REVIEW ARTICLE

Fisheries in large tropical reservoirs in South America

Miguel Petrere Jr
UNESP, Departamento de Ecologia, C.P. 199 13506-900, Rio Claro (SP), Brazil

Abstract

The present status of large reservoir fisheries and their management in large reservoirs in South America are reviewed. There is a brief discussion about reservoir typology, and how most of it is inappropriate to fish. Fish in reservoirs and their introduction from other habitats are described, together with comparative yields. The main impacts due to damming are described, including social aspects. Four case studies are presented for the largest reservoirs in South America: Sobradinho, Tucuruí and Itaipu in Brazil, and El Guri in Venezuela.

Key words

El Guri Reservoir, fisheries in reservoirs, Itaipu Reservoir, large tropical reservoirs, reservoir environmental impacts, Sobradinho Reservoir, Tucuruí Reservoir.

INTRODUCTION

Reservoir construction interferes with natural ecosystems but has been a human action since ancient times to store water for domestic consumption, irrigation, flood control and aquaculture. The earliest reservoir is believed to have been built on the Nile River at Kosheish in 2900 BC to supply water to the city of Memphis. The barrage was a masonry structure 15 m high (Encyclopaedia Britannica 1981). After the invention of electricity, generation of electricity became another reason for reservoir construction, although any reservoir may have a multipurpose use.

According to Margalef (1975), a dammed river is an environment intermediate between a river and a lake. A reservoir, different from a lake and a hybrid of a river, has a directional heterogeneity organized by the main flow of the original stretch of river. Margalef considered that reservoirs are typically stressed ecosystems in which two sources of stress combine: input of nutrients with eventual vertical mixing and unidirectional (at different rates according to depth) water flow. Reservoirs begin heterotrophically, as the newly inundated water-body needs to assimilate organic matter in bottom deposits. In tropical reservoirs, this process may be significant and oxidation of organic material consumes a large quantity of oxygen, leading to anoxia. This only slowly tends to be replaced. Later, in reservoirs under human influence, there is an increase in eutrophy, due to the addition of human and industrial wastes (Margalef 1983).

To understand the impacts of a (large) dam along a river, it is necessary to consider the condition of the original terrestrial landscape and water quality before impoundment. As an example, the River Tietê is highly polluted, as it runs east–west in the State of São Paulo, Brazil, crossing the city of São Paulo that has 14 million inhabitants and negligible industrial waste treatment and virtually no sewage treatment. However, the six dams downstream have a positive effect; they cause a gradual improvement in water quality as the river flows from one reservoir to the next. This

This paper was originally presented at the 'Simposio Regional sobre Manejo de la Pesca en Embalses en America Latina', La Habana, Cuba, October 1994. It was written under an FAO contract from the Inland Water Resources and Aquaculture Service, Fishery Resources and Environment Division. Publication has been authorized by the Secretary of COPESCAL/FAO, bearing in mind that the views expressed are those of the author and do not necessarily coincide with those of the organization.

Accepted for publication 5 September 1996.

cascade of reservoirs purifies the water due to: deposition of dissolved solids, following a fall in water speed in each reservoir towards the dam; and forced water aeration through spillways.

Organic pollution adds nutrients, so increasing primary production and improving fisheries, albeit unintentionally. Such ecosystem enrichment is a controversial issue (Tundisi 1988). Thus, fish diversity and stock density increase downstream, giving rise to significant sport and small scale fisheries. In the region of the Três Irmãos dam, the last reservoir on the Tietê River before its confluence with the Paraná River, the fish fauna may be considered representative of a pristine community (Heraldo Britski pers. comm.).

On the other hand, when a reservoir is constructed on an unpolluted river, with a still intact and forested basin, the positive effects—such as intense fisheries development immediately after dam closure in the reservoir and upstream (Petrere 1989), the generation of hydroelectricity, and water for irrigation—are small compensations when compared with the extent of negative ecological impacts, as is the case of the Balbina Reservoir in the Amazon basin. In addition, the impacts above and below the dam must be considered. Goodland *et al.* (1993) have discussed this problem in tropical regions.

Exactly how to define a *large* reservoir is not clear. One obvious criterion is area. In NE Brazil, Paiva *et al.* (1994) considered a large reservoir as one with an inundated area greater than 1000 ha. Another possible criterion relates to the nature of the fisheries present. A small reservoir has major fisheries derived from aquaculture (with regular stocking), whereas a large reservoir has its major fisheries not derived from aquaculture. However defined, large reservoirs are comparatively less vulnerable to precipitation pulses, are more expensive to build, their main task is often to generate electricity, and they are located on river channels of higher stream order.

According to Tundisi (1990, 1993a,b) and Tundisi *et al.* (1988, 1993), the most important features of a reservoir which affect its biota are: (i) *Morphometry.* The more denditric a reservoir, the more complex is its morphometry. This introduces several components and increasing spatial heterogeneity and variability, with extremes of biological diversity, and gradients in physical and chemical state variables; (ii) *Retention time.* Differences introduce considerable changes in the biological community. The higher the retention time, the more stable the water will be, leading to a lowering of oxygen levels and so impairing fisheries; (iii) *The hydrological cycle and flow requirements.* These relate to losses of biomass, water-level fluctuations, and physical and chemical conditions downstream; (iv) *Thermal stratification and circulation.* Most reservoirs in South America are polymictic, due to shallowness and the effect of winds which produce a non-layered system. However, in Amazonian reservoirs, thermal stratification is common, producing vertically a two-compartment system; (v) *Water-level fluctuations.* Change in this factor must be considered for it leads to variations in volume, thus increasing niche availability and higher nutrient input during floods; (vi) *Pulses in forcing functions.* These normally represent abiotic variables such as precipitation, solar radiation, wind and the flow systems controlling biogeochemical and biological processes; (vii) *Effects of turbine operation on the ecological functioning of reservoirs.* Sudden variations in the water-level for flow regulation or energy production at peak times interfere with a number of abiotic variables; (viii) *Wetlands associated with reservoirs.* Most are located upstream of the reservoir and may function as biological reserves; these should be maintained for they function as 'buffer zones' crucial for the recovery of biological diversity downstream; (ix) *Salinization of reservoirs in semi-arid regions.* This process rapidly disturbs the reservoir's biological community; (x) *'Evolution' or ageing.* This is a powerful characteristic of succession within a reservoir. In the High Paraná Reservoir, for example, eutrophication is a major feature of ageing. (xi) *The downstream ecosystem.* River impoundments may produce a complete change in habitat downstream, altering the pristine natural balance. (xii) *Latitudinal differences.* In the case of north–south elongated continents, such as South America, latitudinal differences in reservoirs are also important, as noted by Straskraba (1993).

On the whole, the main effect of a reservoir, in altering the original predominantly lotic environment to a lentic one under the influence of a barrage, is that upstream of the reservoir the original floodplain remains inundated for prolonged periods, while below it the floodplain is more permanently exposed. Clearly these effects decrease the productivity of the original floodplain.

Balon (1974) suggested that the yield of tropical reservoirs is initially high, then decreases, stabilizing at a level usually higher than the original stretch of river along which it was built. But this pattern varies with the location of the reservoir. If it is built in a stretch of rapids and falls, with little floodplain development, Balon's pattern may not be valid. Agostinho and Júlio (in press) compared the commercial catches from the Itaipu Reservoir in SE Brazil with upstream stretches, from 1986 to 1988 and showed that the catches in the reservoir averaged 0.436 kg/m^2 of gillnet/24 h, compared with 0.277 in the main channel and 0.307 in channels of the inundated floodplain. The figure, however, was surpassed by catches in the marginal lagoons (0.578).

Within a reservoir, there are many habitats which are important for fish as sites for the provision of food and shelter, e.g. floating meadows of macrophytes, dead logs, tributary mouths, sites between islands, inundated vegetation, and on beaches. These habitats may be considered as ecotones or patches.

Finally, any reservoir can only be a transitional feature in the landscape; it only lasts for a limited period as it tends to be filled by siltation. This process may be very short or quite long, depending on river basin management and strategies of soil occupation and restoration of vegetation.

To review the subject of fisheries in reservoirs in so vast a continent as South America has many difficulties. Not the least of the difficulties is the fact that most of the information is not available in current international journals, some being buried in government or international agency reports, or published in obscure local journals, often discontinued. Only by chance do such documents usually come to the notice of the interested reviewer. This present review suffered from this difficulty, and thus in parts lacks balance. It is clearly more focused on Brazilian reservoirs as the literature and colleagues to consult were available.

RESERVOIR TYPOLOGY

Presently, reservoir typology is based on the application of multivariate techniques of classification and ordination and aims to detect patterns and similarities between water-bodies. Shadin (1958) and Stepanek (1960) were among the first to publish on this subject. Estrada (1975) used principal component analysis to detect a west–east pattern of ordination in 100 selected Spanish reservoirs; it was shown that they are basically influenced in their water composition by the nature of the substrate of Palaeozoic and igneous siliceous materials, geological strata especially important in the north–west and west of Spain. The eastern group includes reservoirs from Mesozoic and Tertiary zones dominated by more soluble limestones. Margalef (1975) discussed these findings. Estrada (1978) later tried to establish a general framework for more detailed studies, including the ecology of reservoir communities.

Historically, each author has tended to propose a different typology according to his or her speciality. This makes it difficult to establish discrete groups of lakes according to Brinkhurst (1974; *fide* Prat 1978).

In South America, the most consistent attempt to categorize reservoirs forms part of the project, 'Typology of Reservoirs of S. Paulo State', by the group led by Professor J. G. Tundisi, with the first results dating from Tundisi (1981). Since then, several associates have tried to categorize a variable set of 52 reservoirs in the upper Paraná basin in the State of São Paulo, Brazil, with different results using distinct taxa as raw material. None used fish communities, as did Dolman (1990) in classifying Texas reservoirs according to limnological features and fish community associations. Reservoir typology is claimed to be a key factor in the planning of conservation and management operations, which is now increasingly important due to cultural stress upon these impacted water-bodies (Tundisi 1981).

In my view, reservoir typology should be a multidisciplinary task, with only one objective and without division of the data set. It should take into consideration as much as possible of the biological, geological, limnological, economic and cultural characteristics as are available. They should be analyzed as a whole in a large data matrix. This strategy was attempted by Dolman (1990).

FISH IN RESERVOIRS

Fernando and Holcik (1991) considered that in all reservoirs the fish fauna is recruited from riverine ancestors pre-adapted to lacustrine conditions. This is supported by good examples from Brazilian reservoirs. Britski (1994) classified the fish fauna of Brazilian rivers—a classification which can be cautiously extended to some other regions in South America—in seven main groups: (i) Characiformes (lambaris *Astyanax* spp., dourado *Salminus maxillosus*, curimbatás *Prochilodus* spp., etc.); (ii) Siluroidei (catfishes and armoured fishes); (iii) Gymotoidei (electric fishes); (iv) Cichlidae (tucunaré *Cichla* spp., acarás, etc.); (v) Cyprinodontiformes (barrigudinhos, guarus, tralhoto, *Rivulus*, etc.); (vi) Marine invaders (rays, pescadas, linguados, etc.) and (vii) Relicts (pirambóia *Lepidosiren paradoxa*, pirarucu *Arapaima gigas*, aruanã *Osteoglossum bicirrosum*, leaf-fish, etc.).

The percentage of these groups in the composition of the fish fauna of different river basins varies according to their evolutionary history and is closely related to the geological history of the river basin and niche availability. Thus, rivers with extensive floodplains, as in the Amazon basin and the Pantanal, have more fish species pre-adapted to lentic habitats, such as the Cichlidae and marine invaders. These fish are generally non-migratory and are unable to overcome natural barriers as can the Characiformes and Siluriformes. These latter fish are more abundant in rivers where their basins are at higher altitude, as in the Tocantins in the central Brazilian plateau.

As a good example, the pescada or curvina *Plagioscion squamosissimus* is one of the best pre-adapted fish species in Brazilian reservoirs from north to south, as pointed out by Petrere and Agostinho (1993) and Paiva *et al.* (1994). In the Amazon basin, this fish, which belongs to the Sciaenidae (in Brazil represented by 37 marine and 10 freshwater species, including the genera *Pachyurus*, *Pachypops* and *Plagioscion*; Hahn 1991), is primarily a shrimp-eater (Goulding and Ferreira 1984). Together with tucunaré *Cichla* spp., these are the most important fish in the commercial catches in Tucuruí Reservoir. Pescada is also the main carnivorous species caught in the commercial fisheries in some reservoirs in NE Brazil (Paiva *et al.* 1994), followed by the tucunaré, and is the second or third most important fish species landed in the Itaipu Reservoir (Agostinho *et al.* 1994). In these places, it is an introduced species, as is the tucunaré in NE reservoirs. Possible ecological reasons for the success of pescada are discussed by Petrere and Agostinho (1993).

