Conservation of the Biodiversity of Brazil's Inland Waters

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Abstract: *In terms of biodiversity, Brazilian inland waters are of enormous global significance for Algae (25% of the world's species), Porifera (Demospongiae, 33%), Rotifera (25%), Cladocera (Branchiopoda, 20%), and fishes (21%). Threatened freshwater species include 44 species of invertebrates (mostly Porifera) and 134 fishes (mostly Cyprinodontiformes, Rivulidae), primarily distributed in south and southeastern Brazil. Reasons for the declines in biodiversity in Brazilian inland waters include pollution and eutrophication, siltation, impoundments and flood control, fisheries, and species introductions. These problems are more conspicuous in the more-developed regions. The majority of protected areas in Brazil have been created for terrestrial fauna and flora, but they also protect significant water bodies and wetlands. As a result, although very poorly documented, these areas are of great importance for aquatic species. A major and pressing challenge is the assessment of the freshwater biodiversity in protected areas and surveys to better understand the diversity and geography of freshwater species in Brazil. The concept of umbrella species (e.g., certain migratory fishes) would be beneficial for the protection of aquatic biodiversity and habitats. The conservation and improved management of river corridors and associated floodplains and the maintenance of their hydrological integrity is fundamental to preserving Brazil's freshwater biodiversity and the health of its aquatic resources.*

Conservación de la Biodiversidad de las Aguas Interiores de Brasil

Resumen: *En términos de biodiversidad, las aguas interiores de Brasil son de enorme importancia global para Algae (25% de las especies del mundo), Porifera (Demospongiae, 33%), Rotifera (25%), Cladocera (Branchiopoda, 20%) y peces (21%). Las especies dulceacuícolas amenazadas incluyen a 44 especies de invertebrados (la mayoría Porifera) y 134 de peces (en su mayor parte Cyprinodontiformes, Rivulidae), distribuidos principalmente en el sur y sureste de Brasil. Las razones de la declinación en la biodiversidad de aguas interiores de Brasil incluyen contaminación y eutrofización, sedimentación, represas y control de inundaciones, pesquerías e introducción de especies. Estos problemas son más conspicuos en las regiones más desarrolladas. La mayoría de las áreas protegidas en Brasil han sido creadas para fauna y flora terrestres, pero también protegen a considerable número de cuerpos de agua y humedales y, aunque muy deficientemente documentado, como tales son de gran importancia para las especies acuáticas. La evaluación de la biodiversidad dulceacuícola en áreas protegidas y muestreos para un mejor entendimiento de la diversidad y geografía de especies dulceacuícolas de Brasil son un reto mayor y apremiante. El concepto de especies sombrilla (e.g., ciertos peces migratorios) sería benéfico para la protección de biodiversidad y hábitats acuáticos. La conservación y perfeccionamiento de la gestión de corredores fluviales y las llanuras de inundación asociadas y el mantenimiento de su integridad hidrológica son fundamentales para preservar la biodiversidad dulceacuícola de Brasil y la salud de sus recursos acuáticos.*

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Introduction

Conservation awareness in Brazil has grown dramatically in the last two decades, accompanied by a proliferation of nongovernmental conservation organizations and environmental legislation. In addition, relevant government institutions have been consolidated and expanded, which led to the creation of the Brazilian Ministry of the Environment. Numerous protected areas have been created since the early 1980s, and the media has given increasing attention to wildlife conservation

About 14% of the world's species can be found in Brazil (Lewinsohn & Prado 2002). This extraordinary biodiversity is, however, still poorly known. To examine this notion, we carried out a literature survey (papers published from 1990 to 12 December 2004) on the Web site of the Institute for Scientific Information (Thomson Corporation 2005) with the words *Brazil* and *biodiversity*. It produced 217 results—a very low figure that is, it would seem, typical of the Neotropical region, except for the few countries that host major international biodiversity research institutions, such as Costa Rica and Panama.

Of the 217 hits for Brazil, 69% referred specifically to terrestrial ecosystems and only 11% to freshwater. The rest referred to marine and other smaller biomes. As is true for terrestrial biodiversity, studies in freshwater are strongly biased toward larger, more appealing organisms. Unsurprisingly, fish have been studied the most.

