Measuring Connectivity in Floodplains Rivers: Application of FITRAS Function to the Lower Paraná

Sylvina L. Casco[1,2], Matías Neiff[3], Alvaro Wills Toro[4], Rafael Cabral Cruz[5,6], José. A. Arenas-Ibarra[7], Cibelle Machado Carvalho[8], Leonardo Maltchik[9], Alicia S. G. Poi[1] and Juan J. Neiff[1]

ABSTRACT

In major rivers with extensive floodplains, the exchanges between the main channel and the floodplain are the main force that organizes the structure and maintains the stability of the landscape. The time period of flooded soil at each point on the floodplain indicates the extent of connectivity of each landscape with the river's main channel. However, not all populations and organisms and river processes are stimulated (or limited) by these pulse characteristics in the same way. Pulse attributes are synthesized with the function FITRAS, an acronym for Frequency, Intensity, Tension (or Stress), Regularity (or Recurrence), Amplitude and Seasonality. Hydrological variability in a time series is represented by the curve visualized as a sinusoidal function, and the overflow level defines the connectivity of each site by assigning the values of the historical series as "positive" to those that exceed the reference level, and "negative" to the records that are below that overflow line. In this contribution, we provide a discussion of processes related to pulse attributes and a simple procedure for assessing ecohydrological connectivity in river floodplains using the Pulso software, as well as complementary tools for assessing the predictability of cyclical components of the hydrograph and their relationship to vegetation distribution.

INTRODUCTION

The importance of connectivity in maintaining regional stability of terrestrial ecosystems has been a concern since the late 1980s and more recently for large rivers with floodplains. In these rivers (predominantly horizontal flow systems) the connectivity between the river channel and the floodplain is the main force that organizes the structure and maintains the stability of the landscape (Conner et al. 1981; Conner and Day 1988; Amoros and Roux 1988; Hughes 1988; 1990; Junk et al. 1989; Neiff 1990; Ward 1997; Amoros and Roux 1988; Tockner et al. 1998; Schwarzbold 2000; Pringle 2001; Amoros and Bornette 2002; Neiff and Poi de Neiff 2003; Wiens 2002, 2009; Junk and Wantzen, 2004; Cruz et al. 2010). As early as the beginning of the field of limnology (the scientific study of lakes and fresh water), Forbes, in his 1887 article "The lake as a microcosm" stated that the quantity and variety of animal species in river floodplain lakes depended mainly on the "frequency, extent and duration of overflows" and added that "the flexible system of organic life adapts itself, without injury, to widely and rapidly fluctuating conditions" (Forbes 1887).

While connectivity in terrestrial landscapes can be interpreted as the degree of continuity or proximity of patches in the landscape (structural connectivity) or as a measure of how the kind of elements and spatial configuration affect the movement of organisms between patches (Taylor et al. 2006), in floodplain rivers it is related to the horizontal movements of water from the main channel to floodplain and vice versa.

The concept of connectivity emerged from landscape ecology and was introduced into river ecology to describe the lateral connections in large rivers (Amoros and Roux 1988). However it has been tacitly recognized as a fundamental process in river dynamics since the middle of the last century (Arenas-Ibarra and Souza Filho 2010). According to Ward and Stanford (1995a,b), connectivity acts interactively in one temporal dimension (time scales) and three spatial dimensions: longitudinal (headwater-mouth), lateral (main channel/floodplain) and vertical (fluvial channel/groundwater); with the concept being defined as the transfer of energy and matter across the river landscape via the water environment (Ward et al. 2002) or the transfer of matter, energy and/or organisms within or between elements of the hydrological cycle by means of water (Pringle 2001, 2003).

Attempts to assess the influence of connectivity on river dynamics have been related to: 1) distance from the

---

1 - Centro de Ecología Aplicada del Litoral (CONICET-UNNE). Corrientes, Argentina. Corresponding author email contact: sylvina.casco@gmail.com

2 - Facultad de Ciencias Exactas y Naturales y Agrimensura (FaCENA-UNNE). Corrientes, Argentina.

3 - Pulso software, Corrientes, Argentina.

4 - Universidad de Antioquia. Grupo GAIA. Facultad de Ingeniería. Medellín, Colombia

5 - Campus São Gabriel, Universidade Federal do Pampa (UNIPAMPA-CSG). São Gabriel, Brazil.

6 - Programa de Pós-Graduação em Engenharia Ambiental, Universidade Federal de Santa Maria, Santa Maria, Brazil (PPGEAmb/UFSM)

7 - Investigador Asociado. Facultad de Ciencias Biológicas y Veterinarias. Carrera de Biología Marina. Universidad Científica del Sur, Lima, Perú

8 - Laboratório Interdisciplinar de Ciências Ambientais, Campus São Gabriel, Universidade Federal do Pampa (UNIPAMPA-CSG). São Gabriel, Brazil.

main channel (Amoros and Roux 1989; Ward and Stanford 1995b), 2) water body characteristics and type of connection (Bornette et al. 1998; Agostinho et al. 2001; Arenas-Ibarra et al. 2012), 3) time gradient of the connection (Amoros 2001; Okada et al. 2003), 4) relative proportion of the upstream surface connection (Ward et al. 2002), or 5) different time phases reflecting a type of connection and discharges (Tockner et al. 2000). Whol (2017) references 16 different concepts of connectivity in the scientific literature. Obviously, the various theoretical attempts lead to different conclusions, although together they highlight and demonstrate the importance of connectivity in structuring and supporting biodiversity in rivers.

Biogeochemical processes (Tabacchi et al. 1998), diversity in riverine wetlands (Worbes 1985; Budke et al. 2010; Assis and Wittmann 2011; Marchetti and Aceñolaza 2012), and productivity, decomposition and distribution of trees in riverine forests (Brinson 1990; Mitsch and Gosselink 1993; Neiff 2001; Cruz 2005; Neiff et al. 2006; Poi de Neiff et al. 2006; Casco et al. 2010; Marchetti and Aceñolaza 2012; Casco and Neiff 2013; Casco et al. 2015; Balestrin et al. 2019) are influenced by ecohydrological connectivity. Consequently, they all may be affected by hydrological regulation, although difficulties have been noted in assessing them (Furness and Breen 1980; Hughes 1990).

In projects such as landscape restoration in areas affected by hydroelectric dams, it is necessary to have a quantitative understanding of the distribution of vegetation in relation to the dynamics of pulses and levels of connectivity (Casco et al. 2010; Casco and Neiff, 2011; Marchetti and Aceñolaza 2012; Neiff et al. 2020). It is also essential to know the temporal and spatial conditioning associated with the alternation of periods of flooded soil - *potamophase* and periods of emerged soil – *limnophase* (Neiff 1990), because adaptations to both phases are different in each species, in each assembly, and also in each phase of the organism's development. Most processes occurring in wetlands have a positive or negative relationship with the pulse regime (Neiff 1996; Neiff et al. 2020). This contribution, based on the concept of river connectivity, examines a simple procedure for establishing the periods when each landscape or population on the floodplain remains connected (or disconnected) to the river flow and provides an example of its application.

ECOHYDROLOGICAL PULSE

The pulse regime in rivers is the repetition of pulses over a time series (annual, decades, and centuries). Each pulse has two complementary phases (*potamophase* and *limnophase*) whose dynamics are characterized by properties that vary at each site on the floodplain (Neiff 1990; Dawidek and Ferencz 2016). In other words, each pulse is defined as the time between the beginning of the flooding and the end of the isolated phase for each topographic site on the floodplain, from the overflow level (a threshold established by the researcher; Neiff 1996). That level is a reference value recorded from the nearest river gauge station which records height or streamflow, for example, over time. Consequently there is a series of hydrological records that can be used to assess seasonal and annual changes over time. Such data pertain only to sites influenced by river flows.

When the river flow exceeds the hydraulic capacity of the channel, it overflows, covering the land on a floodplain. This scenario is taken as the connectivity level for that topographical position. The operator will repeat this measurement for "n" sites in the study area where he or she wants to evaluate the connectivity with the river course, such as where trees of "species A" (for a population analysis) are found, or where landscape "X" is different from landscape "Z" (if the aim is to explain possible causes of the landscape pattern). Also, another application is to determine the topographic level where active flux of river water to the floodplain begins through a crevasse splay (Cremon et al. 2010).

The phase of the pulse in which the reference site meets the flooded soil is called the *potamophase* and the horizontal flows occur from and to the course of the river. When the water level drops and that reference site is isolated from the river course, the *limnophase* (emerged soil) begins, a period without exchanges (nutrients, sediments, seeds, eggs) with the river. From that moment on, the local water conditions of the site, in the absence of local rainfall, will vary from the condition of soil saturation (field capacity), through a progressive decline of the water table until the soil eventually reaching wilting point. In the classical wetland literature, the seasonal pattern of the water level is referred to as the hydroperiod (Mitsch and Gosselink 1993).

The ecohydrological attributes of the pulses can be represented by the acronym FITRAS which stands for Frequency, Intensity, Tension (or Stress), Regularity (or Recurrence), Amplitude and Seasonality (Neiff 1990; Neiff et al. 1994; Neiff 1999). The curve representing the hydrological variability in a time series is visualized as a sinusoidal form with the overflow level being the reference elevation that defines the connectivity of each site. "Positive" values for a site are those that exceed the reference level, and "negative" ones are those below that line (Figure 1). A pulse consists of the flood and drawdown, ending when the next overflow starts. Frequency is defined as the number of pulses per time unit for each level of connectivity in the hydrographic series considered. Intensity is the level of water above the soil measured by comparison with the nearest river gauge expressed in meters. Tension is the value of the standard deviation of the maximum and minimum means in the analyzed hydrological series. Regularity is the number of times each level of connectivity is repeated over time. Seasonality indicates at what time each phase occurs (Neiff 2001). Amplitude represents the duration, in days, of each phase of the pulse.

