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A Classification of Major Naturally-Occurring Amazonian Lowland Wetlands

Wolfgang J. Junk · Maria Teresa Fernandez Piedade · Jochen Schöngart · Mario Cohn-Haft · J. Marion Adeney · Florian Wittmann

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Abstract Our estimates indicate that about 30% of the seven million square kilometers that make up the Amazon basin comply with international criteria for wetland definition. Most countries sharing the Amazon basin have signed the Ramsar Convention on Wetlands of International Importance but still lack complete wetland inventories, classification systems, and management plans. Amazonian wetlands vary considerably with respect to hydrology, water and soil fertility, vegetation cover, diversity of plant and animal species, and primary and secondary productivity. They also play important roles in the hydrology and biogeochemical cycles of the basin. Here, we propose a classification system for large Amazonian wetland types based on climatic, hydrological, hydrochemical, and botanical parameters. The classification scheme divides natural wetlands into one group with rather stable water levels and another with oscillating water levels. These groups are subdivided into 14 major wetland types. The types are characterized and their distributions and extents are mapped.

W. J. Junk (✉)
Universidade do Estado do Amazonas (UEA),
Manaus, Brazil
e-mail: junkwolfgang@gmail.com

M. T. F. Piedade · M. Cohn-Haft
Instituto Nacional de Pesquisas da Amazônia (INPA),
Manaus, Brazil

J. Schöngart · F. Wittmann
Max Planck Institute for Chemistry, Biogeochemistry Department,
Mainz, Germany

J. M. Adeney
Nicholas School of the Environment, Duke University,
Durham, NC, USA

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Introduction

The Amazon basin is situated at the equator within the circumglobal belt of evergreen tropical rainforest. Approximately 68% of the basin is located in Brazil and the remainder is divided between Bolivia, Colombia, Ecuador, French Guiana, Peru, Suriname, and Guyana. All of these except for Guyana are signatory countries of the Ramsar Convention on Wetlands of International Importance (www.ramsar.org). Along the Amazon River and most of its tributaries, high annual rainfall that is unevenly distributed between rainy and dry seasons leads to large oscillations in stream and river discharge; this results in extensive seasonally flooded areas. Furthermore, because large areas of the Amazon basin are flat and the stream network drains excess rainwater slowly, many interfluvial areas also become waterlogged or shallowly flooded during the rainy season.

Scientific research and management of wetlands require their classification and inventory. Cowardin et al. (1979) stated that there is no single, indisputable, and ecologically sound definition for wetlands. This is primarily because of their diversity and the fact that there is a continuum between dry and wet environments. However, one requirement for all wetlands is that they must have enough water present at some time during the growing season to stress plants and animals that are not adapted for life in water or in water-saturated soils. Thus, the definition of wetlands emphasizes three key attributes: (1) hydrology (especially the degree of flooding or soil saturation); (2) wetland vegetation (hydrophytes); and (3) hydric soils. Definitions of wetlands include (among others) those of the International Biological

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Program (IBP) (Westlake et al. 1988), the Ramsar Convention (IUCN 1971), the U.S. Fish and Wildlife Service (USFWS) (Cowardin et al. 1979), the Scientific Committee on Problems of the Environment (SCOPE) (Gopal et al. 1990), and the geomorphic definition and classification system of Semeniuk and Semeniuk (1995). Here, we follow the USFWS definition of 1979.

Problems that may be encountered when elaborating a classification system were discussed by Finlayson and van der Valk (1995) who stressed the need to resolve differences among existing systems in the definition of wetlands and wetland types. Furthermore, they called for standardization of data collection, storage, and dissemination techniques in order to generate more extensive international inventories. However, many international classification systems were formulated decades ago, and often they do not satisfy modern scientific requirements or include distinctive national characteristics. For instance, despite the existence of large riverine floodplains along the Mississippi, Ohio, and Missouri Rivers, the USFWS system does not treat floodplains as a specific wetland category, nor does it consider the enormous diversity of habitats present in these systems. Planners and scientists working with wetland ecosystems require a classification system of habitat “types” that are comparable with respect to structures and functions and that are independent of geographic locations. Such a functional approach was proposed by Brinson (1993a, b, 2009), and it will be followed here. It allows for the comparison of results from numerous wetland studies and for the determination of knowledge gaps; it also facilitates prediction of effects of human activities on the respective wetland types.

In South America, wetland classification systems (or descriptions of wetland vegetation types) exist for several countries or regions and use different parameters. For example, Neiff (2001) used 12 parameters to characterize geomorphology, soils, fire stress, vegetation, fauna, water sources, and several hydrological parameters that differentiate nine wetland types for Argentina**.** Brinson and Malvárez (2002) also differentiated nine major wetland types for Argentina but used the climate, hydrology, soils, and vegetation of geographic regions as criteria. Pouilly et al. (2004) characterized the vegetation of the Mamoré River floodplain and Navarro and Maldonado (2002) described the wetland vegetation of Bolivia.

In 1993, Brazil signed the Ramsar Convention, which requires a national policy for the wise management and protection of wetlands and their organisms. However, Brazil has been slow to conduct inventories and the scientific basis for a classification remains inadequate (Diegues 1994, 2002). Even today, there is little political interest in wetlands. This is probably because the abundance of wetlands and the difficulties associated with their transformation to conventional croplands give them the status of wastelands of low economic importance in the public opinion and in the political decision-making process. For managing water resources, the Brazilian Government focuses on the diversion of water from surface water bodies and groundwater (for domestic, industrial, and agricultural purposes), navigation, hydroelectric power generation, and wastewater treatment. Wetlands as such are not defined and their management is not specifically considered.

In what follows, we present a general classification scheme for Amazonian wetlands. We use climate, hydrology, water and sediment chemistry, and botanical criteria to delineate the wetland types. Our classification serves to: (1) organize and facilitate scientific research by determining key parameters for the definition and classification of different wetland types; (2) provide baseline information for environmental protection; (3) offer arguments for sustainable development policy; and (4) fulfill the demands of the Ramsar convention, signed by the Brazilian Government in 1993.

Existing Classification Systems in Amazonia

Pre-Columbian populations categorized rivers by the color of their water. This criterion was adopted by European immigrants and is evident today in names like Rio Claro, Rio Preto, Rio Negro, Rio Branco, and Rio Verde (Clear River, Black River, Black River, White River, and Green River, respectively). Native and colonial inhabitants of the Amazon knew that water color was related to specific ecological properties such as fish richness, soil fertility, or mosquito abundance. A glossary of indigenous, Portuguese, and Spanish terms is given in the “Appendix”.

The first scientific classification of Amazonian water bodies was elaborated in the 1950s by Sioli (1956). He used water color, as well as physical and chemical parameters, to explain limnological characteristics of the large Amazonian rivers and to relate these characteristics to the geological and geomorphological properties of their catchments (Table 1, Figs. 1, 2).

Whitewater rivers (such as the Amazon main course and the Juruá, Japurá, Purus, and Madeira) have their origins in the Andes, from which they transport large amounts of nutrient-rich sediments (Figs. 1, 2). Their waters have near-neutral pH and relatively high concentrations of dissolved solids (mainly alkali-earth metals and carbonates). Because of dilution with water from electrolyte-poor tributaries, the electrical conductivity of the Amazon River decreases from about 100 $\mu S\ cm^{-1}$ near the Andes to about 40 $\mu S\ cm^{-1}$ in its lower course. Whitewater rivers deposit their sediments in large fringing floodplains that are locally called *várzeas*. These are fertile and are covered with highly productive terrestrial and aquatic herbaceous plant communities and floodplain forests.

