AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. **24**: 5–22 (2014)
Published online 15 August 2013 in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2386

Brazilian wetlands: their definition, delineation, and classification for research, sustainable management, and protection

W. J. JUNK[a], M. T. F. PIEDADE[b], R. LOURIVAL[c], F. WITTMANN[d,*], P. KANDUS[e], L. D. LACERDA[f], R. L. BOZELLI[g], F. A. ESTEVES[h], C. NUNES DA CUNHA[i], L. MALTCHIK[j], J. SCHÖNGART[d], Y. SCHAEFFER-NOVELLI[k] and A. A. AGOSTINHO[l]

[a]*Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas, Universidade Federal de Mato Grosso, Cuiabá, Brazil*
[b]*Instituto Nacional de Pesquisas da Amazônia, Grupo MAUA, Manaus, Brazil*
[c]*Ministério da Ciência, Tecnologia e Inovação – Brasil, Ecology Centre - University of Queensland, Australia*
[d]*Max Planck Institute for Chemistry, Biogeochemistry Department, Mainz, Germany*
[e]*Laboratorio de Ecología, Teledetección y Eco-Informática, Instituto de Investigaciones e Ingeniería Ambiental, Universidad Nacional de General San Martín, Argentina*
[f]*Instituto de Ciências do Mar, Universidade Federal do Ceará, Fortaleza, Brazil*
[g]*Universidade Federal do Rio de Janeiro, Instituto de Biologia, Departamento de Ecologia, Laboratório de Limnologia, Rio de Janeiro, Brazil*
[h]*Universidade Federal do Rio de Janeiro, Núcleo em Ecologia e Desenvolvimento Socio-Ambiental de Macaé, Brazil*
[i]*Departamento Botânica e Ecologia, Universidade Federal de Mato Grosso, Cuiabá, Brazil*
[j]*Lab. Ecologia e Conservação de Ecossistemas Aquáticos, Unisinos, Porto Alegre, Brazil*
[k]*Instituto Oceanográfico, Universidade de São Paulo, Brazil*
[l]*Universidade Estadual de Maringá – Nupélia, Maringá, Brazil*

ABSTRACT

1. Although 20% of Brazilian territory is covered by wetlands, wetland inventories are still incomplete. In 1993, Brazil signed the Ramsar Convention but a coherent national policy for the sustainable management and protection of wetlands has yet to be established.

2. Major gaps in the definition of a specific wetland policy are twofold: (1) the lack of standardized criteria by which wetlands are defined and delineated that reflects the specific ecological conditions of the country and (2) the lack of a national classification of wetlands that takes into account specific hydrological conditions and respective plant communities.

3. In recent years, efforts have been made at a regional level to improve public awareness of the ecology of Brazilian wetlands, their benefits to society, and the major threats endangering them. Studies have shown that wetlands play a crucial role in the regional hydrological cycle and provide multiple benefits for local populations. Furthermore, Brazilian wetlands contribute significantly to South American biodiversity. Therefore, wetland conservation and sustainable management should be given high legislative priority.

4. This article provides a synthesis of the current body of knowledge on the distribution, hydrology, and vegetation cover of Brazilian wetlands. Their definition, delineation, and classification at the national level are proposed in order to establish a scientific basis for discussions on a national wetland policy that mandates the sustainable management of Brazil's extremely diverse and complex wetlands. This goal is particularly urgent in the face of the continuing and

*Correspondence to: Florian Wittmann, Max Planck Institute for Chemistry, Dep. Biogeochemistry, Hahn-Meiner Weg 1, 55128 Mainz – Germany. Email: f-wittmann@web.de; f.wittmann@mpic.de

dramatic deterioration of wetlands resulting from large-scale agro-industrial expansion, and hydroelectric projects as well as the projected impact of global climate change on hydrological cycles.

Received 05 February 2013; Revised 28 June 2013; Accepted 29 June 2013

KEY WORDS: Amazonian wetlands; *cerrado* wetlands; coastal wetlands; flood pulse; Pantanal; Ramsar Convention; wetland vegetation; wetland policy

INTRODUCTION

Wetlands are among the most threatened ecosystems worldwide despite several international treaties that recommend both their regular inventory and efforts aimed at their protection (Millennium Ecosystem Assessment, 2005; Darwall *et al*., 2008; SCBD, 2010). Brazil is the fifth largest country in the world, covering an area in the Neotropics of about 8.5 million km^2, in which a wide variety of wetland types occupy an estimated 20% of the national territory (Junk *et al*., 2011). Different types of forested wetlands cover about 30% of the humid tropics of the Amazon lowlands. This percentage decreases toward the dryer areas in the northern and southern parts of Brazil, but even in the savanna belts there are extensive wetland systems. Some of these cover tens of thousands of square kilometres, e.g. the Panatanal Matogrossense and the flooded savannas of the Araguaia River, including Bananal Island. Along the Atlantic coast, mangroves are found down to 28–30ºS, covering about 13 800 km^2 (Kjerfve and Lacerda, 1993). Indeed, extended lagoons and connected wetlands are characteristic of the entire Brazilian coast.

Wetlands provide many services for society, such as water storage, the buffering of river and stream discharge, groundwater recharge, sediment retention, water purification, microclimate regulation, recreation and ecotourism, organic carbon storage, timber production, and the provision of non-timber products, medicinal plants, fish, agricultural products, drinking water for humans and livestock, and pasture land for animal husbandry. Furthermore they contribute to cultural safeguarding by providing home for traditional communities (Millennium Ecosystem Assessment, 2005).

Wetlands also contribute significantly to biodiversity (Gopal *et al*., 2000). Predictable flood-pulsing wetlands can be considered as centres of speciation, as evidenced by the many endemic species of terrestrial invertebrates and trees in Amazonian floodplains (Erwin and Adis, 1982; Adis, 1997; Junk, 2000; Wittmann *et al*., 2013, and the development of morphological, anatomical and physiological adaptations as well as specific life-history traits of invertebrates (Adis and Junk, 2002). Furthermore, wetlands influence in multiple ways species diversity of adjacent upland and deep-water habitats. For example, in the Pantanal, there are 104 wetland-dependent bird species and 286 upland species. Some upland species are, outside the Pantanal, in danger of extinction, such as the hyacinth macaw (*Anodorhynchus hyacinthinus*), but have large populations inside the Pantanal (Junk *et al*., 2006). Marine fish species, such as *Mugil* spp., *Anchoa* spp., *Centropomus* spp., *Sphoeroides* spp., and *Lutjanus* spp., use the mangroves for spawning and as juvenile nurseries, analogous to the use by riverine freshwater fish species of the adjacent floodplains. The long-distance spawning migrations of some characids, such as *Semaprochilodus* spp., *Prochilodus nigricans*, and *Brycon melanopterus*, link deep-water habitats of the river channel to the periodically inundated floodplains (Junk, 2007). The negative impacts of human-imposed pulse regulations on biodiversity and fisheries have been demonstrated in several studies of the Paraná River and its floodplain (Hoeinghaus *et al*., 2009; Barletta *et al*., 2010).

The mean global value of these services was originally estimated by Costanza *et al*. (1997), while more recent estimates were based on efforts of an international initiative on 'The Economics of Ecosystems and Biodiversity' (TEEB, 2013). Both estimates show values for wetlands that are higher than those of most other ecosystems; however, economic valuations of specific wetlands may vary widely. For example, according to Seidl and

Moraes (2000), who used methods similar to those of Costanza *et al*. (1997), the global wetland value for services of the Pantanal of Nhecolândia is half that of the annual 14 785 US\$ ha^{-1} estimated by the latter authors. Regardless of exact values, available data already point out the magnitude of the economic, ecological, and social value that intact wetlands provide to Brazilian society.

Despite their geographic extension, diversity, and economic importance, wetlands are rarely mentioned in federal legislation, state constitutions, or environmental legislation. There is no national policy that regulates their protection and management. Only the Pantanal is distinguished as a National Heritage site by the 1988 constitution. Moreover, as noted above, some large wetlands, e.g. the floodplains of the Amazon River and several of its tributaries, as well as those of the Paraná and Paraguai Rivers, along with the Pantanal Matogrossense, cross national boundaries into other countries, such that international efforts are needed if harmonious environmental policies are to be established.

In 1993, Brazil signed the Ramsar Convention and since then has declared several Ramsar sites, but it has been very slow in the implementation of wetland inventories and in wetland classification (Diegues, 1994, 2002). This process is complicated by the dozens of local terms for different wetland types and by the lack of broadly accepted parameters to define wetlands, both of which are essential preconditions for a modern and efficient national wetland policy aligned with the terms of the Convention. Such a policy is essential, particularly considering the impact of recurrent catastrophic floods and droughts throughout the country's territory and the likelihood that such events will increase in response to the forecasted global changes in climate (IPCC, 2007).

