process and directly benefits from protection measures (Junk, 2000).

Attempted protection measures legislated in Brazil, as well as similar approaches in Peru, have included prohibition of the capture of some species during the spawning season [e.g., tambaqui, pirarucu, mapará (*Hypophthalmus* spp.)], definition of minimum market size (e.g., tambaqui 55 cm, pirarucu 150 cm), and the regulation for specific species of minimum stretched gillnet mesh size [e.g., curimatá (11–13 cm), *Pseudoplatystoma* spp. (22–25 cm), and pirarucu (24–27 cm) (Furtado, 1988; Evangelista, 1992)]. It has been argued, however, that these approaches cannot work without subsidizing the fisheries (Bayley and Petrere, 1989). In addition, further regulations apply to fisheries in specific habitats (e.g., rapids and waterfalls), although their implementation has been problematic. For example, according to the Brazilian legislation (*Decreto Lei 221/67*), all water bodies and the animals living therein belong to the public and fish can be captured by all people with the respective authorization. Thus, the lack of a coherent fisheries policy and the confusion resulting from several self-contradicting regulations often exacerbate conflicts between local and visiting fishermen, and between different riverine communities.

On a multi-species basis, in the 1990s, fisheries took only about half of the projected average maximum yield of 900,000 t yr^{-1} (see previous section); therefore, in terms of protein production, they did not overexploit fish stocks. Nevertheless, the demand for large and valuable fish species and the more recent practice of fishing smaller species (Welcomme and Henderson, 1976) will inevitably have a negative effect on the sustainability of high-value stocks (overexploitation). However, there is no danger of extinction if the river-floodplain system does not suffer large-scale environmental damage. Multi-species/multi-use fisheries, including those of the Amazon, need to be managed according to the regional needs of protein supply and the sustained profitability of particular species (Bayley, 1981). In other words, the worst strategy would be to apply a single approach to all parts of the basin. Instead, a more workable strategy would be to designate areas closer to urban centers for multi-species fisheries with limited regulation while progressively restricting the entry of boats exceeding defined capacities into more remote catchment areas (Bayley, 1995). In some respects, this process is evolving, albeit as a collection of tactics rather than as defined national strategies consistent with international conventions that also include environmental protection.

Ornamental fish trade

The primary exporters of ornamental fishes from the Amazon River basin are Colombia, Brazil, and Peru, with 42, 33, and 21% of the declared South American export value in 1999 (Olivier, 2001). In the Brazilian Amazon basin, along the middle Negro River, the export of ornamental fish is an important economic activity and it contributes about 90% of the total number of ornamental fish exported from Manaus to Europe, the USA, and Japan (Leite and Zuanon, 1991; Chao, 1993; Prang, 1996; Chao et al., 2001). In 1998, about 16 million ornamental fish were exported from Amazonas, corresponding to 2.2 million US$ (IBAMA, 1999). In 1999, the number increased to 35 million specimens. These statistics have limited reliability and may underestimate the truth by as much as 50% (Chao, 2001). Mortality rates during transport have decreased considerably and are currently about 5%, but reliable statistics are missing (Ferraz, 1999).

Thirty-six companies are registered in Manaus, but only 16 were active in 1997 and only three accounted for about 70% of the fish exported. The IBAMA allows the export of about 200 species but only about 50 species from the Negro River are of economic importance. Cardinal tetra (*Paracheirodon axelrodi*) comprises 65–85% of the total number of fish exported (Chao, 2001). Although only 120,000 specimens of brown and blue discus varieties (*Symphysodon discus, S. aequifasciatus*; about 0.5% of the total number) were exported, they comprise about 10% of the total value. Ornamental fishes are exported to more than 30 countries, dominated by the USA (25%), Germany (19%), and Japan (17%). The center of collection of ornamental fishes is the Municipality of Barcelos, with about 16,000 inhabitants and an area of 122,000 km^2. More than 1,000 fishermen (*piabeiros*) are involved in capturing ornamental fishes and many of their family members participate in activities related to their maintenance and transport (Prang, 2001). Chao (1993) estimated that, in Brazil, 8,000–10,000 people are involved in the ornamental fish trade, of which about 6,000 live along the middle Negro River.

The only recent study on the aquarium fish trade of Peru indicated that trade is centered in Iquitos. The export of a total of 12.4 million specimens was estimated for 2001, perhaps 40% of which consisted of non-declared specimens. More than 700 different fish varieties were exported but the top 10 species made up about 70% of the declared export volume (Moreau and Coomes, Dept. of Anthropology, University College, London, UK, in press). Mortality rates are estimated at 3–5% and thus are similar to those for the Brazilian fishery.

In Peru and Colombia, the neon tetra (*Hyphessobrycon innesi*) used to be as important as the cardinal tetra in Brazil. However, exports declined strongly in the late 1970s because of successful breeding in Southeast Asia (Hanek, 1982). The silver arawona (*Osteoglossum bicirrhosum*) has since dominated Peruvian exports, accounting for 11% in number but 42% of the international export value. About 68% of Iquitos' international export goes to the USA, 9.3% to Hong Kong SAR, 9% to Germany, and 7.4% to Japan. About 14,000 people in Peru directly depend on the aquarium trade.

The discussion about the impact of ornamental fisheries on Amazonian stocks is controversial. Some ichthyologists consider the ornamental fish trade a threat to species diversity, and many environmentalists support fishery restrictions through the establishment of "white lists" that contain only a few very common species and thus exclude many species from export. However, it must also be acknowledged that: (1) the fishery pressure in most Amazon waters is low because there is a significant market for only a few species; (2) natural fish mortality in Amazonian river-floodplain systems is very high because of the dramatically changing environmental conditions resulting from high- and low-water levels, and most species reproduce quickly enough to compensate for natural and fishery-induced losses; (3) species diversity is much more threatened by habitat deterioration than by fishing; (4) techniques for maintaining and reproducing ornamental fishes have improved dramatically, and while commercial aquaculture has increased market size, it has competed successfully with the wild-caught industry; and (5) aquarists contribute substantially to knowledge of the biology, ecology, and reproduction of ornamental fishes, which is important in order to maintain genetic resources and biodiversity.

For the Amazon region, there is no evidence of a serious threat to the stocks of most ornamental fishes, except in the case of a few species with complex reproductive strategies, low reproduction rates, and territorial behavior, such as the discus (Crampton, 1999), or those species whose area of distribution is very restricted. In Brazil and Peru, the export of juvenile food fishes is prohibited. The IBAMA restricts the number of ornamental species that can be exported to about 200. Although this restriction does not exist in Peru, the statistics of both countries show that a few species make up the bulk of exported fishes. The market for most other species is too small to affect stocks. Chao (2001) argued that the negative impact on the environment would be much larger if those currently involved in the ornamental fish trade would shift to timber extraction, agriculture, and cattle ranching, all of which would further destroy the rain forest and degrade aquatic habitats. *Piabeiros* treat their fishing areas very cautiously because they know that healthy fish stocks depend on an intact ecosystem (Junk, Max-Planck-Institute for Limnology, Plön, Germany. pers. observation). The most appropriate measure to protect ornamental fishes and the human population depending on the ornamental fish trade would be the establishment of Reserves for Sustainable Management in core areas of fisheries, where the exploitation of ornamental fishes and ecotourism would be the principle management tools.

Fish culture

Fish culture does not have a long tradition in Amazonia. Pre-Columbian Indians stored surplus fish and turtles alive in cages or small tanks (Acuña, 1865) but fish culture was not practiced, probably because there were enough steadily available fish and/or because fluctuations in water levels and rainfall made pond-based culture difficult. The first fish-culture experiments were started in 1920, in Belém, by Rudolpho von Ihering and were continued by Pedro de Azevedo in northeast Brasil (Ihering and Azevedo, 1934, 1936). In the following decades, several Amazonian species, such as pirarucu, tucunare (*Cichla ocellaris*), acará açu (*Cichlasoma biocellatum*), and tambaqui were successfully cultured in water-retention basins, but tilapias became the mainstay of fish culture because of its simple reproductive needs. In Manaus, fish-culture experiments with native species started at the INPA in 1976 (Saint-Paul and Werder, 1977; Resende et al., 1985; Graef et al., 1987; Graef, 1995; Val and Honczaryk, 1995). Studies were also undertaken in Venezuela (Valdez, 1984), Colombia (Valencia and Puentes, 1989), and Peru (IMARPE, 1979; Eckmann, 1983, 1984). The Instituto de Investigaciones de la Amazonia Peruana (IIAP), in Iquitos, Peru, has a long history of culturing pirarucu.