Table 1 Ecological attributes of Amazonian whitewater, blackwater, and clearwater rivers based on the classification of Sioli (1956)

Ecological attributes	Whitewater	Blackwater	Clearwater
PH	near neutral	acidic, <5	variable, 5–8
Electric conductivity	40–100	<20	5–40
Transparency (Secchi depth)	20–60 cm	60–120 cm	>150 cm
Water color	turbid	brownish	greenish
Humic substances	low	high	low
Inorganic suspensoids	high	low	low
Relationship of			
Alkali earth (Ca, Mg) and alkali (Na, K) cations	Ca, Mg>Na, K	Na, K>Ca, Mg	variable
Dominating anions	CO_3^-	SO_4^-, Cl^-	variable
Fertility of substrate and water	high	low	low to intermediate

Blackwater rivers (such as the Negro River) drain the Precambrian Guiana shield, which is characterized by large areas of white sands (podzols). Their water is transparent, with low quantities of suspended matter but with high amounts of humic acids that give the water a brownish-reddish color. The pH values of such rivers are in the range of 4–5 and their electrical conductivity is <20 $\mu S\ cm^{-1}$. The floodplains of blackwater rivers are of low fertility and are locally called *igapós*. They are covered by a slowly growing floodplain forest in which litter production is approximately 30% lower (summarized in Furch and Junk 1997) and diameter-increment growth rates of trees are up to two-thirds lower than those found in *várzea* forests (Schöngart et al. 2010). Terrestrial and aquatic herbaceous plants are scarce and many whitewater species are absent because of the low fertility and/or low pH (Junk and Piedade 1997). *Paleo-várzeas* consist of sediments of Andean origin that were deposited during former interglacial periods and that are of lower

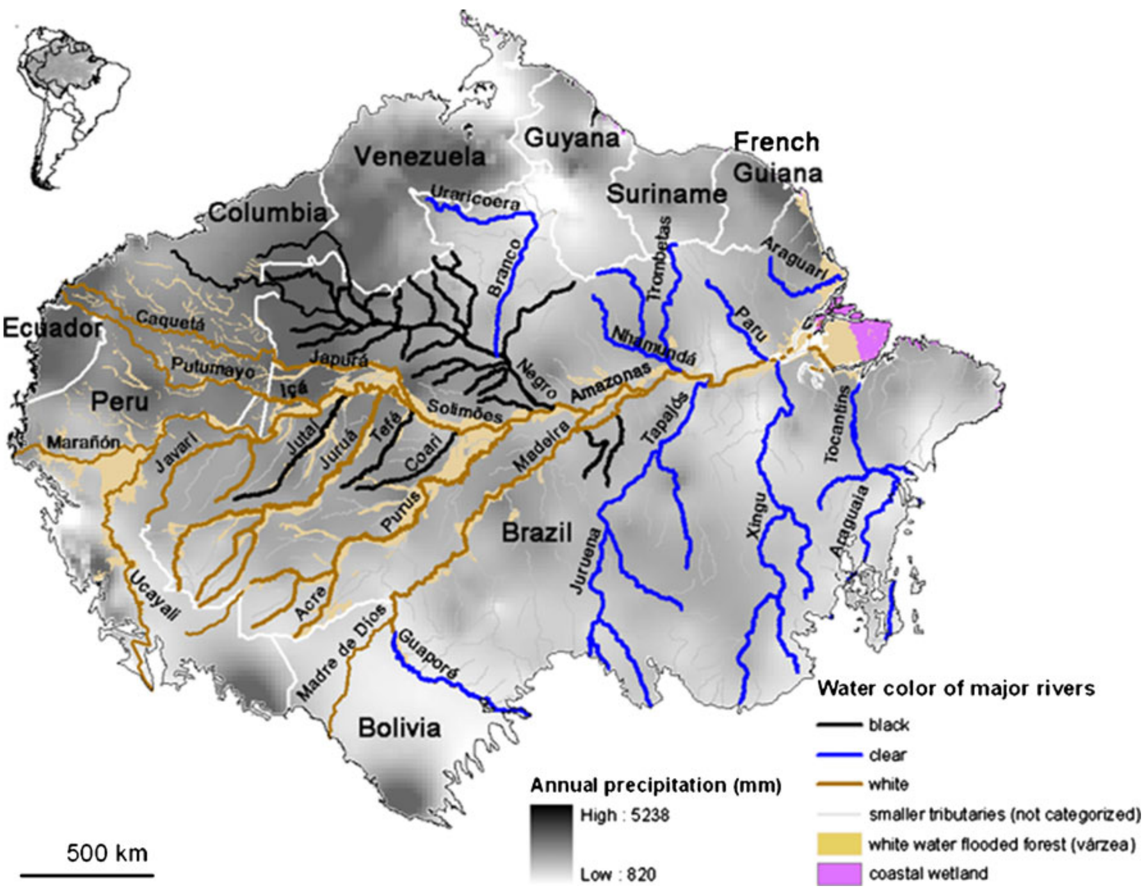

Fig. 1 The distribution of major whitewater, blackwater, and clearwater rivers in the Amazon basin

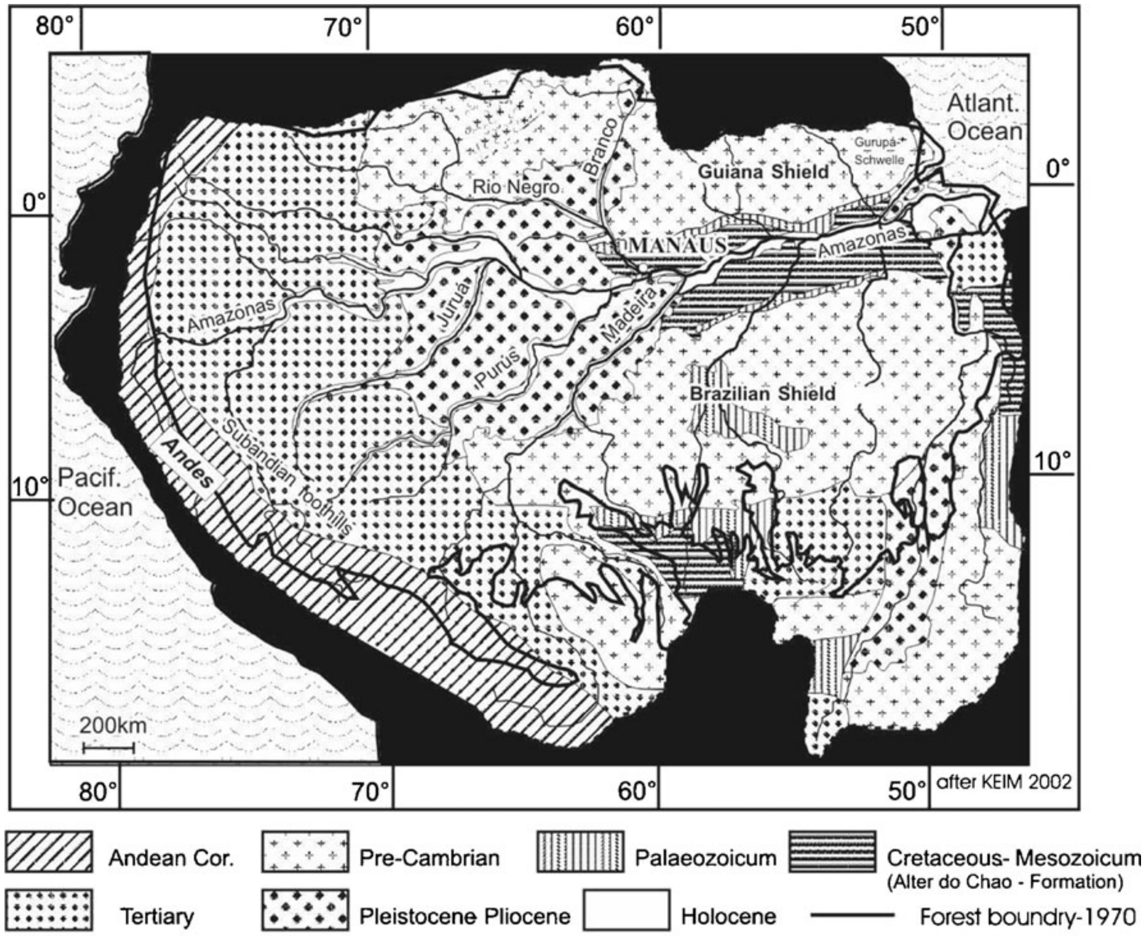

Fig. 2 Geological map of the Amazon basin (Irion and Morais 2011) and the boundaries of the rainforest region (not considering deforestation by large agricultural activities). For savanna areas within the forest region, see Fig. 5

nutrient status than those of *varzeas*. Ecological characteristics and vegetation species compositions are intermediate between whitewater and blackwater floodplains. *Paleo-várzeas* occupy large areas along whitewater rivers in Central Amazonia (Irion et al. 2010). Clearwater rivers (such as the Tapajós, Xingu, and Tocantins Rivers) have their upper catchments in the *cerrado* region of the Central Brazilian archaic shield. Their waters are transparent and greenish with low amounts of sediments and dissolved solids and an acidic pH that varies between 5 and 6 in large rivers. Electrical conductivity in large rivers is in the range of 20–40 μS cm^{-1} but can decrease to 5 μS cm^{-1} in low-order streams. The floodplains of clearwater rivers are of intermediate fertility and also called *igapós*.

Sioli's classification was supported by botanists (such as Prance 1979 and Kubitzki 1989) and by limnologists (Irmler 1977; Junk 2000) who found corresponding differences in the occurrence of tree species, aquatic macrophytes, and aquatic animals (such as snails, bivalves, and others). Prance (1979) classified Amazonian floodplain forests based on hydrological and hydrochemical aspects.