Another important pre-adapted species of fish that is one of the most abundant fish in catches from the Itaipu Reservoir is the sardela *Hypophthalmus edentatus*, a zooplankton filterer of open waters which feeds in surface waters and is one of the main items in the diet of the local pescada. This is the only case where the sardela dominates the commercial fisheries in any South American reservoir. At present, we do not have a clear reason to explain this particular case.

Agostinho *et al.* (fig. 16.3, 1994) have shown the remarkable change in the fish community composition of the Itaipu Reservoir before and after dam closure. From the twelve most abundant fish species in the pre-impoundment time, only two became abundant later viz. *Plagioscion squamosissimus* and *Prochilodus scrofa*, followed by 10 previously very rare species. Clearly, the large migratory species, such as the dourado *Salminus maxillosus* and the catfish *Pseudoplatystoma corruscans*, and with the exception of *Prochilodus scrofa*, almost disappeared from commercial and experimental catches. Some species pre-adapted to lentic habitats, such as *Hoplias malabaricus*, were also unable to colonize the new habitat. Agostinho *et al.* (1994) discussed these findings.

Finally, together with river pollution, improper soil use, and road and embankment construction, reservoirs have a major impact in decreasing species richness in their area of influence. This is due mainly to the physical changes in the original river channel, where the presence of the barrage provokes a major habitat alteration, or even the disappearance of some species. The species most damaged are the migratory ones, as in general they are unable to spawn in lentic waters, and below the barrage the timing for upriver migration is disturbed by river regulation.

Introduced species

Fernando (1991) wrote a comprehensive review of introduced fish species in tropical regions. With the exception of the introduction of tucunaré, *Cichla ocellaris*, in Gatun lake in Panama (Zaret and Payne 1973), there has been no detailed study of the introduction of an exotic fish species into any South American reservoir and its consequences.

Even so, extensive introductions have occurred. Thus, in the reservoirs locally called 'açudes' of NE Brazil, which have been stocked with fish since 1933 due to the chronic shortage of protein in the region, stocking has relied on exotic species because the natural fish fauna of the region is relatively poor. To date, 39 fish and 3 exotic crustacean species have been introduced from other basins and overseas (Gurgel & Oliveira 1987). Of these, the Nile tilapia, *Oreochromis niloticus*, was the main fish caught (35 345 t, 25.9%) in ten years of records from 17 'large' reservoirs, followed by pescada *Plagioscion squamosissimus* (21.9%) and tucunaré comum *Cichla ocellaris* (10.9%), then 15 other fish and two prawn species (Paiva *et al.* 1994). Paiva *et al.* (1994) showed that in these reservoirs 77% of the variability in total catches was explained by the number of predatory species, the inundated area, the mean depth, and the number of fishermen. The highest catches were observed in reservoirs with two predatory species. With increased or decreased number of predators, catches fall quite sharply. This result was interpreted as the effects of competition.

Moreau *et al.* (1990) used the program ECOPATH II to conduct a box model of the Kenyan sector of Lake Victoria to understand the trophic changes in the fish community after the introduction of the Nile perch

Lates niloticus. They demonstrated a change in ecosystem structure, and an increase in the ecotrophic efficiencies of most components of the ecosystem following the introduction. It is remarkable that the total fish biomass increased from about 27 t/km² in the early 1970s to about 43 t/km² in the mid 1980s. Similar research is needed for tropical reservoirs.

Ross (1991) and Allendorf (1991) discussed several general ideas concerning fish introductions. The subject was reviewed by Welcomme (1988).

Comparative yield of reservoirs

Large reservoirs in South America have comparatively low fish production. Petrere and Agostinho (1993) compared the yields (ton/yr) and production (kg/ha/yr) for seven Paraná basin reservoirs. Their production values are low (average = 4.51 kg/ha/yr) when compared with values elsewhere [58.4 kg/ha/yr for African lakes (Bayley 1988), 99.5 kg/ha/yr for African reservoirs (Marshall 1984) and 151.8 kg/ha/yr for 17 NE Brazilian reservoirs (Paiva *et al.* 1994)]. The three main reasons given for these comparatively low values were: (i) a low fishing intensity. In the set of reservoirs examined, the average fishing intensity was 0.2 fisherman/km²/yr, a very low figure when contrasted with that for NE Brazil reservoirs (average = 3.2 fishermen/km²/yr) and with African lakes (average = 1.5 fishermen/km²/yr). Welcomme (1990), in a review of the status of fisheries in South American rivers, considered that densities of fishermen less than 0.5 fisherman/km²/yr indicate an underfished floodplain; (ii) a lack of systematic stocking, although some stocking was undertaken by the hydroelectric authority, CESP, but probably with the wrong species; and (iii) possibly, low densities of tilapia, thus few fish which could occupy a probably empty plankton-grazing niche in the open waters of reservoirs, as discussed by Fernando (1991) and Fernando and Holcik (1991).

IMPACTS

Impacts on fish migration

The most direct effect of dams on migratory fish species is the effect of the dam itself. In this way, obligatory migrants are unable to continue upstream movement and young may not disperse properly downstream. In genetic terms, for some species, the population may be split and mating disturbed, altering the genetic pool. Thus, the impoundment of any river causes a drastic reduction in the density of migratory species. Bini (1993) presented an extensive list of fish reductions for some reservoirs in South America. If the reservoir has a large river (and/or a set of smaller tributaries) draining into its main body, these effects are minimized, as in the case of the Itaipu Reservoir in the Paraná River.

There are some engineering constructions that may help mitigate the impact of dams. The main devices include: fish ladders, fish lifts, canal locks, transportation of spawning schools, and spawning channels. The efficiency of fish ladders is controversial. It seems that they are effective for only some species and if not very high. This seems to be the case for the well-studied Cachoeira (Fall) de Emas on the River Mogi Guaçu (SP), where the curimbatá *Prochilodus lineatus* and the dourado *Salminus maxillosus* ascend easily, particularly larger individuals. However, some catfishes (such as *Pimelodus maculatus*) and armoured fishes are quite unable to scale the ladder. Furthermore, smaller specimens of curimbatá cannot find the ladder as they keep trying to jump through the spillways and badly injuring themselves. Capeletti (1993) showed that only larger fish tend to concentrate at the ladder entrance. Godinho *et al.* (1991) drew attention to the efficiency of the fish ladder at the Salto do Morais dam on the Tijuco River, a tributary of the River Paranaíba in the upper Paraná basin. The efficiency of this fish ladder is extremely low, with only 2% of the fish that attempt the ascent reaching the top of ladder. The ladder has 25 steps and is 78.3 m long and 10.8 m high. Quirós (1988) reviewed the subject.

Fish lifts are not very common as they are expensive to build and operate. The reservoir of Yaciretá in Argentina has such a device (M. Bini, pers. comm.).

Canal locks, although not originally constructed as fish passes but to allow for ship navigation, may have a marginal effect in assisting fish movements.

The transportation of spawning schools is a comparatively inexpensive procedure, but distances must not be long and the transporting vehicles must have efficient water-oxygenation apparatus for the transportation.

Spawning channels may offer an adequate water flow and optimum substrate condition for fish spawning. The survival of eggs and juveniles in these artificial areas is usually higher than in the natural environment. Mundie (1979; *fide* Bini 1993) pointed out that artificial channels result in a survival rate nine times higher than natural channels. This efficiency depends greatly on the extent of maintenance, especially cleaning, control of algal growth, avoidance of siltation, the collection of dead fish and preventative actions against predators after spawning. In the Itaipu

Reservoir, there is a spawning channel in operation, but it is not completely efficient because a low percentage (9–15%) of adult fish such as curimatá *Prochilodus lineatus* are still immature (Itaipu staff of the Environment Section, pers. comm.).

Impacts above the barrage

Prolonged inundation upstream may decrease reproductive areas for fish. The building of the Gulum Mahommed Reservoir on the River Indus (Iran) destroyed about 60% of the migratory area of *Hilsa ilisha* (Welcomme 1979). If the reservoirs are arranged in a series of cascades, the life-cycle of migratory fish species may be severely disturbed, as observed for juveniles of the chinook salmon and steelhead in the Columbia and Snake rivers (Raymond 1979; *fide* Bini 1993).

As reservoirs tend to concentrate pollution, they may also constitute an unsuitable environment for juvenile fish, being often more sensitive to noxious substances.

Impacts below the barrage

In reservoirs with an increased concentration of gases (H_2S, nitrates), massive fish mortalities may be a frequent phenomenon. Surviving fish may then become more vulnerable to predators (Beiningen & Ebel 1970; Petts 1988; Bini 1993).

Turbine operation that is not synchronous with the original water regime may also constitute a major problem, as many migratory species begin to migrate upstream after sudden rises in water-level. Thus, in December 1989 in one day, I witnessed all spillways of the Amazonian Tucuruí Reservoir open, with water of good quality, and fish started to school and migrate upstream. Two days later, however, only one spillway was open, the water-level had fallen suddenly, and water quality had become low, as most of it had passed through turbines. These events certainly decreased the reproductive success of the fish species.

Another impact occurs when most of the water is retained for long periods, thus impeding the entrance of fresh water to marginal lagoons below the reservoir, and so decreasing the amount of food for juveniles. Alternatively, in times of unexpectedly high rainfall, additional amounts of water may be released, so increasing the level of the marginal lagoons at the wrong season and allowing migratory predators to enter the lagoons before juveniles can escape (J. J. Neiff and L. Bini pers. comm.).

A decrease in water turbidity, following the retention of nutrients and solids by the reservoir, may also be responsible for the decline of populations of migratory fish not adapted to water of low turbidity.

River bank erosion by water from the reservoir may lead to the destruction of spawning grounds (as in the Tucuruí Reservoir).

Finally, predators may concentrate in the tailrace below a dam during spawning. They wait for stressed fish coming down river (Bernacsek 1984).

Impacts following human occupation of drainage areas

The main impacts following human occupation of drainage basins are: deforestation, increases in the natural rate of siltation due to inadequate agricultural and management practices, and pollution by domestic, industrial and agricultural waste water—which may often lead to an increased rate of natural eutrophication.

Mayer *et al.* (1981), in a study of 17 reservoirs in the State of São Paulo (Brazil), detected the presence of a number of metallic elements. They found chromium (0.05–0.09 ppm), which is toxic to zooplankton, in 4 reservoirs; lead (0.05–0.10 ppm), toxic for fishes, in 7; nickel (0.03–0.04 ppm), toxic for zooplankton and fishes, in 7; zinc (0.06–0.30 ppm), toxic for zooplankton and fishes, in 8; aluminum (0.20–1.49 ppm), toxic for zooplankton and fishes, in 3, and cadmium (0.02–0.03 ppm), toxic for for phytoplankton, zooplankton and fish, in 5 reservoirs.

Cáceres *et al.* (1987) studied the concentration of organochloride pesticides in 38 reservoirs of seven hydrographic basins in the State of São Paulo. In all samples collected in surface water, residues of BHC and DDT were detected. Traces of other residues, such as heptachlor, chlordane, aldrin, dieldrin and endrin, were also detected. Reservoirs in areas with intensive agricultural activities showed higher concentrations of BHC and DDT, as expected, than did reservoirs in less developed areas. In most parts of the reservoirs, the concentrations of pesticide residues were in lower concentrations than those usually cited for continental waters in temperate climates. However, this is regarded as a temporary transitional stage as these concentrations will tend to rise after more intensive agricultural production has developed.

Calheiros (1993) studied contamination by organochlorine pesticides in summer in water, sediments and fish in the Barra Bonita Reservoir on the Tietê River, the first large reservoir below (170 km) the capital city of São Paulo. She studied *Astyanax* *bimaculatus* (an omnivore fish), *Steindachnerina insculpta* (a mud-eating fish), *Serrasalmus spilopleura* (a carnivorous fish), and the filtering bivalve *Anodontites trapezeus*. Her main findings were that the levels of HCH_{TOTAL}, DDT_{TOTAL}, aldrin, dieldrin and PCB_{1260} were normal, with the exception of DDE and PCB_{1260} which had contaminated *Serrasalmus spilopleura*. Fortunately, this species is not consumed commercially.

Social aspects

The main social aspects of the construction of large reservoirs concern the re-location of large numbers of people, so disrupting their traditional systems of agriculture and fisheries. Re-location also affects people economically and emotionally, bringing cultural dissatisfaction, and altering temporal and spatial perceptions of the environment (since communities are used to planting and fishing according to water-level fluctuations and these are generally disrupted by river regulation). The loss of fertile floodplains to these people represents a destructive alienation of their former living conditions (Costa 1990; Petrere 1992).