Decreasing catches of high-value species, increasing demand, and rising prices are strong stimuli for the cultivation of the above-mentioned species as well as many exotic ones. Today, 17 species are cultivated in the Brazilian Amazon, including three exotic species: common carp (*Cyprinus carpio*), *Nile tilapia* (*Oreochromus niloticus*), and *Tilapia* sp. The 4,319 fish farmers make use of ponds that total about 3,000 ha in surface area, of which 2,500 are in the state of Acre (Val et al., 2000). About 60% of the farmers employ extensive methods, while only 1.8% practise intensive cultivation methods. The mean yield in Amazonas is about 4.5 t ha^{1} yr^{-1}. Tambaqui and matrinchã (*Brycon melanopterus*) are successfully cultivated in ponds around Manaus and fed with specially produced pellets. They are sold when their wild-caught fish conspecifics are scarce. Tambaqui, pirarucu, and/or matrincha are also cultivated in Colombia, Peru, Venezuela, and Bolivia.

Despite encouraging results in terms of technical feasibility, Amazonian fish culture is still in its infancy. Lack of research, insufficient technical assistance, high production costs, and difficult access to financial credit are limiting factors (Saraiva, 2003). The basin-wide availability of large amounts of water of generally good quality favors the development of fish culture, but high flood amplitudes and periodic limitations in dissolved oxygen in the floodplains are strong limitations. It may be argued that fish culture is not economically viable when fisheries exist for the same species. However, the stocks of high-value species are already at low levels in some areas and prices are rising. Moreover, landings are highly seasonal, which results in periods of scarcity, and fisheries are concentrated along large whitewater rivers that are distant from the new urban centers that have developed in proximity to the new highways. Therefore, aquaculture should be considered as complementary to inland fishery. It has the potential to supply year-round demand while creating a viable economic sector, providing that it does not become a target for permanent government subsidies.

Habitat health and the protection of species diversity

Considering that the 7.3 million square kilometers of the Amazon basin are inhabited by only 25 million people, and nearly 70% of them live in cities, aquatic habitats should be relatively healthy and little threat should be posed to fishes and other aquatic organisms. This holds true in many regions, but there are rising concerns and serious threats in others (Figure 1).

Large, highly mechanized agro-industries have already transformed more than 50% of the two million square kilometers of Brazilian *cerrado* vegetation in the southeastern part of the Amazon basin into soybean plantations and pasture for cattle ranching. These activities employ very few people, but they have a dramatic impact on the integrity of small streams and rivers, because the riparian vegetation is destroyed, soil erosion is accelerated, and excessive sediment deposition in streams destroys in-channel habitat diversity. The impact of these processes on aquatic species diversity has received little notice, but the few studies and observations on riparian vegetation, submersed macrophytes, and aquatic invertebrates reported dramatic impacts. *Cerrado* streams, which in 1976 had a luxurious submersed flora (Furch and Junk, 1980), were devoid of submersed plants about 15 years later because the substrate had become dominated by mobile bed-loads of sand. The littoral vegetation had been partly destroyed by farmers and strongly modified by the increased siltation rates, which negatively affected the oxygen conditions near the root system (Junk, Max-Planck-Institute for Limnology, Plön, Germany, pers. obs.).

Wantzen (1998) showed that increased sediment load leads to the reduction of habitat diversity and the disturbance of aquatic invertebrates due to the fine sediment particles that decrease the abundance of invertebrates in streams. While there are no studies concerning the impact on fishes, there can be little doubt that these changes strongly affect those species that depend on invertebrates and on the physical habitats that have been destroyed. Since about 50% of the fish species of the Amazon basin occur in the headwaters of Amazonian rivers and many of them have rather limited distribution ranges, there is a danger of broad-range species extinction. For instance, in South America about 190 *Corydoras* species have been described (Reis et al., 2003) and more will certainly be discovered in the future. Many *Corydoras* species inhabit small Amazonian rivers and have restricted distribution ranges. A comparison of the fish fauna of 38 stretches, each 50 m long, in first- and second-order streams in a 100-km^2 reserve located near Manaus showed considerable heterogeneity in species composition according to habitat conditions (Mendonça et al., 2005).

In the Paramo of the Andes, increasing population pressure, together with economic development, has increased the cultivation of land that was formerly extensively used as grazing area. In disturbed catchment areas, water release is up to 40% faster than in undisturbed areas, such that the flow pattern of streams and rivers is dramatically changed (Buytaert et al., 2004). At the Andean hill slopes, the agrarian population is forced to work potentially hazardous areas for cultivation that are less suitable for agriculture, and rangelands. Slope movement is an important regional problem and sediment production by slope movement directly influences the transport and deposition of sediments in streams and rivers; it also affects channel morphology and habitat diversity (Vanacker, Vanderschaeghe, et al., 2003; Vanacker, Govers, et al., in press).

Habitat deterioration is also increasing in the forested parts of Amazonia. More than 550,000 km^2 (about 15%) of the 3.7 million km^2 Brazilian Amazon rainforest have been destroyed, mainly by timber exploitation and cattle ranching. Hundreds of thousands of gold diggers have devastated even remote areas. The pollution of terrestrial and aquatic environments by mercury released from gold mining is a major cause for concern in many parts of the Amazon basin. In some rivers, bioaccumulation of mercury in fishes led to subclinical accumulations in humans that ate those fishes, e.g., from the Tapajos River (summarized in Nogueira and Junk, 2000). In gold-, cassiterite-, and aluminum-mining areas, the deposition of inorganic sediments has heavily impacted streams, rivers, and wetlands. In areas of oil exploitation, there is a serious risk of rivers and wetlands pollution, as was demonstrated by the break of an oil pipeline at the Iguaçú River in southern Brazil in 2000.

The "Advance Brazil" project of the Brazilian government has allocated about $40 billion over the next years for new highways, railroads, gas lines, hydroelectric projects, power lines, and river rectification projects. These projects will fragment undisturbed forest and open vast areas to uncontrolled development activities. Assuming best-case and worst-case scenarios, by 2020 between 25 and 42% of the Amazon basin, respectively, will be heavily degraded (Laurance et al., 2001). Forest degradation has similar or even worse negative effects on streams and their fauna and flora than the destruction of *cerrado* vegetation. Unfortunately, for aquatic systems, debates about the destruction of the Amazonian rain forest have concentrated on terrestrial plants and animals.

The fish fauna of large rivers is, to a certain extent, better protected than that of small rivers and streams, because most species occur over large river stretches and are more resilient to local habitat deterioration. However, human impact has begun to affect important habitats on a large scale, with the floodplain forest being the most seriously threatened. Wittmann et al. (2006) has compiled a list of about 1,000 flood-tolerant tree species found in Amazonian whitewater rivers. The list is only preliminary and does not include flora from the floodplains of blackwater and clearwater rivers. Destruction of the forest for agricultural, cattle- and water-buffalo ranching purposes is already far-advanced at the lower Amazon and has spread upriver in the wake of timber extraction. The floodplain forest is of utmost importance for fishes, as shown by Goulding (1980), Araujo-Lima and Goulding (1997), and many others.

A major threat is also posed by large reservoirs for hydroelectric-power generation. Reservoirs modify the natural flood regime downriver of the dams, retain sediments and nutrients in the reservoirs, interrupt longitudinal connectivity in river systems (e.g., interrupt migrations of aquatic organisms), and modify habitat conditions in large areas upriver and downriver of the dams. Brazil currently obtains about 93% of its electric energy from hydropower (World Commission on Dams, 2000), mostly from reservoirs constructed in other river basins, e.g., the Paraná River (about 150 reservoirs) and the Sao Francisco River (six large reservoirs at the main river, six smaller ones at the tributaries; Sato and Godinho, 2004). Compared to pristine river-floodplain systems, reservoirs harbor relatively species-poor fish assemblages because they exclude many rheophilic species. Detailed studies of the impact of reservoirs on neotropical fish communities exist on the heavily impacted Paraná River (in Agostinho et al., 2007).