Recently, a few Brazilian institutions have initiated efforts to achieve wetland classification. These institutions include the National Institute for Science and Technology in Wetlands (INCT-INAU) at the Federal University of Mato Grosso, Cuiabá, the working group Monitoring Amazonian Wetlands (MAUA) at the National Amazon Research Institute (INPA) at Manaus, the Laboratory for Ecology and Conservation of Aquatic Ecosystems (UNISINOS) at São Leopoldo, Rio Grande do Sul, the Center for Research in Limnology, Ichthyology and Aquaculture, at the State University of Maringá, Paraná, the Institute of Marine Sciences of the Federal University of Ceará (LABOMAR-UFC), the Institute of Oceanography of Sao Paulo University, the Institute of Oceanography of the Federal University of Rio Grande, and the Museu Paraense Emilio Goeldi in Belém, Pará. Consequently, classification systems are already available for Brazilian mangroves (Kjerfve and Lacerda, 1993), the permanent swamps of the *cerrado* (*veredas*) (Ribeiro and Walter, 1998; Araújo *et al*., 2002), parts of the semi-arid north east (Maltchik *et al*., 1999), the southern part of the country (Maltchik *et al*., 2003, 2004), the upper Paraná River floodplain (Thomaz *et al*., 2004), the Pantanal (Nunes da Cunha and Junk, 2011a), the wetlands of the Amazon basin (Junk *et al*., 2011), and the wetland habitats of the central Amazon River floodplain (*várzea*) (Junk *et al*., 2012b).

In this paper, a definition of Brazilian wetlands is proposed that corresponds to the specific hydrological conditions of the country and suggests a basis for wetland delineation. A short ecological characterization of major wetland types is presented and a hierarchical wetland classification method is introduced that considers hydrological and vegetation parameters as the main wetland attributes. The classification is discussed in the context of other national and international classification efforts. As the first step in the formulation of a Brazilian wetland policy, it aims to contribute to worldwide efforts to achieve a better understanding of the extent, structures, and functions of wetlands as well as the threats that endanger them.

PRECIPITATION, RIVER HYDROLOGY, AND THEIR IMPACT ON FLOOD PULSES IN BRAZILIAN WETLANDS

Precipitation is not uniformly distributed within the different regions of Brazil; rather, rainfall is highest in the north west (>3500 mm yr^{-1}) and lowest in the semi-arid north east (300 mm yr^{-1}). Moreover, most of the country's regions face pronounced dry and wet seasons, with the exception of the rainfall-rich north-western tropical forests and the southern coastal areas (Figure 1).

Figure 1. Precipitation curves for different areas of Brazil (Salati and Marques, 1984, completed by J. Schöngart).

Large fluctuations in water level, also called 'flood-pulsing', differentiate most wetlands in Brazil and other countries of the tropics and sub-tropics from those in countries at higher latitudes. Wetlands in the latter include bogs, fens, and mires, which typically have a relatively stable water level. In regions exposed to flood-pulsing, excess precipitation during the rainy season leads to periodic sheet-flooding of large, flat interfluvial areas, the periodic filling-in of depressions with water, and the lateral inundation of large areas along streams and rivers. These events result in the formation of extended river floodplains along most of the large rivers and a dense network of riparian wetlands along streams and low-order rivers. Flood pulses are monomodal and predictable in the large floodplains because they are part of the cycle of wet and dry seasons at regional or even continental scale. The average amplitude of large-river flood pulses can exceed 10 m in Amazonia but are considerably lower towards the south, depending on changes both in the total amount and the periodicity of the rainfall (Figure 2). Pulses in interfluvial wetlands reach up to 2 m on average. Lower-order rivers are subjected to short, unpredictable flood pulses of varying height, according to the intensity of local rainstorms (Figure 3), while depressions in the semi-arid north east have unpredictable inundations of short duration every few years. Structures and functions of large river floodplains are described by the flood pulse concept (Junk *et al.*, 1989; Junk and Wantzen, 2004; Junk, 2005).

Coastal wetlands with direct marine influence are subject to plurimodal, predictable tidal pulses whereas, further inland, wetlands in coastal sand plains are subject to short, unpredictable, or monomodal pulses during the rainy season. A general classification of the flood pulses is given in Table 1. Only a few Brazilian wetlands are permanently wet and have a mostly stable water level.

CHARACTERISTICS OF BRAZILIAN WETLANDS AND PROPOSALS FOR THEIR DEFINITION AND DELINEATION

The extended terrestrial phases in flood-pulsing wetlands lead to the occupation of higher-lying wetland areas by a specific vegetation comprising woody and herbaceous plants with a large ecological tolerance of flood and drought stress. In the Amazon rainforest, highly flood-tolerant, species-rich floodplain forests dominate wetlands. In savanna areas, the severe drought stress that often characterizes the terrestrial phase favours a mixture of savanna vegetation and forested patches (Drechsler *et al.*, 2009; Lourival *et al.*, 2011; Nunes da Cunha and Junk, 2011b). Wild fires are additional potential stress factors for wetland biota. Aquatic and palustrine herbaceous plant species and invertebrates usually develop during the aquatic phase, often from seed banks in the sediments or from vegetative resting stages. Fishes, aquatic birds, insects, reptiles, amphibians, and mammals tend to recolonize temporary wetlands by emigration from permanently aquatic habitats. Then, at the beginning of the next dry period they return to the permanent water bodies or become stranded, die, and are incorporated within terrestrial food webs.

Some wetlands, such as the large-river floodplains and the large periodically inundated savannas, cover huge areas and are very complex. For instance, the main-stem Amazon River

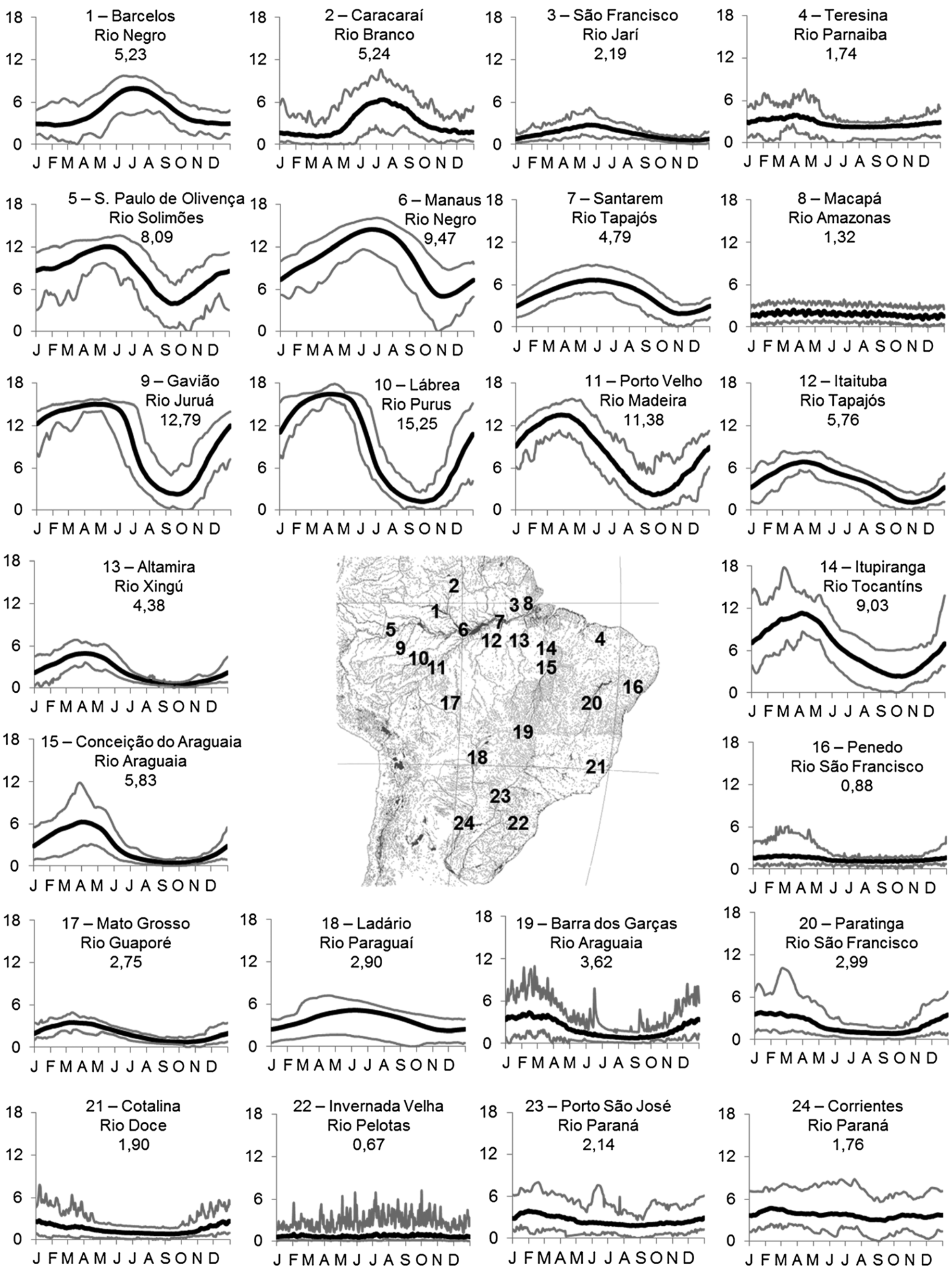

Figure 2. Flood curves for large Brazilian rivers. The geographic positions of the respective data collection points are indicated by the numbers on the map. The curves represent the water-level fluctuation (m) during the annual cycle between 1970 and 2010. The black curve represents the daily mean water level and the curves above and below it the daily maximum and minimum values for this period (for comparative reasons, the absolute minimum value of all curves was defined as zero on the height scale).The numbers below the river names indicate the mean values of the flood pulse amplitude (m).