In many cases, this alienation of land requires riverine people to learn how to cultivate more territorial and generally less fertile areas than the original floodplain. If new living areas are far from the river, the diet of the people may be impoverished in fish protein. If the new reservoir is large and deep, they will face new problems in navigation in windy conditions. Their neighbors or relatives may have moved to different villages, altering their social life. Cemeteries may be inundated, bringing strong emotional stress, etc.

Some large reservoirs in the tropical world, such as Lake Volta in Africa and Guri and Tucuruí Reservoirs in South America, were built mainly to provide large amounts of energy for aluminum smelting. In these cases, the local people were only benefited minimally. This represents an ethical constraint to the construction of large reservoirs.

If the reservoir is to be constructed near or in Indian reserves, the situation may be even worse. This is the case for the Amazonian Tucuruí Reservoir which inundated part of the reserve of 280 Parakanã Indians. In these cases, part of the reserves for hunting and

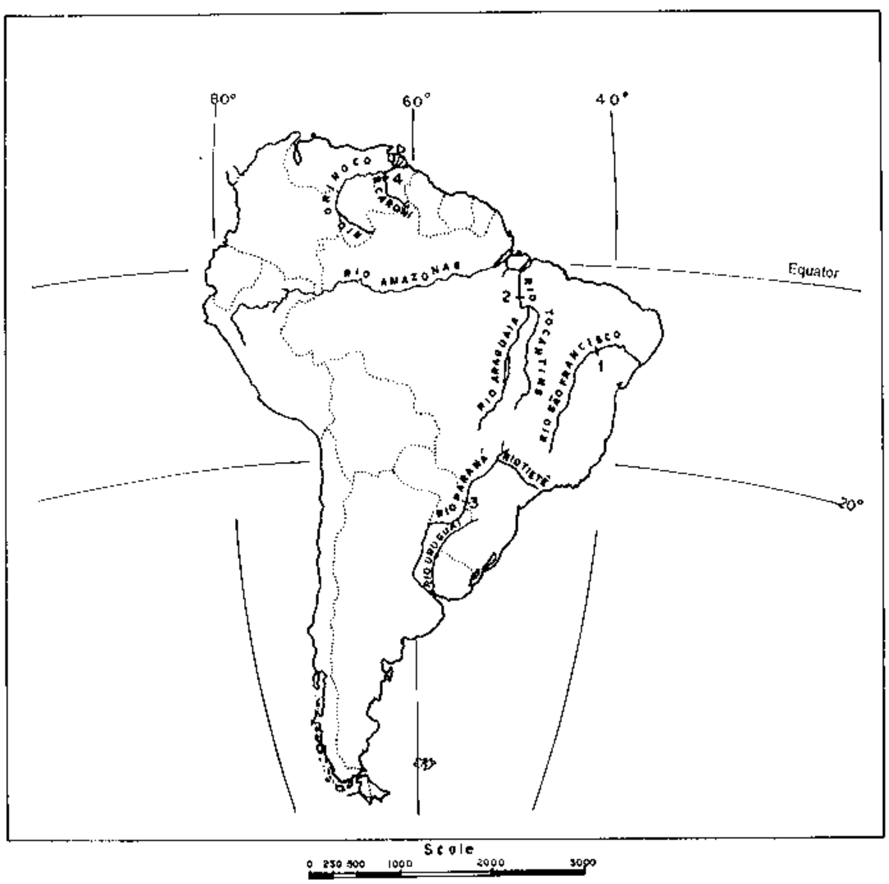

Fig. 1. South America and the location of reservoirs: 1, Sobradinho Reservoir; 2, Tucuruí Reservoir; 3, Itaipu Reservoir; and 4, El Guri Reservoir.

Table 1. Main reservoir management strategies. Adapted from Agostinho (1994)

Type of management	Action	Characteristics	Advisable situations	Comments
Population manipulation (aiming to alter the population or community abundance)	Reduction	Selective fishing, electric fishing, controlled blasts, application of fish poisons	Problems with undesirable predation, competition, improving swimming conditions, improve fisheries of desirable species, dwarfism, etc.	It is very difficult to eliminate an undesirable fish species, especially if it has managed to establish a sustainable fishing population
	Stocking	Stocking with native fish species or with species from other basins	Depletion of the target stock	The size of the individuals to be stocked, the stocking site or habitat, the reproductive viability and the adequacy of the environment are some aspects linked to the success of stocking. Predation, competition, diseases, genetic erosion, hybridization are potential impacts to be considered here
Habitat manipulation (generally associated with improvement of competitive advantage, increased biogenic capacity of the waterbody, and increments of the reproductive potential and rate of survival)	Control of aquatic macrophytes	Mechanical, chemical or biological reduction	Problems with planktonic productivity, water quality, and fishing activity due to excess macrophytes	The importance of macrophytes as shelter and substrate to young fish must be taken into account
	Water-level control	Manipulation of conditions in the littoral zone of the reservoir and floodable areas upriver	Depletion or excessive proliferation of fish stocks which utilize the littoral zone for feeding, reproduction or refuge. Effects on the reproduction of fish species which depend on the upstream floodplain	Precise knowledge of the biological needs of the target species or other (non-target) species which may be affected by this action is needed. Difficulties in conforming this control with other water uses.
Habitat manipulation	Shelter manipulation	Increase or decrease the availability of shelter by building artificial reefs, maintenance of riparian vegetation, and assisting macrophyte colonization	Problems in the proportion of predator/prey species. Enhanced juvenile mortality due to increased predation	The maintenance of riparian arboreal vegetation and of the buildings in the area should be considered; their localization and intensity may be undesirable for aquatic sports, turbine maintenance, and they also affect water quality

Table 1. (continued)

Type of management	Action	Characteristics	Advisable situations	Comments
	Manipulation of spawning sites or natural nursery areas	Enhancement of these areas	Especially in reservoirs where these areas suffered considerable reduction	This is a promising practice, as it acts upon the factors affecting mortality and natality of young forms. The precise localization of these areas is fundamental for the success of this action
Fisheries control (generally associated with the protection of spawning stocks, young forms and fishing intensity)	Temporal prohibition	Fishing prohibition in critical periods such as spawning and migration seasons, overfishing, etc.	Depletion of the fish stocks related to growth or recruitment	This practice should be adopted when indicated by fish stock monitoring systems. Correct knowledge about the reproductive cycle of the target species is needed
	Spatial prohibition	Prohibition of fisheries in habitats where stocks are more vulnerable to overfishing	Below the barrage due to tailrace fisheries, natural obstacles as rapids and falls, natural nursery sites or collective breeding sites	This action requires a precise knowledge of the distribution and life-cycle of the target species to be protected
	Prohibition of fishing gear	Prohibition of the employment of non-selective gears or fishing methods	Depletion of stocks due to excess fishing effort	The monitoring of the fish stock is essential, as well as knowledge of the selectivity of fishing gear
	Fishing effort control	Restriction of the number of operating fishermen or gear	Depletion of stocks due to excess fishing effort	The monitoring of fishing activity is necessary
Water management	Water condition improvement	Reduce deforestation, mining, discharge of domestic and industrial sewage, etc.	Reservoirs in critical conditions, especially in the littoral zone and in the floodplain upstream	This action needs strong central coordination, preferably from a consortium of the councils of the cities and towns located in the river basin
	Turbine operation	If the water intake for the turbines is located well below the water surface, in the critical months of summer some of the spillways must remain open to improve water quality below the dam	During this time of the year, low oxygen concentration may impair economic fisheries below the dam	This action is difficult to enforce as the conflict between other (multiple) uses of the reservoir and electricity production is critical at this time

fishing may be lost forever, so causing severe psychological stress among these fragile social groups.

RESERVOIR MANAGEMENT

In addition to the conservation of endangered species, the management of commercial fish stocks, and the control of insect pests on aquatic macrophytes, reservoir managers should also consider the management of the fish community as a whole, water quality, and landscape management. Recent publications on this subject are by Tundisi (1988), Stråskråba *et al.* (1993), Jørgensen and Volleweider (1993).

Reservoirs are ecosystems that are transitional in time. As important assets, it is necessary to manage them carefully. After all, they may have been extremely expensive to construct.

For fish stock management, it is essential to have data on long-term catch and effort. Ideally, programs to collect these data should be set up before reservoir construction. Unfortunately, this rarely occurs; often the collection of data is the first activity to be discontinued when there is a shortage of funds. The decision on this matter is never under the control of the ecologist working for the hydro-electric authority. Generally, the management of this is dominated by engineers.

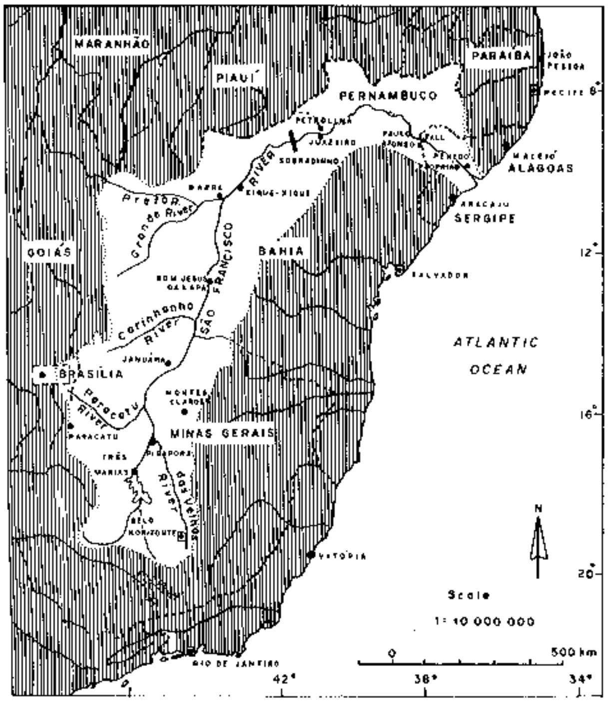

Fig. 2. São Francisco River basin in Brazil.

Agostinho (1994) has produced a code of conduct for managing a large reservoir. Table 1 is adapted from his proposals.

CASE STUDIES

Sobradinho Reservoir (Brazil)

The original purpose of the Sobradinho Reservoir, located in the middle São Francisco River (Figs 1, 2), was to regulate river flow at 200 m^3/s. This would allow optimum operation of the series of reservoirs downstream, namely, Paulo Afonso, Itaparica, Xingó and Moxotó reservoirs. Later, turbines were installed and these now generate 1000 MW (0.24 MW/km^2). Sobradinho is the second largest reservoir in South America (4200 km^2 maximum inundated area), and is surpassed only by the Guri Reservoir in Venezuela (4300 km^2). This is on the River Caroni, a blackwater affluent of the Orinoco River (Novoa *et al.* 1989; CEPED/PROTAM 1987; Fig. 3). The Sobradinho Reservoir began operations in 1977, and needed the re-allocation of 14 000 families of small farmers.

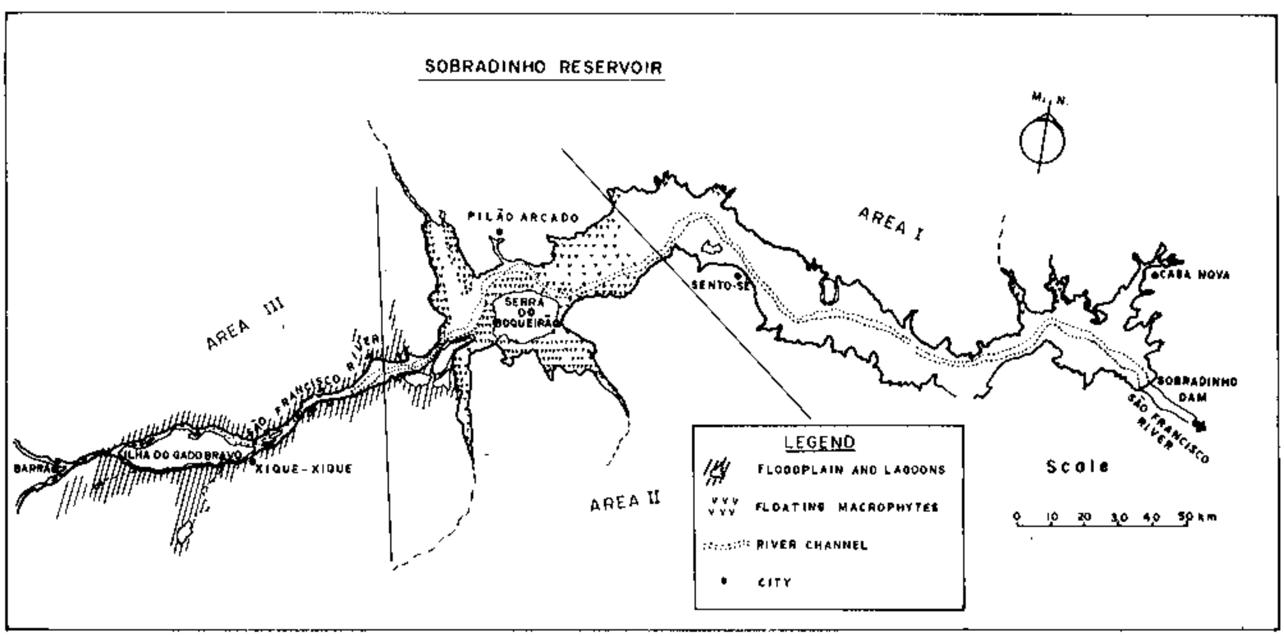

Fig. 3. Sobradinho Reservoir (CEPED/PROTAM 1987).