Currently, five reservoirs operate in the Brazilian part of the Amazon basin: Curua-Una (72 km^2), near Santarém; Tucurui (2,247 km^2), near Belém; Balbina (2,360 km^2), near Manaus; Samoel (465 km^2), near Porto Velho; and, Coaracy Nunes (23 km^2), in Amapá (Figure 1). The rising demand for electric energy is stimulating the construction of additional reservoirs. A feasibility study of the Brazilian Company for the Production of Electric Energy (ELETROBRAS) indicated 90 potential sites for reservoirs and estimated the hydroelectric potential of the rivers in the Brazilian part of Amazonia to be on the order of 100,000 MW. These reservoirs would affect all major tributaries of the Amazon, covering an area of about 100,000 km^2 (Junk and Mello, 1987). Many of these reservoirs will have very low energy output per unit area but dramatic negative ecological side effects, so that there is little justification for their construction. However, political decisions often do not follow scientific or even economic criteria, as shown by the construction of the Balbina reservoir, which provides energy for the city of Manaus. Located on the Uatuma River, the reservoir destroyed about 2,360 km^2 of pristine rainforest although it produces an average of only 112.2 MW (Fearnside, 1989). There is no doubt about the economic importance of hydropower, but careful environmental impact analyses are required to minimize negative side effects (Fearnside, 1995).

The longitudinal connectivity of rivers is of particular importance for long-distance migratory species. Large catfishes, such as piramutaba (*Brachyplatystoma vailantii*), dourada (*B. flavicans*), and piraiba (*B. filamentosum*), undertake lengthy migrations between their juvenile feeding grounds in the Amazon estuary and their spawning grounds in the headwaters of Colombia, Bolivia, and Peru (Barthem and Goulding, 1997). Juveniles are then transported back by the current to the estuary, where they mature. Thus, the interruption of migration routes, e.g., by the construction of hydroelectric power plants on the Madeira River, will heavily affect stocks (Barthem et al., 1991). Complex migration patterns are also characteristic of other species, such as the jaraqui (*Semaprochilodus insignis, S. taeniurus*) and the matrincha (*Brycon melanopterus*). Experiments with fish ladders in several rivers were carried out by ELETROBRAS but were not very successful because of both the different abilities of the many migrating species to pass obstacles and the height of the dams, which required large and expensive construction projects (Agostinho et al., 2002).

Expansion of national parks and other types of protected areas can substantially contribute to the conservation of habitat and species diversity.

Table 1. Total number and protected area (in ha) of national parks, biological and ecological stations, national reserves, wildlife refuges, and sustainable development reserves in the Amazon region *sensu latu* (about 7,000,000 km^2, Amazon Basin + Guyanas + Pre-Amazônia Maranhense + Southern Venezuela extending into the state of Bolivar) (CABS/CI, 2000, *for Brazil Azevedo-Ramos et al., 2006).

Country	Number	Area (ha)
Bolivia:	16	9,155,120
Brazil total:	?	80,666,306*
Federally protected areas:	?	47,391,829*
State-protected areas:	?	33,274,477*
Colombia:	12	5,869,849
Ecuador:	6	2,145,513
French Guyana:	No information	
Guyana:	1	58,600
Peru:	9	6,630,264
Surinam:	8	1,870,900
Venezuela:	8	8,640,050
Total protected area:		115,036,602

Currently, about 16.4% of the Amazon basin area is legally protected (Table 1). The establishment of protected areas was based mostly on the now-controversial refuge theory (Haffer and Prance, 2001; Colinvaux et al., 2001). Centers of species richness and endemic species of terrestrial plants and animals were mapped and became the scientific basis for the delineation of protected areas, but only a few areas were selected for their aquatic habitats. Major floodplains are found in Brazil, for instance, in the National Park on Bananal Island, at the Araguaia River (5,623 km^2); the Ecological Station of the Anavilhanas, in the Negro River upstream of Manaus (3,500 km^2); the Sustainable Development Reserve of Mamiraua, in the Amazon River floodplain (11,240 km^2) (Mamirauá, 1996); and the Jaú National Park (22,720 km^2), at Jaú River in the Negro River basin (Fundação Vitória Amazônica, 1998). Peru supports the Manu Biosphere Reserve (15,328 km^2) (Wilson and Sandoval, 1996) and the National Park Pacaya-Samiria Reserve (20,800 km^2), which is the only area designated specifically for the protection of an aquatic species (*Arapaima gigas*). Colombia has the natural national parks La Paya (4,420 km^2) and Amacayacu (2,930 km^2), and Bolivia has the Beni River Biosphere Reserve (1,350 km^2) (Herrera-MacBryde et al., 2000) and the National Reserves of Noel Kempff Mercado (219 km^2) (Killeen and Schulenberg, 1998) and Rios Blanco y Negro (14,000 km^2). Additional reserves are being planned, but new approaches are needed to protect the aquatic biodiversity of large river systems that extend over hundreds of thousands of square kilometers and which harbor aquatic long-distance migrants.

Protection in existing reserves is often nominal rather than real, because there are not enough funds to enforce environmental legislation. Poaching, invasion by squatters, timber extraction, gold mining, road construction, reservoir construction, and man-made fires are considered the most frequent serious threats to the integrity of protected areas in the Brazilian Amazon (Rylands and Pinto, 1998). Similar problems no doubt exist in the other Amazonian countries.

A high level of protection is also provided by indigenous reserves, which occupy about 1,250,000 km^2 in the Amazon basin (Azevedo-Ramos et al., 2006; Nepstad et al., 2006). The same is true for extractive reserves in Brazil (about 11,000 km^2), national forests (*flonas*) (about 91,000 km^2), and military areas (51,418 km^2). Brazil has set a goal of creating 500,000 km^2 of new *flonas* by 2010. In these reserves, the use of natural resources is less intensive and thus less harmful to the environment (Verissimo et al., 2002).

A major threat to aquatic ecosystems in the entire Amazon basin is the lack of coherent national policies for the sustainable management of wetlands and water bodies and their flora and fauna. The lack of an appropriate classification of wetlands and water bodies, incomplete inventories of their flora and fauna, and insufficient knowledge about their ecology and species diversity results in a low priority being assigned to aquatic and wetland systems when large development projects are planned. The consequences of this neglect are, inevitably, dramatic. While overfishing has affected the stocks of only a few commercial fish species that are not in peril, the major risk to aquatic species is not excessive exploitation, which can be reversed, but rather habitat alteration or destruction through hydrological damage and deforestation. It is likely that many fish species of small size and limited distribution range are already threatened by habitat destruction. Nonetheless, there are no programs to analyze these threats in order to prevent or mitigate their negative effects. This situation can only be changed when the management of aquatic resources receives high priority by responsible governments.

Conclusions

With about 2,500 described and probably more than 1,000 not described fish species, the Amazon basin is a center of ichthyological megadiversity. The fish fauna is characterized by the great antiquity and static history of almost all modern lower taxa, as can be shown by fossils and a low speciation rate since Pleistocene times. Based on current knowledge, ichthyologists have identified 13 ecological sub-regions according to different sub-basins or parts of sub-basins, but this number will likely change as better data become available.

The Amazon basin offers a high abundance and variety of habitats for fishes. Species are adapted to life in flowing water, wetlands, and/or periodically inundated floodplains. Many species migrate between different habitats according to hydrological season and life-history stage. As a result of their dynamic environment, they make use of a broad range of food items, including many of terrestrial origin. Fishes also have a high diversity of reproductive strategies, although the bulk biomass is made up by one-shot spawners that do not provide parental care. Adaptations to survival in low-oxygen concentrations occur across many taxa, allowing fish species to live periodically or permanently in the hypoxic water bodies that are common in floodplains and other wetland habitats.

The fish fauna of the large Amazonian rivers and their floodplains is rich but varies little over large distances because regular flood pulses have resulted in life cycles that include longitudinal migrations; these, in turn, provide access to floodplains, spawning places, and refuges (Junk et al., 1989). Large interconnected distribution areas confer upon the fish fauna a certain amount of resiliency in the face of local environmental changes. About half of the basin's fish species, however, are restricted to headwaters and small tributaries or specific habitats, such as rapids. This limited distribution makes them very vulnerable to changes in habitat conditions. However, as studies have concentrated mostly on the ecology of large river systems, there is comparatively little information on small rivers and streams.

Food fisheries play an important role in the protein supplies of local populations and those in cities throughout the basin, and are driven by highly productive whitewater river and floodplain systems, whose potential has yet to be fully exploited. For economic reasons, the current commercial fisheries concentrate on a few selected species. However, the stocks of some of the larger species, such as pirarucu, tambaqui, and the large migratory catfishes, show signs of overexploitation. Despite their large economic and social importance, fisheries are a low priority of the governments concerned. Some fishery regulations are wrong, some are impractical or inadequate, and there are serious deficits in the implementation of others. Armed conflicts between riverine populations and professional fisherman in Brazil led to experiments with the decentralized management of fisheries in selected lakes. While promising results have been obtained for the decentralized management of non-migratory species, such as the pirarucu, the process is inadequate for species undergoing migrations among lakes and between lakes and rivers.