Quantitative relationships between ecological characteristics (e.g., species richness, abundance, and diversity) at each level of floodplain connectivity can be linked to the upstream or downstream duration of each area of the landscape using Pulso software (Neiff and Neiff 2004; https://neiff.com.ar/) which allows the correlation of hydrological fluctuation with the biological characteristics of the landscape, e.g., the distribution of vegetation patterns relative to flooding (Figure 2). With this objective, Neiff and Poi de Neiff (2003) proposed the Fluvial Connectivity Quotient (FCQ):

FCQ = FD/LD

where FD = number of days in potamophase and LD = number of days in limnophase.

Pulso version 2.0 has a frequency estimation function (Prism) that uses genetic algorithms to decompose the frequencies that make up a series to complete an incomplete series of hydrological data, as well as to anticipate a future trend based on available historical information. We have a simple way to evaluate the ecohydrological connectivity in wetlands, using the Pulso software. Although this application was developed for floodplains of large rivers, it can be used in coastal wetlands (such as mangroves), lagoons, and lakes formed by groundwater rises or to study the organisms that live in the area of fluctuation of lakes and ponds or in the intertidal zone of the sea as long as there is recorded hydrologic data available from a nearby gauging station. The procedure has been used to study the dynamics of the plankton (Frutos et al. 2006), periphyton (Rodrigues et al. 2008), fish populations (Fernandes et al. 2009; Neiff et al. 2009), and the process of formation of the islands and the texture of the soils that compose them (Neiff et al. 2005), since it is possible to process flow values and thus analyze any process that varies over time according to a sinusoidal function (e.g., rainfall). It is also very useful for ex-post environmental evaluation of structural interventions on the river such as dams, course straightening, or marginal dikes (Neiff et al. 2020), such as to reveal effects of those structures on the hydrological connectivity (Arenas-Ibarra 2008).

In addition to the properties of the pulse regime that are characterized in the FITRAS function, Cruz (2005) proposed the analysis of the predictability of different

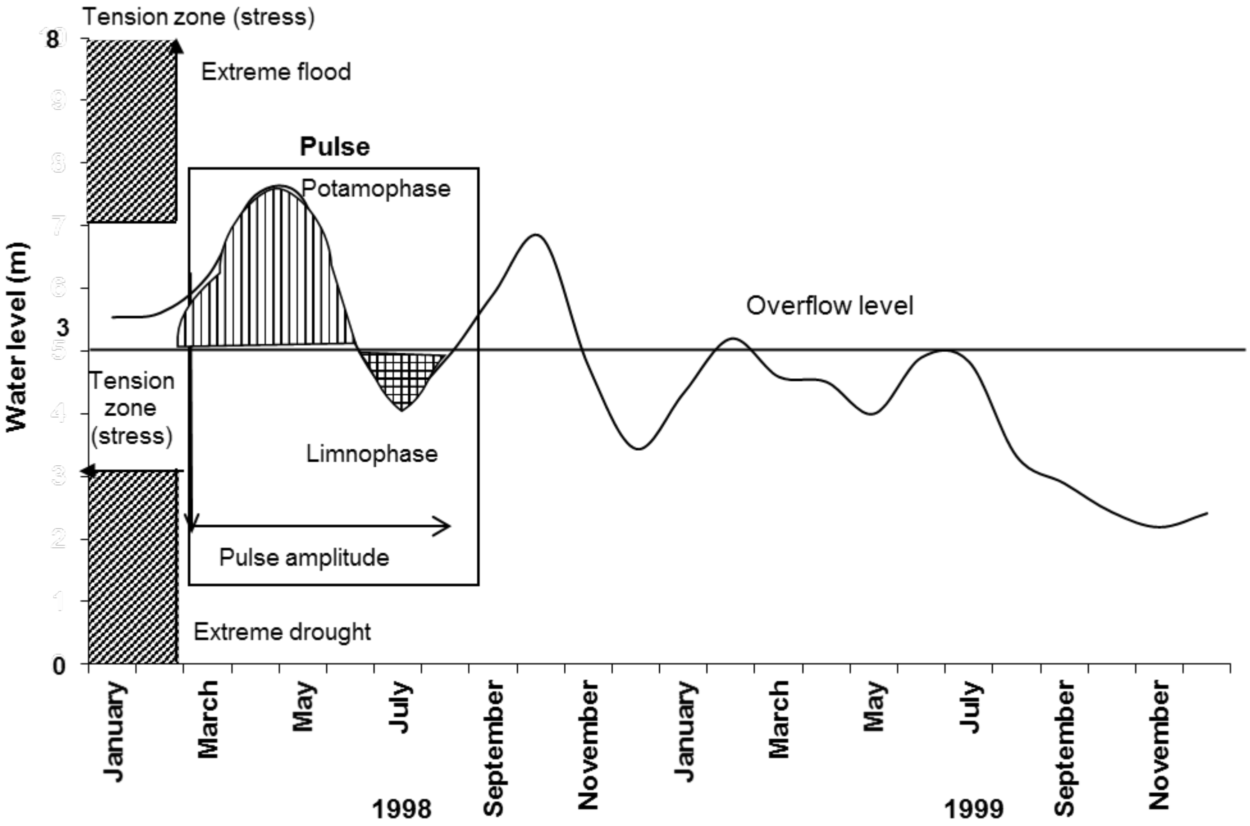


FIGURE 1. Graphic representation of the ecohydrological Pulse for a site containing willow tree (Salix humboldtiana). Potamophase represents the flooding period, while the limnophase is the drying period. In this example, two flood pulses are shown. (Modified from Casco 2003)

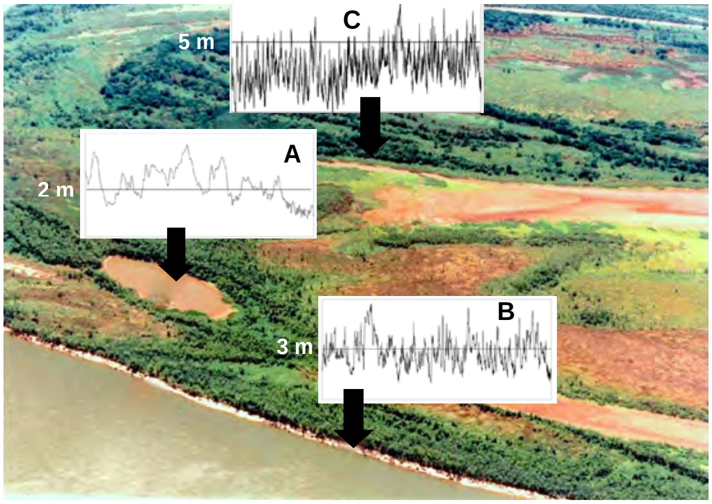


FIGURE 2. Paraná River floodplain showing hydrograms of study sites from various time periods: A - floodplain lake (January 1997-December 1999), B - willow gallery forest (January 1979- December 1999), and C - mixed gallery forest (January 1949-December 1999). Note that the horizontal line represents the elevation at which overflow occurs.

periodic components of the hydrograph and their relationship with the distribution of the functional characteristics of the plants (for example: growth form (solitary, rosette, caespitose); plant slope (prostrate, semierect, erect); type of leaves (membranous, herbaceous, other); waxiness in the leaves (Yes, No); glands on the leaves (Yes, No); type of stem (herbaceous, woody); stem with inter-nodes (Yes, No) along the flood profile of a river section. Cruz developed the application (FFTSint) to filter the most predictable components of the time series, allowing the degreeof predictability of each pulse to be identified. He assumes that the more predictable pulses, with more recurrence, favor the adaptation processes, while the less predictable ones provoke succession and regression processes (Cruz 2005; Cruz et al. 2015). This complementary approach can be used to compare functional diversity, in applications related to prescription of ecological flow regimes and for restoration of riparian vegetation (Cruz 2005; Silveira et al. 2006; Silveira et al. 2009; Cruz et al. 2010; Balestrin et al. 2019).

THE METHOD AND AN EXAMPLE OF ITS APPLICATION

The proposed method will be described using Argentina's Lower Paraná as an example. Before describing the method let us introduce the study area.

Study Area

The Paraná River below the confluence with Paraguay River has distinguishing features: the west bank has suspended solids from the Bermejo River, a tributary of the Paraguay River, and the east bank is influenced by the transparent water of the Upper Paraná River. The main channel has a braided design (Orfeo 1995) and the floodplain of stretches over 8 km on the west bank, with more islands than the east.

The landscape units (lakes, forests, marshlands) of floodplain are distributed in different levels of connectivity with the river main channel (Figure 3). *Salix humboldtiana* (willow) forests whose seeds are provided mainly by the river and colonize the sandbanks, constitute monotypic stands that have a wide distribution in the topographic gradient (Figure 3 B).

We propose an example of Pulso application during the hydrological series 1970-2020 with extraordinary high and low water phases (El Niño/La Niña events), to determine when adults trees of willow forest located at 2 m in the topographic gradient colonized that site, how long the soil was covered or uncovered with water and how many flood events occurred since the willow forest established.

The Method

The method uses different scales of analysis involving four stages 1) laboratory analysis, 2) field investigations, 3) data analysis, and 4) study findings.