Before reservoir construction, fish landings for the whole São Francisco River (2780 km long, basin area 611 000 km^2; Showers 1979) were estimated as 2500 t/yr (Silva 1980; CEPED/PROTAM 1987), mostly from subsistence fisheries. However, in 1980, in the Sobradinho Reservoir alone catches totalled 24 000 t (57.1 kg/ha/yr).

Two sorts of fishermen were initially involved in the first years after Sobradinho Reservoir had been constructed: (i) itinerant fishermen, who came to the region just after the damming from many places elsewhere in north–northeast Brazil. They were professional, highly specialized fishermen employing large gillnets (600 m long). They lived in camps on the edge of the reservoir and on islands until the fisheries, which were highly productive initially, started to decline. These fishermen, who represent a new social entity, are also referred to as barrage fishermen. They are nomadic, moving from one newly inundated place to another; and (ii) re-located fishermen, the original peasants who became fishermen (many only part-time). They lived in the rural settlements set up by CHESF (Centrais Hidrélétricas do São Francisco).

Initially the relationship between the professional fishermen and the local ones was not easy. The itinerant fishermen brought social disarray because they had a different lifestyle and philosophy. Because they sold their produce daily, they always had some money and therefore caused local prices to rise. This disadvantaged local people, who had money only periodically. There were many cases of local agricultural crops being stolen, and there were many quarrels and fights for a variety of reasons. However, despite these events, the professional fishermen taught the re-located fishermen to fish more efficiently, and the present fishing community on the reservoir is derived from this association (Petrere 1986).

The São Francisco basin fish fauna

The River São Francisco has a well-defined basin, according to Paiva's (1983) classification. It runs north-east, mostly across a very arid terrain, the 'caatinga', then drains directly to the ocean (Figs 1, 2). In many places, it is the only local source of water because many of its tributaries are temporary. For this reason, water abstraction for irrigation (sugar cane, soybean, fruits, onion, beans, etc.), cattle ranching, and human consumption is significant along its entire course. Fisheries are a traditional activity in the river itself.

Britski *et al.* (1984) listed 73 species of fish in the Três Marias Reservoir region, located above Sobradinho, and Sato *et al.* (1988) listed 37 species of fish in seven permanent and two temporary floodplain lakes above the Três Marias in the upper São Francisco River. Some species are endemic to the basin. The main orders are: Characiformes (important species, *Salminus brasiliensis, Prochilodus affinis, P. marggravii, P. vimboides,* all endemic to the basin, *Hoplias* cf *lacerdae,* and *H. malabaricus*), Siluriformes (*Pimelodus maculatus, Pseudoplatystoma coruscans*) and Perciformes (*Geophagus brasiliensis, Pachyurus francisci* and *P. squamipinnis*).

Reservoir fisheries

The fish are caught with gillnets (the main fishing gear), hooks and harpoon using canoes. CEPED/PROTAM (1987) reports that average mesh sizes have decreased since the fishery began.

There was no major stocking with exotic fish species in Sobradinho, even though a consultant from ELETROBRAS (the Central Government board for electricity) recommended this. The only introductions, made by DNOCS (Departamento Nacional de Obras Contra as Secas, CE), were of the Amazonian shrimp (*Macrobrachium amazonicus*) the pescada do Piauí (*Plagioscion squamosissimus*) as a forage fish, and the Amazonian apaiari or oscar (*Astronotus ocellatus*). Tilapias and carps were not introduced. The reason given was that it was to avoid competition with similar resident species (Petrere 1986).

Figure 4 shows the commercial landings from the reservoir from 1979 to 1986. Unfortunately, as so often in South America, catch and effort records have been interrupted since then, thus preventing a better assessment of what is happening to the fish community in

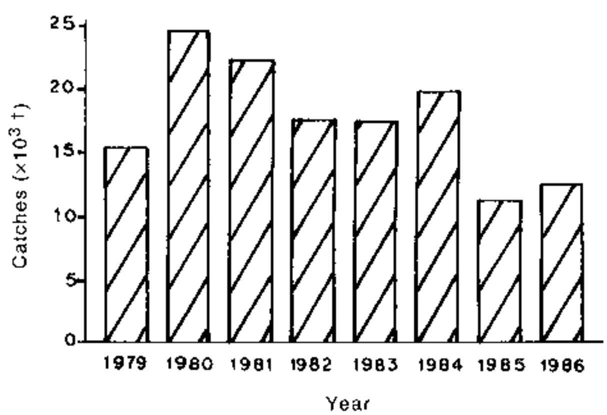

Fig. 4. Total fish landings from Sobradinho Reservoir from 1979 to 1986 (CEPED/PROTAM 1987).

the reservoir. However, it can easily be concluded from Fig. 4 that catches started to decline following closure, when fish are usually more vulnerable to capture.

For purposes of reporting catch data, CEPED/PROTAM (1987) used limnological data to divide Sobradinho into three main regions from the dam to upstream: (i) Area I. A predominantly lentic zone. This corresponds to 60% of the reservoir area and has an average depth of 15 m. Bordering hills on one side of the reservoir direct the prevailing wind (SE–NW) and this gives rise to waves of > 1 m height, interfering with navigation and fisheries. Marginal vegetation is usually thin and scarce, but in places that are protected from the wind macrophytes are abundant. Catch yields were lower in this area, although the largest individual fish were caught there. Fishing effort is restricted to the margins of the reservoir and islands. Average landings in this area were 500 kg/day. Area II. A transitional zone. This zone, averaging 6 m depth, amounts to 30.5% of the reservoir area, has extensive areas of macrophytes associated with drowned vegetation, and is a nursery zone. 75% of the fish are caught here. Area III. A permanently lotic region. It has an area of 400 km², low primary production, and is turbulent and turbid. It is the main route for migratory fish, with several marginal lagoons considered as reproductive zones.

Table 2. Total annual catches (kg), productivity (kg/ha) and percentage of total catch in three areas (I,II,III) of Sobradinho Reservoir in Rio São Francisco (Brazil). The average (Source PROTAM/CEPED 1987)

Year	1982			1983			1984			1985			1986		
Reservoir Area	Catch (kg)	(kg/ha)	%	Catch (kg)	(kg/ha)	%	Catch (kg)	(kg/ha)	%	Catch (kg)	(kg/ha)	%	Catch (kg)	(kg/ha)	%
I	1401945	6.60	8.05	2404207	10.70	13.90	3216984	15.82	16.43	2730212	12.85	24.54	2728057	14.02	22.07
II	14046487	13.19	81.10	13744195	122.30	79.47	14597613	143.58	74.54	7515617	70.73	67.55	9144594	94.02	73.98
III	1871415	52.83	10.81	1146292	30.60	6.63	1767781	52.16	9.03	880929	24.87	7.91	488297	15.06	3.95
Total	17319847	48.90	100.00	17294694	46.17	100.00	19582378	57.78	100.00	11126758	31.41	100.00	12360948	38.13	100.00

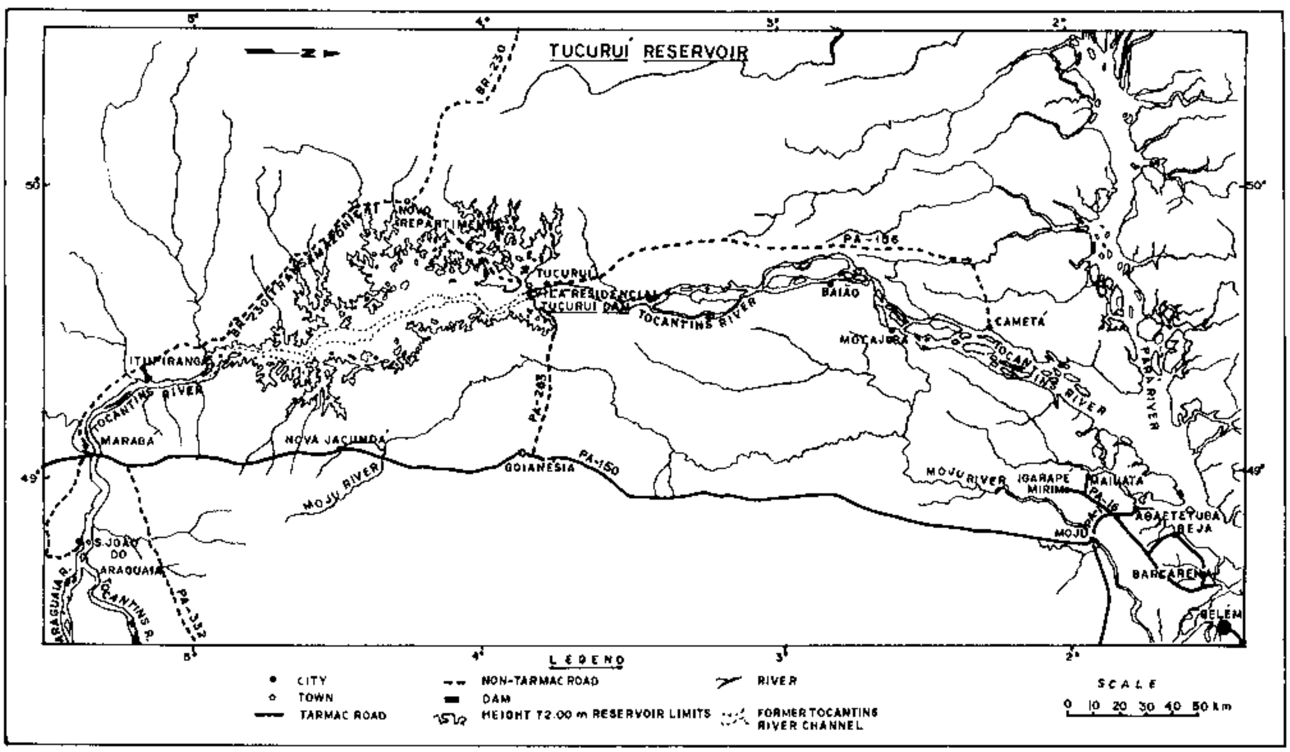

Fig. 5. Area affected by the Tucuruí Reservoir.

Table 2 summarizes the results of total annual catches from 1982 to 1986. It shows that the transitional zone is by far the most productive zone; as transitional zones are deposition zones, higher catches are to be expected due to increased primary production (Kimmel *et al.* 1990). In the Itaipu reservoir, 50% of the fish catch also comes from the transitional zone (Okada *et al.* 1994). Note that although the conductivity in Sobradinho is extremely low ($<1\ \mu$mho/cm, CEPED 1983), fish production in the first years was fairly high. Sato *et al.* (1988) reported that in the floodplain lakes above Três Marias Reservoir (Fig. 2) conductivity ranged from 34–140 μmho/cm, and Esteves *et al.* (1985) characterized this reservoir as oligotrophic, with conductivities ranging from 30–55 μmho/cm.

The main species of fish caught in Sobradinho were: curimatá pacu (*Prochilodus marggravii*) and the catfish surubim (*Pseudoplatystoma coruscans*). These comprised 73% of the total catch from 1982 to 1985, decreasing to 50% in 1986. Both species are migratory. The curvina (*Pachyurus squamipinnis*), the piaus (*Leporinus elongatus* and *Schizodon knerii*), and the introduced pescada (*Plagioscion squamosissimus*) increased in importance. The average weight of most species declined from 1982 to 1986, the exception being the surubim whose average weight increased from 1982 to 1985, but showed an abrupt fall (28%) in 1986.