Several native species and a few exotics, mainly tilapias, are cultivated, but fish culture is still in its infancy. The culture of high-value native species for sale during seasons in which wild-caught fishes are scarce has proved to be economically viable, since pronounced annual water-level fluctuations in river-floodplain systems result in seasonal variations in landings.

There are several threats to the integrity of aquatic ecosystems and their aquatic biodiversity. One of the most serious is the large-scale transformation of natural vegetation by an increasingly agrarian population at the Andean hill slopes, and by agro-industries in the Amazon lowlands. Headwaters, mainly in the southern *cerrado* belt of the basin and in the Andean Piedmont, are heavily stressed by the severe environmental degradation of riparian and in-stream habitats. Major species losses that are likely to go unnoticed are expected to occur in these areas. Forest degradation due to illegal logging increasingly deteriorates the habitat quality of rain forest streams. Destruction of the highly adapted and species-rich floodplain forests threatens the stocks of fruit-eating species.

Another emerging threat is the construction of large reservoirs for hydroelectric-power generation. If built as projected, dams for hydroelectric-power plants will interrupt the longitudinal connectivity of many large Amazonian rivers and negatively affect hydrological regimes, as they have already done in the Paraná and Sao Francisco River basins. Environmental impact analyses should therefore be made in order to select sites with the lowest environmental costs.

There are many areas in Amazonia that are already under different degrees of protection, and certainly more will be delineated. Many of these areas contain important wetlands and water bodies; by contrast, knowledge about fish species distribution is insufficient to designate priority areas for the protection of diversity. Plans for the establishment of protected areas must consider the specific requirements of the different species, their habitat requirements, and, by extension, their biodiversity. Strategies for the protection and exploitation of migratory fish species are particularly challenging, and joint strategies through international conventions are needed, for example, for large catfishes, which undergo extensive migrations. In addition to the creation of protected areas, the protection of fishes requires long-term strategies that include catchment management plans, which give high priority to preserving aquatic habitats and their resources. Species inventories and an ecological classification of water bodies and wetlands are needed to provide a sound basis for their sustainable management.

References

Acuña, C., 1865. Novo descobrimento do grande rio das Amazonas. (New discovery of the large river of the Amazons. In Portuguese) Rev. Inst. Hist. e Geogr. Bras. 28 (2), 163–265.

Agostinho, A. A., Okada, E. K., Gomes, L. C., Fernandez, D. R., Fontes Jr., H. M., 2002. Fishery management in the Itaipu Reservoir. In: International Commission of Large Dams (Ed.), *Symposium on Reservoir Management in Tropical and Sub-Tropical Regions*, pp. 507–518. International Commission of Large Dams, Iguassu, Brasil.

Agostinho, A. A., Pelicice, F. M., Petry, A. C., Gomes, L. C., Júlio Jr., H. F., 2007. Fish diversity in the upper Paraná River basin: habitats, fisheries, management and conservation. Aquatic Ecosystem Health & Management, 10(2).

Araujo-Lima, C., Goulding, M. (Eds.), 1997. *So fruitful a fish: ecology, conservation, and aquaculture of the Amazon's tambaqui*. Columbia University Press, New York.

Azevedo-Ramos, C., Domingues do Amaral, B., Nepstad, D. C., Soares Filho, B., Nasi, R., 2006. Integrating ecosystem management, protected areas, and mammal conservation in the Brazilian Amazon. Ecology and Society 11(2), 17. URL: http://www.ecologyandsociety.org/vol11/iss2/17

Barthem, R. B., 2004. O desembarque na região de Belém e a pesca na foz amazônica (The landings in the Belem region and the fishery in the Amazon River mouth.) In: M. L. Ruffino (Ed.), *A pesca e os recursos pesqueiros na Amazônia brasileira* (*The fishery and the fishery resources in the Brazilian Amazon*. In Portuguese), pp. 153–183. IBAMA/ProVárzea, Manaus.

Barthem, R. B., Fabré, N. N., 2004. Biologia e diversidade dos recursos pesqueiros da Amazônia. (Biology and diversity of the fishery ressources in Amazonia.) In: M. L. Ruffino (Ed.), *A pesca e os recursos pesqueiros na Amazônia brasileira* (*The fishery and the fishery resources in the Brazilian Amazon*. In Portuguese) pp. 17–62. IBAMA/ProVárzea, Manaus.

Barthem, R. B., Goulding, M. (Eds.), 1997. *The catfish connection: ecology, migration, and conservation of Amazon predator*. Columbia University Press, New York.

Barthem, R., Petrere, M. Jr., 1995. Fisheries and population dynamics of *Brachyplatystoma vallantii* (Pimelodidae) in the Amazon Estuary. In: N.B. Armantrout, R.J. Wolotira Jr. (Eds.), *Condition of the World's Aquatic Habitats*, pp. 329–240. Oxford & IBH Publishing, New Delhi.

Barthem, R., Petrere, M., 1996. Fisheries and population dynamics of *Brachyplatystoma vaillantii* (Pimelodidae) in the Amazon Estuary. In: R.M. Meyer, C. Zhang, M.L. Windsor, B.J. McCay, L. J. Hushai, R. M. Muth (Eds.), *Fisheries resource utilization and polica*, pp. 329–340. Proceedings of the World Fisheries Congress, Theme 2. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

Barthem, R., Ribeiro, M. C. L. B., Petrere, M. Jr., 1991. Life strategies of some long distance migratory catfishes in face of hydroelectric dams in the Amazon Basin. Biological Conservation 55, 339–345.

Barthem, R., Petrere, M. Jr., Issac, V., Ribeiro, M. C. L. B., Mcgrath, D., Vieira, I. J. A., Barco, M. V., 1995. A pesca na Amazônia: Problemas e perspectivas para o seu manejo. In: C. Valladares–Pádua, R. E. Bodmer, E., L. Cullen Jr. (Eds.), *Manejo e conservação da vida silvestre no Brasil*, pp. 173–185. (In Portuguese) MCT/CNPp/Sociedade Civil Mamirauá, Brasil.

Batista, V. S., 1998. Distribuição, dinâmica da frota e dos recursos pesqueiros da Amazônia Central. (Distribution and dynamics of the fishing fleet and fishery resources of Central Amazonia. In Portuguese) PhD-Thesis, INPA/FUA, Manaus.

Batista, V. S. (Ed.), 2000. *Biologia e administração pesqueira de alguns cracifomes explotados na Amazônia Central*. (*Biology and fishery administration of some Characiformes, exploited in Central Amazonia.* In Portuguese) FUA, Manaus.

Batista, V. S., Isaac, V. J., Viana, J. P., 2004. Exploração e manejo dos recursos pesqueiros da Amazônia. In: M.L. Ruffino (Ed.), *A pesca e os recursos pesqueiros na Amazônia brasileira* (*The fishery and the fishery resources in the Brazilian*. In Portuguese), pp. 63–151. IBAMA/ProVárzea, Manaus.

Batista, V. S., Inhamuns, A. J., Freitas, C. E. C., Freire-Brasil, D., 1998. Characterization of the fishery in river communities in the low-Solimões/high-Amazon region. Fisheries Management and Ecology 5, 419-435.

Batista, V. S., Freitas, C. E. C., Inhamus, A. J., Freire-Brasil, D., 2000. The fishing activity of the river people in the floodplain of the Central Amazon. In: W. J. Junk, J. Ohly, M. T. F. Piedade, M. G. M. Soares (Eds.), *The central Amazon floodplain: Actual use and options for a sustainable management*, pp. 417–432. Backhuys Publishers, Leiden, The Netherlands.

Bayley, P. B., 1981. Fish yield from the Amazon in Brazil: comparisons with African river yields and management possibilities. Trans. Am. Fish. Soc., 110, 351–359.

Bayley, P. B. 1983. Central Amazon fish populations: biomass, production and some dynamic characteristics. PhD Thesis, Dalhousie University. Halifax, Nova Scotia, Canada.

Bayley, P. B., 1995. Sustainability in tropical inland fisheries: the manager's dilemma and a proposed solution. In: M. Munasinghe, W. Shearer (Eds.), *Defining and Measuring*

Sustainability: The Biogeophysical Foundations, pp. 321-328. The World Bank, Washington, D.C.

Bayley, P. B. (Ed.), 1998 *Fisheries and aquatic biodiversity management in the Amazon*. Desk Study. 98/055 CP-RLC to Food and Agriculture Organization, UN, Rome.

