WETLANDS CONSERVATION:AN INTEGRATIVE APPROCH

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Abstract

The emergence of an epistemology of complexity is a contemporary phenomenon strongly based upon technology that has claimed new research needs and revitalize old studied themes. The study of wetlands can be considered in this interdisciplinary context. The ability to respond in an organized manner to disturbances caused by seasonal flooding, a characteristic of wetlands ecosystems, define them as complex systems. The spatio-temporal heterogeneity of floodplain river systems is responsible for a diverse array of dynamic aquatic habitats. Thus, natural disturbances, represented by flooding and responsible for intensifying ecosystem heterogeneity, are the main factor in maintaining the ecological integrity. This requires knowledge of long-term patterns of inundation to preserve geomorphic formations, in other words, habitat diversity. Nevertheless, the processes that control water, sediment and nutrients transfer through the floodplain are not well understood. The maintenance of river-floodplain connectivity has been recognized as a central strategy in ecosystem management. In this sense, remote sensing technology for a broad-scale systematic focus is particularly relevant. Research studies in this area provide new approaches for models useful in management on a regional scale. This chapter aims therefore to illustrate this wide research field involving current concepts and methodologies in order to improve the comprehension of the wetlands ecosystems as well as establish conservation criteria.

Keywords: Wetlands, complexity, remote sensing, Amazon region

Introduction

Wetlands are actually a generic, fairly imprecise designation for quite singular ecosystems in waterlogged terrain, be it flooded or subject to flooding, generally situated between aquatic and terrestrial ecosystems. Indeed, adaptation to the strong presence of water on the surface or in the root zone is the prime hallmark shared by a wide variety of ecotones assembled under the one label (Mitsch & Gosselink, 1993). Despite this singular characteristic, criticism has been levelled at the idea of classifying these ecosystems as transition zones between land and water. This has serious implications for the management criteria and conservation strategies to be adopted. If that were the case, they should at least be recognised as unstable areas of tension that display unique patterns of variability, especially in the case of alluvial plains (Neiff, 2008).

The wealth of communities and species occupying wetland areas is another characteristic trait. Thus, classifying associations encountered in discrete units across wetland areas is a tough, even arbitrary task, given that their limits are frequently hard to determine. Moreover, conservation and recovery of these ecosystems are strongly dependent on advances in knowledge regarding the dynamics and functional organisation of such communities (Krebs, 1996).

The dynamics of wetlands environment is extremely complex, given its variations in short intervals of space and time, when compared to other terrestrial environments. The spatial and temporal patterns of flood inundation have a crucial role in the wetland ecology. Thus, the need of mapping and monitoring the surface (intrinsic vegetation processes, fluvial or coastal dynamic, land-use changes and flood inundation patterns), over a range of spatial and temporal scales, is of paramount importance for assessing the status of wetland ecosystems. In this context, the remote sensing becomes a powerful tool for inventorying and monitoring those environments due to its capability of generating a large amount of information on surrounding land uses and their changes over time (vegetation phenology and wetland losses by human-induced changes).

Riparian wetlands as complex systems

According to systemic theory (Bertalanffy, 1975), flows of matter and energy mediate between community and non-living environment, maintaining an organised state of life. This elementary understanding is essential for grasping the way integral ecosystems in general work. In actual fact, these flows produce clearly defined biotic structures besides performing the cycling of matter among the living and non-living components. It is likewise acknowledged that abiotic structures are shaped by the importing of matter rich in energy (Odum, 1983). As a result, components, or rather physical subsystems (i.e. self-organised patterns) emerge. They establish environmental gradients directly proportional to the biodiversity encountered. In the case of wetlands, greater variation in such gradients can be interpreted by combining, for example, hydrometric levels, duration of surges, and so on, making for a diversity of landscapes and composition of species (Neiff, 2008). Ab'Saber (2002) provides a detailed description of Amazonian wetlands that highlights not only the biodiversity but especially the wealth of physical subsystems:

> It is a highly diversified, labyrinthine patchwork of water and land: low-lying dykes along the flanks that were once covered by forest, immersed during the great floods, tall floodplain forests in some sectors where the plain backs up against the adjacent uplands, strands of biodiverse forest flanking dykes that run inland; meadows in scrolls of white sand following the meandering course of streams that have since run dry, herbaceous or meadowland vegetation in abandoned riverbeds, native grasses on the banks of floodplain lakes, exposed or submersed as the waters rise and fall. Finally, asymmetric ecosystems along the banks of side channels where *terra firma* forests cover uplands, steep banks or terraced embankments on the inner side of these discontinuous side channels, while on the other side a multifarious array of aquatic and sub-aquatic terrestrial ecosystems sprawls out across the alluvial plains. This veritable interspersed land-water patchwork supports a variety of ecosystems that are highly differentiated from each other although they all belong to a single family from the hydrogeomorphological standpoint.

As one type among a prolific classification (Mitsch & Gosselink, 1993), the riparian wetland ecosystems described above are a fine example of the interaction of various ecosystems producing a high degree of complexity. The description also draws attention to the fact that the evolution of living organisms is interconnected with the evolution of their habitat, there thus being a single process that could be described as co-evolution (Capra, 2006). Nevertheless, in a context of hierarchical relations between numerous subsystems, there is clearly a need for further knowledge about their basic properties and functions, for new and better data or new principles associated with abiotic factors.

It has thus been observed that hydrological characteristics fundamentally control such ecosystems. In these environments, specifically variations in discharge on time scales ranging from minutes to months and the frequency of exceptional flooding determine a river's every biological, chemical and physical attribute. Hey (1997) points out that even in unpolluted rivers biodiversity will not grow richer if hydraulic and morphological variations are limited, although the quality of the water also affects biological response.

In his chapter on the geomorphic activity of water, Sternberg (1998) identifies the structure and functioning of floodplains as the key factor – one that correlates closely with riparian vegetation – when it comes to the genesis of floodplains and other fluvial aspects:

> The importance of the waters is not confined to the fact that they periodically cover and uncover the land, nor can it be measured by the depth of the expanse of water lying above it. The river's geological activity must be taken into account. And the result of this activity, besides being subordinate to the nature of the terrain on which the water acts, depends on its properties, on the matter it carries with it and on the characteristics of its flow. Indeed, rivers that flow through alluvial plains are peculiar in that they themselves establish the discontinuous surfaces flanking and defining them. In the case under consideration, therefore, it is in the water, and in the water alone, that we should seek the key to the plains' morphology.

Indeed, fluvial hydrometric series can be acknowledged as a form of disturbance. By analysing them, one can detect recurrent phenomena (lymnophases and potamophases) whose characteristics (intensity, amplitude and seasonality) hinge on a tension peculiar to each river, section or even sector of the floodplain. Rocha *et al.* (2003) identify five components related to ecological processes in riparian ecosystems: magnitude, duration, periodicity, frequency and rate of alteration to the flux. As a result, fluctuations in the physical-chemical environment can be predicted on the basis of climatic and hydrosedimentological factors, without ignoring the fact that "The spatial and temporal patterns of the hydrology are in turn influenced by the topography, soils, and vegetation of the floodplain" (Mertes *et al.*, 1995).

Hence, the river system to which the riparian wetlands belong can be conceived as a complex unit, with non-linear connections and interconnections produced by the transference of matter and energy among its component parts. In this sense, two features of complex systems present in riparian wetlands become crucial to understanding their physical structure and the way they operate: self-regulation and interconnectivity. These can be viewed as deriving from complex patterns of fluvial aspects encountered in the riparian environment that provide the key to monitoring and recovering such ecosystems.