Today, an increasing amount of hydrochemical data indicate that the chemical composition of Amazonian water bodies varies much more than assumed by Sioli. In addition, the geology of the Amazon basin is very complex (as shown by the simplified geological map in Fig. 2). Road construction in the Amazon allows access to low-order rivers in remote areas that were previously inaccessible to Sioli and other limnologists. Even so, hydrochemical data are scarce for many low- to medium-order rivers, and a detailed classification covering the entire Amazon basin is not yet possible. Therefore, Sioli's simplified classification will be used here for describing the hydrochemical and soil-chemical properties of the large water bodies and wetlands of Central Amazonia. Differences will be mentioned in the specific sections.

In 2005, Junk and Piedade published a preliminary classification system of Amazonian wetlands based on hydrological and hydrochemical parameters; this classification served as a basis for the present approach. The Nature Conservancy (TNC) (Abell et al. 2008) published a map of the freshwater ecoregions of the world that includes a division of the Amazon basin into sub-basins according to biogeographic parameters (mainly according to the occurrence of fish species). This is a different approach that does not conflict with our proposed classification.

The New Classification System

Parameters for the Classification of Major Wetland Types

Our classification system of Amazonian wetlands is an ecological approach from the perspective of wetland scientists. We consider it an addition, rather than an alternative, to other classification systems. Corresponding to the underlying assumptions used to create the "Hydrogeomorphic Wetland Classification System" (HWC) of Brinson (1993a), we use climate, hydrology, water and sediment chemistry, and botanical criteria to delineate the wetland types. However, we have adapted the criteria used to the specific geomorphologic, hydrologic, and botanical conditions of the Amazon basin.

Climate

Climate has the greatest influence on wetlands because it influences all other criteria. In lowland Amazonia, two climate types occur. The central Amazon basin is covered by evergreen lowland rainforest. Wetlands in this region harbor many plant and animal species that occur in the rainforest. The southern portion of the Amazon basin, as well as the area along the basin's northern border, both have a pronounced wet/dry climate; these areas are covered by savanna vegetation. Wetlands in these regions are affected by strong seasonal drought and fire stress and harbor many plant and animal species of the *cerrado*.

Hydrology

Hydrology is the second most important factor for wetland classification because the availability and sources of water determine the wetland type. Wetlands can be classified into two groups, one group that is permanently covered with water or permanently waterlogged (permanent wetlands) and another that is periodically dry (periodically inundated or periodically waterlogged).

Because of the pronounced periodicity of precipitation and of water-level fluctuations in the rivers, most Amazonian wetlands belong to the periodically inundated (or periodically waterlogged) wetland class. They are "pulsing systems" with wet and dry periods, as described by the Flood Pulse Concept (FPC) (Junk et al. 1989; Junk and Wantzen 2004; Junk 2005). The flood pulse can be characterized by amplitude, duration, frequency, shape, and predictability (as shown in Figs. 3 and 4). Periodic floods and droughts severely affect organisms and require the development of specific adaptations and survival strategies. However, the effects of the flood pulse on organisms within the floodplain may vary considerably because of the geomorphologic heterogeneity of the habitats. For instance, the flood pulse of the Amazon River affects low-lying areas as a predictable, monomodal pulse of long duration and high amplitude. However, it affects the highest levees in the floodplain as a pulse of short duration and low amplitude that occurs only every couple of years. This variability of the flood-pulse impact increases habitat and species diversity in the floodplain and favors the lateral ingression of upland (*terra firme*) species into the floodplain.

Chemical Quality of Water and Sediments

Chemical composition of water and sediments ranks third in importance for wetlands classification because of its fundamental importance for life in water and wetlands. Chemical content influences not only the occurrence of organisms but also primary and secondary production in wetlands. Water and soil chemistry provide important parameters for biogeochemical cycles and determine management options.

A summary of the chemical characteristics of the different water types is given by Furch (1997). Near-neutral pH values of water and high levels of essential plant nutrients (such as nitrogen, phosphorous, and potassium) favor plant growth. The nitrogen cycle is very complex because of the intensive nitrification and denitrification processes that are triggered by the flood pulse (Kern and Darwich 1997; Kern et al. 2010). The chemical composition of the water within the floodplain varies considerably according to parameters that include connectivity with the main channel, water-level stage, groundwater influx, and internal biogenic nutrient cycles (Junk and Weber 1996; Weber et al. 1996; Furch and Junk 1997).

Sediments transported by whitewater rivers contain high quantities of fine-grained material. This material increases water-retention capacity during the dry phase but also hinders soil aeration. When drying during the non-flooded phase, large and deep mud cracks can damage the root systems of plants. The clay fraction contains caolinite, illite, and smectite. In contrast to caolinite, smectite has a high ion-exchange capacity and illite releases potassium during weathering. Both of these minerals are essential for the fertility of *várzea* soils (Irion 1978; Furch 1997, 2000).

Blackwater and clearwater rivers transport mostly sandy bed load and a small fraction of low-fertility caolinite. Sand beaches suffer severe drought stress because of low water-retention capacity. In Roraima, many tributaries of the Branco River transport a high load of suspended matter and have the appearance of whitewater rivers. However, chemical characteristics of these rivers indicate that they generally have low nutrient status and a closer relationship to clearwater rivers. This is also supported by the species composition of the plant communities (Wittmann and Schöngart unpubl.). There are few studies of soils of clearwater-river floodplains and interfluvial wetlands and, because the geology of the Amazon

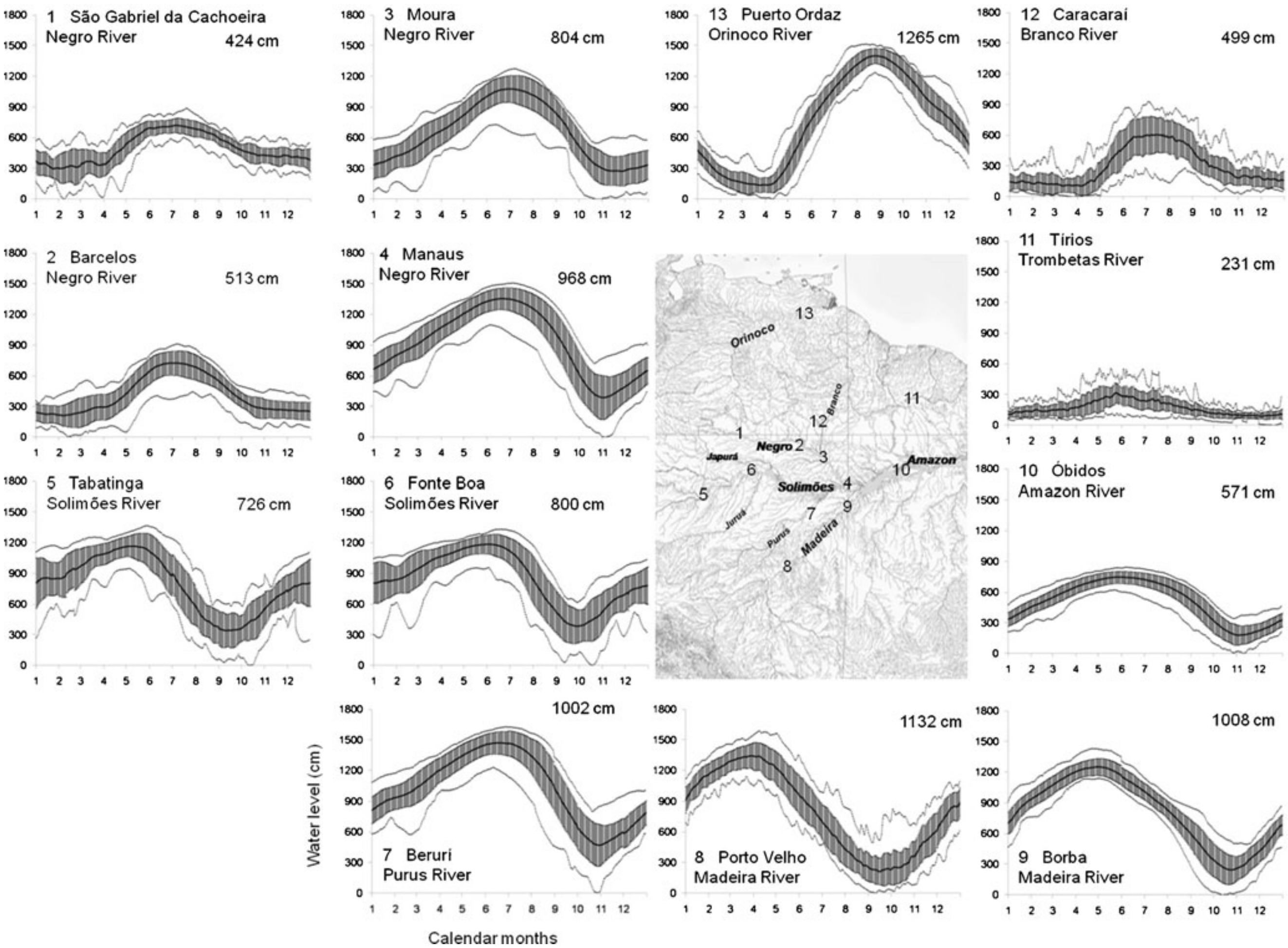

Fig. 3 Flood-pulse patterns of 13 hydrological stations located at the Amazon, Solimões, Negro, Branco, Trombetas, Purus, and Madeira Rivers. The geographical locations of the stations are indicated by numbers on the map. The hydrographs indicate the yearly mean water level, standard deviation, minima and maxima based on analysis of the period from 1983 to 2005 (n=23). The numbers indicate the mean annual amplitude (data: stations 1,2,3,6,7,8,9,10,11,12: Agência Nacional de Águas – ANA; stations 4,5: Superintendência Estadual de Navegação, Portos e Hidrovias - SNPH; station 13: Ministerio del Poder Popular para Ciencia y Tecnología, The Environmental Research Observatory (ORE) HYBAM)