Bayley, P. B., Petrere, M., Jr., 1989. Amazon fisheries: Assessment methods, current status, and management options. Canadian Special Publication of Fisheries and Aquatic Sciences 106, 385–398.

Becker, B. K., 1995. Undoing myths: The Amazon—an urbanized forest. In: M. Clüsener-Godt, I. Sachs (Eds.), *Brazilian perspectives on sustainable development of the Amazon Region*, pp. 53–89. UNESCO, Taylor & Francis Group, Paris.

Buytaert, W., De Bièvre, B., Wyseure, G., Deckers, J., 2004. The use of the linear reservoir concept to quantify the impact of changes in land use on the hydrology of catchments in the Andes. Hydrology and Earth System Sciences 8(1), 108–114.

CABS/CI (Ed.), 2000. *Data base on Amazonian protected areas*. Center for Applied Biodiverstiy Science (CABS), Conservation International (CI), Washington D.C., and Conservation International do Brazil, Belo Horizonte.

CADMA (Comision Amazonica de Desarrollo y Medio Ambiente) (Ed.), 1992. *Amazonia sin mitos*. (Amazonia without myths. In spanish). New York: Banco Interamericano de Desarrollo Washington), Programa de las Naciones Unidas para el Desarrollo, Tratado de Cooperacion Amazonica.

Cerdeira, R. G. P., Ruffino M. L., Isaac, V. J., 1997. Consumo de pescado e outros alimentos pela população ribeirinha do lago Grande de Monte Alegre. (Consumption of fish and other food items by the riverine population of Lago Grande de Monte. In Portuguese) Acta Amazonica 27(3), 213–227.

Chao, N. L., 1993. Conservation of Rio Negro ornamental fishes. Tropical Fish Hobbyist 41(5), 99–114.

Chao, N. L., 2001. Fisheries, diversity and conservation of ornamental fishes of the Rio Negro Basin, Brazil—a review of Project Piaba (1989–1999). In: N.L. Chao, P. Petry, G. Prang, L. Sonneschien, M. Tlusty (Eds.), *Conservation and management of ornamental fish resources of the Rio Negro Basin, Amazonia, Brazil—Project Piaba*, pp. 161–204. Editora da Universidade do Amazonas, Manaus.

Chao, N. L., Petry, P., Prang, G., Sonneschien, L., Tlusty, M. (Eds.), 2001. *Conservation and management of ornamental fish resources of the Rio Negro Basin, Amazonia, Brazil—Project Piaba*. Editora da Universidade do Amazonas, Manaus.

Colinvaux, P. A., Irion, G., Räsänen, Bush, M. B., Nunes de Mello, J. A. S., 2001. A paradigm to be discarded: Geological and paleoecological data falsify the Haffer & Prance refuge hypothesis of Amazonian speciation. Amazoniana XVI(3-4), 609–646.

Crampton, W. G. R., 1999. The impact of the ornamental fish trade on the Discus (*Symphysodon aequifasciatus*): A case study from the floodplain forests of Estação Ecológica Mamirauá. In: C. Padoch, J. M. Ayres, M. Pinedo-Vasquez, A. Henderson (Eds.), *Várzea: diversity, development, and conservation of Amazonia's whitewater floodplains*. New York Botanical Garden Press. Advances in Economic Botany 13, 29–44.

Eckmann, R., 1983. Zur Situation der Fischerei im peruanischen Amazonasgebiet. (About the situation of the fishery in the Peruvian Amazon region. In German) Arch. Hydrobiol. 97, 509–539.

Eckmann, R., 1984. Crecimento, composición bromatológica y eficiencia de conversion bruta en juveniles de *Colossoma macropomum* alimentados con diferentes dietas peletizadas. (Growth, chemical composition and conversion efficiency of juvenile *Colossoma macropomum* fed with different pellet foods. In Portuguese) Mem. Asoc. Latinoam. Acuicult. 5, 495–500.

Evangelista, E. (Ed.), 1992. *Aspectos técnicos da pesca: Levantamento das artes de pesca.* (*Technical aspects of fishery: Description of fishing techniques.* In Portuguese) Projeto IARA/IBAMA-Informe Técnico, Brasília.

Fabré, N. N., Alonso, J. C., 1998. Recursos ícticos no Alto Amazonas. Sua importância para as populações ribeirinhas. (Fish resources of the Upper Amazon: Its importance for the riverine people. In Portuguese) Boletim do Museu Paraense Emílio Goeldi, série Zoologia 14, 19–55.

Ferraz, E., 1999. Management and diseases of the ornamental fish exported from the Rio Negro basin. In: A.L. Val, V. M. Almeida-Val (Eds.), *Biology of tropical fishes*, pp. 99–111. INPA, Manaus.

Fearnside, P. M., 1989. Brazil's Balbina Dam: environment versus the legacy of the pharaohs in Amazônia. Environmental Management 13, 401–423.

Fearnside, P. M., 1995. Hydroelectirc dams in the Brasilian Amazon as sources of "greenhouse gases". Environmental Conservation 22, 7–19.

Fernandes, C. C., Podos, J., Lundberg, J. C., 2004. Amazonian ecology: tributaries enhance the diversity of electric fishes. Science 305, 1960–1962.

Fisher, C. F. A., Chagas, A. L. de G. A., Dornelles, L. D. C., 1992. Pesca de agues interiors. IBAMA, Coleção Meio Ambiente, Série Estudos Pesca 2, 1–32.

Fundação Vitória Amazônica (Ed.), 1998. A gênese de um plano de manejo: O caso do Parque Nacional do Jaú (The genesis of a management plan: the case of National Park of Jaú. In Portuguese). Fundação Vitória Amazônica, Manaus.

Furch, K., Junk, W. J., 1980. Water chemistry and macrophytes of creeks and rivers in Southern Amazonia and the Central Brasilian shield. In: J. I. Furtado (Ed.), *Tropical ecology and development, part 2,* pp. 771–796. The International Society of Tropical Ecology, Kuala Lumpur, Malaysia.

Furtado, L. G., 1988. Os caboclos pescadores do Baixo Rio Amazonas e o processo e mudança social e econômica. (The riverine fishermen of the Lower Amazon and the process of social and economic change.) In: A. C. Diégues (Ed.), (*Ciências Sociais e o Mar no Brasil, Social sciences and the sea in Brazil*), pp. 180–203. (In Portuguese) II. Programa de Pesquisa e Conservação de Áreas Úmidas no Brasil, São Paulo.

Goulding, M. (Ed.), 1980. *The fishes and the forest: explorations in Amazonia natural history*. University of California Press, Berkeley, CA.

Goulding, M., Carvalho, M. L., Ferreira, E. G. (Eds.), 1988. *Rio Negro: rich life in poor water*. SPB Academic Publishing, The Hague.

Graef, E. W., 1995. As espécies de peixes com potencial para criação no Amazonas. (Fish species with aquaculture potential in Amazonia.) In: A.L. Val, A. Honczaryk (Eds.), *Criando* *peixes na Amazônia* (*Cultivating fishes in Amazonia*), pp. 29–43. (In Portuguese) INPA, Manaus.

Graef, E. W., Resende, E. K., Petry, P., Storti, A. F., 1987. Policultivo de matrinchã (*Brycon* sp) e jaraqui (*Semaprochilodus* sp) em pequenas represas. (Polyculture of matrinchã (*Brycon* sp) and jaraqui (*Semaprochilodus* sp) in small reservoirs. In Portuguese) Acta Amazonica 16/17, 33–42.

Haffer, J., Prance, G. T., 2001. Climatic forcing of evolution in Amazonia durino the Cenozoic: On the refuge theory of biotic differentiation. Amazoniana XVI, 579–607.

Hanek, G. (Ed.), 1982. *La pesqueria en la Amazonia peruana: presente e futuro*. (Fishery in the peruvian Amazonia: presence and future. In Spanish). FAO, FI:DP/PER/76/022, Documento de Campo, Rome.

Herrera-MacBryde, O., Dallmeier, F., MacBryde, B., Comiskey, J.A., Miranda, C. (Eds.), 2000. *Biodiversity, conservation, and management in the region of the Beni Biological Station Biosphere Reserve, Bolivia*. SI/MAB Series No. 4, Smithsonian Institution, Washington, DC.

IBAMA (Ed.), 1994. *Relatório preliminar sobre ordenamento pesqueiro para a bacia Amazônica*. (*Preliminary report about the situation of the fishery in the Amazon basin*. In Portuguese) Relatório técnico, IBAMA, Brasília.