We examined estimates of species richness in Brazil's freshwater ecosystems—lakes, ponds, reservoirs, streams, rivers, and associated wetlands—and list the threatened species here. We also discuss the major threats to aquatic biodiversity and some strategies for its conservation.

Species Diversity

The precise number of species in Brazilian inland waters is unknown and difficult to estimate because numerous hydrographic basins have never been sampled; the number of researchers and the infrastructure required for sampling and monitoring are insufficient; aquatic inventories have, until recently, been few; information is scattered and often difficult to access; and a number of groups need major taxonomic revisions. Despite this, the numbers presented in Table 1, although undoubtedly underestimates, show some interesting patterns. Brazilian inland waters, for example, are evidently extraordinarily rich for some groups such as freshwater algae (25% of the world's species), Porifera (Demospongiae, 33%), Annelida (12%), Rotifera (25%), Cladocera (Branchiopoda, 20%), and freshwater Decapoda (10%). Recent reviews of parasites of aquatic organisms, especially fishes, have revealed a very high diversity (650 species), and this number accounts for only platyhelminths (Monogenea, Digenea, and Cestodes), acanthocephalans, and nematodes (Takemoto et al. 2004 and references therein).

Brazil is also a leader in number of freshwater fishes, with 2122 cataloged species (approximately 21% of the world list; Buckup & Menezes 2003). Isolated basins can present high endemism; for example, 60% of the 75 species of the Rio Iguaçu are endemic. Probably 30 to 40% of the Neotropical freshwater fish fauna remains undescribed, however, and the ultimate total for Brazil could be as high as 5000 species (Reis et al. 2003). Schaefer (1998) argues that, based on historical trends of species descriptions, the total could be over 8000. The number estimated to occur in the Amazon alone is 2000 (Winemiller et al. 2005). Approximately 400 new species of freshwater fishes are described each decade, and Vari and Malabarba (1998) posit an eventual 50% increase in fish species richness worldwide (approximately 33,000), with Neotropical fishes (8,000) contributing 24% of the total. Neotropical fishes contribute 13% of all vertebrate biodiversity, occurring in <0.003% (by volume) of the total world's water. In addition, there are 732 amphibian species in Brazil (approximately 13% of the world's total), most of them with an obligatory freshwater stage (IUCN et al. 2004).

Number and Distribution of Threatened Species

The list of aquatic threatened species presented by the Ministry of the Environment (Normative Instruction 3, 27 May 2003 and Normative Instruction 5, 21 May 2004) includes 44 invertebrates, 134 fishes, and 16 amphibians (Table 2). Of the invertebrates, most of the critically endangered species are Porifera: *Corvoheteromeyenia* and *Racekiela* in the state of Rio Grande do Sul and *Corvospongilla* in the state of Paraíba (all Spongillidae).

As Table 2 shows, 33 fishes (Osteichthyes) are critically endangered. Most of them are Cyprinodontiformes, family Rivulidae of the genera *Leptolebias* (six species in the states of Bahia and Rio de Janeiro) and *Austrolebias* (three species in Paraná and Rio Grande do Sul). Critically endangered Characiformes species include members of the genera *Brycon* (Minas Gerais, São Paulo, and Rio de Janeiro), *Hasemania* (Paraná), *Henochilus* (Minas Gerais), and *Hyphessobrycon* (São Paulo). Siluriformes genera include *Steindachneridion* (three species in Minas Gerais, Espirito Santo, and Rio de Janeiro), *Pogonopoma*, *Delturus* (both in Minas Gerais and Rio de Janeiro), and *Harttia* (Rio de Janeiro). The Perciformes genera include *Crenicichla* and *Teleocichla*, both in Pará.

All of the Brazilian states have at least one threatened aquatic invertebrate, and Rio Grande do Sul and São Paulo have the most. When analyzed by region, differences in

Table 1. Estimated number of species in freshwater environments in Brazil and the world.