Stage 1. *Laboratory Analysis*. Landscape features are defined by examining satellite images at an appropriate scale. For the Lower Paraná we are using maps of 1:10000 to 1:30000 scale derived from satellite images with spatial resolutions of 30, 20 or 15 m (e.g., Landsat TM5, ETM7, CBERS 2, 2B, 4, Resourcesat-1, Resourcesat-2 or Aster) for the floodplain of the Paraná River to establish the survey sites for field sampling. A false color composition R(4)G(3)B(2) or R(5)G(6)V(2) could be useful for recognition of landscape features (Ponzoni et al. 2012). Also,

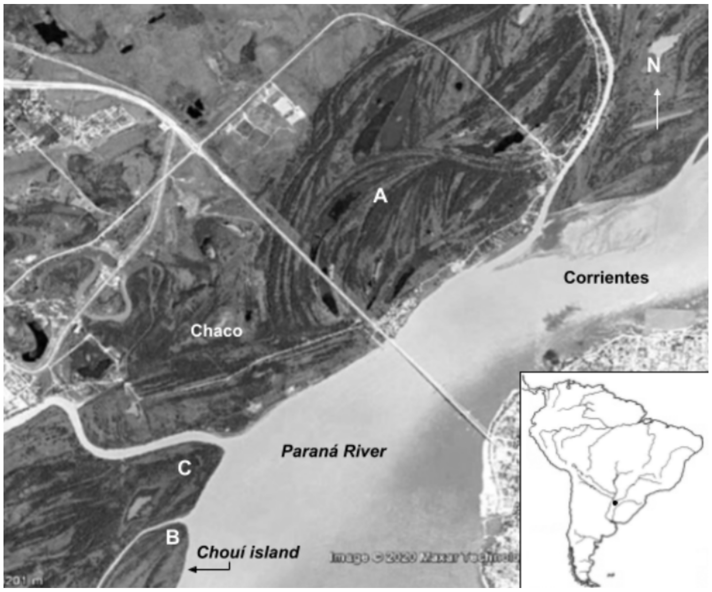


FIGURE 3. Study sites: A - floodplain lake, B - willow gallery forest, and C - mixed gallery forest. Image below shows a willow forest of Lower Paraná.

SAR products and UAV images could be used to accurately discrimination of wet soil and vegetation (Plank et al. 2017; Van Iersel et al. 2018). For these types of projects, one could use a variety of technological tools and image processing software, whatever is available. In fact, we have also used only the images of Google Earth-Pro with good results, identifying different landscape units (forests, marshlands, and lakes) that are readily observed at study area (Figure 3).

Stage 2. *Field Investigations*. In this stage, the topographical position of the survey sites is established and the biological information at each site is recorded. For example, we identify the species that make up the landscape unit, the strata that are present, the diameter at breast height (DBH) and the height of the trees, the separation between them, or for grasses, their biomass based on small plot sampling.

In high water, when the river overflows the floodplain, sites must be accessed by boat (e.g., 3-5m in length). The topographic position of each site is established by measuring water depth in several ways. The simple way is to drop a plumb into the water and when it hits bottom, record the depth. We use a 200g metal disc (Figure 4), located at the end of a thin cord that is graduated every 10 cm. Alternatively, when possible, an echo sounder with built-in GPS should be used; this provides the most accurate depth and geographical position information. If a highly accurate diagnosis is required for each site, the thickness of the water sheet is measured through the same process. Detailed bed topography could also be obtained with an Acoustic Doppler Current Profilers (ADCP) river profiler, Light Detection And Ranging (LiDAR) images, Unmanned Aerial Vehicle Laser Scanning (UAV), Synthetic Aperture Radar (SAR) topographic models or a combination of ADCP and Digital Elevation Model (DEM) products (Straatsma 2009; Guerrero and Lamberti 2013; Rudorff et al. 2014; Cao et al. 2018; Resop et al. 2019). These measurements are then related in the laboratory to the level of the river at the nearest hydrometric station.

We also establish elevations on the islands that are inundated at different frequencies, thereby establishing connectivity between the river course and the floodplain. This connectivity can take place in two ways: 1) where the islands have inland courses that remain connected to the main course even in low water and the connection is made by crevasses that allow flow from the river to the plain, and 2) where the inflow is produced by lateral overflow (laminar, or not) on the islands. In the first case, the connectivity was defined determining the date for initial connection to the river in relation to the water level of the Paraná River in the gauge located near the study site. In the second situation, the procedures are illustrated by the example in willow forest at Lower Paraná.

An individual willow tree on Chouí island (Figure 3) that has the soil covered by a two-meter water column, in the field, was noted as -2m, which is the depth of the ground surface with respect to the current level of the water sheet at that site. This is calibrated to current reading at the nearest hydrometer (at Corrientes city) which reads 5m on January 26, 1998. So, the zero position of the hydrometer at that point is 3m. That is, whenever the river is above 3m on the hydrometric ruler in the historical data series, the ground at our sample location should have been covered by water (Figure 5). The 3m value is the reference level or “overflow level” that will be used to obtain the attributes of the ecohydrological pulse, using the Pulso software. If the objective is to relate the topographic position to the sea level, we use the zero position of the hydrometer at Corrientes city, which is known to be 44.57 m.a.s.l. (meters above sea level) and add the 3m from our current readings for a level of 47.57 m.a.s.l. for the site-example.

While it is desirable to conduct the survey during the flood phase in order to save effort and time in accessing

FIGURE 4. Measurement of the topographical position of a floodplain point during high water (left picture) with a metal disc ("scandal"), placed at the end of a thin cord which is graduated every 10 cm (right picture).

floodplain sites, the procedure can also be applied when the river is at low water using other technological resources (Marchetti and Aceñolaza 2012; Stevaux et al. 2013). Topographic data could be taken from LIDAR or SAR images (Yuan et al. 2017; Lague and Feldmann 2020) and DEM (Tandem-X, ALOS World 3D30, SRTM, Aster G-DEM), corrected by some geoprocessing tools that increase its vertical resolution (Shastry and Durand 2019; Mudd 2020). AUV DEM is another good source of topographic data in small areas (Woodget et al. 2017; Annis et al. 2020).

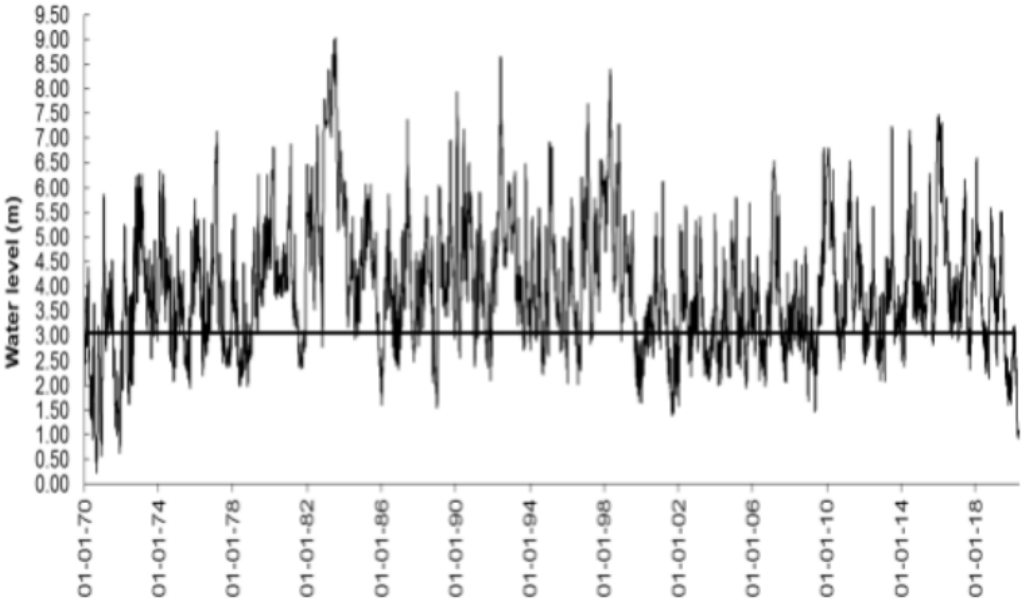


FIGURE 5. Hydrometric fluctuation of the Paraná River at Corrientes gauge during last 50 years. The solid horizontal line represent the overflow of floodplain where willow forest growth that was mentioned as an example.

In sampling during the limnophase (low water), since the sites are emergent (not flooded soil) in this period all topographic measurements will be positive. For example, for the willow forest, which is located at 3m in the topographic gradient and the Paraná River level in nearest hydrometer (in Corrientes city) has a reading of 2m on October 6, 1999 the estimation would be:

2m (near hydrometer)+3m (place) = 5m from the hydrometer. Every time when the water marks over 5m on the hydrometer, the water will be covering the soil where this willow forest are growing.

Pulso will divide the series of historical hydrometric data into two groups: those above 3m will be recorded as "potamophase" (flooded soil) and those below 3m as "limnophase" (emergent soil) for that point where willow forest is located.

Stage 3. *Data analysis*. In the laboratory, the daily hydrometric data are analyzed over a time series. In our example we take the period 1970-2020 at Corrientes gauge, because we know that the willow trees are 30-50 years old. It is important to filter the information to ensure the right notation, integrity and reliability of the series. When only incomplete series are available, we should previously try to complete the series using the Prism module included in the Pulso 2.0 application. The next step is to calculate the frequency, amplitude (such as number of flooding days and number of days of emergent soil) and seasonality for each site. In our example, for the 3m overflow level of willow trees, the attributes of the hydrosedimentological pulse for the years 1998-1999 of the hydrological series considered are shown in Figure 1.

Stage 4. *Study Findings*. With the pulse analysis, we can obtain information about the connectivity of our object of study with the course of the river.

The willow tree used as in our example was connected to the course of the Paraná River for 6,422 days (1979-1999), receiving 52 pulses and a FCQ of 7.26 (Table 1).

Figure 6 shows the seasonality with which the flooding and emergent soil phases occurred, as a frequency histogram. In ordinary phases, potamophases are more frequent in spring-summer and limnophases in autumn-winter. Because three "El Niño" events were recorded during 1979-1999 (1982/1983, 1992 and 1998), for willow forest, there was a higher frequency of potamophases (Figure 6 B).

