Chapter 6
Amazonia: Water Resources and Sustainability

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Abstract Water resources in Amazonia affect all natural and human-altered ecosystems in the region, including their human populations. Evapotranspiration by the Amazon forest provides water vapor that is transported by wind to other regions of Brazil and to neighboring countries. The enormous quantities of water involved in hydrological processes in Amazonia give great importance to the region's water resources and to potential impacts if these cycles are altered. The diversity of fish and other aquatic organisms is enormous, as is the importance of this fauna as economic and food resources for the human population. There are impacts from pollution, including mercury methylation in hydroelectric reservoirs. Dams also block migration of fish and alter the flooding cycles of rivers. Hydroelectric dams release methane, thereby contributing to global warming. The chemical characteristics of different types of water affect processes such as the transport of organic carbon, the supply of nutrients to the plankton that are the base of the food chain in aquatic ecosystems, and the quantity of bio-available ions that affect sensitivity of organisms to copper and other toxic elements. Several of the major rivers in the region drain more than one country, as is the case for the Madeira River, whose basin drains parts of Bolivia and Peru, in addition to Brazil. International treaties require protecting the rights of other countries that share aquatic resources in trans-border watersheds. The hydroelectric dams under construction in Brazil on the Madeira River imply a variety of impacts in the neighboring countries, including blocking the migration of large catfish. One of

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the priorities for rational decision making on aquatic resources in Amazonia is expansion of scientific knowledge on aquatic systems in the region. A series of national and international projects are engaged in improving this knowledge, and masters and PhD programs are increasing the capacity for research in the area. The human population in the region depends on the functioning of aquatic ecosystems. People share the fate of these ecosystems, in which they constitute a central component.

Keywords Biodiversity • Dam • Development • Environmental impact • Fish • Global warming • Hydrological cycle • Hydroelectric dam • Reservoir • River • Water

Characterization and Extent of Water

Only 3 % of the existing water in the world is running fresh water and of this, one fifth is due to the Amazon River's discharge into the ocean. The hydrographic basin of Amazonas is the most extensive hydrographic network in the world, spreading through all the countries in Northern Latin America, ranging from the Andean foothills all the way to the Atlantic Ocean (Eva and Huber 2005). Navigable rivers total 25,000 km. The basin covers about 7 million km^2, of which 3.8 million are in Brazil (IBGE 2007). This continental basin extends through all of the northern South America, with the Brazilian portion representing 63 %. This raises a number of transnational issues in the social, economic, biodiversity and environmental areas, among others, which require a plural analysis of the normative space and of the cultural diversity of the region. The issue of scale has had and still has profound implications for the regional planning processes, and it is not on rare occasions that it is totally neglected.

The Amazon River discharges into the Atlantic Ocean 175,000 m^3 of fresh water per second, which represents 20 % of all the fresh water entering the oceans in the entire world. The encounter of this huge volume of water with the ocean results in a very loud noise, called the "pororoca" (from the Tupi language, meaning "big bang") (reviewed by Val et al. 2006). This water volume results from the contribution of a multitude of small bodies of water that are interconnected inside the forest, and have an important role in the water cycle of the Amazonian region and of the adjacent regions. This discharge is equivalent to five times that of the Congo River (Africa) and 12 times that of the Mississippi River (United States of America). The water bodies of all forms and origins create a unique topographic plan with an extensive set of transition areas between the aquatic environment and solid soil, which (Sioli 1984) called the "aquatic landscape". More than 20 % of the Amazon region can be considered to be wetlands (Junk 2000).

Amazonian wetlands associated with the great rivers are defined as environments that periodically receive lateral inflows of water from these rivers due to annual variations in water levels. These areas cover 6 % of Brazilian Amazonia, or about 300,000 km^2, and they are classified in accordance with their fertility as várzeas (4 %) and igapós (2 %). The várzeas are areas with higher fertility and are inhabited by 90 % of the rural population of Amazonia (Junk 2000). The igapós are, in contrast, low in inorganic nutrients, rich in dissolved organic material, and their waters are extremely acid and clear, or more frequently black, in color (Sioli 1975; Furch 2000).

Environmental diversity in Amazonia is increased by the different types of water, such as the black water of the Negro River, the white water of the Amazon River and the clear water of the Tapajós River. In addition, from a biological point of view, the connection with the Orinoco Basin also has a relevant role. The Cassiquiare Channel in the upper part of the Negro River makes this connection. The main tributaries of the Orinoco River, originate in the Andes, and also bring from there, significant quantities of sediments. However, an even greater quantity of sediments, about 1.2×109 t, is transported annually by the Amazon River to the Atlantic coast (reviewed by Lara et al. 1997), where an extensive interface zone is located.

The difference in density and the volume of water cause the freshwater to move above the salt water for hundreds of kilometers, transporting the sediment directly into the Atlantic Ocean instead of depositing it as it enters the estuary. Circulation in this coastal zone is influenced by strong local currents. Approximately half of the sediments are accumulated along the coast while the other half is spread in the ocean. Thus, this interface zone, which is the largest in the world, is strongly influenced by the dynamics, of the Amazon River, with its maximum flow at the end of May and its minimum in November.