Taxa	*Brazil*	*World*	*References*
Macrophytes	500–600[a]	?	Irgang & Gastal 1996; Pott & Pott 2003
Algae	10,000	37,700	Rocha 2002; Hammond 1992
Protozoa	186[b]	?	Lansac-Tôha et al. 2001
Porifera (Desmospongiae)	44	149	Volkmer-Ribeiro 1999
Cnidaria (Hydrozoa)	7	27	Silveira & Schlenz 1999
Platyhelminthes			
Turbelaria	92	4,500	Forneris 1999
Monogenea	253	?	Kohn & Paiva 2000
Digenea	80	6,000	Thatcher 1993
Cestoda	96	>1,000	Rego 2000
Acanthocephala	128	500	Amin 2000
Nematoda	93	?	Moravec 1998
Nemertinea	2	13	Forneris 1999
Gastrotricha	63	250	Forneris 1999
Nematomorpha	10	230	Forneris 1999
Bryozoa	10	50	Forneris 1999
Tardigrada	61	700	Assunção 1999
Annelida			
Oligochaeta	70	600	Steiner & Amaral 1999
Polychaeta	4	40	Righi 1999
Mollusca			
Bivalvia	115	?	Avelar 1999
Gastropoda	193	5,000	Simone 1999
Rotifera	467	2,000	Oliveira-Neto & Moreno 1999
Arthropoda			
Acari	332	14,000	Forneris 1999
Crustacea			
Copepoda	76[c]–65[d]	1,550	Matsumura-Tundisi & Silva 1999
Cladocera	112	602	Rocha 1999
Syncarida	10	160	Forneris 1999
Decapoda	116	1,000	Magalhães 1999
Insecta			
Ephemeroptera	166	2,000	Salles et al. 2004
Chironomidae	208	20,000	Mendes 2004
Odonata	661	5,300	Paulson 2004
Plecoptera	110	2,000	Froehlich 1999
Trichoptera	378	?	Paprocki et al. 2004
Megaloptera	16	300	Froehlich 1999
Pisces	2,122	10,000	Buckup & Menezes 2003
Amphibia	732	5,743	IUCN et al. 2004

[a] *Data obtained only in the south plus Pantanal.*
[b] *Testate amoebae only.*
[c] *Planktonic species.*
[d] *Nonplanktonic species.*

the number of listed species are slight: 43 in the south, 39 in the southeast, 31 in the northeast, 29 in the north, and 20 in the central west. For fish, on the other hand, only 14 states have species listed and most are found in the southeast and south in Minas Gerais, São Paulo, Rio de Janeiro, and Rio Grande do Sul. This may be a result of several factors: (1) the southeast and south are the most developed regions in the country and aquatic ecosystems have suffered accordingly, (2) most scientists studying aquatic organisms are located in these regions and more threatened species are documented as a result, and (3) there are many endemic (restricted-range) species in these regions.

Overfishing, or near overfishing, has resulted in the listing of a number of fishes: tambaqui (*Colossoma macropomum* [Characidae]) and jaraquis (*Semaprochilodus* spp. [Prochilodontidae]) from the Amazon basin, and pimelodid, migratory long-whiskered catfishes (*Brachyplatystoma vaillantii* [Amazonia], *B. filamentosum* [Amazonia], and *Zungaro zungaro* [widespread]).

Major Present and Future Threats

The most common direct causes of biodiversity loss in Brazilian inland waters are pollution and eutrophication, siltation, impoundments and flood control, fisheries, and species introductions. Threats to aquatic ecosystems vary

Table 2. Number of threatened freshwater species recognized by the Brazilian Ministry of Environment according to the categories used by The World Conservation Union (IUCN 2001).

Taxa	*Vulnerable*	*Endangered*	*Critically endangered*	*Total*
Porifera	2	6	3	11
Gastropoda	1			1
Bivalvia	12	13	1	26
Crustacea	6			6
Osteichthyes	69	32	33	134
Cyprinodontiformes	25	16	14	55
Characiformes	19	9	9	37
Siluriformes	22	6	7	35
Perciformes	1	1	3	5
Gymnotiformes	2			2
Amphibia	4	3	8	16*

**Including* Phrynomedusa fimbriata *Miranda-Ribeiro, 1923, considered extinct.*

enormously in number and importance according to the different regions of Brazil, human population density, land use, and the predominant socioeconomy. Tundisi (2003) discusses the principal threats to freshwater biodiversity by geographic region: (1) poor water treatment (especially in the north); (2) large urban areas, industry, and agriculture (southeast); (3) agriculture, industry, irrigation, and aquaculture (south); (4) water shortage (northeast); and (5) deforestation, construction of waterways and canals, predatory fisheries, and intensive cattle ranching (central west, including the Pantanal). To this list we add dam construction and poorly treated or untreated sewage (in all states <30% is treated; Tundisi 2003) in all regions of the country.