The time period analyzed in the example comprises a multi-year series corresponding to the approximate life span of the willow trees in the landscape. However, for the study of populations with a high rate of change (plankton, periphyton), the length of the hydrological series analyzed can be annual or seasonal. As a synthesis, the sequence of tasks is presented in Figure 7.

Geographical distance from the river may not always predict connectivity because disparities in floodplain slopes whereas hydrologic distance (topographic position) appears a good predictor of connectivity.

In a sector of the Lower Paraná River floodplain the oxbow lakes that were more connected during high water (Sites 1, 2 and 3 in Figure 8) showed higher values of fish density and species richness than sites less connected (Neiff et al 2009), although site 1 is the most distant of the Paraná

	Floodplain lake	Willow forest	Mixed gallery forest
Overflowing level (m)	2	3	5
Frequency of pulses	6	52	126
Number of days with hydrologic connectivity	1086	6422	3688
Number of emerged soils days	9	884	14575
Fluvial Connectivity Quotient (FCQ)	120.66	7.26	0.25

TABLE 1. Ecohydrological connectivity of floodplain lake, willow forest and mixed gallery forest, during January 1997-December 1999; January 1979-December 1999 and January 1949-December 1999, respectively and pulse's attribute obtained with Pulso software. FCQ = FD/LD. where FD = number of days in potamophase and LD = number of days in limnophase.

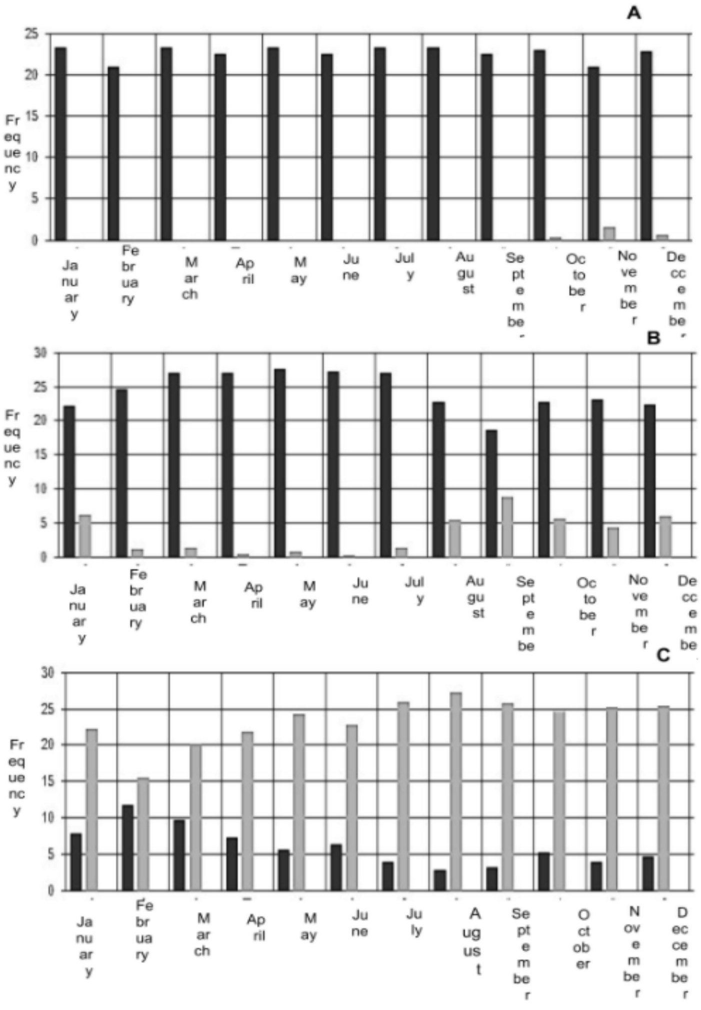


FIGURE 6. Histogram of frequencies of seasonality of potamophase (black bars) and limnophase (grey bars) for each landscape unit: A - floodplain lake, B - willow forest, and C - mixed gallery forest.

River (Figure 8). Sites 2 and 3 are near the Paraná River but separated by alluvial levees occupied by gallery forest and has indirect connection. Other work carried out on the floodplain of large river such as the Missisippi (Miranda 2005), the Volga (van de Wolfshaar et al. 2011) and the Bug River (Dawideck and Ferencz 2016) have highlighted the importance of considering the slope.

RESULTS FOR THE PARANA RIVER FLOODPLAIN

We compared the ecological attributes of willow forest (B) with other landscape units, floodplain lake (A) and a mixed gallery forest (C), that occur in different topographic positions on the floodplain: 2 m and 5 m, respectively (Figure 2).

Hydrographs were prepared using the Pulso software for period January 1997-December 1999 to analyze the floodplain lake; between January 1979 and December 1999, for willow forest, and between January 1949 and December 1999 for the mixed gallery forest (Figure 2).

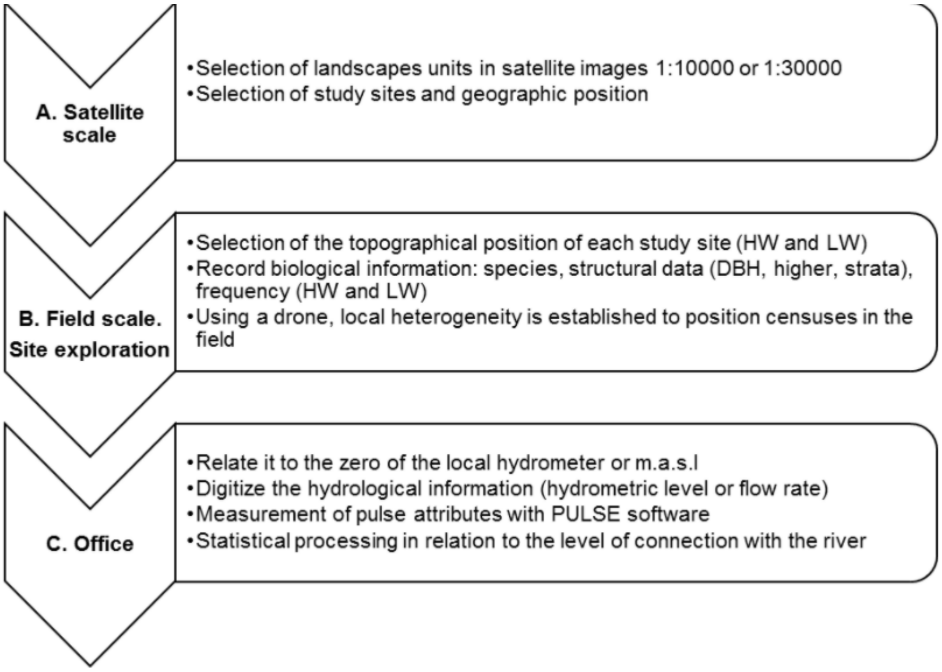
The floodplain lake was connected with the main channel during 1086 days, with a lower pulse frequency (6), highest FCQ (120.66) and more frequency of potamophases than the other landscape units (Table 1, Figure 6 A). The forests receiving between 52 (willow) and 126 pulses (mixed gallery) and the number of days with emerged soils was more in mixed gallery forest (Table 1).

The frequencies of limnophases were the highest during the whole period (1949-1999) in the mixed gallery forest (Figure 6 C), while potamophases were more frequent in summer (Figure 6 C).

In the Lower Paraná, topographic position is an indicator along the complex gradient of floodplain, of the flood/drought periods and the resilience of trees to extreme hydrological phases. Because of disparities in the slopes of the study floodplain, topographic position of each site rather than distances from the river indicated the connectivity of each sites.

FINAL REMARKS

The approach presented here extends the scope that is traditionally used to characterize river ecohydrological dynamics, which focuses on the main river course and its low, medium, high and extreme flows in a time series (Richter et al. 2003). With the methodology presented, it is possible to obtain the ecohydrological dynamics of different sectors of the alluvial plain and verify the dynamics of their connectivity over time, associating them with biotic variables such as species richness, distribution and abundance of populations, life forms, biomass and other characteristics of the biotic arrangement of both the aquatic media and the floodplain landscape. Theoretically, the procedure is useful to establish the age of each sedimentary stratum or the age of the trees in each location of the floodplain.



A. Satellite scale

- Selection of landscapes units in satellite images 1:10000 or 1:30000
- Selection of study sites and geographic position

B. Field scale. Site exploration

- Selection of the topographical position of each study site (HW and LW)
- Record biological information: species, structural data (DBH, higher, strata), frequency (HW and LW)
- Using a drone, local heterogeneity is established to position censuses in the field

C. Office

- Relate it to the zero of the local hydrometer or m.a.s.l
- Digitize the hydrological information (hydrometric level or flow rate)
- Measurement of pulse attributes with PULSE software
- Statistical processing in relation to the level of connection with the river

FIGURE 7. Summary of proposed procedure for measuring connectivity in river plains. HW - High water (potamophase), LW - Low water (limnophase), and DBH –Diameter at breast height.