Quality and Monitoring of Water Systems

Aside from their color, waters from Amazonia also have significant chemical, physical and biological differences, which are also strongly related to their drainage areas. In fact, the muddy waters of the Solimões-Amazon system have pH close to neutral, a large quantity of suspended material originating from the Andes and from the land near the edges of the rivers, low levels of dissolved organic carbon and levels of nutrients that are relatively higher than those found in other types of water in the region. In contrast, the black waters are acid, with pH between 3.2 and 5, rich in dissolved organic carbon, particularly in humic and fulvic acids, and are severely lacking in ions, with concentrations similar to those in distilled water. In addition, water in Amazonia often undergoes episodes of low oxygen availability (Furch 1984; Val et al. 2006). The existence of a rich ichthyofauna in these environments is possible thanks to an unparalleled diversity of morphological, biochemical and physiological adjustments in order to maintain ionic homeostasis, as well as ensuring the transfer of oxygen to the tissues (Val and Almeida-Val 1995). This set of biological characteristics can be used to monitor environmental quality, since it directly correlates with the natural variations of the environment. Note, however, that changes in environmental characteristics, aside from those within their natural amplitudes, can be reflected at other levels of the biological organization (Val et al. 2003).

The biotic ligand model predicts the amount of bioavailable ions that can cause toxicity to aquatic organisms. In order to do so, the model takes into consideration several physical-chemical characteristics of the aquatic environment, including the varying “quantity of dissolved organic carbon”, which previous models did not do. The implementation of this model for fish in three different environments in Amazonia showed that the sensitivity of these animals to copper is strongly related to the levels of calcium and dissolved organic carbon in the water (Bevilacqua 2009). This model, in addition to defining molecular bioindicators for monitoring of environmental quality, is of extreme importance for Amazonia because a number of anthropogenic pressures can already be noted in the area.

Functioning of Water Systems

Due to the seasonality of rainfall, the large rivers of the region have flood pulses with cycles of high and low water levels that constitute the main driving force of the Amazonian system. Flooding can last several months. In wetlands, the interaction between the water body and the biota in the edge areas is decisive. Allochthonous primary production of riparian forests is of great importance for the food chains both in the water bodies and in the floodplains. When the water recedes, the flooded areas can be reduced to only 20 % of the total area of the aquatic phase, resulting in important ecological implications. The suppression of environments breaks the connectivity between individuals, confining and isolating organisms of many species. These communities respond adaptively to the special conditions created by the flood pulses. Many trees in the wetlands form growth rings (because of reduced rates of growth) as a response to flooding (Worbes 1997), which allows this information to be used in managing these areas, which are currently threatened by agriculture and the inadequate use of natural resources (Junk 2000) (Figs. 6.1, 6.2, and 6.3).

The changes of global climate will also affect Amazonia, where significant decreases of rainfall are predicted, at least on the eastern side of the watershed, as well as an increase in the effects of events such as El Niño and La Niña. In addition, the forecasts indicate (Junk et al. 2009):

1. That the humid coastal areas will be affected by rising sea levels and that the occurrence of fires will increase in an alarming way.
2. That the small streams and their flooded areas might dry up completely during the dry season, with severe consequences for the fauna and flora.
3. That the disconnected areas in the interfluves, especially in the cerrado (central Brazilian savanna) will experience tremendous impacts, affecting the biodiversity of these locations.

The humid areas along large rivers are relatively flexible. However, protection systems for the local human population are necessary, such as robust programs to predict the levels of the river (Schöngart and Junk 2007), so that economic activities like fishing, agriculture and timber extraction can be done in line with the fluctuations of the levels of the rivers. However, prior to the impacts of climatic changes being felt, the inadequate management of the ecosystem in flooded areas will cause significant imbalance (Junk et al. 2009).

Fig. 6.1 Spillway of the Tucuruí Dam in the Tocantins River, state of Pará. Water leaves the reservoir at a depth of 20 m, where it carried great quantities of methane. Pulverization in the form of droplets releases this greenhouse gas in the atmosphere, contributing to global warming (photograph by Philip M. Fearnside)

Diversity of Aquatic Organisms in Amazonia

In general terms, the aquatic diversity in the Amazon is composed of the same groups that are widely distributed throughout the world, in other words, by algae, surface plants, sponges, rotifers, insects, mollusks, crustaceans, amphibians, reptiles, birds, fish, and mammals, highlighting that some of these groups live in water, but spend some time on land and vice-versa. The last three of these and the aquatic plants deserve special attention due to the biomass they represent.

The fish of Amazonia stand out due to the enormous variety of species found there. They constitute 10 % of the world's freshwater ichthyofauna or 80 % of Brazilian ichthyofauna. More important is the fact that the fish constitute the main source of food, employment, pleasure and income of the local population, whose per capita annual consumption is of 100 kg, or more than six times the world average. Without a doubt, the fishing industry (including the resources from sport fishing, ornamental fish fishing and fish farming) constitutes one of the mainstays of the economy in Brazilian Amazonia, creating over 100 thousand direct jobs (Cabral Jr. and Almeida 2006) and about ten times this amount if indirect jobs are considered.