IBAMA (Ed.), 1997. *Relatório anual sobre exportação de peixes ornamentais de 1997*. (Annual report about the export of ornamental fishes in 1997. In Portuguese). Relatório técnico, IBAMA, Brasília.

IBAMA (Ed.), 1999: *Recursos pesqueiros do Médio Amazonas: Abordagem socioeconômica*. (*Fishery resources of the Middle Amazon: A socioeconomic approach*. In Portuguese) Coleções meio ambiente, Série estudos pesca, n° 21, Brasília.

IBGE (Ed.), 2002. *Censo Demografico 2000* (*Demographic census 2000*). Instituto Brasileiro de Geografia e Estatística. (Monitoring of the Brazilian Amazon forest by satellite 2000–2005. In Portuguese) URL: http://www.sidra.ibge.gov.br

INPE (Ed.), 2006. Dados de entrada 2000–2005 (Monitoring of the Brazilian Amazon forest by satellite 2000–2005). URL http://www.obt.inpe.br/prodes

Ihering, R. von, Azevedo, P., 1934. A curimatá dos açudes nordestinos (*Prochilodus argenteus*). (The curimatá of the reservoirs in the Northeast (*Prochilodus argenteut*). In Portuguese) Arq. Inst. Biol. São Paulo 5, 142–184.

Ihering, R. von , Azevedo, P., 1936. A desova e a hipofisação dos peixes. Evolução de dois Nomatognatas. (Spawning and hypophysation of fishes. Evolution of two Nemognathi. In Portuguese) Arq. Inst. Biol. São Paulo 7, 107–118.

IMARPE, 1979. La acuicultura en el Perú. Rev. (The aquaculture in Peru. In Spanish) Latinoam. Acuicult. 2, 13–21.

Irion, G., Junk, W. J., de Mello J. A. S. N., 1997. The large central Amazonian river floodplains near Manaus: geological, climatological, hydrological, and geomorphological aspects. In: W.J. Junk. (Ed.), *The Central Amazon Floodplain: Ecology of a Pulsing System*, pp. 23–46. Ecological Studies, Vol. 126, Springer Verlag, Berlin Heidelberg New York.

Isaac, V. J., Ruffino, M. L., 1996. Population dynamics of tambaqui, *Colossoma macropomum* Cuvier, in the Lower Amazon, Brazil. Fisheries Management and Ecology 3, 315–333.

Isaac, V. J., Ruffino, M. L., McGrath, D., 1998. In search of a new approach to fisheries management in the middle Amazon. In: T. J. Quinn II, F. Funk, J. Heifetz, J. Ianelli, J. Power, J. Schweigert, P. Sullivan, C.I. Zhang (Eds.), *Fishery Stock Assessment Model*, pp. 889–902. AS-SG-98-01, Alaska Sea Grant College Program, University of Alaska, Fairbanks.

Junk, W. J., 1993. Wetlands of tropical South America. In: D. Whigham, S. Hejny, D. Dykyjova (Eds.), *Wetlands of the World*, pp 679–739. Dr. W. Junk Publ., Dordrecht, Boston, Lancaster.

Junk, W. J., 2000. The Central Amazon River Floodplain: Concepts for the Sustainable Use of its Resources. In: W. J. Junk, J. Ohly, M. T. F. Piedade, M.G.M. Soares (Eds.), *The Central Amazon Floodplain: Actual Use and Options for a Sustainable Management*, pp. 75–94. Backhuys Publishers b.V., Leiden.

Junk, W. J., Mello, J. A. S. de N., 1987. Impactos ecológicos das represas hidrelétricas na bacia amazônica brasileira. (Ecological impacts of hydroelectric reservoirs in the Brazilian Amazon basin. In Portuguese) Tübinger Geografische Studien 95, 367–385.

Junk, W. J., Piedade, M. T. F., 1997. Plant life in the floodplain with special reference to herbaceous plants. In: W.J. Junk, W.J. (Ed.), *The Central Amazon Floodplain: Ecology of a Pulsing System*, pp. 147–186. Ecological Studies, Vol. 126, Springer Verlag, Berlin.

Junk, W. J., Piedade, M. T. F., 2005. Amazonian wetlands. In: P. Keddy, L.H. Fraser (Eds.), *Large wetlands: Their ecology and conservation*, pp. 63–117. Cambridge University Press, Cambridge.

Junk, W. J., P. B. Bayley, R. E. Sparks, 1989. The flood pulse concept in river-floodplain systems. Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences 106, 110–127.

Junk, W. J., Soares, M. G. M., Saint-Paul, U., 1997. The fish. In: W. J. Junk (Ed.), *The Central Amazon Floodplain: Ecology of a Pulsing System*, pp. 385–408. Ecological Studies, Vol. 126, Springer Verlag, Berlin.

Killeen, T. J., Schulenberg, T. (Eds.), 1998. *A biological assessment of Parque Nacional Noel Kempff Mercado, Bolivia*. RAP Working Papers 10, Conservation International, Washington, DC.

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamônica, P., Barber, C., D'Angelo, S., Fernandes, T., 2001. The future of the Brazilian Amazon. Science 291, 438–439.

Leite, R. G., Zuanon, J. A. S., 1991. Peixes ornamentais—Aspectos de comercialização, ecologia, legislação e proposta de ações para um melhor aproveitamento. (Ornamental fishes—commercial aspects, ecology, legislation and proposal of actions for a better use). In: A. L. Val, R. Figliuolo, E. Feldberg (Eds.), *Bases científicas para estratégia de preservação e desenvolvimento da Amazônia: Fatos e perspectivas* (*Scientific basis for a strategy of preservation and development of Amazonia: facts and myths*), pp. 63–89. (In Portuguese) INPA, Manaus.

Lowe-McConnell, R. H. (Ed.), 1987. *Ecological studies in tropical fish communities*. Tropical Biology Ser., University Press, Cambridge.

Lundberg, J. G., Marshall, L. G., Guerrero, J., Horton, B., Malabarba, M. C. S. L., Wesselingh, F., 1998. The stage for neotropical fish diversification. In: L.R. Malabarba, R.E. Reis, R.P. Vari, Z. M. S. Lucena, C. A. S. Lucena (Eds.), *Phylogeny and Classification of Neotropical Fishes,* pp. 13–48. EDIPUCRS, Porto Alegre, Brasil.

Lundberg, J. G., Kottelat, M., Smith, G. R., Stiassny, M. L. J., Gill, A. C., 2000. So many fishes, so little time: an overview of recent ichthyological discovery in continental waters. Annals of the Missouri Botanical Garden 87(1), 26–62.

Machado, R. B., Ramos Neto, M. B., Pereira, R. G. P., Caldas, E. F., Gonçalves, D. A., Santos, N. S., Tabor, K., Steininger, M. (Eds.), 2004. *Estimativas de perda da área do Cerrado brasileiro*. (*Estimation of area loss of the Brazilian Cerrado*. In Portuguese.) Relatório técnico não publicado. Conservação Internacional, Brasília, DF, Brasil.

Mamirauá (Ed.), 1996. *Mamirauá management plan*. Sociedade Civil Mamirauá (SCM), National Council for Scientific & Technological Development (CNPq), Environmental Protection Institute of the State of Amazonas (IPAAM), Brazil.

McGrath, D., Castro, F., Futema, C., 1994. Reservas de lago e o manejo comunitário da pesca no Baixo Amazonas: uma avaliação preliminar. (Lake reserves and community management of fishery at the lower Amazon: apreliminary evaluation. In Portuguese) In: M. A. D'Inaco, I. M. Silveira (Eds.), *A Amazônia e a Crise de Modernização* (*The Amazon and the crisis of modernization*), pp. 389–402. (In Portuguese) MPEG, Belém.

Meade, R. H., 1994. Suspended sediments of the modern Amazon and Orinoco rivers. Quat. Int. 21, 29–39.

Mendonça, F. P., Magnusson, W. E., Zuanon, J., 2005. Relationship between habitat characteristics and fish assemblages in small streams of Central Amazonia. Copeia 4, 751–764.

Menezes, N. A., 1996. Methods for assessing freshwater fish diversity. In: C. E. de M. Bicudo, N. A. Menezes (Eds.), *Biodiversity in Brazil: a first approach*., pp. 289–296. Proceedings of the Workshop Methods for the Assessment of biodiversity in Plants and Animal held at Campos do Jordão, SP, Brazil, 26–30 May 1996, Jordão.