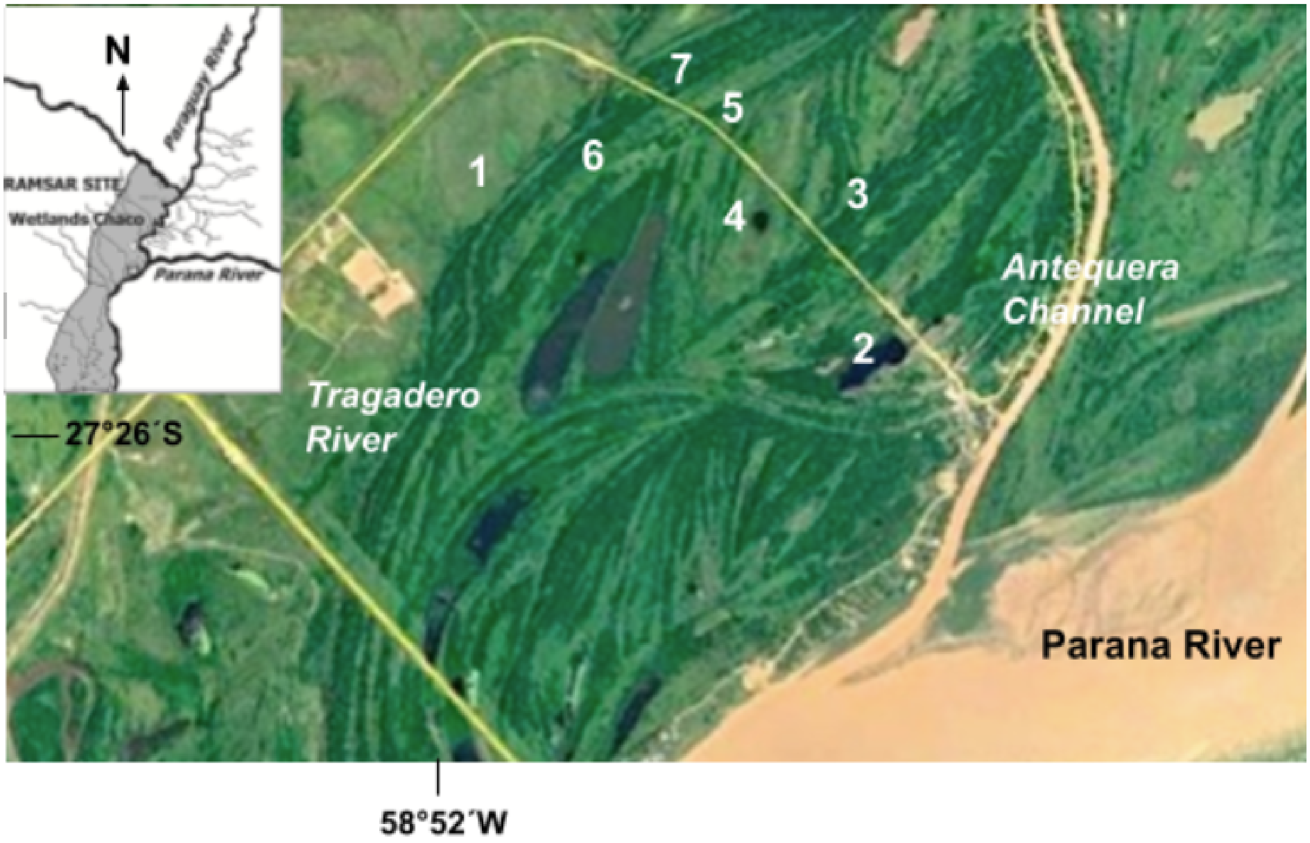


FIGURE 8. Floodplain of the Paraná River downstream of the confluence with Paraguay River. The sites were connected to the river above different hydrometric levels measured in the in the gauge located near the study sites Scored from 1 to 7 indicated the decreasing order in connectivity according the number of days in which sites were connected to the river channel. 1 = 3.8 m, 2 = 4.2 m, 3 = 4.8 m, 4 = 5.2 m, 5 = 5.4 m, and 6 and 7 = 5.6 m. (Adapted from Neiff et al. 2009)

The assessment of the connectivity of the floodplain elements with the river flow is the basis for comparing spatial differences and temporal variability. However, its analysis should be taken as an approximation to the knowledge of the influence of horizontal flows from/to the river course in a wide environment of variability.

According to Burel and Baudry (2002), landscapes, as self-organizing systems, have a time delay in their adaptive response, such that there is always an asynchrony between the moment of perturbation and the moment of the adaptive response. This asynchrony results in the imbalance that maintains the potential energy of self-organization. The identification of the pulse patterns and their relationship with the landscape structure must be analyzed taking into account the possibility of this delay and also the possibility of non-stationarity in the hydrograph. Carvalho (2020), through wavelet analysis and the KPSS non-stationarity test, found no stationary segments for more than three years and that 99% of the time the stationary segments are less than two weeks, for a historical series of 71 years (Station 87440000 - Passo das Canoas, Gravataí River Watershed, RS, Brazil). The incorporation of non-stationary and self-organized dynamics in the analysis of ecohydrological pulses are challenges that arise for the future development of large rivers of South America and other rivers (Dawidek and Ferencz 2016). ■

REFERENCES

Agostinho, A.A., L.C. Gomes and M. Zalewski. 2001. The importance of floodplains for the dynamics of fish communities of the upper river Paraná. Ecohydrology Hydrobiology 1: 9-17.

Amoros, C. and A.L. Roux. 1988. Interaction between water bodies within the floodplain of large rivers: function and development of connectivity. *Munstersche Geographische Arbeiten* 29: 125–130.

Amoros, C. 2001. The concept of habitat diversity between and within ecosystems applied to river side-arm restoration. *Environmental Management* 28: 805-817.

Amoros, C. and G. Bornette. 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology* 47: 761–776. https://doi.org/10.1046/j.1365-2427.2002.00905.x.

Annis, A., F. Nardi, A. Petroselli, C. Apollonio, E. Arcangeletti, F. Tauro, C. Belli, R. Bianconi and S. Grimaldi. 2020. UAV-DEMs for small-scale flood hazard mapping. *Water 12:* 1717. https://doi.org/10.3390/w12061717.

Arenas-Ibarra, J.A. 2008. Aplicações fluviológicas na planície do alto rio Paraná (PR-MS). Tese (Doutorado em Ecologia), Universidade Estadual de Maringá.

Arenas-Ibarra, J.A. and E. Souza-Filho. 2010. Revoluções Kuhnianas na evolução da ecologia fluvial. A (pouca?) importância das anomalias. Ciencia & Ambiente 41: 21-40.

Arenas-Ibarra, J.A., A. Michiyo Takeda and D.S. Fujita. 2012. O regime hidrológico do rio Ivinhema (Estado do Mato Grosso do Sul) e sua influência na assembléia zoobentônica. Acta Scientiarum. Biological Sciences 34: 47-57.

Assis, R. and F. Wittmann. 2011. Forest structure and tree species composition of the understory of two Central Amazonian varzea forests of contrasting flood heights. Flora - Morphology Distribution Functional Ecology of Plants 206: 251-260. https://doi.org/10.1016/j.flora.2010.11.002

Balestrin, D., R.C. Cruz, G.L. Silveira and S.V. Martins. 2019. Hydric and edaphic influence on floristic composition in an altered riparian area. Floresta e Ambiente 26(3): e20171002 http://dx.doi.org/10.1590/2179-8087.100217.

Bornette, G., C. Amoros and N. Lamouroux. 1998. Aquatic plant diversity in riverine wetlands: the role of connectivity. Freshwater Biology 39: 267–283.

Brinson, M.M. 1993. A Hydrogeomorphic Classification for Wetlands. U.S. Army Corps of Engineers, Washington, D.C. Wetlands Research Program Technical Report WRP-DE-4.

Budke, J.C, J.A. Jarenkow, A.T. Oliveira-Filho. 2008. Tree community features of two stands of riverine forest under different flooding regimes in Southern Brazil. Flora 203: 162-174. https://doi.org/10.1016/j.flora.2007.03.001.

Burel, F. and J. Baudry. 2002. Ecología del Paisaje: Conceptos, Métodos y Aplicaciones. Ediciones Mundi-Prensa, Madrid.

Cao, N., H. Lee, H.C. Jung and H. Yu. 2018. Estimation of water level changes of large-scale Amazon wetlands using ALOS2 ScanSAR differential interferometry. Remote Sensing 10: 966. https://doi.org/10.3390/rs10060966.

Carvalho, C. M. 2020. Série hidrológica não estacionária e os riscos e incertezas nas tomadas de decisões no planejamento dos recursos hídricos. Tese (Doutorado em Engenharia Civil) - Universidade Federal de Santa Maria. Santa Maria.

Casco, S.L., J.J. Neiff, and A.S.G. Poi de Neiff. 2010. Ecological responses of two pioneer species to a hydrological connectivity gradient in riparian forests of the lower Paraná River. Plant Ecology 209: 167-177. https://doi.org/10.1007/s11258-010-9734-9.

Casco, S.L. and J.J. Neiff. 2013. Distribution pattern of trees in a hydrological gradient below the Paraná-Paraguay River confluence. American Journal of Plant Sciences. Special Issue: The Future of the Forests 4: 663-673. doi:10.4236/ajps.2013.43A085

Casco, S.L., M.E. Galassi, E.K. Mari., A.S.G. Poi and J.J. Neiff. 2015. Linking hydrologic regime, rainfall and leaf litter fall in a riverine forest within the Ramsar Site Humedales Chaco (Argentina). Ecohydrology 9: 773–781. https://doi.org/10.1002/eco.1673.

Conner, W.H., and J.W. Day Jr. 1988. The impact of rising water levels on tree growth in Louisiana. In: Hook. D.D. (ed.). The Ecology and Management of Wetlands. Croom Helm Ltd., London. pp. 219-224.

Conner, W.H., J.G. Gosselink and R.T. Parrondo. 1981. Comparisons of the vegetation of three Louisiana swamp sites with different flooding regimes. American Journal of Botany 68: 320-331.

Cremon, É.H., O.C. Montanher and J.A. Arenas-Ibarra. 2010. A influência das crevasses na dinâmica de inundação da planície do Alto rio Paraná. Anais VIII Simpósio Nacional de Geomorfologia, Recife.

Cruz, R.C. 2005. Prescrição de Vazão Ecológica: Aspectos Conceituais e Técnicos para Bacias com Carência de Dados. Tese (Doutorado em Ecologia). Universidade Federal do Rio Grande do Sul. Porto Alegre.