The chelonians, especially the turtles, stand out for their historical and cultural importance in human nutrition, not only in the form of eggs, but also in the form of meat. Because of the pressure of fishing and of the destruction of the aquatic habitat

Fig. 6.2 Place originally chosen for the Jirau Hydroelectric Dam, Madeira River, state of Rondônia (during the low-flow season). The Madeira River carries large quantities of sediments, a factor that aggravates the formation of a backwater stretch that is expected to cause flooding in Bolivia in the river stretch above the reservoir (photograph by Philip M. Fearnside)

in which they live and nest, one of the 14 Amazonian species, the tracajá *Podocnemis inifilis*, is on the IUCN list (International Union for Conservation of Nature) as a vulnerable animal. The alligators, represented by four species (*Caiman crocodilus*, *Melanosuchus niger*, *Paleosuchus palpebrosus* and *P. trigonatus*) have an important role in the ecosystem as head of the food chain and as voracious predators. They have been hunted for decades for their skin and for their meat, which is used in the local cuisine.

The mammals stand out for their large sizes and for the fact that one of the five existing species in the region's aquatic ecosystems, the giant otter (*Pteronura brasiliensis*), is currently on the IUCN list as an endangered species. The other four species (manatee *Trichechus inunguis*, otter *Lontra longicaudis*, tucuxi dolphin *Sotalia fluviatilis* and the Amazon River dolphin *Inia geoffrensis*) are listed as insufficiently known. Despite this, they continue to be hunted.

The macrophytes stand out for being primary producers, from which organic matter originates and becomes the main link in the food chain. They are particularly important in the floodplain ecosystems, where the *Paspalum repens* and *Echinochloa polystachia* wild grasses predominate. This last one is one of the plants with the highest known productivity (100 t ha^{-1}) and a solar energy conversion factor of 4 % (Piedade et al. 1992). Aside from their role as a food source, these plants supply refuge to a multitude of organisms that live in out of the water.

Fig. 6.3 Samuel Reservoir, on the Jamari River, state of Rondônia. Decomposition of dead trees releases CO_2, which contributes to global warming (photograph by Philip M. Fearnside)

The environment of each species is a complex set of chemical, physical and biological factors that interact throughout the evolutionary process, supplying the conditions for life and determining the ranges of these species. It is also through the interactions among species, populations and communities that the relations of predation, competition, parasitism and symbiosis are developed, which in Amazonia take on huge proportions.

In spite of the importance of aquatic biodiversity, or maybe because of its importance, the aquatic biota in Amazonia has been suffering extreme pressures, alterations and losses. Its balance, already fragile, runs the risk of being broken. Among the many causes, deforestation and the many problems that result from deforestation, such as siltation, alterations and elimination of habitats and the pollution of steams, especially of those that run through cities, stand out and need to be assessed and have measures taken in order to completely eliminate them.

Function, Valuation and Social Issues

In Amazonia, water is primordial to humans because, aside from its physiological function, it represents the most important means of transport, the main source of energy and of food. However, the use and the exploitation of water can cause social impacts. The calculation of the value of these resources in large projects should include the social costs.

Domestic consumption of water by the human population of Amazonia is very small when compared to the volume of water that exists in the region. Nevertheless, water suitable for consumption in Amazonia can become scarce due to environmental disturbance, including pollution, and due to episodes of infections and parasites in rural and urban populations.

Transportation by water is the only way or reaching many parts of Amazonia. The majority of human settlements are located along the navigable rivers and the waterways are important for the populations to access their homes. Although it might seem like an activity that does not damage the environment, the waves created by the transit of boats can affect areas on the river banks.

With regards to generating energy, the hydroelectric potential of the Brazilian Amazonia is very large due to topographical slopes along the tributaries of the Amazon River, starting from the Brazilian Shield (on the southern part of the region) up to the Guiana Shield (on the northern side). The hydroelectric development plan for Amazonia is enormous: 68 hydroelectric dams were expected in the "2010 Plan". However, the social and environmental problems caused by hydroelectric dams are also enormous. The relocation of rural and indigenous populations from the areas of the reservoirs can result in severe impacts in some places. The Tucuruí Dam, on the Tocantins River, flooded part of three indigenous reserves (Parakanã, Pucuruí and Montanha) and its transmission lines crossed an additional four reserves (Mãe Maria, Trocará, Krikati and Cana Brava). There is a disparity in the magnitude of costs and benefits, with great inequalities with regards to who pays the costs and who collects the benefits. Local populations frequently suffer the main impacts, while the rewards usually benefit large urban centers, and in the case of the largest dam of them all (Tucuruí), the benefits are for other countries (Fearnside 1999, 2001).

The electricity generated by Amazonian dams, usually does very little to improve the quality of life of the people who live near the projects. The Tucuruí Dam supplies subsidized energy to multinational aluminum plants in Barcarena, in the state of Pará (ALBRÁS and ALUNORTE, of Nippon Amazon Aluminum Co. Ltd. or NAAC, a consortium of 33 Japanese companies) and in São Luis, in the state of Maranhão (ALUMAR, of Alcoa), while the populations that live near the project use querosene lamps for lighting.