floodplain (*várzea*) covers 98 110 km^2 (Melack and Hess, 2010); the periodically flooded savannas in Roraima in Northern Amazonia (and Rupununi in Guiana), about 16 500 km^2 (Melack and Hess, 2010); the periodically flooded savannas of the Guapore River, extending into the Bolivian savannas of the Mamoré and Mortes Rivers (Llanos dos Moxos), 92 100 km^2 (Hamilton *et al.*, 2004); the Pantanal at the border of Brazil, Bolivia, and Paraguay, 109 590 km^2 (Hamilton

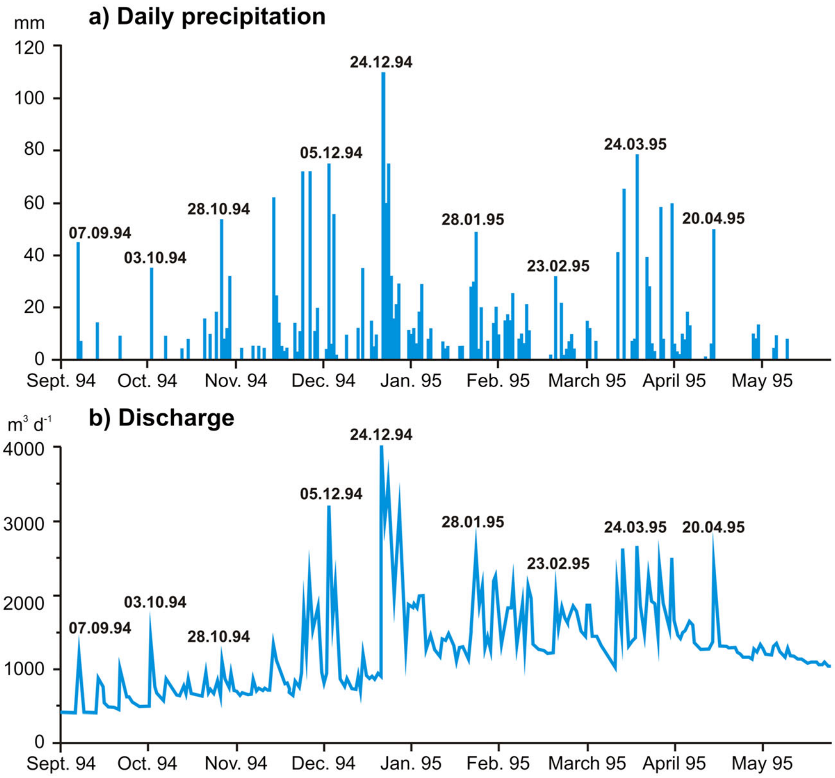

Figure 3. Daily precipitation and discharge in a low-order savanna stream near Cuiaba (according to Wantzen, 2003).

Table 1. Types of flood pulses and affected wetlands

Predictability	Frequency	Amplitude	Wetland type
Predictable	Monomodal	High	Large river floodplains
		Low	Large interfluvial wetlands, wetlands in coastal sand plains (e.g. the *Lençóis maranhenses*)
Predictable	Polymodal	Varying	Tidal wetlands
Unpredictable	Polymodal	Varying	Wetlands along low-order rivers, in depressions, and in coastal sand plains
Unpredictable	Pluriannual	Low	Wetlands in semi-arid zones of north-eastern Brazil

et al., 1996); and the Araguaia River wetlands, including Bananal Island, 58 600 km^2 (Melack and Hess, 2010). Also of note are the coastal tidal wetlands, mostly mangroves and salt marshes along the Maranhão/Pará littoral, which cover about 7000 km^2 (Lacerda, 2001) (Figure 4).

Many of these wetlands include elevated and permanently dry areas of up to a few square kilometres, deriving from outcropping base-rocks (inselbergs), palaeo-fluvial terraces, or ancient sea-level relict sand ridges. In shallow flooded savanna areas, termite mounds form small, permanently dry islands of a few square metres each (hyperseasonal termite savannas; Eiten, 1983). These permanently dry islands are of utmost importance as periodic refuges of terrestrial organisms and they contribute decisively to the maintenance of biodiversity cycles, functions, and processes. They must therefore be considered as indispensable parts of the large wetland systems. The extraordinary habitat diversity of the large Neotropical wetlands requires individual habitat classifications, as already proposed for the Pantanal (Nunes da Cunha and Junk, 2011a) and the central Amazon River floodplain (Junk *et al.*, 2012b).

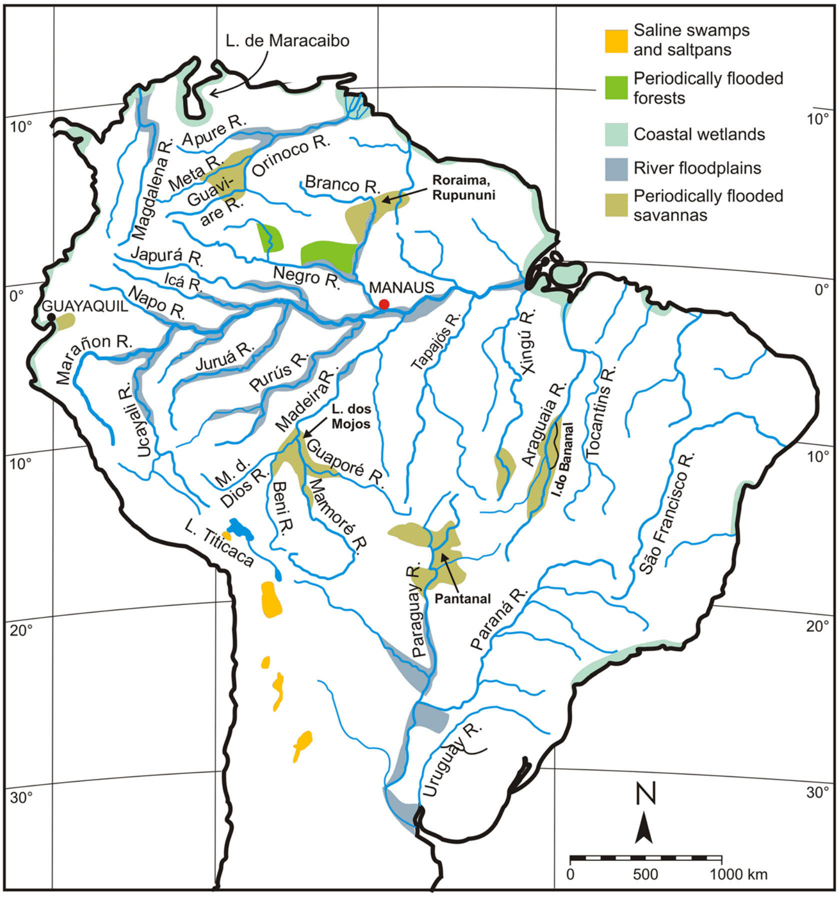

Figure 4. Distribution of major wetlands in northern South America (according to Junk, 2007).

Despite their smaller sizes, wetlands in the dry north east, along the tropical coast to the south east and in the wet subtropical portion of Brazil, play a significant role in the regulation of the regional hydrological regime and maintenance of biodiversity. Many of these wetlands harbour endemic and endangered species (Maltchik *et al*., 1999, 2003, 2004), and provide water and food for many local communities and for livestock. They also serve as essential sources of recreation (Esteves, 2011).

Traditional communities have developed many strategies to use specific wetland resources during the terrestrial and aquatic phases. Nevertheless, politicians and urban planners often consider wetlands as wastelands, allowing their exploitation as solid-waste dumping sites or housing areas or their disruption by road construction. In many regions modern agro-industries have destroyed wetlands, and thus their multiple benefits, by converting large areas of wetlands into croplands. In southern Brazil, this transformation is already extensive. The resulting reduction in wetland buffer capacity together with the increased surface run-off leads to annual catastrophic floods, as occurred in 2011 in Minas Gerais, with many victims and heavy losses of public and private goods (Junk *et al*., 2012a). Furthermore, the leaching of fertilizers and pesticides as well as the run-off of untreated sewage from urban areas causes a deterioration of water quality in rivers, streams and other downslope wetlands. Coastal wetlands have been destroyed by the expansion of cities and in response to demands for waterfront or scenic homes. Brazil has enormous hydroelectric potential but some of its reservoirs have destroyed river floodplains, interrupting the longitudinal connectivity of rivers and damaging downstream wetlands through the alteration of flood pulses, sediment load, and other limnological parameters, as shown for the Paraná River and its floodplain (Hoeinghaus *et al.*, 2009; Barletta *et al.*, 2010). These numerous adverse effects highlight the importance of including the flood-pulse concept in the definition of Brazilian wetlands and integrating it into plans for their protection.

We propose the following definition and delineation of Brazilian wetlands:

> Wetlands are ecosystems at the interface between aquatic and terrestrial environments; they may be continental or coastal, natural or artificial, permanently or periodically inundated by shallow water or consist of waterlogged soils. Their waters may be fresh, or highly or mildly saline. Wetlands are home to specific plant and animal communities adapted to their hydrological dynamics.
>
> The extent of a wetland can be determined by the border of the permanently flooded or waterlogged area, or in the case of fluctuating water levels, by the limit of the area influenced during the mean maximum flood. The outer borders of wetlands are indicated by the absence of hydromorphic soils and/or hydrophytes and/or specific woody species that are able to grow in periodically or permanently flooded or waterlogged soils. The definition of a wetland area should include, if present, internal permanently dry areas as these habitats are of fundamental importance to the maintenance of the functional integrity and biodiversity of the respective wetland.