Cruz, R.C., J.C. Cruz, G.L. Silveira and F.S. Vilella. 2010. Vazões Ecológicas e Remanescentes em Rios Alterados por Barragens: Estudo de Caso. Ciência & Ambiente 41: 175–190.

Cruz, R.C., M.L. Porto, G.L. Silveira, J.C. Cruz, R.D. Pereira and R.L. Daru. 2015. FFTSINT: A tool for recurrence analysis of peaks in the spectral analysis of daily hydrologic series. Revista Brasileira de. Biometria 33: 426-444.

Dawidek, J. and D. Ferencz. 2016. Historical changes of hydrological connectivity of selected Polish floodplain lakes. River Research and Applications 32: 1862–1871. https://doi.org/10.1002/rra.3035.

Fernandes R, A.A. Agostinho, E.A. Ferreira, C.S. Pavanelli, H. I. Suzuki, D. P. Lima, L.C. Gomes. 2009. Effects of the hydrological regime on the ichthyofauna of riverine environments of the Upper Paraná River flood plain. Brazilian Journal of Biology 69:669–680. http://dx.doi.org/10.1590/S1519-69842009000300021.

Forbes, S. 1887. The lake as a microcosm. Bull. Sci. Assoc. Peoria, Illinois, pp. 77-87, (Reprinted, Ill. Nat. Hist. Surv. Bull., Vol. 15, pp. 537-550, Nov. 1925.)

Furness, H.D. and H.C. Breen. 1980. The vegetation of seasonality flooded areas of the Pongolo River floodplain. Bothalia 13: 217-230.

Guerrero, M. and A. Lamberti. 2013. Bed-roughness investigation for a 2-D model calibration: The San Martín case study at Lower Paraná. International Journal of Sediment Research 28: 458–469. https://doi.org/10.1016/S1001-6279(14)60005-6.

Hughes, F.M.R. 1988. The ecology of African floodplain forests in semiarid zones, a review. Journal of Biogeography 15: 127-140.

Hughes, F.M.R. 1990. The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya. Journal of Applied Ecology 27: 475-491.

Junk, W.J, P.B. Bayley and R.E. Sparks. 1989. The flood pulse concept in river– floodplain systems. Canadian Special Publications for Fisheries and Aquatic Sciences 106: 110–127.

Junk, W.J. and K.M. Wantzen. 2004. The Flood Pulse Concept: new aspects, approaches, and applications-an update. In: R Welcomme and T. Petr (eds.). Proceedings of the 2nd Large River Symposium (LARS), Pnom Penh, Cambodia [Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16]. pp. 117–149.

Lague, D. and B. Feldmann. 2020. Topo-bathymetric airborne LiDAR for fluvial-geomorphology analysis. In: P. Tarolli and S.M. Mudd (eds.). Remote Sensing of Geomorphology, 23, Elsevier, Berkeley. pp. 25-54.

Marchetti, Z.Y. and P. Aceñolaza, P. 2012. Pulse regime and vegetation communities in fluvial systems: The case of the Parana River floodplain, Argentina. Flora 207: 795-804.

Miranda, L.E. 2005. Fish assemblages in oxbow lakes relative to connectivity with the Mississippi river. Transactions of the American Fisheries Society 134:1480–1489.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands, 2nd edition. Van Nostrand Reinhold, New York.

Mudd, S.M. 2020. Topographic data from satellites. In: P. Tarolli and S.M. Mudd (eds.). Remote Sensing of Geomorphology 23, Elsevier, Berkeley. pp. 91–128.

Neiff, J.J. 1990. Aspects of primary productivity in the lower Paraná and Paraguay riverine system. Acta Limnologica Brasiliensia 3: 77-113.

Neiff, J.J. 1996. Large rivers of South America: toward the new approach. Verhandlungen des Internationalen Verein Limnologie 26:167–181.

Neiff, J.J. 1999. El régimen de pulsos en ríos y grandes humedales de Sudamérica. In: A.I. Malvárez (ed.). Tópicos sobre humedales subtropicales y templados. Oficina Regional de Ciencia y Técnica para America Latina y el Caribe (ORCyT) MAB/UNESCO, Montevideo. pp. 97-146.

Neiff, J.J. 2001. Diversity in some tropical wetland systems of South America. In D. Gopal, W. Junk and J. Davis (eds.), Biodiversity in wetlands: assessment, function and conservation, Backhuys Publish., The Netherlands. pp. 157-186.

Neiff, J.J. and M. Neiff. 2004. Pulso, software for the analysis of recurrent phenomena. Dir. Nac. de Derecho de Autor Nº 236164 (Argentina) Buenos Aires, 17 February. http://www.neiff.com.ar.

Neiff, J.J. and A.S.G. Poi de Neiff. 2003. Connectivity processes as a basis for management of aquatic plants. In: Thomaz, S.M. and L.M. Bini (eds.). Ecologia e Manejo de Macrófitas Aquáticas. EDUEM Maringá. pp 39-59.

Neiff, J.J., M.H. Iriondo and R. Carignan.1994. Large tropical South American wetlands: an overview. In: G.L. Link and R.J. Naiman (comps.). Proceedings of the international workshop on the ecology and management of aquatic-terrestrial ecotones. Seattle: Unesco, MAB, IHP, Center for Stream-side Studies-University of Washington. pp. 156-165.

Neiff, J.J., C.A.E. Patiño and S.L. Casco. 2006. Atenuación de las crecidas por los humedales del Bajo Paraguay. In: J. Capatto (ed.). Humedales fluviales de América del Sur. Hacia un manejo sustentable. Fundación Proteger, Santa Fe. pp. 261-276.

Neiff, J.J, A.S.G. Poi de Neiff and M.B. Canón Verón. 2009. The role of vegetated areas on fish assemblage of the Paraná River floodplain: effects of different hydrological conditions. Neotropical Ichthyology 7: 37-48.

Neiff, J.J., S.L. Casco, A.S.G. Poi and V.A. Zambiasio. 2020. Influence of Yacyretá dam on trees distribution in the Paraná floodplain. Ecological Engineering 154: 1-10. 105931 https://doi.org/10.1016/j.ecoleng.2020.105931.

Okada, E.K., A.A. Agostinho, M. Petrere and T. Penzack. 2003. Factor affecting fish diversity and abundance in drying ponds and lagoons in the upper Paraná basin, Brasil. Ecohydrology and Hydrobiology 3: 97-110.

Plank, S., M. Jüssi, S. Martinis and A. Twele. 2017. Mapping of flooded vegetation by means of polarimetric Sentinel-1 and ALOS-2/PALSAR-2 imagery. International Journal of Remote Sensing 38: 3831–3850.

Poi de Neiff, A., J.J. Neiff and S.L. Casco. 2006. Leaf litter decomposition in three wetlands of the Paraná River floodplain. Wetlands 26: 558-566.

Ponzoni, F.J., Y. Shimabukuro and T. Kuplich. 2012. Sensoriamento remoto da vegetação. Atualizada e ampliada. Oficina de Textos, São Paulo.

Pringle, C. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. Ecological Applications 11: 981-998.

Pringle, C. 2003. What is hydrologic connectivity and why is it ecologically important? Hydrological Process 17: 2685–2689.

Resop, J.P., L. Lehmann and W.C. Hession. 2019. Drone laser scanning for modeling riverscape topography and vegetation: comparison with traditional aerial Lidar. Drones 3: 35. https://doi.org/10.3390/drones3020035.

Richter, B.D., R. Mathews, D.L. Harrison and R. Wigington. 2003. Ecologically sustainable water management: managing river flows for ecological integrity. Ecological Applications 13: 206–224.

Rodrigues, L., J. Zanon, L. Carapurnala and S. Biolo. 2008. Perifiton In: A Planície Alagável do Rio Paraná: estrutura e Processo Ambiental. Available http:// www.peld.uem.br/Relat2008/pdf/Capitulo04.pdf. Access date: 30 June 2020.

Shastry, A., and M. Durand. 2019. Utilizing flood inundation observations to obtain floodplain topography in data-Scarce regions. Frontiers in Earth Science 6: 1-10. https://doi.org/10.3389/feart.2018.00243

Schwarzbold, A. 2000. O que é um rio? Ciência & Ambiente 2: 57–68.

Silveira, G. L., J.C. Cruz, R.C. Cruz, F.S. Vilella, C.A.O. Irion, A.T. Antolini and A.S. Rosário. 2009. Elaboração de Estudo de Prescrição das Vazões Ecológicas para a Alça de Vazão Reduzida da UHE Passo São João. Relatório para ELETROSUL. Santa Maria: UFSM, RS.

Silveira, G.L.; R.C. Cruz, J.C. Cruz, A.L.L Silveira and A.S. Rosário. 2006. Prescrição do regime de vazões ecológicas para a alça de vazão reduzida da UHE São João. Relatório Final. FEPAM/SEMA-RS. (Relatório de pesquisa).

Stevaux, J.C., F.A. Corradini and S. Aquino. 2013. Connectivity processes and riparian vegetation of the Upper Paraná River Brazil. Journal of South American Earth Sciences 46: 113-121. https://doi.org/10.1016/j.jsames.2011.12.007.

Straatsma, M. 2009. 3D float tracking: in situ floodplain roughness estimation. Hydrological Processes: An International Journal 23: 201–212.

Tabacchi, E, D. Correll, R. Hauer, G. Pinay, A. Planty-Tabacchi and R. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40: 497-516.

Taylor, P.D., L. Fahrig and K.A. With. 2006. Landscape connectivity: A return to the basics. In: K.R. Crooks and M. Sanjayan (eds.). Connectivity Conservation, Conservation Biology. Cambridge University Press, Cambridge. pp. 29-43.

Tockner K., F. Schiemer and J.V. Ward. 1998. Conservation by restoration: the management concept for a river-floodplain system on the Danube River in Austria. Aquatic Conservation: Marine and Freshwater Ecosystems 8: 71–86.