Hydroelectric dams also cause health problems for the populations who live there, such as malaria and arboviruses. Malaria is endemic in the areas where the dams are built, and incidence increases when populations migrate to these areas. The environmental imbalance can cause these diseases to increase by increasing the number of vectors (Tadei et al. 1983; Tadei et al. 1991). Another problem is mercury methylation, which occurs in hydroelectric reservoirs as indicated by the elevated mercury levels in fish and in human hair in Tucuruí (Leino and Lodenius 1995). High concentrations of Mercury are found in Amazonian soils, which originated millions of years ago (Roulet et al. 1996; Silva-Forsberg et al. 1999). Other water uses can also result in social and economic asymmetries. Water resources are essential for the production of food, both on land and in aquatic ecosystems. Irrigation, however, still only affects a small portion of the agriculture in Amazonia, although this could change in the future. The most famous large-scale initiative in Amazonia was the now-abandoned rice irrigation project at Jari (Fearnside and Rankin 1985; Fearnside 1988). The provision of water for cattle represents a significant alteration of the water resources in deforested landscapes. This water is mainly supplied by small reservoirs created by damming streams that run through pastures. The lack of water is already a limitation on fishing in dry years. On the other hand, at the interface between terrestrial and aquatic environments the deposition of nutrients by sedimentation during the flood periods is essential to agriculture in the Amazonian floodplains (Junk 1997).

Lastly, it is important to mention the role of Amazonian water in the climate and in the maintenance hydrological parameters in several regions of the country. Aquatic ecosystems in Amazonia are linked to the regional water cycle and to the transportation of water vapor to neighboring regions, including the central-south of Brazil (Fearnside 2004). The water enters the region in the form of vapor coming from the Atlantic Ocean. Prevailing winds in the area run from east to west, and much of the water that falls as rain the region is returned to the air by means of evapotranspiration (Salati 2001). When the air reaches the Andes, a significant part is directed to the south, taking the water vapor to the Brazilian central-south and to neighboring countries. Models indicate that approximately half of the water vapor that enters Amazonia is transported out of the region to the south, by means of wind (Marengo et al. 2004; Correia et al. 2006; Marengo 2006; D'Almeida et al. 2007).

Amazonian aquatic ecosystems also play an important role in the global carbon cycle. The sediments from the Andes and from soil erosion within the Amazonian region are transported to the ocean by the Amazonian rivers, especially by the Madeira, Solimões (upper Amazon) and Amazonas (Lower Amazon) Rivers. These sediments, which can be deposited and remobilized in the floodplains, carry a significant amount of carbon. Dissolved organic carbon enters the rivers through terrestrial runoff and from water from the soil throughout the region, and it represents an important carbon flow to the oceans. Large quantities of CO_2 are released from the water in the Amazon River (Richey et al. 2002). Nutrients, which are also transported by the Amazon River, sustain the high productivity of plankton in the estuary of the Amazon River and the consequent removal of atmospheric CO_2 by ocean sediments (Subramanian et al. 2008). Hydroelectric dams can cause the rupture of these flows and increase other greenhouse gasses such as the methane (Kemenes et al. 2007).

Waters of Amazonia and International Environmental Law

The Amazon Hydrographic Basin is the most extensive hydrographic network on the globe and runs from the Andes to the Atlantic Ocean (Eva and Huber 2005). As it was already mentioned this basin of continental dimensions affects several countries of South America.[1] The issue of water in Amazonia and international environ-

[1] One should not confuse the Amazonian Hydrographic Basin (international hydrographic basin) with the Amazonian Hydrographic Region, which is made up by the hydrographic basin of the

mental law requires a plural analysis of the normative space and of the region's cultural diversity. As the poet Thiago de Mello says, the water regime corresponds to one element within the life of humans in which the economic cycles are determined by: large ebbs, bountiful harvests (great times for fishing and for planting), major floods, severe calamities and bitter miseries (the fish disappear from the river, the plantations are destroyed) (Mello 2002). With regards to international environmental law, we should consider three perspectives:

1. The multinational nature of the basin.
2. The biological migrations.
3. The shared and sustainable use of the region's resources.

The notion of an "International river", referring to navigable rivers that cross or separate the territory of two or more states, has changed with the acknowledgment of the concept of international water flow and international hydrographic basin. However, no consensus exists, either in theory or in practice, with regards to the extension of these expressions. The "Helsinki Rules" regarding the use of water in international rivers, adopted in 1966 by the International Law Association and reviewed in 2004 by means of the "Berlin Rules" had the objective of regulating and protecting the use of continental waters. The concept of an "international river" was essential in the formulation of the rule of equitable utilization of transboundary waters, as well as in the development of protection rules for continental waters and shared natural resources (Silva 2008a), where, in the context of the revision of these rules, there was an acknowledgement of the ecological integrity of the waters in three dimensions: biological, (2) chemical and (3) physical, without disassociating these features from the social and economic dimensions.