PROS AND CONS OF SOME EXISTING CLASSIFICATION SYSTEMS

The scientific literature contains many definitions of wetlands as well as systems for their classification (summarized in Mitsch and Gosselink, 2008). However, most of them emphasize wetlands with permanent or long-term wet conditions while largely neglecting those subjected to flood-pulsing, with long terrestrial phases. Organic matter accumulation as a result of permanent shallow inundation or long-term waterlogging is a good indicator of permanently wet conditions. In contrast, flood-pulsing wetlands with long terrestrial phases do not exhibit accumulation of organic matter as periodic aeration facilitates the decomposition of organic matter. Thus, by exclusively focusing on hydric soil indicators we fail to achieve wetland delineation and protection, not only in Brazil but also worldwide, i.e. in all regions where there is a pronounced seasonality in rainfall. In fact, all of the well-known large African wetlands, such as the Okawango Delta, the Niger River floodplain, and the Sudd, annually undergo an extended dry phase. Many Australian wetlands become wet only every few years but they are of utmost importance for the maintenance of biodiversity. Likewise, in temperate regions, large areas of river floodplains fall periodically dry. In many cases, wetland status of high-lying floodplain areas inundated only during peak floods is not recognized, often facilitating exploitation of these areas as cropland and protected by dikes, e.g. along the Mississippi, Missouri, and Ohio Rivers in the USA and the Rhine River in Germany. This has had far-reaching adverse consequences for the flood regime, nutrient cycles, and habitat and species diversity not only of former and still active river–floodplain complexes but also of river deltas and the adjacent sea (Mitsch and Day, 2006).

The Ramsar Convention (Scott and Jones, 1995) classifies wetlands worldwide, differentiating between marine and coastal, inland, and man-made wetland systems. These systems are subdivided for hydrological characterization using the terms subtidal, intertidal, perennial, intermittent, permanent, and seasonal. Sub-units are characterized by geomorphological, hydrological, and/or botanical parameters. The inclusion of shallow-water coral reefs in the definition is questionable and may over-extend the wetland concept. The classification system of wetlands and deep water habitats of the US Forest and Wildlife Service (UFWS) (Cowardin *et al.*, 1979) differentiates between marine, estuarine, riverine, lacustrine, and palustrine systems and uses the terms subtidal, intertidal, tidal, lower perennial, higher perennial, intermittent, limnetic and littoral for hydrological classification of the subsystems. Classes are characterized by geomorphological, hydrological, and/or botanical parameters. The hydrogeomorphic classification of Brinson (1993) relies on geomorphic, physical, and chemical parameters to provide a better understanding of the relationship between organisms and their environment. It is 'a generic approach to classification and not a specific one to be used in practice' (Brinson, 1993). Based on the Australian experience, Semeniuk and Semeniuk (1995) proposed a geomorphic approach, combining landforms and degrees of wetness, to the global classification of inland wetlands. The authors correctly extended the definition of the peripheral wetland boundary to periodic 'dampness, or hydric soils or vegetation indicative of wet conditions.' Their system does not reflect the geomorphic heterogeneity of large-river floodplains and internal deltas such as the Amazonian large river floodplain, the Pantanal, and the Okawango Delta. There are two classification systems for Argentinian wetlands: Neiff (2001) differentiates between nine types, using 12 parameters to describe their geomorphology, soils, fire stress, vegetation, fauna, water origin, and several hydrological factors; Brinson and Malvárez (2002) also differentiate between nine types, but use climate, hydrology, soils and the regional vegetation as criteria.

The problems arising during the elaboration of classification systems were discussed by Finlayson and Van der Valk (1995), who pointed out the necessity of resolving differences between regional wetland definitions and regional typologies. They also drew attention to the need to standardize data collection and disseminate new technologies in order to establish ample international inventories. Indeed, many definitions and classification systems were formulated decades ago for specific purposes and do not correspond to current scientific and regulatory requirements. Modern approaches, such as the Asian Wetland Inventory (AWI), provide powerful tools for the Assessment and Monitoring of Wetland Biodiversity and Wise Use (Lopez *et al*., 2002). The need for a better wetland classification was recognized by the Ramsar Scientific and Technical Review Panel, which called for the 'development and testing of a hydro-geomorphically-based system of wetland classification' (Davidson and Finlayson, 2007).

The new Brazilian classification differentiates between coastal, inland, and artificial wetlands and concentrates on hydrology and vegetation cover. Hydrology is the most important factor determining wetland characteristics and is given highest priority. The approach is a practical one since human impact on wetlands in Brazil and in most other countries often starts with destruction of the natural vegetation cover, e.g. by timber extraction, cattle ranching, and crop plantations, which in turn cause changes in the hydrological regime through water abstraction, drainage, flood control, and reservoir construction and is inevitably followed by inappropriate civil construction. These steps can be monitored by remote-sensing techniques and the consequent measures required for wetland protection, including proposals for sustainable management, can easily be explained to politicians, planners, decision-makers, and the public. Nonetheless, the large number of Brazilian wetlands with oscillating water levels requires that greater emphasis be placed on the different types of flood pulses, which are under-represented in all of the classification systems discussed above. While the hydro-geomorphic arguments provided by Brinson (1993) and Semeniuk and Semeniuk (1995) are very helpful from a scientific point of view, they contribute little to the continuing political discussion on wetland management in Brazil.

For management purposes, the inclusion of local terms in national classification systems, as was done by Gopal and Sah (1995) for Indian wetlands, is likely to be beneficial because it often increases the local population's willingness to accept the imposed regulations for the sustainable management and protection of wetlands. This approach is included in the habitat classification systems provided for large and complex wetland systems, such as the Pantanal (Da Silva *et al*., 2000; Nunes da Cunha and Junk, 2011a) and the central Amazon River floodplain (Junk *et al*., 2012b).

PROPOSAL FOR THE CLASSIFICATION OF BRAZILIAN WETLANDS

The current classification for Brazilian wetlands uses the structure proposed for the classification of Amazonian inland wetlands (Junk *et al*., 2011). It differs, however, in that one category of the regional Amazonian classification system, which differentiates wetlands on the basis of water colour (white-water, black-water, and clear-water rivers), indicative of physicochemical conditions, has been removed from the national classification system, since it is applicable only to the Amazon and not to the entire country. However, in the future, the physical and chemical characteristics of waters and soils are likely to provide the basis for a more detailed classification.

The Brazilian classification of wetlands is segregated into three levels: (1) systems, (2) units defined by hydrological parameters, and (3) units defined by higher plants, as shown in Figure 5. The first (system) level is divided into three categories:

1. **Coastal wetlands** are defined as all wetlands, permanent or temporary, with fresh, brackish, or saline waters, under direct influence of the tides, or subject to saline intrusions, or influenced by the atmospheric deposition of dissolved or particulate substances and/or propagules from the ocean.
2. **Inland wetlands** are defined as all wetlands, permanent or temporary, with fresh, saline, or salt water, that are located in the Brazilian inland and are thus without direct or indirect marine influence.
3. **Artificial wetlands** are all wetlands, coastal or inland, derived from human activities either in organized (e.g. fish farms, rice paddy plantations), or unorganized forms (wetlands around reservoirs or those that progressively develop by the damming of streams or that form in depressions caused by the excavation of soil for road construction, etc.).

The second hierarchic level is based on hydrological parameters and is composed of five subsystems: three describe coastal wetlands and two describe inland wetlands. The two inland wetland subsystems are divided into three orders and two sub-orders. The differentiation into sub-units emphasizes the importance of hydrology and acknowledges the hydrological diversity of Brazilian natural inland wetlands and wetland systems. This approach was also used in the classification of Amazonian inland wetlands (Junk *et al*., 2011).

The hydrological characteristics of wetlands identify the origin of their waters (mainly from rain, a parent river, or the sea) and whether they are permanent, with a rather stable water level, or subject to fluctuating (pulsing) water levels and thus to dry and wet periods. As noted above, the majority of Brazilian wetlands belong to the category of pulsing systems. These are classified with respect to the amplitude, duration, predictability, and frequency of the flood pulse (Table 1).

The third hierarchic level is based on the community structure and the occurrence of higher plants and is divided into classes, subclasses, and macrohabitats. The communities of higher plants are particularly appropriate for wetland classification (Drechsler *et al*., 2009), especially considering their visibility, dynamics, and longevity, all of which respond and reflect environmental conditions over periods of months, years (herbaceous plants), decades, and even centuries (trees) (Naiman and Decamps, 1997; Casanova and Brock, 2000; Lourival *et al*., 2011). At the macrohabitat level, the absence of herbaceous plants can also serve as a criterion, for example in descriptions of sandbanks, rocky shores, rocky outcrops, and steep erosion cliffs.

Current knowledge of the community structure of wetland vegetation and the occurrence of species varies between the different wetland systems. Species diversity is very large and cannot be discussed here in detail. One of the challenges of future studies is the characterization of macrohabitats by species lists and the determination of specific indicator species. The following provides a brief summary of the wetland vegetation in coastal and inland wetlands.

The vegetation of coastal wetlands is characterized by mangroves, estuaries, and other types of wetland vegetation communities. Mangrove species composition is well documented for classification purposes (Schaeffer-Novelli *et al*., 1990; Bigarella, 2001; Menezes *et al*., 2008) but there is much less information on the vegetation of the other coastal subsystems, because of the high diversity of these environments, ranging from temporary to permanent wetlands along a salinity gradient of freshwater to hypersaline (Araújo and Henriques, 1984; Irgang *et al*., 1984; Irgang and Gastal, 1996; Costa and Dias, 2001; Bove *et al*., 2003). In coastal lagoons other salt-tolerant vegetation types may develop in addition to mangroves. In particular, salt marshes with *Spartina* spp., *Salicornia* spp., *Juncus* spp., *Paspalum* spp., *Crenea* spp., *Sesuvium* spp., *Cyperus* spp., *Batis* spp., and *Sporobolus* spp are prevalent (Costa and Davy, 1992; Araújo *et al*., 1998).