Tucuruí Reservoir (Brazil)

The Tocantins (2750 km long) and Araguaia (2200 km long) Rivers (Fig. 1) constitute a separate basin (area, 803 250 km^2) from the main Amazon basin (Showers 1979; Paiva 1982). Draining the Brazilian shield, they are clearwater rivers according to the classification of Sioli (1964). The main human impacts on Amazonia in the last two decades have occurred in this basin. They include road construction, expansion of cattle ranching followed by extensive deforestation of the fragile ecotone of cerrado/forest, gold mining, and the construction of the Tucuruí Reservoir. The latter may be considered as the main impact on the fisheries in the lower Tocantins River (Amamaral 1994).

The fish fauna of Tocantins–Araguaia is not rich by Amazonian standards. There are approximately 300 species (Paiva 1982; Santos *et al.* 1984).

The Tucuruí Reservoir (Fig. 5) was completed in September 1984. The impounded water inundated an area of 2830 km^2 of rainforest after 206 days. The reservoir has an average depth of 17.3 m, and a maximum one of 75 m near the dam. It has a perimeter of 6400 km, is 130 km long and has an average water residence time of 51 days. When all the turbines operate fully, Tucuruí will generate 8000 MW (2.83 MW/km^2) of power (CET/ELETRONORTE 1988). This should save US$2 044 000/yr, the amount presently spent on importing oil [in June 1994, a barrel of oil cost US$14, including transport and insurance, and 1 MW is equivalent to a daily use of 50 barrels according to Caufield (1982)].

Leite (1993) showed that after dam closure, the reservoir retained 90% of total dissolved solids, alkalinity increased, and important nutrient concentrations changed. At present, the reservoir is regarded as responsible for a number of undesirable impacts, some predicted before construction (Baxter 1977; Goodland 1978; Edington & Edington 1979).

Impacts on the fish fauna

Leite (1993) analyzed the results of experimental fishing with gillnets from 1980 to 1987. In 100 samples, comprising 92 248 fish of 223 species, 126 genera and 34 families, 85% belonged to the Characiformes, Siluriformes and Perciformes, in this order of importance. From the species sampled, 141 were common both before and after impoundment. Fifty species occurred only before the impoundment, and 32 only after impoundment.

After impoundment, catch per unit effort, expressed in numbers of fish sampled, decreased by 80% below the dam, by 71% in the reservoir area, and by 56% above it. Expressing the catch in biomass per unit effort, below the dam the decrease was 71%, in the reservoir area, 49%, and above it, 45%. Species richness and diversity (Shannon H′) also decreased. Below the dam, there was a reduction in richness from 71 to 41 species (and of H′ from 5.1 to 4.5), in the reservoir area, from 70 to 32 (4.7 to 3.4), and above the reservoir from 71 to 39 (4.6 to 3.6).

In trophic terms, although the figures (12, 13, 14) of Leite (1993) show considrable variation in different years, there was a definite change in composition. Below the dam in 1982 and before impoundment, iliophagous species were predominant in number of individuals (36.7%), followed by carnivores (29%), piscivores (13.3%), omnivores (13.2%), and herbivores (2%). After impoundment (1987), carnivores became predominant (51%), followed by iliophagous species (24%), piscivores (12.7%), omnivores (4.7%) and herbivores (1%).

If Leite's (1993) data are further analyzed and used to calculate an index of diversity (Shannon, base 10) for community trophic structure, then using the percentages of these five trophic levels (irrespective of the species names) H′ (before) = 0.582 and H′ (after) = 0.494 [unfortunately, Leite (1993) did not give the number of individuals at each trophic level to enable calculation of the respective variances (Magurran 1988) and significance tests between these indices, but numerically the fall in H′ is considerable and seems highly likely to be significant]. This indicates that the community was originally dominated by iliophagous fishes, with a comparatively shorter foodchain, implying the presence of a higher biomass.

In the reservoir area, the same ranking was repeated. The iliophagous species predominated (45.3%), followed by piscivores (18.0%), carnivores (16.7%), omnivores (12.0%) and herbivores (4.0%). After impoundment (1987), the piscivores, as expected, became dominant (46.0%), followed by iliophagous species (24.7%), carnivores (22.0%), omnivores (6.7%) and herbivores (2.0%). [H′ (before) = 0.586 and H′ (after) = 0.562, with a less pronounced fall in the H′s.] Above the dam and before impoundment, the carnivores were predominant (82%), though Leite (1993) did not explain why, followed by iliophagous species (10%) and piscivores (7%). After impoundment, the carnivores still dominated (52%), followed by iliophagous species (32%), piscivores (11%), omnivores and herbivores, both with 6.0%. [H′ (before) = 0.252, H′ (after) = 0.558]. Perhaps diversity increased upstream because this region became a refuge after construction of the dam as fish migrated upstream from the inundated area looking for suitable habitats. More data are necessary to confirm this.

Impacts on fisheries

The fisheries in the Tocantins valley were studied during an excursion between the cities of Porto Nacional and Cametá (about 1200 km), when professional and subsistence fishermen were interviewed (Ribeiro & Petrere 1988).

The fisheries above the reservoir. Fishermen were unanimous that after dam closure there was a general increase in fish abundance, with immediate benefits to the regional economy. Between the city of Imperatriz and the reservoir (360 km), the total estimated catch for the Tocantins basin is comparatively low, not exceeding 4000 t/yr in its more productive stretch. Between the cities of Porto Nacional and Estreito (540 km), where the River Tocantins flows within a deep valley, the total landing must be <400 t/yr. These regions are exploited by small groups of professional fishermen organized in syndicates (Colônias de Pescadores). They fish with small diesel-powered boats, and keep their catch in ice boxes. There are also subsistence fishermen, fishing sporadically, mainly with rod and line and hook and line. In the 'O Povo Merece' market in Imperatriz, during 1988 when they were commercialized, the local fishing fleet caught 45 groups of fish species totalling 841 t, of which the curimatã (*Prochilodus scrofa*) represented 54% of the total. Most catches were from the river bed, using beach seines (47% of catches), castnets (29%), and gillnets (24%). In 76% of interviews, shifts in abundance of some species were attributed to the formation of the reservoir. The curimatã was reported to have increased and the large migratory catfishes to have undergone a general decline (ELETRONORTE 1989).

Barthem *et al.* (1991) presented evidence that the large migratory catfish (*Brachyplatystoma filamentosum*, *B. flavicans*, *B. vaillantii*, *Goslinia platynema* and *Lithodoras dorsalis*) spawn in the headstreams of the Amazon and its tributaries and that the Amazon estuary is the main nursery ground for their alevins. The impact of hydroelectric dams on populations of these species was also discussed as an impediment to fish migration upstream and larval migration downstream—provided that the views of Barthem *et al.* (1991) are correct.

Fisheries in the reservoir. From October 1987 to September 1988, 1424 t (5.0 kg/ha/yr) of fish were

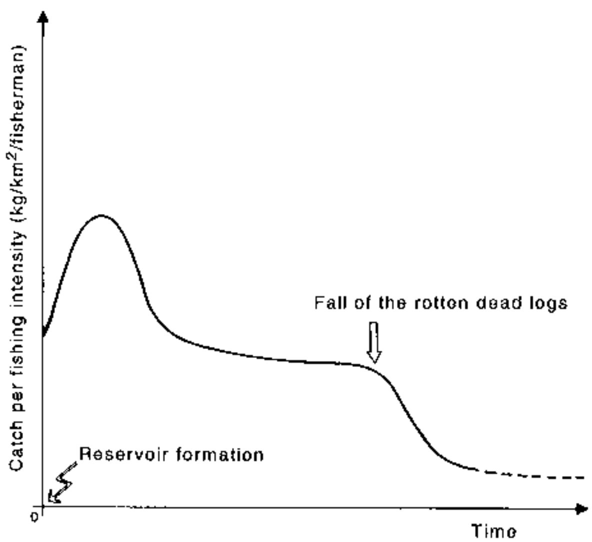

Fig. 6. Predicted fish production (kg/km²/fisherman) in time after dam closure in a reservoir (After Petrere 1992).

caught in the Tucuruí Reservoir. Of this total, the tucunaré (*Cichla* spp.) contributed 57% of catches, and the pescada (*Plagioscion* spp.), 21% by weight. A total of 49 fish species was involved. This indicated that species richness (but not species composition, which could be expressed in a descriptive species abundance relation, e.g. lognormal) in the reservoir did not change after dam closure. The main types of fishing gear employed were rod and line (68%) and gillnet (20%). Rare species were caught in small numbers by castnet and longline (ELETRONORTE/ENGEVIX/THEMAG 1989). Thus, fisheries in the reservoir itself are very different from those above it.

In 1988, there were 800 licensed fishermen operating on the reservoir. Licenses are highly valued by the professional fishermen, according to interviews. Professional fishermen claimed that in the reservoir fish stocks are more abundant and chances of catching fish are higher than in the river. Presently, it is estimated that 2300 fishermen (0.8 fisherman/km^2) operate on the reservoir. In 1993, they caught 1726 t (750 kg/fisherman/yr) (Amaral 1994).

The increase in fish abundance in the reservoir, compared to the river, is due to the occurrence of drowned vegetation which seems to benefit fisheries because the highest catches are from this biotope (Edington & Edington 1979; ELETRONORTE/ENGEVIX/THEMAG 1989). In addition to acting as a nutrient reserve and so increasing primary production, in Tucuruí—where decomposition is probably predominantly anaerobic (Caufield 1982)—submerged logs provide a highly suitable surface for incrustations of algae and invertebrates upon which fish feed. This augmented abundance may not be sustainable, however, as dead logs rot and sink so that the general productivity may drop, as hypothesized in Fig. 6. Note here the conflict between submerged trees as a health problem as they assist mosquito larvae to increase, and as a benefit to fisheries. Paiva (1988) discussed the deforestation of large reservoir basins and argued in favour of zoned deforestation. He took into account future uses and the commercial value of wood in areas to be deforested. Total deforestation may not be a good strategy for it may be an extremely expensive exercise in an Amazonian reservoir.

Fisheries below the reservoir. Below the dam fisheries greatly diminished, with a fall of 65% in the two years following dam closure (Collart 1986). Presently, it seems that there is a slow recovery of stocks, with the mapará (*Hypophthalmus* spp.) and the curimatã, which had virtually disappeared, becoming more abundant and including larger specimens in the upper stretches near Tucuruí. Ribeiro, Petrere and Juras (1995) have provided more information about impacts.

Impacts on human populations

In the reservoir area. The main negative impact that Tucuruí has caused upon the human riverine population in the reservoir area is an infestation of the mosquito 'muriçoca' (*Mansonia titilans*). This transmits two different arboviruses to humans and comprises 98% of mosquitoes caught in the area. Populations of the voracious hematophagous mosquito 'mutuca cabo verde' (*Lepiselaga crassipes*), whose bites wound the skin, have also increased. Both species of mosquito breed in the roots of the macrophytes *Salvinia auriculata* and *Eichhornia crassipes* which are very abundant in the reservoir. Immediately after dam closure, when the macrophytes started to develop, scientists from INPA (Instituto Nacional de Pesquisas da Amazônia) detected increasing numbers of muriçoca, with a biting incidence reaching an average of 500 bites/man/hour. In a report to ELETRONORTE (Centrais Elétricas do Norte do Brasil S/A) (1989), INPA's scientists drew attention to the seriousness of the problem, and noted that this mosquito has a dispersal radius of up to 30 km so that the level of infestation first detected could make the region uninhabitable. According to local populations, these mosquitoes were present in the reservoir area before impoundment, but in low densities. A plague of muriçoca started in 1985 in the localities 'Vicinal 45' and 'Gleba Parakanã' four months after dam closure. Since then, the problem has expanded. The incidence of this mosquito is high all year but worsens at the beginning of the rainy and dry seasons. They attack day and night but with higher intensities at sunset and sunrise. During daytime, they remain in foliage but bite when the vegetation is touched, so disrupting farmwork. During the night, they disturb sleepers. They attack and can cause the death of young domestic animals such as cattle and fowl. As a result, many settlers have had to leave their land, which is then bought cheaply by cattle ranch owners. After 1987, the mutuca also started to increase in density. Dr Inocêncio Gorayeb, an entomologist of the MPEG (Museu Paraense Emílio Goeldi) has suggested that ELETRONORTE should lower the water-level of the reservoir by 1 m to control macrophytes. Stranded macrophytes would die on the dry beach. Dr Gorayeb has also reported from settlers that ELETRONORTE has provided DDT tablets to be burnt in fires or dispersed by smoke and intended to control mosquitoes.