The 1997 United Nations Convention on the Use of International Watercourses for Navigation did not adopt either the concept of International River or of International Hydrographic Basin (McCaffrey 2001). It did, however, adopt the concept of international watercourse as "a system of surface and ground waters constituting, by virtue of their physical relationships, a unitary whole that flow into a common terminus".[2] This Convention established the need for: (1) the equitable and reasonable use and participation; (2) the general obligation to not cause significant damages; (3) the obligation of cooperating, founded on sovereign equality, territorial integrity and mutual benefit; (4) the regular exchange of data and information on the quality of waters; and (5) the principle of equality among all uses.

The Amazonian Cooperation Treaty (TCA) was signed on July 3rd, 1978 by the Republics of Bolivia, Brazil, Colombia, Ecuador, Guiana, Peru, Suriname and

Amazon River located in the Brazilian territory, by the hydrographic basins of the rivers at the Marajó Island, aside from the hydrographic basins of the rivers located in the state of Amapá (which flow into the North Atlantic), totaling 3,870,000 km^2, according to the National Hydrographic Division (Resolution of the National Council of Water Resources CNRN number 32, of October 15, 2000).

[2] Two types of aquifers are excluded from the definition: those that are not rechargeable and those that are connected to a water body.

Venezuela, with the objective of promoting the harmonious development of their respective Amazonian territories and the assertion of national sovereignty over natural resources, entered into force on August 2nd, 1980. The concept of the "Amazon Basin" encompassed not only the international hydrographic basin, but also their eco-regions (Silva 2008b). The TCA addresses the functions that the Amazon River and the other international Amazonian rivers have with regards to communication among the countries, and the reasonable use of the water resources, without, however, establishing specific criteria for reasonable use. The Protocol of Amendment to the Treaty of Amazonian Cooperation, adopted in Caracas on December 14th, 1988, and which entered into force on August 2nd, 2002, instituted the Organization of the Amazonian Cooperation Treaty (OTCA), a legal entity that is competent to enter into agreements with contracting parties, with non-member states and with other international organizations (Silva 2008c). TCA and OTCA have as their primary function the production and diffusion of information, and they act as an international political forum. Since there is no rule for the resolution of disputes or for delegation to the OTCA, domestic legal norms regarding environmental issues have an essential role in regulating the means of appropriation and use of natural resources in the region.

Among the biological migrations in the waters of the hydrographic basin of Amazonia, that of the giant catfish stands out, especially the dourada and the piramutaba, whose stocks are economically important for Brazil, Colombia and Peru and, to a lesser extent, in Bolivia and Ecuador. Throughout their lives, the migrating catfish swim through the main white water rivers of the Amazonian basin, crossing both state and international borders (Vieira 2005). Current knowledge about the migration of these species suggests that they migrate from Brazil, along the Amazon River and up the Madeira and Solimões rivers to their spawning areas in Bolivia, Colombia and Peru (Ruffino 2000). Although one can identify informal agreements for the periods of closure of fishing for certain species like the Arapaima in the region of the frontier between Brazil, Colombia and Peru (Vieira 2005), there is still a need for adoption of legal norms for the management of shared fishing resources, as well as for allocating financial means and human resources to control the fishing industry.

The provisions of the Amazonian Cooperation Treaty establish the preservation of the species in the region by means of promoting "scientific research and the exchange of information and of technical personnel among the competent entities of the respective countries, in order to increase knowledge about the resources (…) about the fauna in their Amazonian territories, which will all be articles of an annual report presented by each country" (art. VII). In addition, the Commission on Continental Fishing, in its Tenth Meeting, held in Panamá 7–9 September 2005, recommended:

1. The acknowledgment by the governments of Latin America, of the social, economic and environmental value of continental fishing.
2. The strengthening of institutional and local (communitarian) capacities for the ecosystem management of fishing.
3. The strengthening of cooperation among countries for the management and sustainable use of shared basins.
4. The development of integrated assessments to optimize recreational fishing in shared basins.

5. The improvement of data collection and the development of tools to facilitate the management of data bases.
6. The creation of areas of biological conservation in shared basins.

And lastly, infrastructure projects and potentially pollutant activities need to be submitted to studies of environmental impacts.[3]

The concept of shared natural resource was included in international law through the Letter of economic rights and obligations of the States, which established on one hand, the obligation to cooperate in the exploitation of shared natural resources, and, on the other hand, the principle of permanent sovereignty of the States over the natural resources in their territories. The nature and spatial extent of human actions in these areas constitute the subjects of fruitful and profound studies in the sciences, especially in the natural, human and social science areas. The regularizing of these spaces and of the human relationships that transform them require studies, reflections and the creation of legal norms, which need to be taken into account by the law.

Throughout history, Amazonia has always been the stage for paradoxes, and there have been frequent mistaken ideas, and there have been many fights and disputes over the control and appropriation of these riches. It is in this latter sense, regarding control and appropriation of wealth, in this case of everything that is found in its water or that interacts with it that one must consider the biological totality that is found in Amazonia, and these concerns take on a political nature. Thus, Amazonia becomes the subject to different regulatory implications, whether formal or not, both within the internal scope of national states and in the context of international communities of sovereign states.