Inland wetlands are very diverse with respect to their hydrology and vegetation cover. The majority of central Amazonian wetlands are forested (Schöngart *et al*., 2010; Wittmann *et al*., 2010;

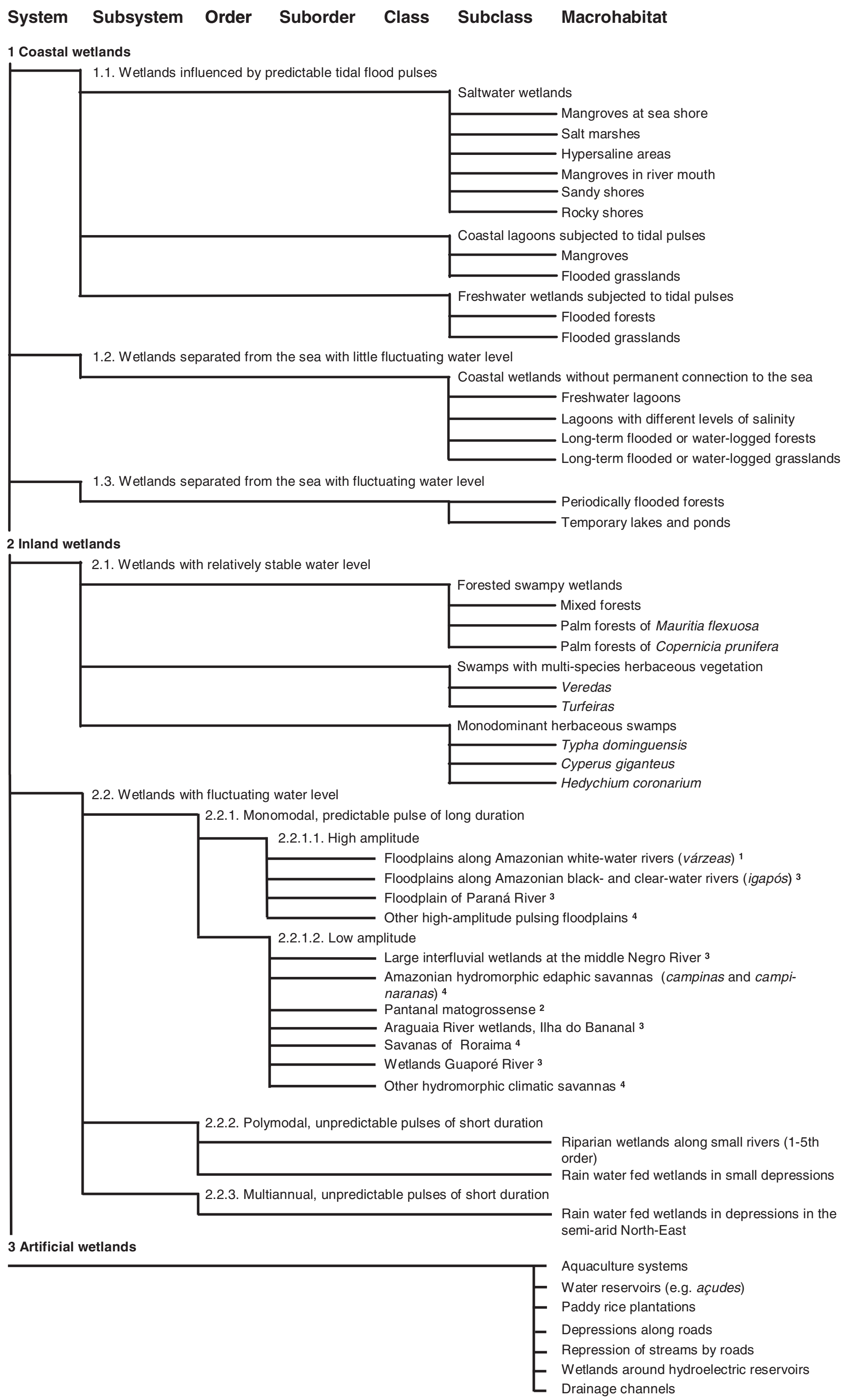

Figure 5. Classification system of Brazilian wetlands according to hydrological and botanical parameters (woody and herbaceous plants). [1]For the classification of subclasses and macrohabitats see Junk *et al*. (2012b); [2]for the classification of subclasses and macrohabitats see Nunes da Cunha and Junk (2011a); [3]classification of subclasses and macrohabitats in preparation by Junk *et al*.; [4]classification of subclasses and macrohabitats not yet available.

Wittmann, 2013). In nutrient-rich white-water river floodplains (*várzeas*), extended communities of fast-growing, highly productive, emergent, and free-floating aquatic macrophytes develop at rising and high waters in front of the floodplain forest (Piedade *et al*., 1991; Junk and Piedade, 1997). At low water, these areas are occupied by terrestrial, mostly annual grasses, sedges, and herbs. Aquatic macrophytes are restricted to free-floating mats and emergent species because high flood pulses create unfavourable light conditions near the bottom in deep water. In shallow waters, the floodplain forest canopy absorbs too much light for herbaceous plant growth in the understorey. Consequently, there are fewer aquatic macrophyte species in Amazonian forested wetlands than in *cerrado* wetlands, e.g. the Pantanal, and the wetlands of southern Brazil (Table 2). In black-water river floodplains (*igapós*), coloured humic substances in the water absorb light and the nutrient status is extremely low, which together limit the growth of free-floating and emergent aquatic macrophytes during the aquatic phase and that of terrestrial species during the terrestrial phase.

Both the genesis of Amazonian white-sand habitats (*campinas* and *campinaranas*) and the composition of their vegetation are poorly understood. Hydrological conditions can vary considerably among the different *campina* types. Some, or at least parts of them, are waterlogged or flooded during the rainy season and should be considered as wetlands. Herbaceous vegetation is scarce because of the very low nutrient status and extreme drought stress that characterize the dry season. Little is known about Amazonian swamp and riparian forests along low-order rivers. In the discussion about the Amazonian rainforest, they are erroneously included in the category of upland rainforests. Clearly, a list of wetland indicator species for these areas must be elaborated. Palm forests of *Mauritia flexuosa* (*buriti*) are a specific and widespread wetland type. They range in area from 55 000 to >100 000 km^2, forming extended swamps in moist depressions in the forests and savannas of tropical South America and often storing considerable amounts of organic material (Kahn, 1991; Ruokolainen *et al*., 2001; Householder *et al*., 2012).

Table 2. Taxonomic diversity of trees and herbaceous plants in the Amazon River floodplain (*várzea*) (Junk and Piedade, 1993; Wittmann *et al*., 2010; Wittmann, 2013), the Pantanal (Pott and Pott, 2000; Junk *et al*., 2006), and the freshwater wetlands of southern Brazil (Rio Grande do Sul) (Rolon *et al*., 2010)

	Amazon floodplain	Pantanal	South Brazilian wetlands
Woody plants			
Total	>1000	750	179
Terrestrial[a]	none	400	none
Palustrine[b]	>1000	350	179[c]
Herbaceous plants			
Total	390	1150	280
Terrestrial	340	900	no data
Aquatic/palustrine	50	250	280
Endemics	68 tree species	none	1 herb. species[d]

[a]In non-flooded areas inside the Pantanal.
[b]In periodically flooded or waterlogged areas.
[c]Mostly in riparian habitats of the *campos sulinos* (Wittmann, unpublished).
[d]*Regnellidium diphyllum*.

Cerrado wetlands include *veredas* and wet grasslands (Ribeiro and Walter, 1998), gallery forests (Felfili, 1995), but also large and very complex wetlands, such as the Pantanal Matogrossense (Nunes da Cunha *et al*., 2007). Forested belts composed of flood-tolerant trees occur along river channels, around floodplain lakes, and in moist depressions. Dryer areas are commonly occupied by tree species that are highly drought- and fire-tolerant but also resistant to several months of shallow flooding or waterlogging. The diversity of aquatic macrophytes is much larger here as both shallow, transparent water and the absence of dense forest favour a rich submerged and floating flora (Table 2).

On southern Brazilian plateaux there are permanently wet grasslands on organic deposits (*turfeiras*) that are heavily threatened by reclamation for agricultural purposes. Ephemeral wetlands in the north-eastern dry region of Brazil are small (± 1 ha for ponds) and are prone to shallow flooding every couple of years for a few weeks only (Maltchik *et al*., 1999). They are very important for the maintenance of regional biodiversity, such as anurans. In coastal areas, wax palm swamps (*Copernicia prunifera*) replace the *buriti* palm swamps (*Mauritia flexuosa*).

Among the most threatened of Brazilian wetlands are those of the Atlantic forest, for which little information exists. The original vegetation cover of this biome has been reduced to 11.7% by deforestation (Ribeiro *et al*., 2009). Wittmann (2012) differentiated inland wetlands of the Atlantic forest in riparian forests along streams and interfluvial montane fens, bogs, and hygrophile forests and provided a synopsis of the existing literature on forest inventories and the most common wetland tree species. The wealth of regional terminologies attributed to forests subjected to phreatic flooding suggests that a large variety of forest types should be expected but also that further work is required to allow their comparison with respect to their floristics, ecology, and biogeography (Scarano, 2006). Information on herbaceous plant communities is scarce.