The main reasons for mosquito infestations according to the Commission of 13 different institutions are (ELETRONORTE 1989): (i) the formation of the lake provided an extensive surface for mosquito proliferation; (ii) as the original forest was not cleared, the dead logs form a nutrient reserve, so enhancing macrophyte proliferation and thereby aiding mosquito reproduction; (iii) there is an increased number of secondary mosquito breeding places due to human occupation; (iv) an increase in the density of wild animals, concentrated in a smaller area after dam closure, and the intensification of human occupation on the lake margins as well as the presence of many domestic animals provided potential sources for mosquito feeding.

The recommendations of the Commission to solve this problem may be classified in three ways:

(1) Actions in the lake, the primary focus of infestation: (i) remove submerged dead logs, as the higher densities of macrophytes are in areas of 'paliteiros' (Portuguese for the standing dead logs); (ii) attempt to use the macrophytes as a source of energy, fertilizer and foodstuffs. The phytomass in the areas invaded by the macrophytes was estimated as 300 t/ha; (iii) set up programs to raise buffaloes, which besides feeding on macrophytes, produce insecticidal faeces.

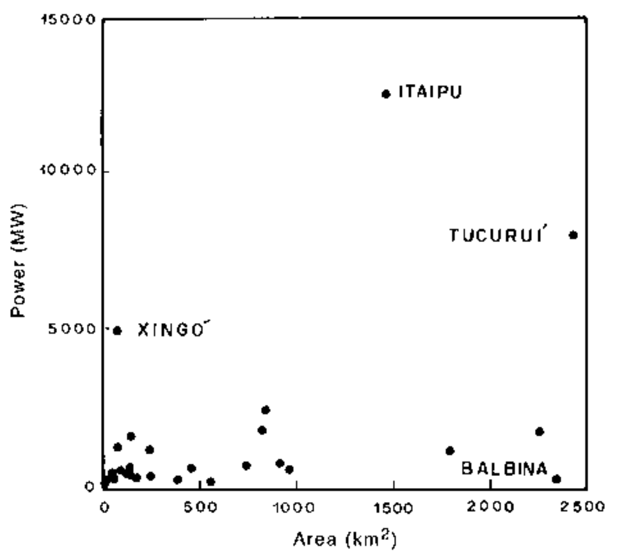

Fig. 7. Power (MW) X inundated area (km²) for some selected Brazilian reservoirs. These data are illustrative only; they are not from random sampling of existing reservoirs in the country (After Petrere 1992).

(2) Actions in the secondary breeding places, around villages: (i) clear small streams, and so drain stagnant water; (ii) eliminate mosquito larvae by biological control.

(3) Actions for individual protection: (i) screen houses; (ii) use mosquito nets.

Below the reservoir

After dam closure, 80–90% of sediment carried by the Tocantins River is retained in the reservoir due to the presence of the dam. Lacking annual sediment renewal, islands in the lower Tocantins, originally areas of sedimentation, are now eroding. The loss of nutrients seems to be affecting the growth of açaí (*Euterpe oleracea*) and buriti (*Mauritia vinifera*), both important agricultural crops. These now need additional fertilizer (P. Magee & M. Brasil pers. comm.). Following the decrease in agricultural productivity, farmers are migrating to Belém, the capital city of Pará State.

The intake of water for the turbines is 30 m below the surface of the reservoir. As a result, this water, which constitutes most of the waterflow in summer, is of low quality. It is not potable, because it tastes and smells of H_2S. Inhabitants of the small village of Nazaré dos Patos need to walk considerable kilometers in this season to obtain clean water from a small creek because, ironically, a well built by ELETRONORTE dries out in summer. The outflow water appears rich in filamentous algae for professional fishermen complain that it is not possible to use gillnets in the reservoir because nets quickly become clogged with a green slime. Moreover, the occasional fish that is caught has a bad taste (Ribeiro & Petrere 1988).

Tucuruí Reservoir is not compared with less familiar Amazonian reservoirs. Even so, it is stressed that Tucuruí has some positive impacts. Balbina Reservoir, constructed on the black-water River Uatumã near Manaus, on the other hand, seems to have provoked an irreversible ecological disaster (Fearnside 1990; Noda & Noda 1990). Figure 7 plots power production (MW) against inundated area (km²) for some Brazilian reservoirs representative of their size class. Note that Balbina has the least efficiency (efficiency = generated power/inundated area). Paiva (1982) has discussed general ideas about impacts of large reservoirs.

Itaipu Reservoir (Brazil)

Of the main river basins in South America, the Paraná is the one most intensively dammed, primarily for hydropower. By the end of the twentieth century, it is expected that 69 hydro-electric reservoirs of area greater than 200 ha will have been built in the Brazilian portion of the basin alone. The 45 extant reservoirs have transformed the main Paraná tributaries (Grande, Paranaíba, Tietê, Paranapanema, Iguaçu) into a succession of lakes. Only 483 km of the original 809 km of the river are now flowing. The construction of the Porto Primavera dam, planned for 1995, will decrease the proportion flowing to less than 50%. Later, the construction of the Ilha Grande Reservoir will eliminate the last lotic stretch of the river, after the last Brazilian stretch of 30 km, below the Itaipu Reservoir, has been dammed by the Argentinean–Paraguayan reservoir at Corpus. These dams, combined with excessive human population density, have contributed to a reduction in catches and the disappearance of large migratory fish species, mainly in the upper reaches of the Paraná River (Agostinho *et al.* 1994).

The Paraná basin has a drainage area of 2 800 000 km². It is the second largest basin in South America after the Amazon basin. Its main tributary, the Paraná, is 4695 km long and formed by the Rivers Paranaíba and Grande (Fig. 1). Petrere and Agostinho (1993) presented a detailed review of the fisheries in the Brazilian portion of the Paraná basin, and Espinach Ross and Delfino (1993) one for the Argentinean/Paraguayan portion of the basin.

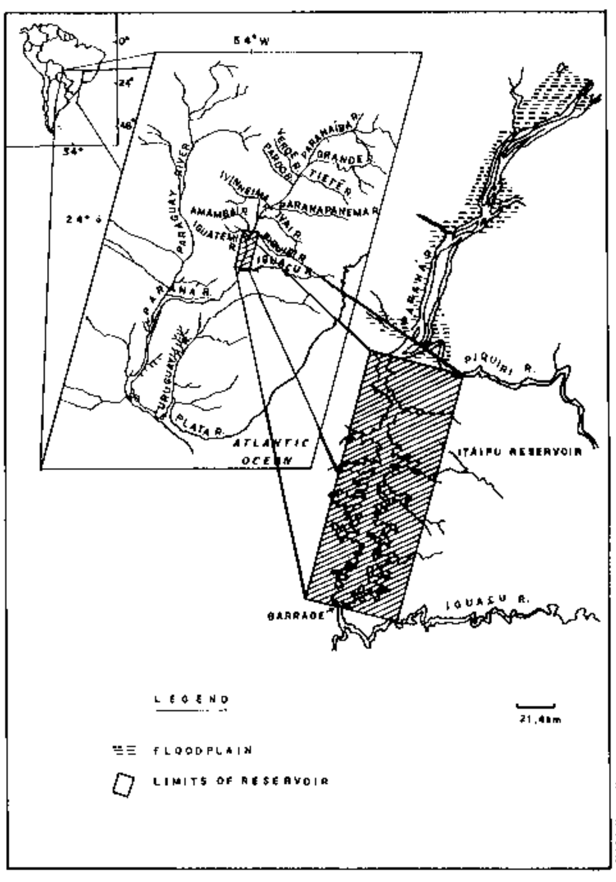

Fig. 8. Area affected by Itaipu Reservoir.

Bonetto (1986) estimated that the Paraná basin contains 600 fish species, predominantly Characiformes and Siluriformes. Petrere and Agostinho (1993), compiling information from different sources, presented a detailed list of fish species of the basin.

The Itaipu Reservoir (Fig. 8) was completed in 1983. It inundated an area of 1350 km², generated a nominal capacity of 12 600 MW (9.33 MW/km²), and has a mean water residence time of 40 days. The Carlson index for phosphorus and chlorophyll indicates that it is mesotrophic, but with eutrophic areas in bays during some of the year. Among factors that may limit its primary production are the low concentrations of phosphorus in the winter and spring (<0.010 mg/L), the abiotic turbidity due to clay in summer, and the low ratio Z_{eu}/Z_{max} (euphotic zone to maximum depth ratio) (Andrade *et al.* 1988).

The reservoir has an annual cycle of thermal stratification (spring–summer). Brunkov *et al.* (1988) gave the reasons for stratification as: (i) the water intake for the turbines is too near the water surface (20 m); (ii) the great depth of the main channel; (iii) the wide variation in annual water temperature (14°C) contributes colder water in autumn–winter, and warmer water in the summer. Although it is completely oxygenated during mixing, there are some anoxic pockets in the metalimnion, and low oxygen concentrations occur in the hypolimnion during stratification.

Professional fisheries in the reservoir only commenced in February 1984. Before then and just after dam closure, they were forbidden by law. This was to avoid intense catches of juveniles of dourado (*Salminus maxillosus*), piracanjuba (*Brycon orbignyanus*) and other fish species.

An efficient collection system for catch and effort data was set up by the Universidade Estadual de Maringá (UEM) from January 1987 to December 1993. ITAIPU BINACIONAL, the hydro-electric agency which runs the dam, discontinued this for bureaucratic reasons, but efforts were exerted by the University to resume it. In the system, individual fishermen completed a form giving information about each trip, the amount of fish caught (kg) by species, the type and the amount of gear employed, etc. The reservoir was divided into three zones: (i) fluvial, a predominantly lotic habitat; (ii) transitional, influenced by tributaries of medium size; and (iii) lacustrine, a predominantly lentic habitat.

The number of fishermen (~900) was constant during the period, and was evenly distributed in the three habitats. Most (51%) employed gillnets, with meshes ranging from 7 to 24 cm aperture, 50 m long on average, and 2 m deep. In 1987, 83% of the professional fishermen employed 614 km of gillnets in the reservoir. The nets were mainly set for sardela (*Hypophthalmus edentatus*), curimba (*Prochilodus lineatus*) and curvina (*Plagioscion squamosissimus*). The longline, employed by 21% of fishermen, was set only in the transitional zone (43% of fishermen) and baited with seasonal fruits for catching the armado (*Pterodoras granulosus*). Professional and sport fisheries were permanently forbidden in the reservoir's tributaries. The average number of hooks per longline was 75 (150 m length of nylon filament) and of different sizes. The castnet (3 m high) was employed only in the reservoir entrance. It was used by 6% of professional fishermen for catching the cascudo preto (*Rhinelepis aspera*) and cascudo-abacaxi (*Megalancystrus aculeatus*). Over the period, 700 000 m^2 of gillnets were employed annually, as well as 17 000 hooks and 50 castnets. In the reservoir, professional fisheries were permitted all year (Petrere & Agostinho 1993; Okada, Agostinho & Petrere, unpubl. data).

The main fish species caught in the period 1987–93 were sardela (*Hypophthalmus edentatus*), curvina (*Plagioscion squamosissimus*), curimba (*Prochilodus lineatus*), and armado (*Pterodoras granulosus*). They accounted for 76% of total landings. Table 3 shows the values for the total catches (and for fishing effort) from 1987 to 1983 according to Okada, Agostinho and Petrere (unpubl. data). Given an area of 135 000 ha, the average productivity in the reservoir for the period was 11.6 kg/ha/year. This productivity is higher than for other reservoirs in the Paraná basin (Petrere & Agostinho 1993).

Table 3. Total catch and fishing effort for the commercial fisheries of Itaipu Reservoir from 1987 to 1993 (Okada, Agostinho & Petrere, unpubl. data).

Year	Total catch (t)	Fishing effort[1]
1987	1562.2	67 525
1988	1499.7	74 332
1989	1 726.68	89 562
1990	1426.9	89 609
1991	1588.7	99 911
1992	1572.3	99 072
1993	1542.0	120 800

[1]Number of fishermen × number of days of fishing.

Although total catches were approximately constant for the period (CV = 5.9%), fishing effort rose steadily. Applying Schaeffer's model to the data:

$$C = 0.03563089.f - 0.000000175.f^2 \ (F = 718.6^{**}, \ r^2 = 99.7\%; n = 7)$$

The maximum sustainable yield is 1609 t, corresponding to an optimum level of fishing effort of 95 895 fishermen each day, which was surpassed in 1991. This result is corroborated by a consistent decline in average length of the main fish species (Agostinho, Ambrosio & Benedito-Cecilio, unpubl. data). The Schaefer model applied to individual species shows the same results for sardela (*Hypophthalmus edentatus*) and curimba (*Prochilodus lineatus*). The stocks of curvina (*Plagioscion squamosissimus*) and armado (*Pterodoras granulosus*) are largely under-exploited (Agostinho, Okada & Gomes, unpubl. data).