Self-regulation and adjustability

In response to the adaptive processes set in motion by the flux of matter and energy, river courses freely adjust their geometric variables, i.e., depth, declivity, and width, including the development of meanders and other planimetric configurations. Knighton (1998) assesses rates the adjustment of the channel to independent variables according to four degrees of freedom: declivity of the riverbed (longitudinal profile), shape of cross-sections (lateral profile), configuration of the riverbed (vertical profile) and the channel's planimetry.This adjustability plane refers to aerial perspectives shot from above the channel. This means that on the drawing board rivers display features and match types intrinsically associated with processes of erosion, transportation and depositing at work on the riverbed, on the banks and in the overflow areas (Amsler, 2004). The planform is thus one outcome of the adjustability of all the other planes, producing a great variety of standard forms that contribute to the evolution of riverine environments.

On the one hand, the channel pattern can be conceived as an amalgam of responses to alterations in dependent and independent variables and to those deriving from human intervention. At the same time, though, the pattern shapes the floodplain resulting from sediments the channel deposits and from seasonal or continuous flooding by the flow of the river. The floodplain and its geomorphic features are relatively constant over time with major adjustment to hydrological surges. This differentiates them from the classical definition of ecotones as transition zones, as mentioned above.

Any natural modification to a river (e.g. climate changes) or alterations resulting from engineering work can destabilise the river system if the pattern of flow is disturbed. Profound changes to the characteristics of the channel and the floodplain will ensue and may adversely affect biodiversity and the potential economic exploration of existing resources. It should be added that flow characteristics are the most widely used and appropriate indicators for assessing the integrity of a riverine ecosystem on account of certain restrictions encountered.

Besides the fact that the morphology of the channel and the alluvial plain is shaped by fluvial processes governed by the flow of the river – high levels of flux in particular – many other abiotic characteristics are affected by flow conditions, including water temperature, distribution of the size of sediments suspended in the water and deposited on the riverbed. Likewise, contrasting with the scarcity of information available and the precarious resolution of temporal series for biological data, the availability of daily fluviometric data can provide a clear picture of the natural variability and the recent history of anthropological disturbance in rivers (Richter *et al*., 1997, *apud* Rocha *et al*., 2005). Attention should thus be focused on data parameters for forces acting on the edges of the channel, represented by the flux of the current and the forces resisting the flow, already extensively reported on in the literature (Bordette *et al*., 1998; Knighton, 1998; Leopold *et al*., 1994; Thorne *et al*., 2003). Similarly, analysis of the channel pattern (i.e. its planform) is based on measurements that help describe and quantify active processes in the light of variables such as discharge, transportation of sediment, and stability of the channel banks, all of which are crucial parameters for wetland management.

One way of approaching river channel processes and morphology is by employing the concept of stream power (Knighton, 1999). The energy moving the river system starts out as potential energy. As the flow moves downstream, the potential energy is progressively converted into kinetic energy, thus triggering erosion and transportation. Hence, if one is to understand the behaviour of the alluvial channel when intervention occurs, one must identify the factors directly controlling the balance or imbalance between force and resistance. Generally speaking, if force and resistance are balanced, the river current will neither erode nor deposit sediment, transporting the sediment brought from upstream and thus maintaining the existing pattern and its attendant features. Such balance indicates stability conditions in the dimensions of the channel and can be mathematically expressed as the stream power proportionality (Lane, 1995; Simon & Castro, 2003):

$$QS_b \propto Q_s D_{50}$$

Where $\mathbf{Q}$ is discharge, $\mathbf{S_b}$ declivity, $\mathbf{Q_s}$ the material deposited on the riverbed and $\mathbf{D_{50}}$ average size of the material on the riverbed, indicating that 50% of the material is comprised by sediment of a particular granulometric size. This equation suggests that if the energy of the flow is increased by added discharge Q or by the gradient in the channel S_b, an excess in the proportion of energy flow relative to the discharge of sediment Q_s from the riverbed will result, resistance being proportional to the diameter of particles D_{50}. In this case, an additional quantity of riverbed material will be eroded.