For Amazonian aquatic areas, the determination of physical borders for the use of transboundary biological resources encounters its first material obstacle in the nature of Amazonia itself, where water predominates, dominates and determines the universe of social and political relationships (Tocantins 2000). Firstly, because Amazonian borders involve peoples with special relations to the state, including indigenous populations and those of the traditional populations; secondly, because the different ways of using the waters, imply in different forms and aspects of regulation. In legal terms, the use of transboundary biological resources is controlled by the Convention on Biological Diversity (CBD), adopted by Brazil and promulgated by Decree number 2519, of March 16th, 1998. The CDB is, within the hierarchical system of norms, an international treaty with the aim of promoting the conservation of biological diversity, the sustainable use of its components, and the fair and equal

[3] One can cite the "Madeira Complex", a set of infrastructure projects involving four dams, forming a complex of four hydroelectric plants and a navigable waterway network of 4200 km, within a future program of transport infrastructure and energy integration between Brazil, Bolivia and Peru, aside from the transmission line associated this river stretch. Neither Peru nor Bolivia were consulted about this project, and despite the negative transboundary impacts, a preliminary environmental license was issued for the first two dams of the "Madeira Complex", with 33 constraints imposed by IBAMA, of which the majority relate to the three issues which previously provided the foundation for the denial of the same license: (a) issues related to sedimentation, (b) issues that indicate the possibility of mercury contamination and (c) issues concerning the effects of the dams on ichthyofauna in the region (Silva 2008b).

partition of the benefits that result from the use of genetic resources, establishing principles, norms and scopes of jurisdictions.

Thus, the protection and conservation of the waters of Amazonia require a vision of the hydrographic basin in its totality, as well as an understanding of the intrinsic relationship of the hydrological cycle of waters, forests, biodiversity and social aspects with regards to the different visions of water and the different ways of living and using. One should also take into consideration the legal norms of the countries in the region, as well as the sources of international law on which international environmental treaties are founded, and of which the countries of the region are members.

Future of Water Systems of Amazonia

The waters of Amazonia represent an environmental, economic and social asset that requires extensive studies embracing its entire dimension in order to enable safer interventions, in such a way as to allow these resources to be used and conserved. The Amazon biome cannot be considered in a fragmented way. There is a need for integrated actions in the entire system, which demands for a set of agreements with other countries and therefore interventions from specific spheres of the governments of these countries. The progress of these agreements will depend upon robust information, which allows for agreements with ample scope. Undoubtedly this in itself is one of the first limitations: there is very limited installed capacity in the institutions of the region, whether Brazilian or in the other countries in the Amazonian region, to produce this information.

In Brazilian Amazonia there is only one specific post-graduate program that is focused on training personnel for the study of water in the region: the Freshwater Biology and Inland Fisheries program at INPA. The study of water of Amazonia, in its many dimensions, is done in this and in other programs, such as the post-graduate programs in Ecology (INPA), Fisheries Resources (UFAM) and Climate and Environment (INPA-UEA). These programs, despite being in high demand, have limited capacities due to the number of professors available. Even so, a considerable number of professionals have been trained and these people work not only throughout Brazil but also in neighboring countries. Scientific cooperation with other countries has had an important role, as exemplified by the almost 50 years of agreement of cooperation between INPA and the Max-Planck Institute.

The current demand for information involves, aside from basic studies on environmental dynamics, those on advanced modeling. These studies need to provide information for the decision-making process regarding the new hydroelectric dams planned for Amazonia, the mining activities (including petroleum), the opening of new roads, the management of aquatic species of commercial importance, and the use of watercourses for transportation and communication. In addition, the use of modern technology for the development of new products and processes, based on the biological and chemical diversity of aquatic environments of Amazonia, is vital.

Initial tests revealed the existence of millions of dissolved organic compounds in the waters of the Negro River alone. These need to be analyzed in order to discover their origin and organic properties. The expansion of these studies to other aquatic environments of Amazonia is necessary.

Therefore, people from the region need to be at the core of the studies of the aquatic environments of Amazonia. In Brazilian Amazonia alone there are about 25 million people who have water as their main source of life, of their interactions with the environment, of their food supply and of their coming and going. Basically, humans are in Amazonia a central aspect of the aquatic environments of this vast region.

References

Bevilacqua, A. H. V. (2009). O uso do Modelo do Ligante Biótico (BLM) para avaliação da contaminação por cobre em águas da Amazônia, p. 32. In Biologia de Água Doce e Pesca Interior. Dissertação de Mestrado, Instituto Nacional de Pesquisas da Amazônia, Manaus.

Cabral, W., Jr., & Almeida, O. T. (2006). Avaliação do mercado da indústria pesqueira na Amazônia. In O. T. Almeida (Ed.), *A indústria pesqueira na Amazônia* (pp. 17–39). Manaus: Ibama/Provarzea.

Correia, F. W. S., Alvalá, R. C. S., & Manzi, A. O. (2006). Impacto das modificações da cobertura vegetal no balanço de água na Amazônia: Um estudo com Modelo de Circulação Geral da Atmosfera (MCGA). *Revista Brasileira de Meteorologia, 21*, 153–167.