About 50% of the total catches were taken in the transitional zone, i.e. about one-third of the reservoir area. In this region, the reservoir is wider, with a well-developed littoral zone, and receives the main tributaries. The sardela (*Hypophthalmus edentatus*) and curvina (*Plagioscion squamosissimus*) were the main species caught here, making up 60% of catches. The second zone of importance is the fluvial zone, and accounted for about 35% of total catches. This region too has important tributaries, but not much littoral zone, and is richer in nutrients. The main species caught (in ranking order in the period) were the armado (*Pterodoras granulosus*), curimba (*Prochilodus lineatus*), and cascudo preto (*Rhinelepis aspera*). The lacustrine zone was the least productive region during the period. It was responsible for only 15% of total catches. The reason for this is the absence of important tributaries, lower nutrient concentrations, and greater depth. The sardela and curvina accounted for 65% of catches here (Okada, Agostinho & Petrere, unpubl. data).

Higher catches (29%) were taken in the summer period (October to December), followed (26%) by the summer–autumn period (January to March). The gillnet catchability is enhanced in the warmer months when fish swim more actively (Okada, Agostinho & Petrere, unpubl. data).

El Guri Reservoir (Venezuela)

In Venezuela, there is no tradition of fisheries in reservoirs, despite the construction of a large number of reservoirs in the past thirty years. By 1990, there were 82, inundating 7000 km², most with areas ranging from 0.1–100 km². This lack of inland fisheries tradition is because Venezuelans are more used to consuming marine fish which are particularly plentiful in that country. With the ever-increasing human population, however, the importance of fisheries is increasing steadily, and fish exports too are becoming important for the national revenue (Novoa 1992, 1993).

The main freshwater fish landed in Venezuela come from extensive floodplain rivers, and are estimated at 30 000 t/yr. Of this catch, the reservoirs produce an estimated 500 t/yr only, of which 300 t/yr comes from the El Guri Reservoir (Novoa 1992, 1993).

Pre-impact studies were undertaken at both the El Guri Reservoir (Fig. 9) and the Brokopondo Reservoir in Surinam (Rabinovich 1977). Unfortunately, future impacts on the fish fauna were not taken into consideration. El Guri has a dam of 270 m, and inundates an area of 4300 km² in the blackwater River Caroni. It generates 6000 MW (1.40 MW/km²). Its average depth is 60 m, and this and the chemical nature of the water (acidic and nutrient-poor) give a morpho-edaphic index (MEI) estimate for a potential catch of 10 kg/ha/yr (Alvarez *et al.* 1986; *fide* Novoa 1993). Novoa *et al.* (1990), on the basis of experimental fishing in the littoral zone (depth <10 m), estimated the fish biomass as between 80 and 220 kg/ha (12 000–20 000 t); they collected 30 fish species, of which the coporo (*Prochilodus rubrotaeniatus*) was the most abundant, and responsible for nearly 65% of all experimental catches in the lake. This migratory fish species, like its congeners in South America, does not spawn in the lake, but resorbs its gonadal products. In the Caroni and Paragua Rivers, small specimens have been caught, as well as juveniles in the floodplain lakes around the reservoir. Only fish older than three years are later found in the reservoir. Other important fish species are the carnivores and piscivores curvinata (*Plagioscion squamosissimus*), pavón (*Cichla orinocensis, C. temensis*), aimara (*Hoplias macrophthalmus*), and caribe blanco (*Serrasalmus rhombeus*). Novoa *et al.* (1990) noted that this reservoir has an extensive drainage basin of 1000 km² which is forested with a diverse vegetation dominated by savannah. Annually, huge amounts of allochthonous material are transported and this would serve to enhance fish stocks.

Besides commercial fisheries in the reservoir, there are also sport fisheries based on the pavón (*Cichla orinocensis* and *C. temensis*).

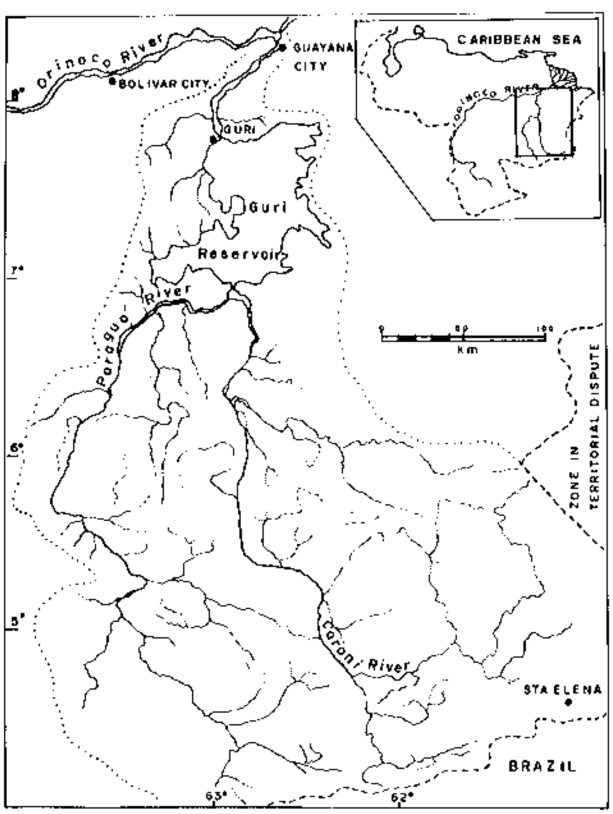

Fig. 9. Area effected by El Guri Reservoir (After Rabinovich 1977).

ACKNOWLEDGEMENTS

Dr Rosemary H. Lowe-McConnell kindly reviewed the manuscript. Dr Robin L. Welcomme, FAO/UN, Rome, is thanked for his support and friendship.

REFERENCES

Agostinho A. A. (1994) Considerações acerca de Pesquisas, Monitoramento e Manejo da Fauna em Empreendimentos Hidrelétricos. In: *Seminário sobre Fauna Aquática e o Setor Elétrico Brasileiro, Caderno 1—Fundamentos* pp. 34–51. MME/ELETROBRÁS/COMASE, Rio de Janeiro, Brazil.

Agostinho A. A. and Júlio H. F. (in press). Peixes da bacia do alto rio Paraná. In: *Ecologia de Comunidades de Peixes Tropicais* (R. H. McConnell Translation by A. E. A. M. Vazzoler, A. A. Agostinho and P. Cunninghan). EDUSP, São Paulo, Brazil.

Agostinho A. A., Julio H. F. & Petrere M. (1994) Itaipu reservoir (Brazil): Impacts of the impoundment on the fish fauna and fisheries. In: *Rehabilitation of Freshwater Fisheries* (ed. I. G. Cowx) pp. 161–84. Fishing News Books, Oxford.

Allendorf F. W. (1991) Ecological and genetic effects of fish introductions: Synthesis and recommendations. *Can. J. Fish. Aquat. Sci.* **48** (Suppl. 1), 178–81.

Alvarez E., Balbás L. & Pacheco J. (1986) Aspectos ecológicos del embalse de Guri. *Interciencia* **11**, 325–33.

Amaral B. D. (1994) *Relatório: Diagnóstico Ambiental da Atividade Pesqueira e Sistema de Monitoramento e Vigilância nas Unidades Demonstrativas 1, 2 e 3 do Programa Piloto Para a Proteção das Florestas Tropicais do Brasil.* Instituto População, Sociedade e Natureza, Brasília.

Andrade L. F, Brunkov R. F., Xavier C. F. & Domingues L. L. (1988) Fitoplâncton e características físico-químicas do reservatório de Itaipu–Br. In: *Limnologia e Manejo de Represas. Série Monografias em Limnologia* (ed. J. G. Tundisi) Vol. 1 pp. 205–68. EESC/USP/CRHEA/ACIESP, São Paulo, Brazil.

Balon E. K. (1974) Fish production of a tropical ecosystem. In: *Lake Kariba, a Man-made Tropical Ecosystem in Central Africa* (eds E. K. Balon & A. G. Coche) pp. 253–676. Monographiae Biologicae, No. 24, Part II. Dr W. Junk, The Hague.

Barthem R. B., Ribeiro M. C. L. B. & Petrere M. (1991) Life strategies and some long-distance migratory catfish in relation to hydroelectric dams in the Amazon basin. *Biol. Conserv.* **55**, 339–45.

Baxter R. M. (1977) Environmental effects of dams and impoundments. *Ann. Rev. Ecol. Syst.* **8**, 255–83.

Bayley P. B. (1988) Accounting for effort when comparing tropical fisheries in lakes, river-floodplains, and lagoons. *Limnol. Oceanogr.* **39**, 963–72.

Beiningen K. T. & Ebel W. J. (1970) Effect of John Day Dam on discharged nitrogen concentrations and salmon in the Columbia River. *Trans. Am. Fisheries Soc.* **4**, 64–671.

Bernacsek G. M. (1984) Guidelines for dam design and operation to optimize fish production in impounded river basins (based on a review of the ecological effect of large dams in Africa). *CIFA Technical Paper* **11**, 1–98.

Bini L. M. (1993) Impactos das Barragens sobre a Migração de Peixes. Manuscript, EESC/CRHEA/USP, Brazil.

Bonetto A. A. (1986) The Paraná river system. In: *The Ecology of River Systems* (ed. B. R. Davies & K. F. Walker) pp. 541–56, Dr Junk Pub., The Netherlands.

Brinkhurst R. O. (1974) *The Benthos of Lakes.* Macmillan, London.

Britski H. A., Sato Y. & Rosa A. B. S. (1984) *Manual de Identificação de Peixes da Região de Três Marias. (Com Chaves de Identificação para os Peixes da Bacia do São Francisco).* Câmara dos Deputados/CODEVASF, Brasília.

Britski H. A. (1994) A fauna de peixes brasileiros de água doce e o represamento de rios. In: Seminário sobre Fauna Aquática e o Setor Elétrico Brasileiro, Caderno 1—Fundamentos, pp. 24–8, MME/ELETROBRÁS/COMASE, Rio de Janeiro, Brazil.

Brunkov R. F., Andrade L. F. & Xavier C. F. (1988) Processo de estratificaçao térmica e oxigênio dissolvido no reservatório de Itaipu. In: *Limnologia e Manejo de Represas. Série Monografias em Limnologia* (ed. J. G. Tundisi) Vol. 1 pp. 269–98. EESC/USP/CRHEA/ACIESP, São Paulo, Brazil.

Cáceres O., Tundizi J. G. & Castellan O. A. M. (1987) Residues of organochloric pesticides in reservoirs in São Paulo State. *Ciência e Cultura*, **39**, 259–64.

Calheiros D. F. (1993) Ecotoxicologia de Compostos Organoclorados Persistentes em um Ecossistema Eutrófico: Represa de Barra Bonita (Médio Tietê–SP). MSc Thesis, EESC–USP, São Carlos, Brazil.

Capeleti A. R. (1993) *A Migração e a Dinâmica da População do Curimbatá* (Prochilodus lineatus) *Revisitado na Cachoeira de Emas no Rio Mogi-Guaçu (SP).* UNESP-Departamento de Ecologia. Monografia de Bacharelado.

Caughley G. (1977) *Analysis of Vertebrate Populations.* Wiley, Chichester.

Caufield C. (1982) Brazil, energy and the Amazon. *New Scientist* **96** (1329), 240–3.

CEPED (1983) *Acompanhamento Evolutivo. Relatório Outubro/82-Janeiro/83.* Secretaria do Planejamento, Ciência e Tecnologia. Governo do Estado da Bahia, Brazil.

CEPED/PROTAM (1987) *Diagnóstico do Acompanamento Evolutivo das Pescas no Reservatório de Sobradinho, 1982/1986.* Sobradinho, Bahia, Brazil.

CET/ELETRONORTE (1988) Subsídios para a normatização da atividade pesqueira no reservatório. Estudo da alimentação e reprodução da pescada. Relatório TUC - 10-26438 - RE.

Collart O. O. (1986) *Estudos da ecologia e controle ambiental na região do reservatório da UHE Tucuruí.* Relatório Setorial. Covênio ELN/CNPq/INPA.

Costa A. L. B. M. (1990) O leitor pergunta. *Ciência Hoje* **11**, 14–15.

Dolman W. B. (1990) Classification of Texas reservoirs in relation to limnology and fish community associations. *Trans. Am. Fish. Soc.* **119**, 511–20.

Edington J. M. & Edington M. A. (1979) *Ecology and Environmental Planning.* Chapman & Hall, New York.

ELETRONORTE (1989) Relatório da Comissão de Estudos da Proliferação de Mosquitos á Montante de Tucuruí. Unpubl. Report.