Van Iersel, W., M. Straatsma, H. Middelkoop and E. Addink. 2018. Multitemporal classification of river floodplain vegetation using time series of UAV images. Remote Sensing 10: 1144. https://doi.org/10.3390/rs10071144.

Ward J.V. 1997. An expansive perspective of riverine landscapes: pattern and process. GAIA: Ecological Perspectives for Science and Society 6: 52-60.

Ward, J.V. and J. A. Stanford. 1995a. The serial discontinuity concept: extending the model to floodplain rivers. Regulated Rivers: Research & Management 10: 159-168.

Ward, J.V. and J.A. Stanford. 1995b. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management 11: 105–119.

Ward, J.V., K. Tockner B. Arscott and C. Claret. 2002. Riverine landscape diversity. Freshwater Biology 47: 517-539.

Wiens, J.A. 2002. Riverine landscapes: taking landscape ecology into the water. Freshwater Biology 47: 501–515.

Wiens, J.A. 2009. Landscape ecology as a foundation for sustainable conservation. Landscape Ecology 24:1053–1065. https://doi.org/10.1007/s10980-008-9284-x.

Wolfshaaran, V.K.E., H. Middelkoop, E. Addink, H.V. Winter and L.A.J. Nagelkerke. 2011. Linking flow regime, floodplain lake connectivity and fish catch in a large river-floodplain system, the Volga-Akhtuba Floodplain (Russian Federation). Ecosystems 14: 920-934. https://doi.org/10.1007/s10021-011-9457-3.

Wohl, E. 2017. Connectivity in rivers. Progress in Physical Geography: Earth and Environment 41: 345-362. doi:10.1177/0309133317714972

Woodget, A.S., R. Austrums, I.P. Maddock and E. Habit. 2017. Drones and digital photogrammetry: from classifications to continuums for monitoring river habitat and hydromorphology. Wiley Interdisciplinary Reviews: Water 4: e1222. https://doi.org/10.1002/wat2.1222.

Worbes, M. 1985. Structural and other adaptations to long term flooding by trees in Central Amazonia. Amazoniana 9: 459-484.

Yuan, T., H. Lee and H.C. Jung. 2017. Congo floodplain hydraulics using PALSAR InSAR and Envisat altimetry data. In: V. Lakshmi (ed.). Remote Sensing of Hydrological Extremes. Springer, Switzerland, pp. 65–81.

Yuan, T., H. Lee, H. Yu, H.C. Jung, A. Madson, Y. Sheng and E. Beighley. 2019. Mapping forested floodplain topography using InSAR and radar altimetry. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 12: 5189-5198. https://doi.org/10.1109/JSTARS.2019.2956400 J.A. and E. Souza-Filho. 2010. Revoluções Kuhnianas na evolução da ecologia fluvial. A (pouca?) importância das anomalias. *Ciencia & Ambiente* 41: 21-40.

Arenas-Ibarra, J.A., A. Michiyo Takeda and D.S. Fujita. 2012. O regime hidrológico do rio Ivinhema (Estado do Mato Grosso do Sul) e sua influência na assembléia zoobentônica. *Acta Scientiarum. Biological Sciences* 34: 47-57.

Assis, R. and F. Wittmann. 2011. Forest structure and tree species composition of the understory of two Central Amazonian varzea forests of contrasting flood heights. *Flora - Morphology Distribution Functional Ecology of Plants* 206: 251-260. https://doi.org/10.1016/j.flora.2010.11.002

Balestrin, D., R.C. Cruz, G.L. Silveira and S.V. Martins. 2019. Hydric and edaphic influence on floristic composition in an altered riparian area. *Floresta e Ambiente* 26(3): e20171002 http://dx.doi.org/10.1590/2179-8087.100217.

Bornette, G., C. Amoros and N. Lamouroux. 1998. Aquatic plant diversity in riverine wetlands: the role of connectivity. *Freshwater Biology* 39: 267–283.

Brinson, M.M. 1993. A Hydrogeomorphic Classification for Wetlands. U.S. Army Corps of Engineers, Washington, D.C. Wetlands Research Program Technical Report WRP-DE-4.

Budke, J.C, J.A. Jarenkow, A.T. Oliveira-Filho. 2008. Tree community features of two stands of riverine forest under different flooding regimes in Southern Brazil. *Flora* 203: 162-174. https://doi.org/10.1016/j.flora.2007.03.001.

Burel, F. and J. Baudry. 2002. *Ecología del Paisaje: Conceptos, Métodos y Aplicaciones*. Ediciones Mundi-Prensa, Madrid.

Cao, N., H. Lee, H.C. Jung and H. Yu. 2018. Estimation of water level changes of large-scale Amazon wetlands using ALOS2 ScanSAR differential interferometry. *Remote Sensing* 10: 966. https://doi.org/10.3390/rs10060966.

Carvalho, C. M. 2020. *Série hidrológica não estacionária e os riscos e incertezas nas tomadas de decisões no planejamento dos recursos hídricos*. Tese (Doutorado em Engenharia Civil) - Universidade Federal de Santa Maria. Santa Maria.

Casco, S.L., J.J. Neiff, and A.S.G. Poi de Neiff. 2010. Ecological responses of two pioneer species to a hydrological connectivity gradient in riparian forests of the lower Paraná River. *Plant Ecology* 209: 167-177. https://doi.org/10.1007/s11258-010-9734-9.

Casco, S.L. and J.J. Neiff. 2013. Distribution pattern of trees in a hydrological gradient below the Paraná-Paraguay River confluence. *American Journal of Plant Sciences. Special Issue: The Future of the Forests* 4: 663-673. doi:10.4236/ajps.2013.43A085

Casco, S.L., M.E. Galassi, E.K. Mari., A.S.G. Poi and J.J. Neiff. 2015. Linking hydrologic regime, rainfall and leaf litter fall in a riverine forest within the Ramsar Site Humedales Chaco (Argentina). *Ecohydrology* 9: 773–781. https://doi.org/10.1002/eco.1673.

Conner, W.H., and J.W. Day Jr. 1988. The impact of rising water levels on tree growth in Louisiana. In: Hook. D.D. (ed.). *The Ecology and Management of Wetlands*. Croom Helm Ltd., London. pp. 219-224.

Conner, W.H., J.G. Gosselink and R.T. Parrondo. 1981. Comparisons of the vegetation of three Louisiana swamp sites with different flooding regimes. *American Journal of Botany* 68: 320-331.

Cremon, É.H., O.C. Montanher and J.A. Arenas-Ibarra. 2010. A influência das crevasses na dinâmica de inundação da planície do Alto rio Paraná. Anais VIII Simpósio Nacional de Geomorfologia, Recife.

Cruz, R.C. 2005. *Prescrição de Vazão Ecológica: Aspectos Conceituais e Técnicos para Bacias com Carência de Dados*. Tese (Doutorado em Ecologia). Universidade Federal do Rio Grande do Sul. Porto Alegre.

Cruz, R.C., J.C. Cruz, G.L. Silveira and F.S. Vilella. 2010. Vazões Ecológicas e Remanescentes em Rios Alterados por Barragens: Estudo de Caso. *Ciência & Ambiente* 41: 175–190.

Cruz, R.C., M.L. Porto, G.L. Silveira, J.C. Cruz, R.D. Pereira and R.L. Daru. 2015. FFTSINT: A tool for recurrence analysis of peaks in the spectral analysis of daily hydrologic series. *Revista Brasileira de. Biometria* 33: 426-444.

Dawidek, J. and D. Ferencz. 2016. Historical changes of hydrological connectivity of selected Polish floodplain lakes. *River Research and Applications* 32: 1862–1871. https://doi.org/10.1002/rra.3035.

Fernandes R, A.A. Agostinho, E.A. Ferreira, C.S. Pavanelli, H. I. Suzuki, D. P. Lima, L.C. Gomes. 2009. Effects of the hydrological regime on the ichthyofauna of riverine environments of the Upper Paraná River flood plain. *Brazilian Journal of Biology* 69:669–680. http://dx.doi.org/10.1590/S1519-69842009000300021.

Forbes, S. 1887. The lake as a microcosm. Bull. Sci. Assoc. Peoria, Illinois, pp. 77-87, (Reprinted, Ill. Nat. Hist. Surv. Bull., Vol. 15, pp. 537-550, Nov. 1925.)

Furness, H.D. and H.C. Breen. 1980. The vegetation of seasonality flooded areas of the Pongolo River floodplain. *Bothalia* 13: 217-230.

Guerrero, M. and A. Lamberti. 2013. Bed-roughness investigation for a 2-D model calibration: The San Martín case study at Lower Paraná. *International Journal of Sediment Research* 28*:* 458–469. https://doi.org/10.1016/S1001-6279(14)60005-6.

Hughes, F.M.R. 1988. The ecology of African floodplain forests in semiarid zones, a review. *Journal of Biogeography* 15: 127-140.

Hughes, F.M.R. 1990. The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya. *Journal of Applied Ecology* 27: 475-491.

Junk, W.J, P.B. Bayley and R.E. Sparks. 1989. The flood pulse concept in river– floodplain systems. *Canadian Special Publications for Fisheries and Aquatic Sciences* 106: 110–127.

Junk, W.J. and K.M. Wantzen. 2004. *The Flood Pulse Concept: new aspects, approaches, and applications-an update*. In: R Welcomme and T. Petr (eds.). Proceedings of the 2nd Large River Symposium (LARS), Pnom Penh, Cambodia [Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16]. pp. 117–149.

Lague, D. and B. Feldmann. 2020. Topo-bathymetric airborne LiDAR for fluvial-geomorphology analysis. In: P. Tarolli and S.M. Mudd (eds.). *Remote Sensing of Geomorphology*, 23, Elsevier, Berkeley. pp. 25-54.