basin is very complex (Fig. 2), these studies are not yet sufficient for a detailed characterization. It can generally be stated that in Amazonian wetlands with pulsing water levels, the soils have low organic matter content and can be considered as mineral wetland soils. Periodic aeration during dry periods and rapid decomposition rates (due to high temperatures) restrict accumulation of organic material. Only in permanently waterlogged habitats can accumulation of organic material occur.

Biological Criteria

Biological criteria form the fourth level of classification. Higher plants are especially important because they are long lived, and thus they represent the impacts of environmental conditions over years, decades, or centuries. Most floodplains in the equatorial Amazon are forested, while those in the savanna belt are periodically flooded savannas (e.g., hyper-seasonal savannas; Eiten 1983) with forested areas occurring along the river channels and in moist depressions.

Forested wetlands support few submersed aquatic macrophytes because of their low-light conditions. In contrast, savanna wetlands are much richer due to high light incidence down to the bottom of the water. The diversity of submersed species depends more on the physical properties of the water (such as transparency, color, depth, and stable water levels) than on nutrient status. For example, undisturbed and transparent *cerrado* streams harbor an abundant and species rich submersed flora despite their low electric conductance of <10 uS (Furch and Junk 1980; Furch 1986). In contrast, the amount and productivity of emergent and free-floating macrophytes depends on the nutrient levels in water and soils (see following). In the main river channels or in large lakes, there are no higher plants to serve as bio-indicators for classification.

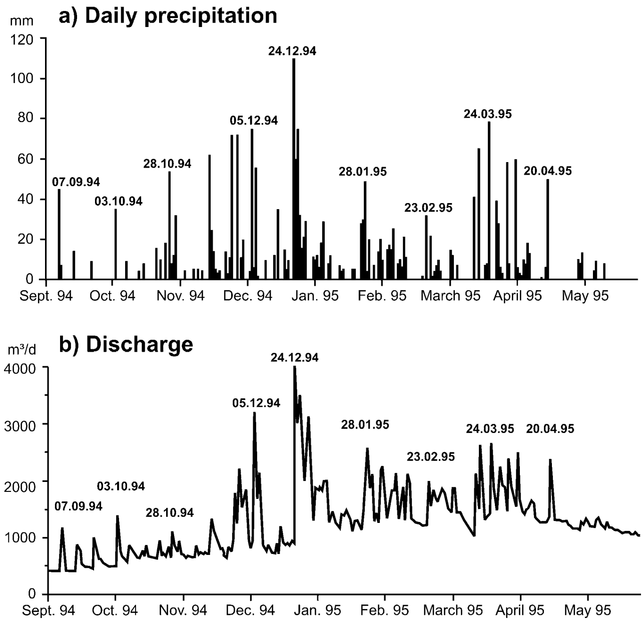

Fig. 4 Hydrograph of the low-order *cerrado* stream Tenente Amaral at the border of the Paraguai River basin and the Amazon River basin. This spiky hydrograph is characteristic for all low-order streams in Amazonia and the adjacent *cerrado* belts and corresponds with the daily rainfall pattern (Wantzen 2003)

Presentation of the New Classification System

The following is our classification of major, naturally occurring, lowland Amazonian wetland types, including hydrological, water- and soil-chemical, and botanical parameters.

1. Wetlands with relatively stable water levels
   - 1.1 Herbaceous and forested swamps (*campos umidos, veredas*, and *buritizais*) in the savanna belt
   - 1.2 Forested swamps in the rainforest (palm swamps—e.g., *buritizais*—and mixed forests)
   - 1.3 Open, waterlogged vegetation on the table mountains of the Guyana shield (*tepuis)*
2. Wetlands with oscillating water levels
   - 2.1. Wetlands subjected to predictable, long-lasting, monomodal flood pulses
     - 2.1.1. River floodplains with high flood amplitudes (large river floodplains of >5th order along the Amazon River and its large tributaries)
       - 2.1.1.1 Floodplains of high fertility (whitewater river floodplains)
       - 2.1.1.2 Floodplains of intermediate fertility type A (clearwater river floodplains)
       - 2.1.1.3 Floodplains of intermediate fertility type B (blackwater floodplains on paleo-whitewater substrates)
       - 2.1.1.4 Floodplains of low fertility (blackwater river floodplains)
     - 2.1.2. Wetlands with low flood amplitudes (large interfluvial wetlands that are inundated mostly by rainwater)
       - 2.1.2.1. Wetlands of low fertility and long flood periods (large areas in the upper Negro River basin)
       - 2.1.2.2. Hydromorphic edaphic savannas of low fertility and of short-to-intermediate flood periods (some Amazonian *campinas*, *banas*, and *varillales*)
       - 2.1.2.3. Hydromorphic climatic savannas on variable soil types and variable flood length (e.g., Humaitá savannas, Bananal/Araguaia savannas, Roraima savannas and Beni savannas)
   - 2.2. Wetlands subjected to short, predictable, polymodal flood pulses
     - 2.2.1. Marine and brackish water wetlands directly affected by the tide (Amazon estuary)
     - 2.2.2. Freshwater wetlands indirectly affected by the tide (Amazon estuary)
   - 2.3. Wetlands subjected to short, unpredictable, polymodal flood pulses
     - 2.3.1. Wetlands associated with small streams and rivers (1–5th stream order)
     - 2.3.2. Wetlands in depressions fed by rainwater

Characterization of Major Wetland Types

Wetlands Subjected to Stable Water Levels

This category includes three types: 1) Forested and grassy swamps in lowland savannas (swampy grasslands, *veredas*, and swampy palm forests); 2) swampy palm forests and mixed swamp forests in the rainforest; and 3) waterlogged vegetation on *tepuis*. The areas are waterlogged during the entire year and some can be shallowly flooded during the rainy season. They store water during the rainy season and release it slowly to connected streams during the dry season. They also buffer surface run-off during heavy rainstorms. All of these areas store organic material. In some cases, organic layers of more than one meter can be found. Organic matter accumulation is limited by high decomposition rates and wild fires during very dry years.

Wetlands Subjected to Oscillating Water Levels

This category includes three sub-categories defined by patterns of water-level oscillation, namely monomodal-predictable, polymodal-predictable, and polymodal-unpredictable oscillations.

Monomodal-predictable pulsing wetlands are further subdivided into two classes: large-river floodplains subjected to high-amplitude pulses and interfluvial wetlands subjected to low-amplitude pulses. The first class receives water, sediments, and biological material from large parent rivers, and can be subdivided according to nutrient status into high fertility (whitewater), intermediate fertility (clearwater), intermediate fertility (blackwater on *paleo-várzeas*), and low fertility (blackwater) floodplains. The second class receives water mostly from rainfall and receives few or no sediments from the catchment. Such wetlands are nutrient-poor, but their nutrient status may vary slightly because of differences in soil quality. This class is subdivided into three types. The first type comprises a range of wetlands in the middle Negro River basin that suffer long-duration flood stress. Some of these can be considered hydromorphic, edaphic savannas, while others are permanently flooded except for minor areas that dry out every year. The second type comprises the Central-Amazonian, hydromorphic, edaphic savannas that experience lower flood stress but that often have high groundwater levels (*campinas* and *campinaranas*). The third type includes the large hydromorphic, climatic savannas in the northern and southern *cerrado* belts.