Of particular concern is that regional economic wealth does not necessarily result in increased investment to improve water quality and conserve natural water resources (Martinelli et al. 2002). The greatest threats to aquatic biodiversity are in the most developed regions. Next, we discuss some cases that illustrate the loss of aquatic biodiversity associated with or directly linked to some of these threats.

Species loss and/or alteration of community structure have been associated with pollution and eutrophication of streams and rivers (Marques & Barbosa 2001; Martinelli et al. 2002), reservoirs (Pinto Coelho 1998; Tundisi & Matsumura-Tundisi 2003), lagoons (Esteves et al. 2002), and lakes (Barbosa et al. 1993), especially in regions with high human population densities, such as São Paulo (Martinelli et al. 2002). A sharp decrease in biodiversity has also been documented in the Amazon near Manaus (Cleto Filho 2003).

Siltation is a problem in a number of Brazilian watersheds, especially when intensive agriculture reaches new frontiers. Effects on biodiversity have been documented in the Gran Pantanal (Mourão et al. 2002) and, for macroinvertebrates, in the Cerrado (Wantzen 2003), the Atlantic Forest (Buss et al. 2004), and Amazonian (Callisto et al. 1998) streams.

More than 600 impoundments (40,000 km^2; volume of 6.5×10^{11} m^3) have been constructed in Brazil, mainly to produce electricity (A.A.A., unpublished data). Dams, which have interrupted the movements of potamodromous fishes, are possibly the main factor affecting the abundance of migratory fishes (reproduction, habitat fragmentation). The biodiversity of downstream floodplains is also affected by flood control regimes through a reduction in floodplain areas, retention of nutrients, and habitat changes prompted by erosion (Agostinho et al. 2004*b*). Upstream from a dam, impacts depend on reservoir features (location, morphometry, hydrology), dam design, operational procedures, discharge, soil types, and interaction with other dams. In general, local extinctions and sharp changes in community structures result from alterations in retention time and water quality. New dam projects, which will worsen a situation already severely prejudicial to aquatic biodiversity, are concentrated in the Amazon basin and smaller rivers elsewhere. The largest rivers have already been exploited fully for their hydroelectric potential.

Species introductions are having major impacts on biodiversity in aquatic ecosystems. Fish introductions of both alien and native species are common in Brazil, and result from irresponsibility on the part of people involved in recreational fisheries, fish stocking, and aquaculture. Surveys in the Paraná basin (51 sites; 2100 samples) revealed that Amazonian piscivores are the most successful colonizers. Introduced fishes thrive in basins with high endemism and those regulated by dams (A.A.A. et al., unpublished data). Fish species richness has declined in all lakes subjected to fish introductions in the Rio Doce State Park, Minas Gerais, over the last 50 years (Godinho 1996).

Invasions by benthic invertebrates also have serious consequences. Two bivalves have invaded Brazilian waters in the last two decades: Asian clam (*Corbicula fluminea*) and Chinese freshwater mussel (*Limnoperna fortunei*) (Darrigran & Drago 2000; Takeda et al. 2004). *C. fluminea* was already registered even in the Amazon (Beasley et al. 2003) and the Pantanal (Callil & Mansur 2002). The Rio Paraná has suffered declines in the populations of a number of native bivalves concurrent with increases in *C. fluminea* densities (Takeda et al. 2004). Two introduced grasses, torpedograss (*Panicum repens* L.) and smallflowered Alexandergrass (*Brachiaria subquadripara* [Trin.] Hitchc.), dominate native species and have invaded the Pantanal (Pott & Pott 2003) and reservoirs in the Paraná basin. Given the important role of aquatic macrophytes in maintaining fish and invertebrate communities, these introductions may have far-reaching effects on the aquatic communities of these areas.

Conservation and Research Initiatives

Conservation of the terrestrial fauna and flora has been the driving force behind the establishment of most of the protected areas in Brazil in the last three decades. Many of these areas also protect significant water bodies and wetlands. Neither the terrestrial nor the aquatic fauna and flora have been surveyed, however, in most of Brazil's protected areas. Recent data show that only 5% of protected areas in the tropics have been inventoried for one or more groups of organisms (Hawksworth 1995).