Marchetti, Z.Y. and P. Aceñolaza, P. 2012. Pulse regime and vegetation communities in fluvial systems: The case of the Parana River floodplain, Argentina. *Flora* 207: 795-804.

Miranda, L.E. 2005. Fish assemblages in oxbow lakes relative to connectivity with the Mississippi river. *Transactions of the American Fisheries Society* 134:1480–1489.

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands*, 2nd edition. Van Nostrand Reinhold, New York.

Mudd, S.M. 2020. Topographic data from satellites. In: P. Tarolli and S.M. Mudd (eds.). *Remote Sensing of Geomorphology* 23, Elsevier, Berkeley. pp. 91–128.

Neiff, J.J. 1990. Aspects of primary productivity in the lower Paraná and Paraguay riverine system. *Acta Limnologica Brasiliensia* 3: 77-113.

Neiff, J.J. 1996. Large rivers of South America: toward the new approach. *Verhandlungen des Internationalen Verein Limnologie* 26:167–181.

Neiff, J.J. 1999. El régimen de pulsos en ríos y grandes humedales de Sudamérica. In: A.I. Malvárez (ed.). *Tópicos sobre humedales subtropicales y templados.* Oficina Regional de Ciencia y Técnica para America Latina y el Caribe (ORCyT) MAB/UNESCO, Montevideo. pp. 97-146.

Neiff, J.J. 2001. Diversity in some tropical wetland systems of South America. In D. Gopal, W. Junk and J. Davis (eds.), *Biodiversity in wetlands: assessment, function and conservation*, Backhuys Publish., The Netherlands. pp. 157-186.

Neiff, J.J. and M. Neiff. 2004. Pulso, software for the analysis of recurrent phenomena. Dir. Nac. de Derecho de Autor Nº 236164 (Argentina) Buenos Aires, 17 February. http://www.neiff.com.ar.

Neiff, J.J. and A.S.G. Poi de Neiff. 2003. Connectivity processes as a basis for management of aquatic plants. In: Thomaz, S.M. and L.M. Bini (eds.). *Ecologia e Manejo de Macrófitas Aquáticas*. EDUEM Maringá. pp 39-59.

Neiff, J.J., M.H. Iriondo and R. Carignan.1994. Large tropical South American wetlands: an overview. In: G.L. Link and R.J. Naiman (comps.). *Proceedings of the international workshop on the ecology and management of aquatic-terrestrial ecotones*. Seattle: Unesco, MAB, IHP, Center for Stream-side Studies-University of Washington. pp. 156-165.

Neiff, J.J., C.A.E. Patiño and S.L. Casco. 2006. Atenuación de las crecidas por los humedales del Bajo Paraguay. In: J. Capatto (ed.). *Humedales fluviales de América del Sur. Hacia un manejo sustentable.* Fundación Proteger, Santa Fe. pp. 261-276.

Neiff, J.J, A.S.G. Poi de Neiff and M.B. Canón Verón. 2009. The role of vegetated areas on fish assemblage of the Paraná River floodplain: effects of different hydrological conditions. *Neotropical Ichthyology* 7: 37-48.

Neiff, J.J., S.L. Casco, A.S.G. Poi and V.A. Zambiasio. 2020. Influence of Yacyretá dam on trees distribution in the Paraná floodplain. *Ecological Engineering* 154: 1-10. 105931 https://doi.org/10.1016/j.ecoleng.2020.105931.

Okada, E.K., A.A. Agostinho, M. Petrere and T. Penzack. 2003. Factor affecting fish diversity and abundance in drying ponds and lagoons in the upper Paraná basin, Brasil. *Ecohydrology and Hydrobiology* 3: 97-110.

Plank, S., M. Jüssi, S. Martinis and A. Twele. 2017. Mapping of flooded vegetation by means of polarimetric Sentinel-1 and ALOS-2/PALSAR-2 imagery. *International Journal of Remote Sensing* 38: 3831–3850.

Poi de Neiff, A., J.J. Neiff and S.L. Casco. 2006. Leaf litter decomposition in three wetlands of the Paraná River floodplain. *Wetlands* 26: 558-566.

Ponzoni, F.J., Y. Shimabukuro and T. Kuplich. 2012. Sensoriamento remoto da vegetação. Atualizada e ampliada. Oficina de Textos, São Paulo.

Pringle, C. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. *Ecological Applications* 11: 981-998.

Pringle, C. 2003. What is hydrologic connectivity and why is it ecologically important? *Hydrological Process* 17: 2685–2689.

Resop, J.P., L. Lehmann and W.C. Hession. 2019. Drone laser scanning for modeling riverscape topography and vegetation: comparison with traditional aerial Lidar. *Drones* 3: 35. https://doi.org/10.3390/drones3020035.

Richter, B.D., R. Mathews, D.L. Harrison and R. Wigington. 2003. Ecologically sustainable water management: managing river flows for ecological integrity. *Ecological Applications* 13: 206–224.

Rodrigues, L., J. Zanon, L. Carapurnala and S. Biolo. 2008. *Perifiton* In: A Planície Alagável do Rio Paraná: estrutura e Processo Ambiental. Available http:// www.peld.uem.br/Relat2008/pdf/Capitulo04.pdf. Access date: 30 June 2020.

Shastry, A., and M. Durand. 2019. Utilizing flood inundation observations to obtain floodplain topography in data-Scarce regions. *Frontiers in Earth Science* 6: 1-10. https://doi.org/10.3389/feart.2018.00243

Schwarzbold, A. 2000. O que é um rio? *Ciência & Ambiente* 2: 57–68.

Silveira, G. L., J.C. Cruz, R.C. Cruz, F.S. Vilella, C.A.O. Irion, A.T. Antolini and A.S. Rosário. 2009. *Elaboração de Estudo de Prescrição das Vazões Ecológicas para a Alça de Vazão Reduzida da UHE Passo São João. Relatório para ELETROSUL*. Santa Maria: UFSM, RS.

Silveira, G.L.; R.C. Cruz, J.C. Cruz, A.L.L Silveira and A.S. Rosário. 2006. *Prescrição do regime de vazões ecológicas para a alça de vazão reduzida da UHE São João. Relatório Final*. FEPAM/SEMA-RS. (Relatório de pesquisa).

Stevaux, J.C., F.A. Corradini and S. Aquino. 2013. Connectivity processes and riparian vegetation of the Upper Paraná River Brazil. *Journal of South American Earth Sciences* 46: 113-121. https://doi.org/10.1016/j.jsames.2011.12.007.

Straatsma, M. 2009. 3D float tracking: in situ floodplain roughness estimation. *Hydrological Processes: An International Journal* 23: 201–212.

Tabacchi, E, D. Correll, R. Hauer, G. Pinay, A. Planty-Tabacchi and R. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. *Freshwater Biology* 40: 497-516.

Taylor, P.D., L. Fahrig and K.A. With. 2006. Landscape connectivity: A return to the basics. In: K.R. Crooks and M. Sanjayan (eds.). *Connectivity Conservation, Conservation Biology*. Cambridge University Press, Cambridge. pp. 29-43.

Tockner K., F. Schiemer and J.V. Ward. 1998. Conservation by restoration: the management concept for a river-floodplain system on the Danube River in Austria. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 71–86.

Van Iersel, W., M. Straatsma, H. Middelkoop and E. Addink. 2018. Multitemporal classification of river floodplain vegetation using time series of UAV images. *Remote Sensing* 10: 1144. https://doi.org/10.3390/rs10071144.

Ward J.V. 1997. An expansive perspective of riverine landscapes: pattern and process. *GAIA: Ecological Perspectives for Science and Society* 6: 52-60.

Ward, J.V. and J. A. Stanford. 1995a. The serial discontinuity concept: extending the model to floodplain rivers. *Regulated Rivers: Research & Management* 10: 159-168.

Ward, J.V. and J.A. Stanford. 1995b. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers: Research & Management* 11: 105–119.

Ward, J.V., K. Tockner B. Arscott and C. Claret. 2002. Riverine landscape diversity. *Freshwater Biology* 47: 517-539.

Wiens, J.A. 2002. Riverine landscapes: taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Wiens, J.A. 2009. Landscape ecology as a foundation for sustainable conservation. *Landscape Ecology* 24:1053–1065. https://doi.org/10.1007/s10980-008-9284-x.

Wolfshaaran, V.K.E., H. Middelkoop, E. Addink, H.V. Winter and L.A.J. Nagelkerke. 2011. Linking flow regime, floodplain lake connectivity and fish catch in a large river-floodplain system, the Volga-Akhtuba Floodplain (Russian Federation). *Ecosystems* 14: 920-934. https://doi.org/10.1007/s10021-011-9457-3.

Wohl, E. 2017. Connectivity in rivers. Progress in Physical Geography: Earth and Environment 41: 345-362. doi:10.1177/0309133317714972

Woodget, A.S., R. Austrums, I.P. Maddock and E. Habit. 2017. Drones and digital photogrammetry: from classifications to continuums for monitoring river habitat and hydromorphology. *Wiley Interdisciplinary Reviews: Water* 4: e1222. https://doi.org/10.1002/wat2.1222.

Worbes, M. 1985. Structural and other adaptations to long term flooding by trees in Central Amazonia. *Amazoniana* 9: 459-484.

Yuan, T., H. Lee and H.C. Jung. 2017. Congo floodplain hydraulics using PALSAR InSAR and Envisat altimetry data. In: V. Lakshmi (ed.). *Remote Sensing of Hydrological Extremes*. Springer, Switzerland, pp. 65–81.

Yuan, T., H. Lee, H. Yu, H.C. Jung, A. Madson, Y. Sheng and E. Beighley. 2019. Mapping forested floodplain topography using InSAR and radar altimetry. IEEE *Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 12: 5189-5198. https://doi.org/10.1109/JSTARS.2019.2956400