Mérona, B., Bittencourt, M. M., 1988. A pesca na Amazônia através dos desembarques do mercado de Manaus: resultados preliminares. (The fishery in Amazonia according to the landings of Manaus market: Preliminary results. In Portuguese) Mem. Soc. Cienc. Nat. La Salle 48, 433–453.

Mertes, L. A. K., 1997. Documentation and significance of the perirheic zone on inundated floodplains. Water Resources Research 33, 1749–1762.

Milliman, J. D., Meade, R. H., 1983. Worldwide delivery of river sediment to the oceans. J. Geol. 91, 1–21.

Moreau, M.- A., Coomes, O. T., in press. Aquarium fish exploitation in western Amazonia; Conservation issues in Peru. Environmental Conservation. Muñoz-Sosa, D. L., 1999. Ecologia de *Brachyplatystoma* sp. En el bajo rio Caqueta, Amazonas, Colombia. In: T. G. Fang, O. L. Montenegro, R. E. Bodmer (Eds.). *Manejo y Conservación de Fauna Silvestre en América Latina*, pp. 237–243. (In Spanish) Instituto de Ecologia, La Paz.

Muñoz-Sosa, D.L., 1999. Ecology of *Brachyplatystoma* sp. in the lower Caqueta River, Amazonas, Columbia. In: T. G. Fang, O. L. Montenegro, R. E. Bodmer (Eds.), *Management and conservation of the forest fauna in Latin America*. pp. 237–243. (In Spanish). Instituto de Ecologia, La Paz.

Nepstad, D., Schwartzman, S., Bamberger, B., Santilli, M., Ray, D., Schlesinger, P., Lefebvre, P., Alencar, A., Prinz, E., Fiske, G., Rolla, A., 2006. Inhibition of Amazon deforestation and fire by parks and indigenous lands. Conservation Biology 20, 65–73.

Nogueira, F., Junk, W. J., 2000. Mercury from goldmining in Amazon wetlands: Contamination sites, intoxication levels and dispersion pathways. In: W. J. Junk, J. J. Ohly, M. T. F. Piedade, M. G. M. Soares (Eds.), *The Central Amazon Floodplain: Actual Use and Options for a Sustainable Management*, pp. 477–503. Backhuys Publishers, Leiden, The Netherlands.

Oliveira, A. C. B., Martinelli, L. A., Soares, M. G. M., Moreira, M. Z., Cyrino, J. E. P., 2006. Seasonality of energy sources of *Colossoma macropomum* in a floodplain lake in the Amazon, Lake Camaleão, Amazonas, Brazil. Fisheries Management and Ecology 13(3), 135–142.

Oliveira, A. C. B., Soares, M. G. M., Martinelli, L. A., Moreira, M., 2006. Carbon sources of fish in an Amazonian floodplain lake. Aquatic Sciences 68, 229–238.

Olivier, K. (Ed.), 2001. *The ornamental fish market*. FAO/Globefish Research Programme, Vol. 67. United Nations Food and Agriculture Organization, Rome.

Petrere, M., Jr., 1978a. Pesca e esforço de pesca no Estado do Amazonas I. Esforço e captura por unidade de esforço. (Fishery and fishery effort in Amazonas State I. Effort and catch per unit effort. In Portuguese) Acta Amazônica 8, 439–454.

Petrere, M., Jr., 1978b. Pesca e esforço de pesca no Estado do Amazonas II. Locais, aparelhos de captura e estatísticas de desembarque. (Fishery and fishery effort in Amazonas State. II. Localities, fishing gear and landing statistics. In Portuguese) Acta Amazônica 8, 1–54.

Petrere, M., Jr. (Ed.), 1982. *Ecology of the fisheries in the river Amazon and its tributaries in the Amazonas States (Brazil).* PhD Thesis, University of East Anglia, UK.

Petrere, M., Jr., 1985. A pesca comercial no rio Solimões—Amazonas e seus afluentes: Análise dos informes do pescado desembarcado no mercado Municipal de Manaus (1976–1978). (Commercial fisheries in the Solimões-Amazon River and its tributaries: Analysis of the landings of the Manaus market (1976–1978). In Portuguese) Ciênc. Cult. 37, 1987–1999.

Petry, P., Zuanon, J., Py-Daniel, L.H.R., de Pinna, M., 2003. On the discovery of a remarkable new family of fishes from the Amazon basin in Brazil. 83rd Annual Meeting of the Amer. Society of Ichthyology and Herpetology, 2003 June. Manaus, AM Brazil.

Prang, G., 1996. Pursuing the Sustainable Development of Wild Caught Ornamental Fishes in the Middle Rio Negro, Amazonas, Brazil. Aquatic Survival 5, 6–8.

Prang, G., 2001. Avaimento and the ornamental fishery of the Rio Negro, Brazil: Implications for sustainable resource use. In: In: N. L. Chao, P. Petry, G. Prang, L. Sonneschien, M. Tlusty (Eds.), *Conservation and management of ornamental fish resources of the Rio Negro Basin, Amazonia, Brazil—Project Piaba*, pp. 43–74. Editora da Universidade do Amazonas, Manaus.

Queiroz, H. L., 2000. *Natural history and conservation of pirarucu, Arapaima gigas, at the Amazonian Várzea: Red giants in muddy waters*. PhD-Thesis, University of St. Andrews, St. Andrews, Escócia.

Reis, R. E., Kullander, S., Ferraris C. J., Jr. (Eds.), 2003. *Check list of the freshwater fishes of South and Central America*. EDIPUCRS, Porto Alegre, Brazil.

Ribeiro, M. de N. G., Adis, J., 1984. Local rainfall variability—apotential bias for bioecological studies in the Central Amazon. Acta Amazonica 14, 159–174.

Ribeiro, W., Falcão, W. O., Oliveira, W. (Eds.), 1999. *Perfil Econômico do Setor Pesqueiro do Estado do Amazonas*. (*Economic profile of the fishery sector of the State of Amazonas*. In Portuguese) Federação dos Pescadores dos Estados do Amazonas e Roraima (FEPESCA), Manaus.

Resende, E. K, Graef E. W., Zaniboni-Filho, E, Paixão, A. M., Storti, A. F., 1985. Avaliação do crescimento e da produção de jaraquis (*Semaprochilodus* spp), em acudes de igarapé de terra firme nos arredores de Manaus, Amazonas. (Evaluation of growth and productivity of jaraquis (*Semaprochilodus* spp) in reservoirs of streams in the surroundings of Manaus, Amazonas. In Portuguese) Acta Amazonica 15, 19–36.

Ruffino, M. L., 1996. Towards participatory fishery management on the lower Amazon. EC Fisheries Cooperation Bulletin 9(1), 15–18.

Ruffino, M. L., Rocha, C., Viana, J. P., Barthem, R. B., Batista, V., Issac, V. J., (Eds.) 2002. *Estatística Pesqueira do Amazonas e Pará 2001*. (*Fisheries statistics of Amazon and Pará States 2001*. In Portuguese) IBAMA, ProVárzea, Manaus.

Ruffino, M. L., Lopes, U. Jr., Soares, E. C., Silva, C. O. da, Barthem, R. B., Batista, V., EstupiÚan, G., Issac, V. J., Fonseca, S., Pinto, W. (Eds.), 2005. *Estatística Pesqueira do Amazonas e Pará 2002*. (*Fisheries statistics of Amazon and Pará States 2002*. In Portuguese) IBAMA, ProVárzea, Manaus.

Ruffino, M. L., Soares, E. C., Silva, C. O. da, Barthem, R. B., Batista, V., EstupiÚan, G., Pinto, W. (Eds.), 2006. *Estatística Pesqueira do Amazonas e Pará 2003*. (*Fisheries statistics of Amazon and Pará States 2003*. In Portuguese) IBAMA, ProVárzea, Manaus.

Rylands, A. B., Pinto, L. P. de S. (Eds.), 1998. *Conservação da biodiversidade na Amazônia Brasileira: Uma análise do sistema de unidades de conservação*. (Conservation of biodiversity in Brazilian Amazonia: an analysis of the system of conservation units. In Portuguese). Cadernos FBDS, No.1, Fundação Brasileira para o Desenvolvimento Sustentável (FBDS) Rio de Janeiro.

Saint-Paul, U., Werder, U. (Eds.), 1977. *Aspectos generales sobre la piscicultura en el Amazonas y resultudos preliminares de experimentos de alimentación de Brycon melanopterus con raciones peletizadas con diferentes composiciones*. (*General aspects of fish culture in Amazonia and preliminary results of feeding experiments of Brycon melanopterus with pellet food of different composition.* In Portuguese) I Simp. Asoc. Latinoam. Acuicult., Maracay, Venezuela.