ELETRORTE/ENGEVIX/THEMAG (1989) UHE Tucuruí. Plano de Utilização do Reservatório. A Pesca nas Areas de Influência e de Jusante. Caracterização Preliminar. Relatório TUC 1026443-RE.

Encyclopaedia Britannica (1981) Dam. *Macropaedia* **5**, 440–6.

Espinach Ross A. & Delfino R. (1993) Las pesquerias de la cuenca del Plata in Bolivia, Paraguay, Argentina y Uruguay. *FAO FIP/R490.* 37–51.

Esteves F. A., Amorim J. C., Cardoso E. L. & Barbosa F. A. R. (1985) Caracterização limnológica preliminar da represa de Três Marias (MG) com base em alguns parâmetros ambientais básicos. *Ciência e Cultura* **37**, 608–17.

Estrada M. (1975) Statistical considerations of some limnological parameters in Spanish reservoirs. *Verh. Internat. Verein. Limnol.* **19**, 1849–59.

Estrada M. (1978) Relationships among biological and physicochemical parameters in Spanish reservoirs. *Verh. Internat. Verein. Limnol.* **20**, 1642–6.

Fearnside P. M. (1990) Balbina: Lições trágicas na Amazônia. *Ciência Hoje* **11**, 34–40.

Fernando C. H. (1991) Impacts of fish introductions in tropical Asia and America. *Can. J. Fish. Aquat. Sci.* **48** (Suppl. 1), 24–32.

Fernando C. H. & Holcik J. (1991) Fish in reservoirs. *Int. Revue ges. Hydrobiol.* **76** (2), 149–67.

Godinho H. P., Godinho A. L., Formagio P. S. & Torquato V. C. (1991) Fish ladder efficiency in a southeastern Brazilian river. *Ciência e Cultura* **43** (1), 63–7.

Goodland R. J. A. (1978) *Environmental Assessment of the Tucuruí Hydroproject, Rio Tocantins, Amazonia, Brazil.* ELETRONORTE, Brasília.

Goodland R. J. A., Juras A. & Pachauri R. (1993) Can hydro-reservoirs in tropical moist forests be environmentally sustainable? *Envir. Conserv.* **20** (2), 122–30.

Goulding M. & Ferreira E. J. G. (1984) Shrimp-eating fishes and a case of prey-switching in Amazon rivers. *Revta. brasil. Zool.* **2** (3), 85–97.

Gurgel J. J. S. & Oliveira A. S. (1987) Efeitos da introdução de peixes e crustáceos no semiárido do Nordeste brasileiro. *Coleção Mossoroense* **453B**, 6–32.1.

Hahn N. S. (1991) Alimentação e dinâmica da nutrição da curvina *Plagioscion squamosissimus* (Heckel, 1940) (Pisces, Perciformes) e aspectos da estrutura trófica da ictiofauna acompanhante no rio Paraná. PhD Thesis, UNESP, Rio Claro, Brazil.

Jorgensen S. E. & Vollenweider R. A. (1993) *Guidelines of Lake Management. Volume 1. Principles of Lake Management.* ILEC/UNEP, Otsu.

Kimmel B. L., Lind O. T. & Paulson L. J. (1990) Reservoir primary production. In: *Reservoir Limnology: Ecological Perspectives* (eds K. W. Thornton, Kimmel B. L. & Payne F. E.) pp. 133–94. Wiley-Interscience, New York.

Leite R. A. N. (1993) Efeitos da Usina Hidroelétrica de Tucuruí Sobre a Composição da Ictiofauna das Pescarias Experimentais de Malhadeiras Realizadas no Baixo Rio Tocantins (Pará). MSc Thesis, INPA/FUA, Manaus.

Magurran A. E. (1988) *Ecological Diversity and its Measurement.* Croom Helm, London.

Margalef R. (1975) Typology of reservoirs. *Verh. internat. Verein. Limnol.* **19**, 1841–8.

Margalef R. (1983) *Limnología.* Ediciones Omega, Barcelona.

Marshall B. E. (1984) Predicting ecology and fish yields in African reservoirs from preimpoundment physicochemical data. *CIFA Tech. Pap./Doc. Tech. CPCA* **12**, 1–26.

Mayer M., Takino M. & Stempniewski H. L. (1981) Avaliação toxicológica de metais em águas represadas do Sudeste de São Paulo, Brazil. *B. Inst. Pesca* **8**, 119–30.

Moureau J., Ligvoet W. & Palomares M. L. (1990) Trophic relationship in the fish community of Lake Victoria, with emphasis on the impact of Nile Perch (*Late niloticus*). ICES, Poster C. M. 1990/L:59. Session Q, Copenhagen.

Mundie J. H. (1979) The regulated stream and salmon management. In: *The Ecology of Regulated Streams* (eds J. V. Ward & Stanford J. A.) pp. 307–20. Plenum Press, New York.

Noda S. N. & Noda H. (1990) A água envenenada. *Ciência Hoje* **11**, 40–2.

Novoa D. (1992) Manejo de embalses con fines piscicolas. Informe Venezuela. In: *Manejo y Explotacion acuicola de Embalses de Agua Dulce en America Latina.* pp. 163–83. Documento de Campo no. 1. Proyecto Aquila II, FAO, GCP/RLA/102/ITA, Mexico.

Novoa D. (1993) Manejo Acuicola de Embalses en Venezuela. In: *Avances en el Manejo y Aprovechamiento Acuicola de Embalses en America Latina y el Caribe* (eds. J. R. J. Palacios & Varsi E.)

pp. 151–62 Documento de Campo no. 8. Proyecto Aquila II, FAO, GCP/RLA/102/ITA, Mexico.

Novoa, D., Koonce J., Locci A. & Ramos F. (1989) La ictiofauna del Lago de Guri: Composicion, abundancia y potencial pesquero. II. Evaluacion del potencial pesquero del lago de Guri y estrategias de ordenamiento pesquero. *Memoria* **131–2**, 159–97.

Okada E. K, Agostinho A. A. & Petrere M. (1996) Catch and effort data and the management of the commercial fisheries of Itaipu reservoir in the upper Paraná river, Brazil. In: *Stock Assessment in Inland Fisheries* (ed. I. G. Cowx) pp. 155–61. Fishing News Books, Bodman.

Paiva M. P. (1983) *As Grandes Represas do Brasil.* Editerra Editorial, Brasília.

Paiva M. P. (1988) Deforestation of large reservoirs. *Reg. Riv: Res. Manag.* **2**, 57–60.

Paiva M. P., Petrere M., Petenate A. J., Nepomuceno F. H. & de Vasconcelos E. A. (1994) Relationship between the number of predatory fish species and fish yield in large North-eastern Brazilian reservoirs. In: *Rehabilitation of Freshwater Fisheries* (ed. I. G. Cowx) pp. 120–9. Fishing News Books, Bodman.

Petrere M. (1986) *Fisheries and fish farming assessment at Itaparica (Northeast Brazil). Consultant's Report to the World Bank.* Washington DC, USA.

Petrere M. (1989) River fisheries in Brazil: A review. *Reg. Riv.* **4**, 1–16.

Petrere M. (1992) As comunidades humanas ribeirinhas da Amazônia e suas transformações sociais. In: *Populações Humanas, Rios e Mares da Amazônia* (ed. A. C. Diegues) pp. 31–68. Proceedings of the IV Encontro de Ciências Sociais e o Mar no Brasil, São Paulo: PPCAUB-USP.

Petrere M. & Agostinho A. A. (1993) La pesca en el tramo brasileno del rio Paraná. *FAO FIP/R490* Rome, Italy.

Petts G. E. (1988) *Impounded Rivers. Perspectives for Ecological Management.* Wiley, Wiltshire.

Prat N. (1978) Benthos typology of Spanish reservoirs. *Verh. Internat. Verein. Limnol.* **20**, 1647–851.

Quirós R. (1988) Estruturas para asistir a los peces no salmónidos en sus migraciones: America Latina. *COPESCAL. Documento Técnico, 5.* 50p.

Rabinovich J. E. (1977) *Modelo Guri. Analisis de un Conflicto de Intereses en el Uso de Recursos Naturales en una Cuenca Tropical.* IVIC, Caracas, Venezuela.

Raymond H. L. (1979) Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake river. *Transactions of the American Fisheries Society* **108**, 505–29.

Ribeiro M. C. L. B. & Petrere M. (1988) *Viagem de Reconhecimento ao Rio Tocantins e Baixo Rio Araguaia entre 20/1/88 a 8/12/88.* Consultancy Report to UNDP/ELETRONORTE, Brasília.

Ribeiro M. C. L. B, Petrere M. & Juras A. A. (1995) Ecological integrity of the Araguaia-Tocantins river basin, Brazil. *Reg. Riv. Res. Manag.* **11**, 325–50.

Ross S. T. (1991) Mechanisms structuring stream fish assemblages: Are there lessons from introduced species? *Envir. Biol. Fish.* **30**, 359–68.

Santos G. M., Jegu M. & Merona B. (1984) *Catálogo de Peixes Comerciais do Baixo Rio Tocantins.* Projeto Tucuruí, ELETRONORTE/CNPq/INPA, Manaus.

Sato Y., Cardoso E. L. & Amorim J. C. C. (1988) *Peixes das Lagoas Marginais do Rio São Francisco a Montante da Represa de Três Marias.* 3rd edn. CODEVASF, Brasília, Brazil.

Shadin W. I. (1958) Probleme der Bildungdes biologischen Regimes und der Typologie in kunstlichen Seen (Stauseen). *Verh. internat. Verein Limnol.* **13**, 446–54.

Showers V. (1979) *World Facts and Figures.* Wiley, New York.

Silva J. W. B. (1980) *Recursos pesqueiros de águas interiores do Brasil, especialmente do Nordeste.* Ministério do Interior, Fortaleza.

Sioli H. (1964) General features of the limnology of Amazonia. *Verh. Internat. Verein Limnol* **15**, 1053–8.

Stepanek M. (1960) Contribution to reservoir typology. *Sci. Pap. Inst. Chem. Technol.* **4** (2), 345–74.

Straskraba M. (1993) Some new data on latitudinal differences in the physical limnology of lakes and reservoirs. In: *Conferencias de Limnologia/Conferences in Limnology* (eds. A. Bolvotsky & López H. L.). pp. 19–39. Instituto de Limnología 'Dr R. A. Ringuelet', La Plata, Argentina.

Straskaba M., Tundisi J. G. & Duncan A. (1993) *Comparative Reservoir Limnology and Water Quality Management.* Kluwer Academic Publishers, Netherlands.

Tundisi J. G. (1981) Typology of reservoirs in Southern Brazil. *Verh. Internat. Verein. Limnol.* **21**, 1031–9.

Tundisi J. G. (ed.) (1988) *Limnologia e Manejo de Represas.* Série: Monografias em Limnologia, 2 vol 1, Tomo 1, 2. ACIESP, São Paulo, Brazil.

Tundisi J. G. (1990) Perspectives for ecological modelling of tropical and subtropical reservoirs in South America. *Ecol. Modelling* **52**, 7–20.

Tundisi J. G. (1993a) Represas do Paraná Superior: Limnologia e bases científicas para o gerenciamento. In: *Conferencias de Limnologia/Conferences in Limnology* (eds A. Bolvotsky & López H. L.) pp. 41–52. Instituto de Limnología Dr. R. A. Ringuelet, La Plata, Argentina.

Tundisi J. G. (1993b) VIII. Man-made lakes. Theoretical basis for reservoir management. *Verh. Internat. Verein. Limnol.* **33**, 1–4.

Tundisi J. G., Matsumura-Tundisi T. & Calijuri M. C. (1993) Limonology and management of reservoirs in Brazil. In: *Comparative Reservoir Limnology and Water Quality Management* (eds. M. Straskaba, Tundisi J. D. & Duncan A.) pp. 25–55. Kluwer Academic Publishers, Netherlands.

Tundisi J. G., Matsumura-Tundisi T., Henry R., Rocha O. & Hino K. (1988) Comparações do estado trófico de 23 reservatórios de Estado de São Paulo: Eutrofização e manejo. In: *Limnologia e Manejo de Represas* pp. 165–204. Série Monografias em Limnologia, ACIESP, São Paulo, Brazil.

Welcomme R. L. (1979) *Fisheries Ecology of Floodplain Rivers.* Longman, London.

Welcomme R. L. (1988) International introductions of inland aquatic species. *FAO Fish. Tech. Pap.* **294**, 1–318.

Welcomme R. L. (1990) Status of fisheries in South American rivers. *Interciencia* **15**, 337–45.

Zaret T. M. & Paine R. T. (1973) Species introduction in a tropical lake. *Science* **182**, 449–55.