Wetlands Subjected to Long-Lasting, Monomodal, Predictable Flood Pulses with High Amplitudes

We consider rivers with a mean flood peak of more than 4 m as high-amplitude rivers. Most high-order rivers (>5th order) show predictable pulsing with one high- and one low-water period of several months duration each (shown by the sinoidal flood curves in Fig. 3). Flood amplitudes are highest in the central part of the Amazon basin; they reach up to 10 m near the confluence of the Solimões and the Negro Rivers (Schöngart and Junk 2007) and at the huge tributaries draining the southern Amazon basin (such as the Madeira and Purus Rivers; Fig. 3). Flood amplitudes generally decline in the eastern and western parts of the basin, reaching approximately 6 m in Óbidos, Pará (Brazil) and approximately 8 m near Iquitos, Peru (Gessner 1968). Exceptions may occur along single tributaries, such as at the lower Juruá River where Campbell et al. (1992) reported a 16-m flood amplitude. Because of their high sediment loads, sedimentation and erosion processes and resulting impacts on the vegetation are much more intense in whitewater river floodplains than they are in blackwater and clearwater river floodplains.

The Aquatic Terrestrial Transition Zone (ATTZ) of these floodplains is the area that alternates between flooded and dry with several months of each per year. Such changing conditions create substantial stress for plants and animals living in this zone, but they also allow for the use of important resources of the ATTZ (such as available habitats, food for animals, and shelter). Fish yields are larger after extended floods than they are after shorter ones (Welcomme 1979). On the other hand, Amazonian floodplain trees show increased stem-diameter increments during periods of prolonged dry phases associated with El Niño events (Schöngart et al. 2004). The development of adaptations to periodic drought and flooding have been shown for herbaceous plants (Junk and Piedade 1997), trees (Junk 1989; Junk et al. 2010), aquatic and terrestrial invertebrates (Adis and Junk 2002), fish (Junk et al. 1997), and birds (Petermann 1997).

Flooding depth affects hydrostatic pressure, light intensity, and oxygen concentration in deeper water layers. Oxygen transport from aerial parts of emergent plants to their root systems is hindered by long transport pathways. In addition, specific respiration organs (such as pneumatophores) are not produced in deep-water habitats. Light intensity in deeper water layers is affected by colored humic substances and by the amount of suspended matter (Furch and Otto 1987). In clearwater, submersed aquatic macrophytes occur at greater depths than they do in turbid or dark-colored water. In deeper water layers, oxygen content is often reduced and this also affects the sediment layers.

The levels of plant nutrients in sediments and waters of river floodplains has led us to establish four types at this level of the classification. These types differ considerably in community structure, species composition, net primary production (NPP), and in some cases, in biomass and life-history traits of organisms.

Nutrient-Rich Whitewater River Floodplains (*várzeas*)

Approximately 75% of the *várzea* landscape is covered by dense-canopy forests. The remaining 25% is covered by the open waters of rivers and lakes and by backwater depressions, non-vegetated sand bars, and herbaceous plants (Melack and Hess 2010). Nutrient-rich whitewater river floodplains show luxurious growth of herbaceous plants on land and in the water. In water, free-floating, floating-leaved, and emergent plants prevail. Along the main river channels and in lakes, herbaceous plants on mud banks predominate, with biomass values of up to 80 Mg ha^{-1} and NPP values of up to 100 Mg ha^{-1} yr^{-1} (Piedade et al. 1991; Morison et al. 2000). Fast-growing, large grasses (such as *Paspalum repens*, *P. fasciculatum*, and *Echinochloa polystachya*) cover extensive areas. They have high nutrient content and are an important resource for herbivorous species such as capybaras, river turtles, manatees, and many fish, as well as for domestic animals such as cattle, water buffaloes, and horses. Forest edges and disturbed areas are covered by many species of annual and perennial herbaceous vines. Vegetation-free sand banks occur only in low-lying deposition areas along the main channels. When they are covered by fine-grained sediments, even small areas between the sand dunes are colonized by herbaceous vegetation.

Várzea forests are the most species-rich wetland forests in the world (Wittmann et al. 2006). They share many tree species with Amazonian upland forests. In addition, *várzea* forests contain elevated numbers of endemic tree species that are adapted to high flood levels. The tree line is generally established at a mean flood level of 7.5-m water depth; this corresponds to a mean flood period of 230 days per year. The hydro-geomorphic dynamism of the constantly migrating river channels is an important characteristic of the *várzea* landscape (Wittmann et al. 2004; Peixoto et al. 2009). Such dynamism leads to both frequent setbacks by erosion of *várzea* vegetation units to earlier successional stages and to rapidly advancing plant succession due to sediment deposition that raises the sediment surface and reduces the flood period. The small-scale mosaic of levees, river channels, lakes, and depressions increases beta-diversity through the creation of various habitats of differing elevations, substrates, textures, and distances to the main river channels. Several *várzea* forest types can be distinguished and differ in species composition, richness, and forest structure. The different *várzea* forest types are detailed in Wittmann et al. (2010). *Várzea* forests have a NPP of up to 33 Mg ha^{-1} yr^{-1} (Schöngart et al. 2010).

Nutrient-Poor Blackwater River Floodplains (*igapós*)

At approximately 10 m, flood amplitudes are highest at the lower Negro River near its confluence with the Solimões River. This region holds the greatest extent of *igapó* forest, including lowlands along the main river channel and smaller tributaries as well as fluvial islands such as those of the Anavilhanas Archipelago. Upstream, water amplitudes decline to approximately 5 m in Barcelos and approximately 4 m in São Gabriel da Cachoeira (Fig. 3)

In contrast with whitewater river floodplains, the herbaceous vegetation in blackwater river floodplains is not well developed. Submersed plants occur only in areas with low water-level fluctuations where light penetrates down to the bottom. Free-floating plants are rare or absent. Along the main river channels, there are large sandy beaches without herbaceous vegetation. Fine-grained, dry sediments are covered by a sparse stratum of herbs that is dominated by hard sedges of low food value. Herbaceous vines are mostly absent. *Igapó* forests are generally poorer in tree species than are *várzea* forests. They share many tree species with Amazonian savannas and *campinarana* forests (Kubitzki 1989; Vicentini 2004). Due to better oxygen availability (in comparison with *várzea* forest) tree lines may become established at mean flood levels of up to 9-m water depth. Due to the reduced habitat dynamics that occur along blackwater rivers, the different *igapó* forest types in our classification are established mainly based on flood height and duration. The wood biomass production and NPP of *igapó* forests are approximately two-thirds to one-half lower than those of *várzea* forests (Schöngart et al. 2005; Fonseca et al. 2009).

Most headwaters of the northwestern Negro tributaries have transparent waters of up to 3-m Secchi-depth. They become blackish in color and very acidic after flowing through areas covered by dense-canopy forests. These differences in water and sediment chemistry have substantial impacts on biological parameters; for example, they influence the tree species composition and diversity of flooded forests. *Igapó* forests of the Anavilhanas Archipelago (in the lower Negro River) are of intermediate fertility because of sediment input from the Branco River; therefore, they share several tree species with *várzea* forests. However, *Igapó* forests of the middle and upper Negro River have a distinct flora with elevated levels of endemism.

Clearwater River Floodplains of Intermediate Fertility (*igapós*)

Clearwater river floodplains are of intermediate nutrient status, but they vary considerably in physical and chemical water and soil parameters. Along the main river channels, large sandy beaches (formed by the bedload of the rivers) occur without herbaceous vegetation. On fine-grained sediments, mixtures of grasses, sedges, and herbaceous plants occur; however, these herbaceous systems often have lower biomass and productivity than those found in the *várzea*. Herbaceous vines occur at forest edges and in disturbed areas. In water, there is free-floating vegetation with intermediate NPP and biomass. Submersed macrophytes can occur in areas with light penetration down to the bottom and with little water-level fluctuation. Due to these conditions, the species diversity of aquatic macrophytes is higher than it is in whitewater or blackwater river floodplains.

Clearwater floodplain forests generally show a mixture of *igapó* and *várzea* species, depending on their nutrient status. Species richness is generally lower than it is in whitewater or blackwater floodplain forests and tree heights are often reduced. Preliminary data on wood-growth increments of trees in the Tapajós River floodplain indicate intermediate growth rates (Schöngart, unpublished).

Blackwater River Floodplains of Intermediate Fertility

Blackwater river floodplains on alluvial *paleo-várzea* substrates are found all over the different-aged quaternary formations occurring in equatorial and western Amazonia. River waters of these areas have intermediate levels of suspended solids, which originate from anciently deposited and newly eroded sediments of Andean origin. Depending on the age of the ancient *várzea* river terraces within the catchment (i.e., Pleistocene, Holocene), water- and soil-nutrient levels may be intermediate. Free-floating plants are rare and semi-aquatic macrophytes may occur but mostly show lower coverage and reduced biomass in comparison with whitewater rivers. The flora of these flooded forests shares many components with the *várzea*, but species richness is substantially lower.