Southern freshwater wetlands belong mostly to the subclass of 'swampy wetlands covered by herbaceous plants', which occupy relatively small areas. An inventory of 260 wetlands of 0.15–10 ha revealed a low number of flood-tolerant trees and a highly diversified herbaceous aquatic and palustric flora (Table 2, Rolon *et al*., 2010).

In Brazil, the number of artificial wetlands as well as their size and extent dramatically increased during the 20th century. The increase reflects the increasing number of hydroelectric power plants and drought prevention measures. The strongly and irregularly fluctuating water levels of these systems expose large areas of land to periodic dry or waterlogged conditions. There is also a growing number of rice paddy plantations within the wetlands of southern Brazil, and some 1500 ha of mangroves have been converted into shrimp ponds on the Brazilian coast (2ºS–20ºS) (Maia *et al*., 2006). The cumulative environmental impact of these cultivation areas has yet to be determined but it is certainly large and provokes the liberation of agrochemicals (Lacerda *et al*., 2006) and increased demand for fresh water that is abstracted from neighbouring intact rivers and wetlands.

The new classification of Brazilian wetlands is presented in Figure 5.

DISCUSSION AND CONCLUSIONS

Classification systems are often dependent on the objective and on the chosen parameters. For Brazilian wetlands, the primary objective is to offer a hierarchical classification system, which would provide scientists working in Brazil with the means to position their wetland studies within broader national and international contexts, thereby facilitating comparisons between different wetlands, with the advantage of understanding the (dis)similarities among them. A second and perhaps more important objective is to provide a scientific basis for politicians and decision-makers to elaborate wetland-specific policies and legislation.

Better regulations are urgently needed given that about 20% of the Brazilian territory is covered by wetlands that are being lost at alarming rates as human activities expand into these areas. The parameters and indicators for wetland definition and delineation and the classification itself, as presented in this article, will equip Brazil with an important tool for structuring and controlling the spread of artificial wetlands, while making the sustainable use of natural wetland systems an environmental, social, and economic asset.

The differentiation of coastal, inland, and artificial wetlands and their hierarchical classification based on hydrology and the community structure of higher plants make the proposed system compatible with other classification systems worldwide, e.g. the system developed for Indian wetlands (Gopal and Sah, 1995). Most of the wetland types described in the Ramsar or USFWS classification can also be found in the new Brazilian classification, albeit often at another hierarchical level, which gives them a different importance in the overall wetland hierarchy. A clear advantage of the new classification is that it allows the introduction of additional units without the need to modify the entire concept. Considering the large size of Brazil and the still precarious level of wetland inventories, the description of additional wetland units, at least at the macrohabitat level, can be expected.

Indeed, the classification includes, at the class and subclass level, highly complex wetlands that extend over tens of thousands of square kilometres and require additional habitat classifications for scientific research, management, and protection. Some of these classifications already exist, e.g. for the Pantanal (Nunes da Cunha and Junk, 2011a) and the Amazon River floodplain (*várzea*) (Junk *et al*., 2012b). Others are in preparation, e.g. for

Amazonian black-water river floodplains (*igapós*), and Paraná, Araguaia, and Guaporé River floodplains, and can be integrated without major difficulty into the general classification presented here. The classification can also be further specified, e.g. by subdividing macrohabitats into smaller units according to water chemistry and/or soil parameters.

The emphasis given to hydrological classification parameters takes into account the specific climatic situation of Brazil. Different rainfall patterns lead to the formation of permanent wetlands but also to large periodic wetlands subject to flood pulses differing in amplitude, duration, frequency, and predictability. These hydrological parameters underlie the structure and function of wetlands and their biodiversity, and thus also determine the possibilities of wetland management and conservation. The fact that most inland wetlands are subject to extended dry periods implies the risk that developers and politicians regard these areas as permanently dry habitats in which natural flooding is not considered an inherent attribute of the system, but rather a catastrophic event that must be avoided or controlled. This view has promoted the encroachment of conventional agriculture and infrastructure development within wetlands, as was emphasized during recent disputes in the Brazilian Parliament over the new Forest Code (Piedade *et al*., 2012).

According to Finlayson (2012) 'the extensive effort to develop international policy, supported by a substantial and expanding information base, has not stopped and reversed the global loss and/ or degradation of wetlands' because national governments have often failed to implement fully the recommendations of the Ramsar Convention. The Brazilian National Report on the Implementation of the Ramsar Convention on Wetlands of 2012 indicates in Section 3.1.1 the existence of a comprehensive wetland inventory (BRASIL, 2012). As discussed herein, there is extensive information on Brazilian wetlands but it is far from being comprehensive. Under Point 1.3.1, the report confirms the existence of a national wetlands policy but in the additional information the authors state that 'there is no specific policy for wetlands. The Brazilian Government believes that the best strategy for the country is to enforce the existing extensive environmental legislation, rather than creating a new policy instrument specifically focusing on wetlands.' However, the continuing political discussion on the new Brazilian Forest Code shows that this strategy provides very little protection for the country's wetlands (Piedade *et al*., 2012). This perspective creates serious impediments to the Brazilian sustainability agenda and the country's commitments to the Ramsar Convention while compromising the opportunities for the wise use of Brazilian wetlands.

Conservation is also a complex issue when definitions and delineation are not well structured and clarified. Wetlands offer an extra level of complexity for institutions in charge of planning their protection. The nature of the aquatic–terrestrial interface of wetlands is a shifting one, spatially, seasonally and temporally, which must be appreciated by planners and decision-makers. Recent studies have provided several potential directions for future research aimed at developing plans for wetland protection, evolution, and persistence (Beger *et al*., 2010). The important contribution of wetlands to water purification, flood control, and food production, both land- and water-based, and the maintenance of high levels of biodiversity and the rich genetic repository of their organisms are just a few issues that clearly distinguish wetlands in terms of their ecosystem relevance to society. The second goal of the Ramsar Convention priorities for the next few years is to propose the designation of new Ramsar sites, to ensure the representativeness of the various types of wetlands in the respective countries. However, this implies the need both for a classification system and a comprehensive inventory of the wetlands.

Certainly, this article is only a first step towards resolving the very complex scientific and administrative problems related to Brazilian wetlands, but we hope that it will stimulate and ultimately help to frame the scientific efforts and research needed to enhance an understanding of wetlands. At the same time, this discussion is intended to contribute to honest and frank debates among scientists, politicians, planners and the public, in order to reach a consensus for the appropriate management of Brazilian wetlands. These discussions must include: (1) the establishment of a programme and database for a

Brazilian-wide wetland inventory following international standards, e.g. the methodology used by the Asian Wetland Inventory (AWI); (2) strengthening of basic and applied wetland research at selected Brazilian universities and research institutions; (3) elaboration and implementation of a specific national policy for the protection and sustainable management of wetlands; (4) improvements in the efficiency of and cooperation among the many organizations working at different administrative levels on wetlands and aquatic resources; (5) strengthening the cooperation between scientists, politicians, planners, and local stakeholders with respect to wetland management and protection. Given the quickly changing economic, ecological, and social conditions in Brazil, and throughout the world, and with the challenges that will be posed by the anticipated dramatic changes in global climate, wetlands will play a crucial role that will benefit future generations.

REFERENCES

Adis J. 1997. Terrestrial invertebrates: survival strategies, group spectrum, dominance and activity patterns. In *The Central Amazon Floodplain: Ecology of a Pulsing System*, Junk WJ (ed.). Ecological Studies 126, Springer Verlag: Berlin/Heidelberg/New York; 299–317.

Adis J, Junk WJ. 2002. Terrestrial invertebrates inhabiting lowland river floodplains of Central Amazonia and Central Europe: a review. *Freshwater Biology* **47**: 711–731.

Araújo DSD, Henriques RPB. 1984. Análise florística das restingas do Estado do Rio de Janeiro. In *Restingas. Origem, Processo e Estrutura*, Lacerda LD, Araújo DSD, Cerqueira R, Turcq B (eds). CEUFF: Niterói, Brazil; 159–193.

Araújo GM, Barbosa AA, Arantes AA, Amaral AF. 2002. Composição florística de veredas no Município de Uberlândia, MG. *Revista Brasileira de Botânica* **25**: 475–493.

Araújo DSD, Scarano F, Sá CFC, Kurtz B, Zaluar HLT, Montezuma RCM, Oliveira RC. 1998. Comunidades vegetais do Parque Nacional da Restinga de Jurubatiba. In *Ecologia das Lagoas Costeiras do Parque Nacional da Restinga de Jurubatiba e do Município de Macaé (RJ)*, Esteves FA (ed). NUPEM/UFRJ: Rio de Janeiro; 39–62.

Barletta M, Jaureguizar AJ, Baigun C, Fontoura NF, Agostinho AA, Almeida-Val VMF, Val AL, Torres RA, Jimenes-Segura LF, Giarrizzo T, *et al.* 2010. Fish and aquatic habitat conservation in South America: a continental overview with emphasis on neotropical systems. *Journal of Fish Biology* **76**: 2118–2176.

Beger M, Grantham HS, Pressey RL, Wilson KA, Peterson EL, Dorfman D, Mumby PJ, Lourival R, Brumbaugh DR, Possingham HP. 2010. Conservation planning for connectivity across marine, freshwater, and terrestrial realms. *Biological Conservation* **143**: 565–575.