Similar response can be expected to a reduction in resistance to erosion on the edges of the channel or to a diminishment in the size of the particles encountered on the riverbed D_{50} (assuming, of course, it is not cohesive). Conversely, a reduction in flux energy brought about by an increase in the size or discharge of riverbed sediment will produce agradation of the channel’s bed. This will depend on where forces are most effective: gravity, should the channel walls be less resistant, or flux, should the bed be less resistant and lowering or incising of the thalweg take place.

Indeed, erosion of the banks plays a major role in controlling and shaping the migration of channels. This is especially true in sections where meanders predominate. Erosion likewise determines the way the alluvial plain develops and is maintained. Riverbank erosion poses a serious challenge for riparian environment management. Consequent loss of potential farmland and endemic species can be acute.

Stream power provenly affects many aspects of river systems, including riverbed shape, channel pattern, and processes like rate of sediment transportation and channel migration. It is also used as a criterion for explaining balance in the development of channel shapes (Knighton, 1999). It should, however, be stressed that, useful as it may be in working out geomorphic classifications, this concept is usually employed in studies dealing with smaller spatial scales, not with reference to the spatial resolution analysis of channel patterns requires.

Adjustments to the internal geometry of river systems produced by flow patterns and alterations to them actually involve a large number of variables. The interdependence of these variables is not very clear given the difficulty of isolating a single variable's effect on the remainder. In other words, flow geometry and channel geometry interact in space and time on the basis of circular feedback processes. It is these processes that account for the formation and maintenance of the floodplain and consequently of the riparian environment. Given the river system's self-regulation and mechanisms for adjusting its geomorphic features, our aim here is to acknowledge the planform as an analytical tool for monitoring riparian wetlands. Gradual evolution and sharp changes observed in the channel pattern can serve to diagnose the conditions under which the river system operates and thus to assist maintenance of its ecosystems.

Interconnection and stability

In view of the considerations made hitherto, it is equally important to establish the way the river system's self-adjustment and the degree of interconnection between the sub-units, main channel and floodplain interact. Alterations to the flux of matter and energy between these subsystems can make for disruptions in transmission and conservation of complex information affording a wealth of components and structures (Bayley, 1995; Capra, 2007; Ward & Stanford, 1985). Besides determining processes of erosion, transportation and depositing performed by the river current, the type of flow establishes the spatial pattern of flooding in riparian ecosystems. Like the river channel itself, the floodplain also contributes water and sediment from the basin. As a result, the flow between channel and floodplain is frequently reversed in riparian ecosystems during low-water or reflux phases and periods of drought. Both subsystems are inter-linked by tributaries and secondary channels, so proving the existence of two-directional flow of matter and energy (Mertes *et al*., 1995; Sklar, 2000). There should thus be keen interest in observing alterations such as the lowering of the riverbed, emergence and incorporation of sandbars on the banks obstructing connecting channels that link the river to its floodplain, among others (Manyari, 2007).

Studies on the need to maintain lateral connectivity cover river systems from all continents across a wide range of biomes (Adams, 1985; Ligon, 1995; Makkaveyev, 1972). An illustrative example of a large hydrographic system in South America being examined can be found in Agostinho & Zalewski (1995), who studied the Paraná River, focussing on the importance of lateral migration of fish to the alluvial plains, essential for the reproduction of many species.

Regulation of hydrological surges caused by the installation of dams, which impairs the natural variability of discharge, similarly generates an interruption of the lateral connectivity between river channel and floodplain, be it by erosion and silting of the channel modifying its internal geometry and pattern or by the elimination of major floods. These effects engender a state of instability and degradation in both the fluvial and riparian ecosystems. It is easy to perceive that the wealth of species is associated as much with variability of physical parameters and diversity of habitats pertaining to the floodplain environments as with the course of the river determined by hydrological fluctuations (Salo, 1986). Hence, if the flow geometry describes a spatial pattern of flooding that correlates in time and space with periods of drought, flooding, high water and reflux of the river course and floodplain (Lewin & Manton, 1975), monitoring of the area flooded deserves attention as a wetland conservation measure. In that case, the natural flow regime should be taken as a paradigm for conserving and restoring river systems, as demonstrated in Neiff (1990) and Poff *et al*. (1997), who relate ecological integrity to the dynamic nature of fluvial and, by extension, riparian ecosystems.