D'Almeida, V., Vörösmarty, C. J., Hurtt, G. C., Marengo, S. L., Dingmanb, S. L., & Keine, B. D. (2007). The effects of deforestation on the hydrological cycle in Amazonia: A review on scale and resolution. *International Journal of Climatology, 27*, 633–647.

Eva, H. D., & Huber, O. (2005). Proposta para definição dos limites geográficos da Amazônia: Síntese dos resultados de um seminário de consulta a peritos organizado pela Comissão Européia em colaboração com a Organização do Tratado de Cooperação Amazônica, CCP ISpra 7–8 de Junho de 2005. European Commission, OTCA. Retrieved from http://ies.jrc.ec.europa.eu/uploads/fileadmin/Documentation/Reports/Global_Vegetation_Monitoring/EUR_2005/eur21808_bz.pdf.

Fearnside, P. M. (1988). Jari at age 19: Lessons from Brasil's silvivultural plans at Carajás. *Interciencia, 13*, 12–24.

Fearnside, P. M. (1999). Social impacts of Brazil's Tucuruí dam. *Environmental Management, 24*, 485–495.

Fearnside, P. M. (2001). Environmental impacts of Brazil's Tucuruí dam: Unlearned lessons for hydroelectric development in Amazonia. *Environmental Management, 27*, 377–396.

Fearnside, P. M. (2004). A água de São Paulo e a floresta amazônica. *Ciência Hoje, 34*, 63–65.

Fearnside, P. M., & Rankin, J. M. (1985). Jari revisited: Changes and the outlook for sustainability in Amazonia's largest silvicultural estate. *Interciencia, 10*, 121–129.

Furch, K. (1984). Water chemistry of the Amazon basin: The distribution of chemical elements among fresh waters. In H. Sioli (Ed.), *The Amazon: Limnology and landscape ecology of a mighty tropical river and its basin* (pp. 167–200). Dordrecht: Junk Publishers.

Furch, K. (2000). Chemistry and bioelement inventory of contrasting Amazonian forest soils. In W. J. Junk, J. Ohly, M. T. F. Piedade, & M. G. M. Soares (Eds.), *The Central Amazonian floodplain ecosystems: Actual use and options for sustainable management* (pp. 109–126). Leiden: Backhuys Publishers.

IBGE. (2007). IBGE participa do mapeamento da verdadeira nascente do rio Amazonas 15 de Junho de 2007. Retrieved February 27, 2009, from http://www.ibge.gov.br/home/presidencia/noticias/noticia_impressao.php?id_noticia=908.

Junk, W. J. (1997). *The Central Amazon floodplain: Ecology of a pulsating system*. Heidelberg: Springer.

Junk, W. J. (2000). Neotropical floodplains: A continental-wide view. In W. J. Junk, J. Ohly, M. T. F. Piedade, & M. G. M. Soares (Eds.), *The Central Amazonian floodplain ecosystems: Actual use and options for sustainable management* (pp. 5–24). Leiden: Backhuys Publishers.

Junk, W. J., Piedade, M. T. F., Parolin, P., Wittmann, F., & Schöngart, J. (2009). Ecophysiology, biodiversity and sustainable management of Central Amazonian floodplain forests: A synthesis. In W. J. Junk, M. T. F. Piedade, P. Parolin, F. Wittmann, & J. Shöngart (Eds.), *Central Amazonian floodplain forests: Ecophysiology, biodiversity and sustainable management*. Berlin: Springer.

Kemenes, A., Forsberg, B. R., & Melack, J. M. (2007). Methane release below a tropical hydroelectric dam. *Geophysical Research Letters, 34*, 1–5.

Lara, L. B. L. S., Fernandes, E. A. N., Oliveira, H., Bacchi, M. A., & Ferraz, E. S. B. (1997). Amazon estuary: Assessment of trace elements in seabed sediments. *Journal of Radioanalytical and Nuclear Chemistry, 216*, 279–284.

Leino, T., & Lodenius, M. (1995). Human hair mercury levels in Tucuruí area, state of Pará, Brasil. *The Science of the Total Environment, 175*, 119–125.

Marengo, J. A. (2006). On the hydrological cycle of the Amazon basin: A historical review and current state-of-the-art. *Revista Brasileira de Meteorologia, 21*, 1–19.

Marengo, J. A., Soares, W. R., Saulo, C., & Nicolini, M. (2004). Climatology of the low-level jet east of the Andes as derived from the NCEP-NCAR reanalyses: Characteristics and temporal variability. *Journal of Climate, 17*, 2261–2280.

McCaffrey, S. (2001). The contribution of the UN Convention on the law of the non-navigational uses of international watercourses. *International Journal of Global Environmental Issue, 1*, 250–263.

Mello, T. (2002). *Amazonas: Pátria das Águas*. Rio de Janeiro: Bertrand Brasil.

Piedade, M. T. F., Junk, W. J., & Mello, J. A. N. (1992). A floodplain grassland of the central Amazon. In S. P. Long, M. B. Jones, & M. J. Roberts (Eds.), *Primary productivity of grass ecosystems of tropics and sub-tropics* (pp. 127–158). London: Chapmann & Hall.