Wetlands Subjected to Long-Lasting, Monomodal, and Predictable Flood Pulses of Low Amplitude

The large Amazonian interfluvial wetlands also show predictable, monomodal flood pulses that result from insufficient drainage of seasonal rainfall. Their hydrological buffer capacity is low and the flood pulse may vary in amplitude and duration. Periods of prolonged drought, and sometimes accompanying fire during strong El Niño events (Sombroek 2001; Adeney et al. 2009), may lead to partial extinction of aquatic plant and animal species. Recolonization during favorable periods depends on the mobility of the species, passive long-distance transport of diaspores, connectivity with major river systems, and (for shorter periods) the seed bank in the wetland soils.

Interfluvial Wetlands in the Middle Negro River Basin

Several patches of interfluvial wetlands that occur in the middle Negro River basin near Barcelos extend over several thousand square kilometers. They contain large open areas covered by sedges and a few species of aquatic macrophytes (e.g., *Mayaca* spp.), forested patches on higher-lying areas with *Mauritia flexuosa*, and large shallow permanent waterbodies. Because of their long flood periods and extremely low nutrient status, these areas may belong to the most species-poor areas near the Equator (with respect to higher vegetation). Food availability for animals is very low, as shown by the scarcity of large fish, caimans, mammals, and aquatic birds. However, a boost of food production occurs during the fruiting period of the palms and periodically attracts many fruit-feeding animals such as parrots and tapirs. Interfluvial wetlands in the Negro River area are visited only by ornamental fish collectors who exploit the stocks in the draining streams but do not enter the core areas.

Hydromorphic Edaphic Savannas of Central Amazonia

This type comprises a large variety of wetlands in interfluvial areas of the rainforest belt (e.g., between the Purus and Madeira Rivers), in the upper Negro River basin, and in the pre-Andean Zone. These wetlands are little studied because of very difficult access. Soils of these interfluvial wetlands are of tertiary origin, strongly leached, and of very low fertility (Anderson 1981; Luizão et al. 2007). Many are on sandy soils with an underlying hardpan of deposited minerals (Horbe et al. 2004). Fine-grained kaolinite depositions may also occur in depressions.

Interfluvial wetlands receive their water from local rainfall. During the rainy season, these areas may be shallowly flooded (0.1 to up to 4-m depth) or have high groundwater tables and saturated soils (Bleackley and Khan 1963; Franco and Dezzeo 1994; Adeney 2009). At the end of the dry season, the ATTZ is dry, but the groundwater table is near the surface. In general, depressions are permanently filled with water, but they may occasionally dry out during extreme dry periods. Due to the underlying hardpan, any rainfall may drastically raise the water table and cause long periods of saturation even when the surface appears dry (Franco and Dezzeo 1994).

Despite their low nutrient status and low productivity, these areas may contain unique plant and animal communities with high proportions of endemic species (Anderson 1981; Fine et al. 2006). Long-term flooding or waterlogging of the soils, increased fire stress during extremely dry periods (Sombroek 2001; Adeney 2009), and the very low nutrient status result in a mosaic of open and closed areas of savanna-like vegetation and stunted forest that are locally called by a variety of names (e.g., *campina, bana, muri* scrub vegetation, *campinarana* forest, Amazonian *caatinga*, and *varillales*). The water-saturation gradient may be an important determinant of the vegetation formation, with the lowest-stature vegetation occurring in areas of longest saturation (Bongers et al. 1985). This correlation is widely noted, including in Peru (Alonso and Whitney 2001), Venezuela (Bongers et al. 1985; Coomes and Grubb 1996), Suriname (Heyligers 1963), and the central (Vicentini 2004) and southern (Jirka et al. 2007) Brazilian Amazon. Interfluvial wetlands are drained by small blackwater and clearwater rivers (Klinge 1967), sometimes to different river systems (see inset in Fig. 5).

Large Hydromorphic Climatic Savannas in the Cerrado Belts

This type includes very large interfluvial wetlands in the *cerrado* belts north and south of the Amazon rainforest biome. These are characterized by a pronounced dry season of several months. They include the periodically flooded savannas of Roraima and the Rupununi district in the north, the periodically flooded Beni savannas in the west, and the flooded savannas of the upper Araguaia River (including the Bananal) in the south. Near the river courses, the Beni and upper-Araguaia River wetlands show the geomorphic structures of river floodplains; at a certain distance away from the rivers, they transition and display the characteristics of interfluvial systems. This complicated system requires a more detailed mapping and habitat classification. The alternating wet and dry *cerrado* climate has a very strong influence on the vegetation physiognomy and on the species composition of these areas, which show many similarities to the Pantanal of Mato Grosso (another very large *cerrado* wetland at the upper Paraguay River).

Wetlands Subjected to a Polymodal, Predictable Flood Pulse

A polymodal, predictable tidal pulse affects most coastal wetlands. Periodic flooding and high (and sometimes variable) salinity create specific ecological conditions. Major habitats are mangroves, sandy beaches, mud flats, and coastal lagoons. Mangrove species include *Avicennia germinans, A. schaueriana, Conocarpus erectus, Laguncularia racemosa, Rhizophora harrisonii, R. mangle,* and *R. racemosa* (Lacerda et al. 2002).

Because of the flat relief of the coastal area, the impact of the tide affects the lower reaches of the rivers more than 100 km upriver. Part of the ATTZ is influenced by a tidal pulse of fresh water. These areas are covered by *várzea* tree species. The impact of polymodal freshwater pulses on the biota of the ATTZ has not yet been studied. In the Amazon estuary at Marajó Island, natural levees protect inland floodplain areas from tidal pulses and create freshwater swamps covered by herbaceous plants and palm swamps of *Mauritia flexuosa*; these are subjected to monomodal flood pulses of varying length.

Wetlands Subjected to a Polymodal, Unpredictable Flood Pulse

Streams and low-order rivers are affected by local rain events. Short flood pulses occur mostly during the rainy season (during and soon after heavy rains) and are unpredictable for fauna and flora (Fig. 4). The effect of these pulses on terrestrial and aquatic fauna is still not well understood. We assume that adaptation of aquatic and terrestrial fauna to these pulses is difficult and limits their use of riparian wetland resources. Risk and avoidance strategies (as described by Adis and Junk 2002) may prevail in floodplains with an oscillating (or spiky) flood pattern in temperate regions. In the Amazon, there is a predictable increase in base flow during the rainy season (in comparison to the dry season) that may favor certain life-history traits (e.g., reproductive strategies of fishes). During the rainy season, trees must cope with long-term waterlogging of soils, but deep flooding occurs only for short periods. Upland tree species likely become adapted to periodic flooding in riparian forests and may later colonize habitats that flood briefly in high-lying *várzea* and *igapó* areas (Wittmann et al. 2010). There are several studies that examine the riparian vegetation of *cerrado* streams (e.g., Veloso et al. 1991, IBGE 1992, Rodrigues and Leitão Filho 2004) but very few that address the riparian vegetation in rainforest areas. Inventories of Amazonian upland forests do not differentiate between riparian and upland communities and species. This omission may severely affect the discussion about biogeochemical cycles, species diversity, and the impact of global climate change on upland forests.

Low-order rivers show considerable variability in hydrochemical parameters. Thus, they provide a better indication of the local geologic conditions than do large rivers, which represent the mean value of the chemical components of all tributaries in their catchments. Most low-order rivers are nutrient poor and have brownish to greenish water color (Furch and Junk 1980; Furch 1986). In undisturbed areas, they are transparent, but in areas used by agriculture and cattle ranching, they become turbid because of increased soil erosion. This reduces habitat diversity within the streams and negatively affects aquatic biodiversity (Wantzen 1998). However, hydrochemical parameters are relatively unaffected because the geology of the catchment does not change. A blackwater stream that becomes turbid because of soil erosion does not become a whitewater stream but continues to be acidic and nutrient-poor; thus, it remains a human-impacted stream in the blackwater category.

Distribution and Extent of Amazonian Lowland Wetlands

The information about the extent of Amazonian wetlands is scattered in the scientific literature. In 2010, Melack and Hess published a synthesis of the extent of wetlands in the different

Amazonian river basins according to remote-sensing data. Here, we summarize the data provided by different authors and link them with our classification system.

Distribution and Extent of Amazonian Whitewater River Floodplains (*várzeas*)

Amazonian whitewater river floodplains cover an area of more than 400,000 km^2 (Melack and Hess 2010). They occur along the Amazon main stream and all major tributaries originating from the Andes and/or the Sub-Andean foothills. Three of the Amazonian whitewater rivers (the Amazon, the Madeira, and the Japurá Rivers) are among the 10 largest rivers in the world (Latrubesse 2008). Extensions of their periodically flooded areas depend on the size of their catchments, river discharge, slope, and the geomorphology of adjacent lowlands, and they vary from widths of few hundreds of meters to up to 100 km. While the extension of the *várzea* in the eastern part of the Amazon basin is restricted to the Amazon main stem and its delta, its extension is greatest within the central and western parts of the Amazonian lowlands where most large whitewater tributaries feed into the Amazon (Solimões) River. In the Andes, the extension of the *várzeas* is small due to higher slopes and smaller catchment areas.