In these riparian environments, it is clear that the function of stability – a premise for conservation – is distinct from that which applies, for instance, to climax forests, as Neiff (2008) points out. He stresses the fact that in these highly variable ecosystems, stability is determined by the system's capacity not to maintain but to recover its balance. The high degree of variability (magnitude, duration and recurrence of hydrological surges) does not make wetlands unstable. Proof of this is that they maintain a standard landscape of biotic communities and dominant physiognomies for both low-water and high-water phases. This means that if, on the one hand, multiple basic states (i.e. various states of balance) are observable, on the other, macroscopic order tends to be robust and stable in the face of modifications to the system's internal order.

The variability river systems display in morphology and states of balance in time and space is thus abundantly clear. According to Knighton (1998), at best, rivers attain an approximate state of equilibrium on an intermediate time scale between short-term fluctuations and long-term evolutionary trends. This holds true for maintenance of the channel's geometric regularity adjusted to independent variables. Hence, maintenance of alluvial plains – understood as a morphological subsystem – depends on maintenance of the variability of hydrological surges: the more variable their spectrum, the more varied the gradients produced by gradual variations introduced in the physical and chemical environment.

In sum, as open systems, the river system's dynamics develop on the basis of a range of possible configurations not characterised by highly precise scales of time and space. This property is referred to as self-organised criticality, and the dynamics of the systems triggering it operate on the verge of chaos. It can equally be observed that "Although the standard is optimal global (a state of minimal energy), it is pointless expecting these systems to attain it."

Remote sensing for wetlands mapping

Remote sensing data offer as advantages: (a) synoptic estimation over large areas, appropriate to analyze the scaling of wetland ecosystems; (b) a rapid, non-destructive and cost-effective inventory of the wetland landscape over varied spatial and temporal scales; (c) estimation of wetlands properties in remote and inaccessible areas; and (d) multi-temporal data (winter/spring and summer) that shows seasonal variability in water regime and vegetation status.In the literature on satellite remote sensing of wetlands, studies have been conducted in different types of wetlands by using several satellites and classification techniques (Ozesmi and Bauer, 2002, Lulla, 1983).

Thus, satellite remote sensing has been used in order to map the following wetland environments: permanently flooded or intermittently exposed open water ponds (FGDC 1992), large wetland ecosystems (i.e. Chopra et al. 2001, Fuller et al. 1998); coastal wetlands (i.e. Hardisky et al. 1986, Hinson et al., 1994, Jensen et al., 1993); forested wetlands (i.e. Hodgson et al., 1987, Townsend & Walsh, 1998); forested wetlands (Ernst and Hoffer 1979;

Ernst-Dottavio et al. 1981; Llewellyn et al. 1996; Sader et al. 1995); and, inland freshwater marshes (i.e. Ernst-Dottavio et al. 1981).

Both optical and microwave sensors are applied in wetland studies, where each technology describes advantages and disadvantages. Amongst the types of optical sensors, it can be mentioned: Landsat MSS, Landsat TM, SPOT, AVHRR, Indian Remote Sensing Satellite (IRS-1B) and Linear Imaging Self-scanning Sensor (LISS-II) (Ozesmi and Bauer, 2002; Lulla, 1983; Hardisky et al., 1986). The optical sensor is suitable for vegetation and land-cover mapping, phenology and flooding study during leaf-off periods.

However, there are some disadvantages of optical remote sensing estimation, such as: (a) the apparent upwelling radiance remotely measured is not only a function of water and vegetation properties, but also a function of data acquisition geometry and atmospheric conditions; (b) the information is limited to the surface, what results in inability to detect flooding in forested wetlands because of the presence of dense canopies; (c) the spectral, temporal and radiometric resolution can be inadequate; and, (e) the occasional presence of cloud and smoke cover.