Bigarella JJ. 2001. Contribuição ao Estudo da Planície Litorânea do Estado do Paraná. *Brazilian Archives of Biology and Technology* Jubilee Volume **2001**: 65–110.

Bove CP, Gil ASB, Anjos RFB. 2003. Hidrófitas fanerogâmicas de ecossistemas aquáticos temporários da planície costeira do Estado do Rio de Janeiro, Brasil. *Acta Botanica Brasilica* **17**: 119–135.

BRASIL. 2012. National report on the implementation of the Ramsar Convention on Wetlands. The Conference of the Contracting Parties, Romania. (Available from: http://www.ramsar.org/pdf/cop11/nr/cop11-nr-brazil.pdf) [June 2012]

Brinson MM. 1993. A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson MM, Malvárez AI. 2002. Temperate freshwater wetlands: types, status, and threats. *Environmental Conservation* **29**: 115–133.

Casanova MT, Brock MA. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities. *Plant Ecology* **147**: 237–250.

Costa CSB, Davy AJ. 1992. Coastal saltmarsh communities of Latin America. In *Coastal Plant Communities of Latin America*, Seelinger U (ed). Academic Press: San Diego CA; 179–199.

Costa AF, Dias ICA. 2001. *Flora do Parque Nacional da Restinga de Jurubatiba e Arredores, Rio de Janeiro, Brasil: listagem florística e fitogeografia: Angiospermas, Pteridófitas, Algas Continentais*. Editora do Museu Nacional: Rio de Janeiro.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, *et al.* 1997. The value of the world's ecosystem services and natural capital. *Nature* **387**: 253–260.

Cowardin LM, Carter V, Golet FC, LaRoe ET. 1979. *Classification of wetlands and deepwater habitats of the United States*. US Department of the Interior, Fish and Wildlife Service, Washington, DC.

Da Silva MP, Mauro R, Mourão G, Coutinho M. 2000. Distribuição e quantificação de classes de vegetação do Pantanal através de levantamento aéreo. *Revista Brasileira de Botânica* **23**: 143–152.

Darwall W, Smith K, Allen D, Seddon M, McGregor Reid G, Clausnitzer V, Kalkman V. 2008. Freshwater biodiversity – a hidden resource under threat. In *The 2008 Review of the IUCN Red List of Threatened Species*, Vié J-C, Hilton-Tylor C, Stuard SN (eds). IUCN: Gland, Switzerland.

Davidson NC, Finlayson CM. 2007. Earth observation for wetland inventory, assessment and Monitoring. *Aquatic Conservation: Marine and Freshwater Ecosystems* **17**: 219–228.

Diegues ACS. 1994. *An Inventory of Brazilian Wetlands*. IUCN – The World Conservation Union: Gland, Switzerland.

Diegues ACS. 2002. *Povos e Águas. Núcleo de Apoio à Pesquisa sobre Populações Humanas e Áreas Úmidas Brasileiras*, 2nd edn. NUPAUB-USP (Universidade de Sao Paulo), São Paulo, Brazil.

Drechsler M, Lourival R, Possingham HP. 2009. Conservation planning for successional landscapes. *Ecological Modeling* **220**: 438–450.

Eiten G. 1983. *Classificação da vegetação do Brasil*. CNPq Brasília: Brazil.

Erwin TL, Adis J. 1982. Amazonian inundation forests. Their role as short-term refuges and generators of species richness and taxon pulses. In *Biological Diversification in the*

Tropics, Prance GT (ed). Columbia University Press: New York; 358–371.

Esteves FA (ed). 2011: *Fundamentos de Limnologia*. Ed. Interciência: Rio de Janeiro.

Felfili JM. 1995. Diversity, structure and dynamics of a gallery forest in Central Brazil. *Vegetatio* **117**: 1–15.

Finlayson CM. 2012. Forty years of wetland conservation and wise use. *Aquatic Conservation: Marine and Freshwater Ecosystems* **22**: 139–143.

Finlayson CM, Van der Valk AG. 1995. Wetland classification and inventory: a summary. *Vegetatio* **118**: 185–192.

Gopal B, Sah M. 1995. Inventory and classification of wetlands in India. *Vegetatio* **118**: 39–48.

Gopal B, Junk WJ, Davis JA (eds). 2000. *Biodiversity in Wetlands: Assessment, Function and Conservation, Volume 1*. Backhuys Publishers: Leiden, The Netherlands.

Hamilton SK, Sippel SJ, Melack JM. 1996. Inundation patterns in the Pantanal wetland of South America determined from passive microwave remote sensing. *Archiv für Hydrobiologie* **137**: 1–23.

Hamilton SK, Sippel SJ, Melack JM. 2004. Seasonal inundation patterns in two large savanna floodplains of South América: the Llanos de Moxos (Bolivia) and the Llanos del Orinoco (Venezuela and Colombia). *Hydrological Processes* **18**: 2103–2116.

Hoeinghaus DJ, Agostinho AA, Gomes LC, Pelicice FM, Okada EK, Latini JD, Kashiwaqui EAL, Winemiller KO. 2009. Effects of river impoundment on ecosystem services of large tropical rivers: embodied energy and market value of artisanal fisheries. *Conservation Biology* **23**: 1222–1231.

Householder JE, Janovec JP, Page S. 2012. Peatlands of the Madre de Dios River of Peru: distribution, geomorphology, and habitat diversity. *Wetlands* **32**: 359–368.

IPCC. 2007. *Climate Change 2007: synthesis report. Part of the Working Group III contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: Cambridge.

Irgang BE, Gastal CVS. 1996. *Macrófitas aquáticas da planície costeira do RS*. CPG-Botanica, UFRGS (Universidade Federal de Rio Grande do Sul), Porto Alegre, Brazil.

Irgang BE, Pedralli G, Waechter JL. 1984. Macrófitas aquáticas da estação ecológica do Taim, Rio Grande do Sul, Brasil. *Rossléria* **6**: 395–405.

Junk WJ. 2000. Mechanisms for development and maintenance of biodiversity in neotropical floodplains. In *Biodiversity in Wetlands: Assessment, Function and Conservation. Vol. 1*, Gopal B, Junk WJ, Davis JA (eds). Backhuys Publishers: Leiden, The Netherlands; 119–139.

Junk WJ. 2005. Flood pulsing and the linkages between terrestrial, aquatic, and wetland systems. *Proceedings of the International Association for Theoretical and Applied Limnology* **29**: 11–38.

Junk WJ. 2007. Freshwater fishes of South America: their biodiversity, fisheries, and habitats: a synthesis. *Aquatic Ecosystem Health & Management* **10**: 228–242.

Junk WJ, Piedade MTF. 1993. Herbaceous plants of the Amazon floodplain near Manaus: species diversity and adapations to the flood pulse. *Amazoniana* **12**: 467–484.

Junk WJ, Piedade MTF. 1997. Plant life in the floodplain with special reference to herbaceous plants. In *The Central Amazon Floodplain: Ecology of a Pulsing System*, Junk WJ (ed). Ecological Studies, Vol **126**. Springer Verlag: Berlin/Heidelberg/New York; 147–186.

Junk WJ, Piedade MTF, Schöngart J, Wittmann F. 2012b. A classification of major natural habitats of Amazonian whitewater river floodplains (várzeas). *Wetlands Ecology and Management* **20**: 461–475.

Junk WJ, Sousa PT, Nunes da Cunha C, Piedade MTF, Candotti E. 2012a. Inundações catastróficas e deslizamento de barrancos em Minas Gerais e o novo Código florestal. *Jornal da Ciência*, Sociedade Brasileira para o Progresso da Ciência. (Available from: http://www.jornaldaciencia.org.br/Detalhe.jsp?id=81006) (accessed on 20.09.2012).

Junk WJ, Wantzen KM. 2004. The flood pulse concept: new aspects, approaches, and applications – an update. In *Proceedings of the 2nd International Symposium on the Management of Large Rivers for Fisheries, Volume 2*, Welcome RL, Petr T (eds). Food and Agriculture Organization & Mekong River Commission FAO Regional Office for Asia and the Pacific: Bangkok, Cambodia; 117–149.

Junk WJ, Bayley PB, Sparks RE. 1989. The flood pulse concept in river–floodplain systems. *Canadian Special Publications for Fisheries and Aquatic Sciences* **106**: 110–127.

Junk WJ, Nunes da Cunha C, Wantzen KM, Petermann P, Strüssmann C, Marques MI, Adis J. 2006. Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. *Aquatic Sciences* **68**: 278–309.

Junk WJ, Piedade MTF, Schöngart J, Cohn-Haft M, Adeney JM, Wittmann F. 2011. A classification of major naturally-occurring Amazonian lowland wetlands. *Wetlands* **31**: 623–640.

Kahn F. 1991. Palms as key swamp forest resources in Amazonia. *Forest Ecology and Management* **38**: 133–142.

Kjerfve B, Lacerda LD. 1993. Mangroves of Brazil. In *Conservation and Sustainable Utilization of Mangrove Forests in Latin America and Africa Regions. Vol.2 Part I- Latin America*, Lacerda LD (ed). Mangrove Ecosystems Technical Reports ITTO/ISME Project PD114/90 (F): Okinawa, Japan; 245–272.

Lacerda LD. 2001. *Mangrove Ecosystems: Function and Management*. Springer Verlag: Berlin.