Richey, J. E., Melack, J. M., Aufdenkampe, A. K., Ballester, V. M., & Hess, L. L. (2002). Outgassing from Amazonian rivers and wetland as a large tropical source of atmospheric CO_2. *Nature, 416*, 617–620.

Roulet, M., Lucotte, M., Rheault, I., Tran, S., Farella, N., Canuel, R., et al. (1996). Mercury in Amazonian soils: Accumulation and release. In S. H. Bottrell (Ed.), *Proceedings of the Fourth International Symposium on the Geochemistry of the Earth's Surface, Ilkely* (pp. 453–457). Leeds: University of Leeds, Department of Earth Sciences.

Ruffino, M. (2000). Perspectivas do manejo dos bagres migradores na Amazônia. In *Recursos pesqueiros do Médio Amazonas: Biologia e estatística pesqueira. Coleção Meio Ambiente. Série Estudos Pesca* (pp. 141–152). Brasília, DF: IBAMA.

Salati, E. (2001). Mudanças climáticas e o ciclo hidrológico na Amazônia. In V. Fleichresser (Ed.), *Causas e dinâmica do desmatamento na Amazônia* (pp. 153–172). Brasília, DF: Ministério do Meio Ambiente.

Schöngart, J., & Junk, W. J. (2007). Forecasting the flood-pulse in Central Amazonia by ENSO-indices. *Journal of Hydrology, 335*, 124–132.

Silva, S. T. (2008a). Proteção internacional das águas continentais: A caminho de uma gestão solidária das águas. In *XVI CONPEDI, Pensar Globalmente: Agir Localmente* (Vol. 16, pp. 957–973). Florianópolis: Fundação Boiteux.

Silva, S. T. (2008b). Tratado de Cooperação Amazônica: Estratégia regional de gestão dos recursos naturais. *Revista de Direito Ambiental, 52*, 183.

Silva, S. T. (2008c). Direitos dos povos indígenas e direitos à água na América Latina: Da proteção internacional. In T. Colaço & J. A. F. Costa (Eds.), *Pueblos indígenas, desarrollo y participación democrática* (pp. 45–59). Florianópolis: Boiteux.

Silva-Forsberg, M. C., Forsberg, B. R., & Zeidemann, V. K. (1999). Mercury contamination in humans linked to river chemistry in the Amazon basin. *Ambio, 28*, 519–521.

Sioli, H. (1975). Tropical rivers as expressions of their terrestrial environments. In F. B. Golley & E. Medina (Eds.), *Tropical ecological systems: Trends in terrestrial and aquatic research* (pp. 275–288). Berlin: Springer.

Sioli, H. (1984). The Amazon and its main affluents: Hydrogeography, morphology of the river courses and river types. In H. Sioli (Ed.), *The Amazon: Limnology and landscape ecology of a mighty tropical river and its basin* (pp. 127–165). Dordrecht: Dr. W. Junk Publishers.

Subramanian, A., Yeager, P. L., Carpenter, E. J., Mahaffey, C., Björkman, K., Cooley, S., et al. (2008). Amazon river enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean. *Proceedings of the National Academy of Sciences, 105*, 10460–10465.

Tadei, W. P., Mascarenhas, B. M., & Podestá, M. G. (1983). Biologia de anofelinos amazônicos, 8: Conhecimentos sobre a distribuição de espécies de Anopheles na região de Tucuruí-Marabá (Pará). *Acta Amazonica, 13*, 103–140.

Tadei, W. P., Scarpassa, V. M., & Rodrigues, I. B. (1991). Evolução das populações de *Anopheles* e de *Mansonia* na área de influência da Usina Hidrelétrica de Tucuruí (Pará). *Ciência e Cultura, 43*, 639–640.

Tocantins, L. (2000). *O rio comanda a vida*. Manaus: Valer.

Val, A. L., & Almeida-Val, V. M. F. (1995). *Fishes of the Amazon and their environments: Physiological and biochemical features*. Heidelberg: Springer.

Val, A. L., Almeida-Val, V. M. F., & Chippari-Gomes, A. R. (2003). Hypoxia and petroleum: Extreme challenges for fish of the Amazon. In G. Rupp, & M. D. White (Eds.), Fish physiology, toxicology, and water quality. EPA, USA, Proceedings of the Seventh International Symposium, Tallin, Estonia, Vol. 1, pp. 227–241.

Val, A. L., Almeida-Val, V. M. F., & Randall, D. J. (2006). Tropical environment. In A. L. Val, V. M. F. Almeida-Val, & D. J. Randall (Eds.), *The physiology of tropical fishes* (Vol. 21, pp. 1–45). London: Elsevier.

Vieira, E. (2005). Legislação e plano de manejo para a pesca de bagres na bacia Amazônica. In N. N. Fabré & R. B. Barthem (Eds.), *O manejo da pesca dos grandes bagres migradores: Piramutaba e dourada no eixo Solimões-Amazonas* (pp. 69–74). Manaus: Ibama, ProVárzea.

Worbes, M. (1997). The forest ecosystem of the floodplains. In W. J. Junk (Ed.), *The Central Amazon floodplain: Ecology of a pulsating system* (Ecological Studies, Vol. 126, pp. 223–265). Berlin: Springer.