Radar data is more appropriate for flood inundation mapping than the optical data. Microwave sensor has proved to be an effective tool for identifying differences between flooded and non-flooded regions, including the detection of the flooding beneath forest canopies (Hess et al., 1990, Hess and Melack, 1994, Townsend & Walsh, 1998). Besides that, the radar has as advantages the data collection at any time of day and under almost any weather conditions (cloud cover).

Ozesmi & Bauer (2002) reviewed the different classification techniques that have been used to identify wetlands. Amongst those it can be mentioned: visual interpretation; unsupervised classification or clustering; principal component analysis; supervised classification; hybrid classifications; vegetation indexes; mixture estimation; spectral mixture analysis; sub-pixel classification and rule-based classifiers.

Amongst the remote sensing studies in wetlands, great progress has been reported for multi-temporal analysis. The high coverage repetition of the satellite data enables seasonal and yearly monitoring of the wetland systems. There are two types of temporal remote sensing data commonly employed in wetland vegetation studies: (a) discrete snapshots with annual data to analyze spatial changes in land cover and (b) seasonal data to infer trends and dynamics of vegetation phenology (growth cycles). The former, is described by Munyati (2000) that used multi-temporal data over a ten-year period to assess a spatial reduction in area of dense green vegetation in upstream sections of the Kafue Flats floodplain wetland system in southern Zambia. The latter, is described by Johnston and Barson (1993) that considered images throughout one year to describe seasonal variability of water dynamic and vegetation pattern.

The Amazon River and its large tributaries present a floodplain region of about 300,000 km^2 (Iron et al., 1997), which represents approximately 56% of floodplain areas on the globe (Mitsch & Gosselink, 2000). The floodplain is a determinant factor for fish habitat quality (Gomes et al., 2006), occurrence of economically significant tree species (Parolin, 2000), and agricultural potential (Barrios et al., 2004). These floodplains are built by the formation of bars and the accumulation of sediment carried in diffuse overbank flows and channelized flows (Dunne et al., 1998). The periodic oscillation between terrestrial and aquatic phases on floodplains causes a constant exchange of the sediments and waters between river channels and floodplains. Floodplains affect erosion, transport and sedimentation processes in the watershed system (Junk, 1997). During residence of water on floodplains, substantial biogeochemical modifications occur under the influence of sorption and redox reactions and biotic processes (Melack et al., 2004; Richey et al., 1988, 1990; Seyler and Boaventura, 2003). The water storage in these wetlands and its outflow represent a significant part of the water balance in the basin (Alsdorf et al., 2001; Richey et al., 1989).**Figure 1**highlights the differences between high and low water stages by using remote sensing orbital products over large Amazonian floodplain.

Sedimentation rates in the Amazonian floodplains vary considerably, both temporally and spatially (Mousinho de Meis, 1971; Filizola, 1999; Bush et al., 2000). Moreira-Turcq et al., (2004) argue that probably the sedimentation rate is directly related to the geographic location, proximity to the Amazon River channel, and duration of connection between floodplain and river.

The Amazon floodplains can be divided into nutrient-rich whitewater (*várz*ea) and nutrient-poor blackwater (*igapó*) ecosystems according to the water quality of the flooding rivers (Prance, 1979). Fertile soils and nutrient-rich waters characterize the *várzea*, which becomes into a productive region within the Amazon Basin (Fiore et al., 2005).

The Amazon floodplain monitoring at basin scale is only possible by using remote sensing data, due to the extent and inaccessibility of the inundation areas. **Figure 2** presents an optical remote sensing image of the diversity of landscape units with open lakes, bogs, large meadows, alluvial forests and land forests. Another example of the central Amazon flood plain is Jarauçu river near the city of Porto de Moz presented in **Figure 3**. This figure shows palisade-huts of the riverine people adapted to the local hydrological floodplain conditions.