Lacerda LD, Vaisman AG, Maia LP, Cunha E, Silva CAR. 2006. Relative importance of nitrogen and phosphorus emissions from shrimp farming and other anthropogenic sources for six estuaries along the NE Brazilian coast. *Aquaculture* **253**: 433–446.

Lopez A, Finlayson CM, Begg G, Davies J, Tagi K, Lowry J. 2002. Asian Wetland Inventory (AWI) – a planning and management tool for wetland conservation and wise use through multi-stakeholder involvement. In *Developing a proposed framework for a wetland inventory, assessment and monitoring system (WIAMS) in Malaysia*, Murugadas (compiler). Proceedings of the workshop on Developing a proposed framework for a wetland inventory, assessment and monitoring system (WIAMS) in Malaysia, April 2002, Kuala Lumpur, Malaysia, Wetlands International – Malaysia Programme, Petaling Jaya, Malaysia; 37–48.

Lourival R, Drechsler M, Watts ME, Game ET, Possingham HP. 2011. Planning for reserve adequacy in dynamic landscapes; maximizing future representation of vegetation communities under flood disturbance in the Pantanal wetland. *Diversity and Distributions* **17**: 297–310.

Maia LP, Lacerda LD, Monteiro LHU, Souza GM. 2006. *Atlas dos Manguezais do Nordeste do Brasil: Avaliação das Áreas de Manguezais dos Estados do Piauí, Ceará, Rio Grande do Norte, Paraíba e Pernambuco*. SEMACE: Fortaleza.

Maltchik L, Costa ES, Becker CG, Oliveira AE. 2003. Inventory of wetlands of Rio Grande do Sul (Brazil). *Pesquisas Botânica* **53**: 89–100.

Maltchik L, Costa MAJ, Duarte MCD. 1999. Inventory of Brazilian semiarid shallow lakes. *Anais da Academia Brasileira de Ciências* **71**: 801–808.

Maltchik L, Rolon AS, Guadagnini DL, Stenert C. 2004. Wetlands of Rio Grande do Sul, Brazil: a classification with emphasis on plant communities. *Acta Limnologica Brasiliensia* **16**: 137–151.

Melack JM, Hess LL. 2010. Remote sensing of the distribution and extent of wetlands in the Amazon basin. In *Amazon Floodplain Forests: Ecophysiology, Biodiversity and Sustainable Management*, Junk WJ, Piedade MTF, Wittmann F, Schöngart J, Parolin P (eds). Ecological Studies 210, Springer Verlag: Berlin/Heidelberg/New York; 43–59.

Menezes MP, Berger U, Mehlig U. 2008. Mangrove vegetation in Amazonia: a review of studies from the coast of Pará and Maranhão States, north Brazil. *Acta Amazonica* **38**: 403–420.

Millennium Ecosystem Assessment. 2005. Ecosystems and human wellbeing: wetlands and water. (Available from: http://www.unep.org/maweb/documents/document.358.aspx.pdf) (accessed on: 20.09.2012).

Mitsch WJ, Day JW. 2006. Restoration of wetlands in the Mississippi–Ohio–Missouri (MOM) River Basin: experience and needed research. *Ecological Engineering* **26**: 55–69.

Mitsch WJ, Gosselink JG. 2008. *Wetlands*. John Wiley: Hoboken, NJ.

Naiman RJ, Decamps H. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* **28**: 621–658.

Neiff JJ. 2001. Humedales de la Argentina: sinopsis, problemas y perspectivas futuras. In *Funciones de los humedales, calidad de vida y agua segura*, Cirelli AF (ed.). El agua en Iberoamérica, Publ. CYTED: Buenos Aires; 83–112.

Nunes da Cunha C, Junk WJ. 2011a. A preliminary classification of habitats of the Pantanal of Mato Grosso and Mato Grosso do Sul, and its relation to national and international classification systems. In *The Pantanal: Ecology, Biodiversity and Sustainable Management of a Large Neotropical Seasonal Wetland*, Junk WJ, da Silva CJ, Nunes da Cunha C, Wantzen KM (eds). Pensoft: Sofia/Moscow; 127–142.

Nunes da Cunha C, Junk WJ. 2011b. Landscape units of the Pantanal: structure, function and human use. In *The Pantanal: Ecology, Biodiversity and Sustainable Management of a Large Neotropical Seasonal Wetland*, Junk WJ, da Silva CJ, Nunes da Cunha C, Wantzen KM (eds). Pensoft: Sofia/Moscow; 299–324.

Nunes da Cunha C, Junk WJ, Leitão-Filho H. 2007. Woody vegetation in the Pantanal of Mato Grosso, Brazil: a preliminary typology. *Amazoniana* **19**: 159–184.

Piedade MTF, Junk WJ, Long SP. 1991. The productivity of the C4 grass *Echinochloa polystachia* on the Amazon floodplain. *Ecology* **72**: 1456–1463.

Piedade MTF, Junk WJ, Sousa PT, Nunes da Cunha C, Schöngart J, Wittmann F, Candotti E, Girard P. 2012. As áreas úmidas no âmbito do Código Florestal brasileiro. In *Código Florestal e a ciência: o que nossos legisladores ainda precisam saber. Sumários executivos de estudos científicos sobre impactos do projeto de Código Florestal*, Comitê Brasil em Defesa das Florestas e do Desenvolvimento Sustentável (ed). Comitê Brasil: Brasília, Brazil; 9–17.

Pott VJ, Pott A. 2000. *Plantas Aquáticas do Pantanal*. EMBRAPA: Brasília, Brazil.

Ribeiro JF, Walter BMT. 1998. Fitofisionomias do bioma cerrado. In *Cerrado: ambiente e flora*, Sano SM, Almeida SP (eds). EMBRAPA-CPAC: Planaltina; 89–166.

Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM. 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation* **142**: 1141–1153.

Rolon AS, Homem HF, Maltchik L. 2010. Aquatic macrophytes in natural and managed wetlands of Rio Grande do Sul State, Southern Brazil. *Acta Limnologica Brasiliensia* **22**: 133–146.

Ruokolainen K, Schulman L, Tuomisto H. 2001. On Amazonian peatlands. *International Mire Conservation Group Newsletter* **4**: 8–10.

Salati E, Marques J. 1984. Climatology of the Amazon region. In *The Amazon - Limnology and Landscape Ecology of a Mighty Tropical River and its Basin*, Sioli H (ed.). Dr W. Junk Publishers: Dordrecht, The Netherlands; 85–126.

Scarano FR. 2006. Plant community structure and function in a swamp forest within the Atlantic rain forest complex: a synthesis. *Rodriguésia* **57**: 491–502.

SCBD. 2010. *Global Biodiversity Outlook 3*. Secretariat of the Convention on Biodiversity: Montreal, Canada.

Schaeffer-Novelli Y, Cintrón-Molero G, Adaime RR, Camargo TM. 1990. Variability of mangrove ecosystems along the Brazilian coast. *Estuaries* **13**: 204–218.

Schöngart J, Wittmann F, Worbes M. 2010. Biomass and net primary production of Central Amazonian floodplain forests. In *Amazonian Floodplain Forests: Ecophysiology, Biodiversity and Sustainable Management*, Junk WJ, Piedade MTF, Wittmann F, Schöngart J, Parolin P (eds). Ecological Studies 210, Springer Verlag: Berlin/ Heidelberg/New York; 347–388.

Scott DA, Jones TA. 1995. Classification and inventory of wetlands: a global overview. *Vegetatio* **118**: 3–16.

Seidl AF, Moraes AS. 2000. Global valuation of ecosystem services: application to the Pantanal da Nhecolandia, Brazil. *Ecological Economics* **33**: 1–6.

Semeniuk CA, Semeniuk V. 1995. A geomorphic approach to global classification for inland wetlands. *Vegetatio* **118**: 103–124.

TEEB. 2013. TEEB for Water and Wetlands. Institute for European Environmental Policy (IEEP) & Ramsar Secretariat, London and Brussels. (Available from: http://www.teebtest.org/wp-content/uploads/2013/04/TEEB_WaterWetlands_Report_2013.pdf) (accessed on: 15.04.2013).

Thomaz SM, Agostinho AA, Hahn NS. 2004. *The Upper Paraná River and its Floodplain: Physical Aspects, Ecology and Conservation*. Backhuys Publishers: Leiden, The Netherlands.

Wantzen KM. 2003. Cerrado streams – characteristics of a threatened freshwater ecosystem type on the Tertiary Shields of Central South America. *Amazoniana* **17**: 481–502.

Wittmann F. 2012. Tree species composition and diversity in Brazilian freshwater floodplains. In *Mycorrhiza: Occurrence in Natural and Restored Environments*, Pagano MC (ed.). Nova Science Publishers: New York; 223–263.

Wittmann F, Householder E, Piedade MTF, Assis RL, Schöngart J, Parolin P, Junk WJ. 2013. Habitat specificity, endemism and the neotropical distribution of Amazonian white-water floodplain trees. *Ecography* **36**: 690–707.

Wittmann F, Schöngart J, Junk WJ. 2010. Phytogeography, species diversity, community structure and dynamics of central Amazonian floodplain forests. In *Amazonian Floodplain Forests: Ecophysiology, Biodiversity and Sustainable Management*, Junk WJ, Piedade MTF, Wittmann F, Schöngart J, Parolin P (eds). Ecological Studies 210, Springer Verlag: Berlin/Heidelberg/New York; 61–102.