The exact extent of *várzea* area cannot yet be given because, from an ecological point of view, only areas directly affected by whitewater rivers can be considered *várzeas*. For instance, large areas of the Beni savannas must be considered as nutrient-poor interfluvial wetlands. Furthermore, Melack and Hess (2010) do not differentiate between recent várzeas and paleo-várzeas. We assume that at least 125,000 km^2 of the total várzea area consists of paleo-várzeas.

Distribution and Extent of Amazonian Blackwater River Floodplains (*igapós*)

Negro River and Tributaries

The catchment area of the Negro River covers approximately 700,000 km^2 (Latrubesse 2008). Blackwater floodplains along the Negro River and its tributaries cover an area of approximately 118,000 km^2 (Melack and Hess 2010) and include the floodplains along the main river channel and the extended headwater regions that are located in the Colombian, Venezuelan, and NW-Brazilian Amazon and south of the Roraima Massive. Although generally characterized by low amounts of suspended solids and low-nutrient status, the black waters of the Negro River may vary substantially in coloration, pH, and nutrient status (depending on their origins). Because of the very flat topography, the river floodplains after some distance are transformed into large hydromorphic edaphic savannas with a low flood amplitude.

Floodplains on Paleo-Várzea Substrates

These floodplains cover an area of of at least 125,000 km^2 and occur along small to intermediate rivers that pass through more or less leached paleo-sediments originating from the Andes (as indicated in the paragraph on the distribution and extent of várzeas). The paleo-alluvial soils were deposited along ancient channels of whitewater rivers during the tertiary and quaternary in central and western Amazonia. Information about water and soil chemistry in this region is scarce. In addition to occurring along rivers such as the Coarí, Jutaí, and Tefé, these floodplains occur in the central and western parts of the Amazon basin along the numerous lakes (e.g., Ria-lakes) that have formed in the submerged lower valleys of minor tributaries of the Amazon River as well as some of its major whitewater tributaries (such as the Purús and Japurá Rivers). However, these areas are not yet mapped. Flood amplitudes are highest near the confluence with the whitewater rivers but decline rapidly upstream. These areas may be temporarily influenced by “true” whitewaters during the highest water periods, but they are flooded by blackwaters during years with low flood levels. Tree species compositions are closer to the *várzea* than to the *igapó* and productivity is intermediate.

Distribution and Extent of Amazonian Clearwater Floodplains (*igapós*)

The largest clearwater rivers are the Xingu, Tapajós, and Trombetas Rivers (with floodplains of 37,000 km^2, 23,000 km^2, and 7,500 km^2, respectively; Melack and Hess 2010), and the Tocantins, Araguaia, and the Guaporé Rivers. The floodplains along the Tocantins River are small because the river flows through a narrow valley. The upper-Araguaia River floodplain passes through a large hydromorphic climatic savanna that covers the Bananal Island and upriver areas (with an estimated area of 58,600 km^2; Melack and Hess 2010). The floodplain of the Guaporé River also passes through the interfluvial wetlands that are included in the hydromorphic-climatic-savanna complex of the upper Madeira River (e.g., the Beni savannas; Fig. 5). The water- and soil-chemical conditions in these areas are variable and require more detailed studies.

The largest tributary of the Negro River is the Branco River, which drains the Precambrian Guayana Shield of mostly metamorphic rocks. Its slightly brownish color originates from sediments of the Roraima Massive and the savannas of its foothills (Ferreira et al. 2007). Despite its designation, the Branco River is (based on water-chemical

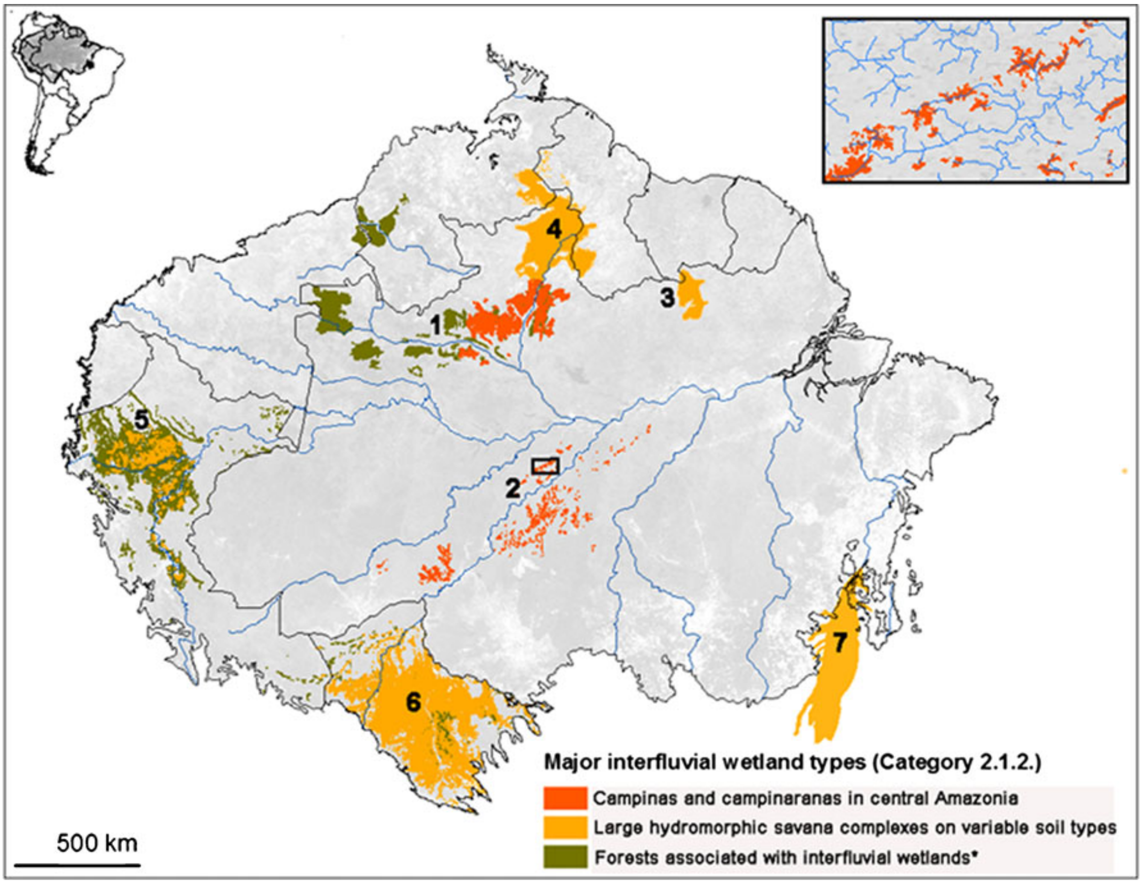

Fig. 5 Map of the important areas of interfluvial wetlands in the Amazon basin. Areas given as examples in the text are numbered and the data sources are given in the accompanying Table 2. Note that patches are not to scale relative to each other; very small patches are drawn larger in order to be visible on the map. The inset illustrates how interfluvial wetlands are often at the headwaters of small blackwater and clearwater streams. *These forests include palm forests, *campinarana* and others

parameters) not a whitewater, but a clearwater, river. At its lower reach, its extended river floodplain becomes a large, interfluvial, hydromorphic edaphic savanna that connects in the west with the forested, interfluvial wetlands of the Negro River blackwater tributaries (Fig. 5).

Distribution and Extent of Amazonian Interfluvial Wetlands

Interfluvial wetlands occur in patches of variable size and shape throughout the Amazon and include the diverse types discussed in section “Wetlands subjected to a monomodal, predictable flood pulse with low amplitude”. Depending on the flood levels of the Branco River, about 17,000 km^2 of savanna area are periodically flooded in Roraima (Hamilton et al. 2002; Fig. 5). These savannas connect to the *campinaranas* and flooded forests of the Negro River, which extend west to the Jufaris River. Interfluvial wetlands between the Purus and Madeira Rivers include patches that range in size from a few hectares to ~150 km^2 (Fig. 5) for a total of approximately 5,000 km^2. Many of these areas are flat with shallow depressions. However, in some cases, the most open areas on saturated soils may be elevated (Bleackley and Khan 1963; Franco and Dezzeo 1994) as low mounds that rise one or two meters over distances of several hundred meters (Bongers et al. 1985). Because there is no comprehensive map of interfluvial wetlands, we have compiled data from various sources. The resulting composite map (Fig. 5) shows phenomena that are visible at this scale for areas of natural open vegetation (e.g., savannas/*campinas*) that we know or suspect are subject to flooding from impeded drainage. Open, seasonally waterlogged vegetation on *tepuis* occurs mostly in Venezuela (not shown on map; likely <10,000 km^2). Table 2 gives approximate areas of each of these examples and the total estimated area.