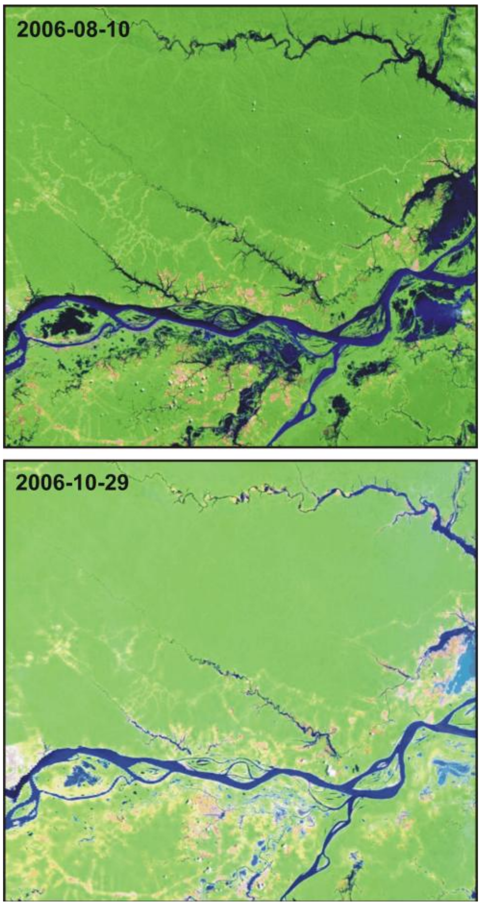

Figure 1 -TM-Landsat sensor image of the annual water level variations between high and low water stages in the Amazon river.

Figure 2 – Satellite image from TM-Landsat sensor depicting the floodplain during flooding period in the Amazon river near Santarém city.

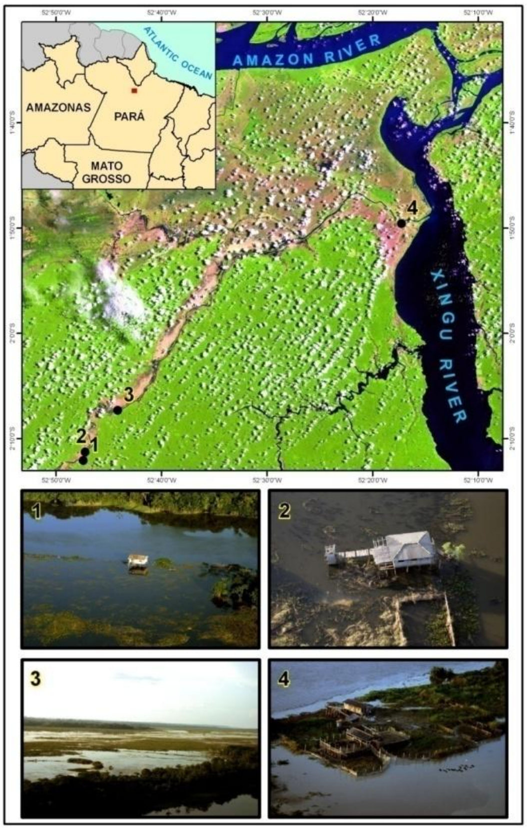

Figure 3 – Satellite image from TM-Landsat sensor of Jarauçu river near the city of Porto de Moz in Pará state. The pictures show floodplain (várzeas) areas with the presence of palisade-huts of the riverine people adapted to the local hydrological conditions.

However, in the Amazon region, the SAR systems are most used because the optical sensor images are strongly affected by cloud cover and cloudless scenes are sparse (De Costa et al. 1998). Thus, several studies using SAR provide a basis for improved estimates of the contribution of wetlands to biogeochemical and hydrological processes in the Amazon.

Wang et al. (1995) simulated the radar backscatter from a floodplain forest with a flooded or non-flooded ground condition at C-band (5.7 cm wavelength), L-band (24 cm wavelength) and P-band (68 cm wavelength). The flooded /non-flooded backscatter ratio was higher: (a) at HH polarization than at VV polarization; (b) at small incidence angles than at large incidence angles; and (c) at a long wavelength than at a short wavelength. The increase of the volumetric moisture from 10% to 50% in non-flooded caused the decrease of the flooded /non-flooded backscatter ratio (small at C- and L-band but large at P-band). The leaf area index (LAI) had a large effect on the simulated C-band (not L-band or P-band) flooded /non-flooded backscatter ratio.