Protected areas where aquatic organisms have been intensively surveyed have demonstrated their importance for biodiversity conservation. Surveys in <10% of the environmental protection area of the Upper Rio Paraná floodplain (526,000 km^2; 0.4% of the Atlantic Forest biome), for example, found about 50% of fish species and 6% of the amphibians recorded for the entire biome (Agostinho et al. 2004*b*) and 58% of the Annelida (Takeda et al. 2004), 50% of rotifers, 49% of cladocerans, 40% of testate amoebae (Lansac-Tôha et al. 2004), and 8% of the algae (Train & Rodrigues 2004) species recorded in Brazil. This testifies either to the richness of the Rio Paraná basin or the lack of equivalent surveys in the remainder of the country. An assessment of the freshwater biodiversity present in parks and reserves in Brazil, and an understanding of the geography of freshwater biodiversity, are major and pressing challenges for the next decade.

Management of aquatic resources, especially fishes, is generally opportunistic and based on poor technical and scientific information (notable exceptions include some isolated initiatives in the Amazon; Ruffino 2004). Historically, management actions include fishery control, stocking, and fish ladders (Agostinho et al. 2004*a*). Fishery control attempts to regulate the capture of juveniles (minimum length and mesh size) and safeguard spawning grounds during spawning. In reality these measures are compromised by the lack of information on the fish populations and financial resources, along with limited enforcement.

Fish stocking has never been carried out for the right reasons (such as the remediation of overfishing or to promote genetic improvement). Stocking efforts are usually cosmetic or for electoral gains—pandering, for example, to the recreational aspirations of local communities or following prescribed and ill-informed reparation for environmental damage (impoundments or accidental pollution). Systematic, informed stocking does not exist in Brazil, and basic procedures such as risk assessment and estimation of carrying capacity are ignored. In the majority of cases where introductions or translocations have been carried out, the fish were never subsequently captured (Agostinho et al. 2004*a*). Often, the wrong species is released, inadequate numbers of fry are used, fry are of the wrong size or age, the release sites are inappropriate, or the release is carried out in the wrong season—most of the attempts fail.

Fish ladders have also been unsuccessful because of their high species selectivity and the fact that they are essentially unidirectional. In the Paraná River basin, some fish ladders resulted in fish entering the reservoir, where adequate spawning sites and/or nursery areas were lacking, when they were capable of spawning below the dam (Agostinho et al. 2002). Rather than contributing to the maintenance of local populations, then, some fish ladders are promoting the extinction of the migratory species they are built to protect.

In Brazil monitoring of the results or efficacy of management actions is generally inadequate, absent altogether, or conducted only for the short term. As a result, numerous inappropriate management techniques continue to be applied, and projects, strategies, and "improvements" are developed that are founded on anecdote, impressions, and flawed systems. (This has been true for three decades of stocking programs and implementation of fish passages.) A perfect example is a recent initiative, supported by the federal government, that encourages the development of aquaculture in public waters (caging), which will inevitably result in the introduction of alien species, spread of diseases, and eutrophication, with accompanying and often toxic algal blooms.

Some important lessons have been learned from failures in the management of aquatic resources in Brazil. First, fishery management has to give equal weight to both fish production and the maintenance of biodiversity. Second, management actions must be focused on habitat integrity, especially critical areas in the basin and maintenance or appropriate regulation of the flood regime. Third, no management action should be carried out without subsequent monitoring. Lastly, fishery legislation and control require efficient communication, realism, and clarity in defining objectives, as well as full involvement of fisher organizations. The public and interested parties need to be made aware that fisheries are indicators of environmental change and therefore play a vital role in conservation (Agostinho & Gomes 2002).

Programs for the conservation of freshwater biodiversity in Brazil should consider the concept of umbrella species, as yet never applied to any aquatic ecosystems. Although most umbrella species are large mammals or birds (Roberge & Angelstam 2004), freshwater candidates include some migratory fishes, which are highly dependent on the integrity of large areas of a basin (headwaters, main channels, and associated floodplains). The laulao catfish (*Brachyplatystoma vaillantii*) and the dorado (*Salminus maxillosus*) are good candidates given their popularity for all types of fishing. The conservation of specific stretches of major rivers and their floodplains (based on the concept of river corridors and an understanding of the life cycles of key species, especially fishes) and maintenance of the hydrological integrity of the

region are fundamental to preserving Brazil's freshwater biodiversity and the health of its aquatic resources.

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