The total wetland areas of some of these interfluvial climatic savannas may be overestimated because not all savanna areas are wetlands; however, there are no studies available. For instance, the savannas of Roraima and Rupununi cover about 80,000 km^2, of which probably only about 40% are periodically flooded. The flooded areas of the Parú/Trombetas savannas are even smaller. Figure 5 shows the extent and distribution of those areas for which

Table 2 Major interfluvial wetlands and their approximate areas (km^2). We provide rough estimates of the percentage of periodically floodable or waterlogged areas, as there are no published studies documenting the extent of flooding for most of these systems. We note with an asterisk (*) cases where the cited map source provides an estimate of flooded area. Sources: a) Olson et al. (2001); b) personal communication, A. Carneiro, Brazilian National Institute for Amazonian Research (INPA) GIS lab; c) Josse et al. (2007); d) Melack and Hess (2010); e) Lehner and Döll (2004); f) IBAMA (http://siscom.ibama.gov.br/shapes/; modified Feb 6, 2007, accessed Dec 15, 2008)

	Map number and name	Open areas (types 2.1.2.1 and 2.1.2.2.)	Associated forests	Total (km^2)	Estimated percent flooded or waterlogged*	Sources
1	Negro river *campina*/*campinarana*	30,927	73,297	104,224	100	a, b
2	Madeira river basin *campina*s	4,717	not mapped	4,717	100	b
3	Paru/Trombetas savannas	15,121	0	15,121	~ 25	a
4	Roraima/Rupununi savannas	79,785	0	79,785	~ 40	a
5	Central Peru savannas & palm forests	9,084	60,628	69,712	100*	c*
6	Beni savannas	111,679	5,923	117,602	100*	c*
7	Araguaia savannas	58,600	0	58,600	100*	d, e*
	Other Amazonian flooded savannas	38,613	0	38,613	100	a, f
	Total			488,374		

maps are available, drawn from a variety of sources and overlaid on the Amazon as defined by the World Wide Fund for Nature (WWF) ecoregions (Olson et al. 2001). In addition to those shown, many small (<100 km^2) patches occur in the Negro river basin and other regions. Most of these small patches are not adequately mapped.

Distribution and Extent of Mangroves

Brazilian mangroves occur mostly along the coasts of Amapá, Pará, and Maranhão states and cover an area of about 10,000 km^2. The largest mangrove area extends southward from Belém and measures at least 7,000 km^2 (Kjerfve et al. 2001; FAO 2007). Little is known about the wetlands along the coastline north of Belém. For Guyana, Huber et al. (1995) estimated that there are about 900 km^2 of coastal mangroves. In areas with very strong freshwater influence, *várzea* forests may replace mangroves.

Distribution and Extent of Riparian Wetlands of Low-Order Rivers

Because of high precipitation, the Amazon basin is covered by a dense network of low-order streams and rivers. Here, we consider all streams and rivers of orders 1–5 as low-order rivers. A detailed soil map of several hundred square kilometers for an area north of Manaus indicates about 40% of soils as hydromorphic (Falesi et al. 1971). Stream density reaches about 2 km per km^2. In the dryer *cerrado* region, this number likely decreases considerably but there are no data available.

Nearly all streams and low-order rivers are accompanied by fringing floodplains. These are easily detected in the *cerrado* because they are characterized by riparian forests or swampy grasslands. The floodplains of the streams in the rainforest biome are also covered by riparian forests, but they are not yet distinguished from upland forests. The areas are often only a few tens of meters wide, but stream density is high. Because canopy structures of both forest types are similar, and because many upland species also occur in the riparian zone, remote-sensing techniques have not yet been sufficient for quantifying these areas. Junk (1993) estimates a total area of about one million square kilometers. Considering the large extent of the Amazon basin and the geographic isolation of the headwater catchments, we assume that the beta-diversity of plants and animals in these streams and fringing floodplains is very high. This will require a further classification according to ecoregions.

Discussion and Conclusions

Classification of Amazonian wetlands suffers from lack of data. Remote-sensing data are of great help in indicating the extent of flooding (Hess et al. 2003), but the extent to which the flooded areas correspond to the areas covered by vegetation adapted to waterlogged soils has not been studied. In very flat interfluvial *campinas* and *campinaranas*, and in riparian vegetation along forest streams, areas influenced by periodic waterlogging may be much larger than the areas affected by flooding.

There are little or no data available about the hydrology, water and soil chemistry, and vegetation cover of many wetlands. Despite increasing data from remote-sensing studies, we cannot yet provide a precise number for the total wetland area. Because of the inclusion of the many small riparian wetlands and waterlogged *campinas* and *campinaranas*, our estimate that 30% of the total area of the Amazon basin is comprised of wetland areas is considerably larger than the estimate given by Melack and Hess (2010). The exact distribution and size of the major wetland types in Central Amazonia are also not yet known, mainly because of the fluid transition between large river floodplains and interfluvial wetlands (e.g., at the Negro, Branco, Araguaia, and Guaporé/Mamoré/Beni Rivers). Numbers given in this article are still preliminary.

The parameters used in classification systems cannot fully take into account the large natural variability of wetlands. While the differences between the classes may appear to be clear, the transitions between them in nature are often fluid. For instance, the distinction between a large river floodplain subjected to a high, monomodal, predictable pulse and a low-order, riparian wetland subjected to a polymodal, unpredictable pulse is easy. However, classification problems may arise for medium-sized rivers where a predictable, well developed, monomodal baseline pulse is overlain by a few unpredictable, short-term flood peaks during heavy rainstorms. Hydrochemical parameters display large variation that may make it difficult to incorporate a specific wetland into a specific chemical category (as shown by the Branco River and its tributaries). Floodplains of rivers that pass through very flat areas may show all of the attributes of large river floodplains near the river channel, but they show attributes of interfluvial wetlands with increasing distance. Nevertheless, these cases do not invalidate the classification system. They only demonstrate that every wetland must be analyzed in detail according to hydrological, chemical, and biological parameters. The combination of these factors will allow for inclusion of a given wetland area in one of the proposed classes or will require the establishment of a new class with specific characteristics. Our classification system is open to this.

The classification presented here should be considered as the first step of a more detailed classification system. For large wetland complexes, individual hierarchical classification systems are required that consider the wetland complex as a landscape unit whose habitats and organisms are interlinked (as shown by the HWC system of Brinson 1993a; b; 2009). To facilitate comparisons, the individual sub-units must be defined by internationally recognized parameters so that they may be easily incorporated into any internationally accepted classification system. A classification system of the major habitats of the Pantanal of Mato Grosso has already been developed (Nunes da Cunha and Junk 2011). Specific habitat classification systems for *várzeas* and *igapós* and recommendations for their sustainable management and protection are in an advanced state of development by the wetland working group at the Brazilian National Institute for Amazonian Research (INPA). Projects to classify the major habitats of the upper Araguaia, Guaporé, and Paraná Rivers have been initiated by the National Wetlands Institute (INAU) at Cuiabá, Mato Grosso (Brazil) using the same approach. For the first time, these habitat classifications and their ecological characterizations will allow for direct comparison of the habitats and species diversity of the large Brazilian wetlands and will provide information to support their sustainable management and protection.

Appendix

A glossary of indigenous, Portuguese and Spanish terms

Buritizal	Palm swamp dominated by *buriti* (*Mauritia flexuosa*)
Campina (Caatinga baixa, Bana, Chamizal, Muri scrub)	Low shrub and tree savanna areas on podzols in the Amazon rainforest. Some areas are periodically waterlogged or shallowly flooded (edaphic hydromorphic savannas)
Campinarana (Caatinga alta, Varillal, Wallaba)	Low stature, thin-trunked forest areas on podzols in the Amazon rainforest, sometimes periodically waterlogged or shallowly flooded (edaphic hydromorphic savannas covered by stunted forest)
Campo úmido	Wetland in the *cerrado* covered by grasses, sedges, and herbs
Cerrado	Brazilian savanna. This general term includes different physiognomies from open grasslands and shrub lands to low dry forests (*cerradão*)
Igapó	Floodplain of blackwater rivers
Paleo-várzea	Ancient whitewater river sediments that were deposited during former interglacial periods and are impoverished in nutrients
Tepui	Table mountain on the Guiana shield
Terra firme	Upland, covered by never-flooded Amazonian rainforest
Várzea	Floodplain of recent whitewater rivers
Vereda	Wetland adjacent to streams in the *cerrado* and covered by shrubs, *buriti* palms, grasses, sedges, and herbs

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