Several studies have reported the classification of the radar images over the Amazon region to discriminate main land cover types and map flooded areas (Hess et al., 2003; Saatchi et al., 2000; Sippel, 1998; Siqueira et al., 2003). Thus, spatial variations in radar pulse amplitudes are accessed for characterization of the floodplain habitat and area of inundation (Hess et al. 1995; 2003). These studies presented the following patterns during Amazon recessional flow conditions: (a) open water yields the lowest radar returns; (b) flooded forest produces the strongest returns; and (c) flooded herbaceous vegetation and non-flooded forest produces intermediate L-band backscatter amplitudes.

Hess et al. (1995) used multi-frequency polarimetric synthetic aperture radar (SAR) data from SIR-C missions and a decision-tree classifier to map the floodplain inundation and vegetation along the Negro and Amazon rivers. Backscattering statistics indicate that both “C” and “L” band are necessary for accurate delineation of herbaceous versus woody and flooded vs. non-flooded cover types.

Hess et al. (2003) mapped wetlands in the Amazon region using L-band synthetic aperture radar (SAR) imagery from the Japanese Earth Resources Satellite-1 (JERS-1). The mapping included segmentation and clustering validated by high-resolution digital videography with an accuracy of 95%. Five cover classes: non-vegetated, herbaceous, shrub, woodland and forest combined with inundation sate (flooded or non-flooded) resulted in 10 possible covers.

Remotely sensed observations of the water surface provide an alternative to permanent gauging, providing new observations of hydrologic exchange between tributaries, floodplains, and mainstem rivers. Recent work has shown that interferometric processing and analyses of spaceborne synthetic aperture radar (SAR) described stage centimeter-scale changes for vegetation covered floodplain lakes and tributaries in flooded forests (Alsdorf et al., 2000, 2001, 2003; Birkett et al., 2002).

Alsdorf et al. (2003) examine the spatial properties of these interferometric measurements and demonstrate that flow routes across the floodplain can be automatically extracted from SAR imagery by using a geographic information system (GIS). In central Amazon floodplain localities, these authors observed one-day decreases in water levels of eleven centimeters. The spatial distribution of the water level is not homogeneous, because the flow through the floodplains includes a maze of interconnected lakes, channelized and non-channelized overbank flow, pans, and swales. Thus, water-level changes are inversely related to lengths of flow paths connecting water bodies to the main channel; that is, long distances result in small water-level fluctuations compared to short paths (Alsdorf et al., 2003).

Recently, studies have evaluated time series of SAR images in Amazon floodplain. Frappart et al., (2005) estimated both flooded area and water levels and determined the water volume stored in the floodplains of the Negro River, during the 1995–1996 seasonal cycle, by using combined observations from the Synthetic Aperture Radar (SAR) onboard the Japanese Earth Resources Satellite (JERS-1), the Topex/Poseidon (T/P) altimetry satellite, and in-situ hydrographic stations. Martinez & Toan (2007) used time series of SAR images (21 images acquired by JERS between 1993 and 1997) to map the flood temporal dynamics and the spatial distribution of landscape units (open lakes, bogs, large meadows, savannahs, alluvial forests and terra firma forest).

Conclusion

Given the foregoing, we trust it is now clear that riparian ecosystems should be interpreted on the basin-river-plain scale through long temporal series of data. On this space-time scale, it has stated that wetlands are peculiar, highly stable ecosystems. Likewise, in view of this interpretation scale, research, monitoring and conservation of these ecosystems require specific strategies, remote sensing figuring as an efficient technology for this purpose. Besides its capacity for covering large tracts of land and manipulating a large volume of data, channel planimetry combined with the prospect of taking satellite images is a significant dimension of analysis that allows fundamental properties of complex systems, self-regulation and interconnectivity to be highlighted.

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