Salati, E., Marques, J., 1984. Climatology of the Amazon region. In: H. Sioli (Ed.), *The Amazon—Limnology and landscape ecology of a mighty tropical river and its basin*, pp. 85–126. Monographiae biologicae, W. Junk Publ, Dordrecht.

Saraiva, N. A. M. (Ed.), 2003. *Diagnostico da Piscicultura na área de expansão do Districo Federal*. (*Analysis of the status of fish culture in the federal district*. In Portuguese) Monografia DEPESCA-UFAM, Brasília, Brazil.

Sato, Y., Godinho, H. P., 2004. Migratory fishes of the São Francisco River. In: J. Carolsfiled, B. Harvey, C. Ross, A. Baer (Eds.), *Migratory Fishes of South America*, pp. 199–232. World Fisheries Trust, IDRC, World Bank, New York, USA.

Schäfer, S. A., 1998. Conflict and resolution: impact of new taxa on phylogenetic studies of the neotropical Cascudinhos (Siluroidei: Loricariidae). In: L. R. Malabarba, R. E. Reis, R. P. Vari, Z. M. S. Lucena, C. A. S. Lucena (Eds.), *Phylogeny and Classification of Neotropical Fishes*, pp. 375–400. EDIPUCRS, Porto Alegre.

Sioli, H. (Ed.), 1984. *The Amazon—Limnology and landscape ecology of a mighty tropical river and its basin*. Monographiae Biologicae, Dr. W. Junk Publishers, Dordrecht.

Smith, N. J. H., 1981. *Man, Fisheries and the Amazon*. Columbia University Press New York.

Soares, M. G. M., Junk, W. J., 2000. Commercial Fishery and Fish Culture of the State of Amazonas: Status and Perspectives. In: W. J. Junk, J. J. Ohly, M. T. F. Piedade, M. G. M. Soares (Eds.), *The Central Amazon Floodplain: Actual Use and Options for a Sustainable Management*, pp. 433–461. Backhuys Publishers, Leiden, The Netherlands.

Soares, M. G. M., Almeida, R. G., Junk, W. J., 1986. The tropic status of the fish fauna in Lago Camaleão a macrophyte dominated floodplain lake in the middle Amazon. Amazoniana 9, 511–526.

SUDEPE (Superintendêcia do Desenvolvimento da Pesca) (Ed.), 1984. *Anuário Estatístico de 1984. Controle de desembarque de pescado e exportação de peixes ornamentais vivos*. (*Statistical yearbook 1984. Control of fishery landings and export of living ornamental fishes*. In Portuguese) SUDEPE (Superintendêcia do Desenvolvimento da Pesca), Brasil.

SUDEPE (Superintendência do Desenvolvimento da Pesca) (Ed.), 1986. *Anuário Técnico Estatístico: Sistemas de controle de desembarque de pescado em 09 Municípios do Estado de Amazonas em 1985*. (*Statistical yearbook: Control systems of fishery landings in 09 municipalities of the State of Amazonas in 1985*. In Portuguese) SUDEPE (Superintendêcia do Desenvolvimento da Pesca), Brasil.

SUDEPE (Superintendência do Desenvolvimento da Pesca) (Ed.), 1987. *Anuário Técnico Estatístico: Sistemas de controle de desembarque de pescado em 09 Municípios do Estado de Amazonas em 1987*. (*Statistical yearbook: Control systems of fishery landings in 09 municipalities of the State of Amazonas in 1987*. In Portuguese) SUDEPE (Superintendêcia do Desenvolvimento da Pesca), Brasil.

Thomé-Souza, M. J. F., Chao, N.L., 2004. Spacial and temporal variation of benthic fish assemblages during the extreme drought of 1997–98 (El Niño) in the middle rio Negro, Amazonia, Brazil. Neotropical Ichthyology 2, 127–136.

Val, A. L., Honczaryk, A. (Eds.), 1995. *Criando Peixe na Amazônia—Manaus*. (*Cultivating fishes in Amazonia*—Manaus. In Portuguese) INPA, Manaus.

Val, A. L., Rolim, P. R., Rebelo, H., 2000. Situação atual da aqüicultura na região Norte. (Actual situation of aquaculture in the northern region.) In: W. C. Valenti, R. C. Poli, J. A.

Pereira, J. R. Borghetti (Eds.), *Aquacultura no Brasil: Bases para um desenvolvimento sustentável* (*Aquaculture in Brazil: Bases for a sustainable development*), pp. 246–266. (In Portuguese) CNPq, Ministério da Ciência e Tecnologia, Brasília.

Val, A. L., Almeida-Val, V. M., Randall, D. J. (Eds.), 1996. *Physiology and biochemistry of the fishes of the Amazon*. INPA, Manaus.

Valdez, J. R., 1984. Fomento de la piscicultura en aquas calidas del Estado Tachira. (Development of warm water fish culture in Tachira State. In Portuguese) Mem. Asoc. Latinoam. Acuicult. 5, 759–762.

Valencia, O., Puentes, R., 1989. El cultivo de la cachama en Colombia. (The culture of cachama in Colombia.) In: R.A. Hernadez (Ed.), *Cultivo de Colossoma* (*The culture of Colossoma*), pp. 117–143. (In Portuguese) Primeras Reunion Grupo de Trabajo Tecnico, junio 20 al 24 de 1982, Pirassununga, SP Brasil. Editora Guadalupe Ltda. Bógota.

Vanacker, V., Vanderschaeghe, M., Govers, G., Willems, E., Poesen, J., Decker, J., De Bievre, B., 2003. Linking hydrological, infinite slope stability and land-use change models through GIS for assessing the impact of deforestation on slope stability in high Andean watersheds. Geomorphology 52, 299–315.

Vanacker, V., Govers, G., Barros, S., Poesen, J., Decker, J., 2003. The effect of short-term socio-economics and demographic changes on landuse dynamics and its corresponding geomorphic response with relation to water erosion in a tropical mountainous catchment, Ecuador. Landscape Ecology 18(1), 1–15.

Veríssimo, A., Cochrane, M. A., Souza Jr., C., 2002. National forests in the Amazon. Science 297, 1478.

Viana, J. P., Damasceno, J. M. B., Castello, L., 2003. Desarrollo del manejo pesquero comunitario en la Reserva de Mamirauá, Amazonas, Brasil. (Development of the community based fishery management in the Mamirauá Reserve.) In: C. Campos-Rozo, A. Ulloa (Eds.), *Fauna Socializada: Tendencias en el manejo partecipativo de la fauna en America Latina* (*Socialized fauna: ways of participatory management of the fauna in Latin America*), pp. 335-351. (In Portuguese) Fundación Natura MacArthur Foundation, Istituto Colombiano de Antropología e Historia, Bogtá, Colombia.

Wantzen, K. M. (Ed.), 1998. *Abschätzung der Umweltwirkungen von anthropogen bedingter Bodenerosion auf Fließgewässer mittels Biomonitoring, Mato Grosso, Brasilien*. (*Evaluation of the impacts of anthropogenic soil erosion on streams by biomonitoring, Mato Grosso, Brazil*. In German) Deutsche Gesellschaft für Technische Zusammenarbeit GmbH—GTZ, Eschborn.

Wantzen, K. M., 2003. Cerrado streams—characteristics of a threatened freshwater ecosystem type on the Tertiary Shields of Central South America. Amazoniana 17(3/4), 481–502.

Water Resources eAtlas, 2006. Watersheds of the World. URL: http://www.waterandnature.org/eatlas

Welcomme, R. L., Henderson, H. F., 1976. Aspects of the management of inland waters for fisheries. FAO Fisheries Technical Paper 161, 36.

Wilson, D. E., Sandoval, A. (Eds.), 1996. *Manu: The biodiversity of Southeastern Peru*. Smithsonian Institution, Washington, DC.

Wittmann, F., Junk, W. J., Anhuf, D., 2002. Tree species distribution and community structure of Central Amazonian várzea forests by remote-sensing techniques. Journal of Tropical Ecology 18(6), 805–820.

Wittmann, F., Schöngart, J., Montero, J. C., Motzer, T., Junk, W. J., Piedade, M. T. F., Queiroz, H., Worbes, 2006. Tree species composition and diversity gradients in white-water forests across the Amazon Basin. Journal of Biogeography 33(8), 1334–1347.

World Commission on Dams (Ed.), 2000. *Dams and development*. Earthscan Publications, London.