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Using CASiMiR-vegetation model to establish riparian vegetation disturbance requirements

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Abstract

The disturbance requirements of riparian vegetation were determined in two Mediterranean rivers based on riparian vegetation modeling. The assessment of the riparian vegetation disturbance requirements were consistent in selecting the best disturbance regime. Such outcome may suggest the probable applicability of this approach to rivers in general and the possibility to preserve artificially the sustainability of the riparian communities in regulated rivers.

Keywords: riparian vegetation, flow regime, river disturbance, vegetation modeling, river restoration

Introduction, scope and main objectives

The river natural flow regime is the foundation of the ecological integrity of aquatic and riparian ecosystems (Poff *et al.* 1997). Accordingly, changes in the natural flow regime are known to influence the geomorphology (Lloyd *et al.* 2004), ecology (Poff and Zimmerman 2010) and biology (Stromberg *et al.* 2010) of these ecosystems. The riparian ecosystems is mostly governed by the flow regime components (Karrenberg *et al.* 2002; Rood *et al.* 2003; Merritt *et al.* 2010) and, despite being particularly vulnerable to flow regimes changes (Perry *et al.* 2012), the assessment of the riparian flow requirements has been seldom investigated. This is particularly important considering that riparian vegetation has a evident significance in the improvement of the aquatic systems habitat (Naiman and Décamps 1997; Naiman *et al.* 2005) and biological conservation (Broadmeadow and Nisbet 2004; Van Looy *et al.* 2013). Among the several disturbances to which riparian vegetation is naturally subjected, flood cycles are particularly significant in influencing riparian vegetation patterns (Loučková 2012). Indeed, the frequency, duration and magnitude of floods are conditioning factors for a well-balanced riparian vegetation dynamics (Tabacchi *et al.* 1998; Gergel *et al.* 2002; Rood *et al.* 2003), which developed adaptations and synchronized life-histories according to the variable conditions of the river dynamics (Stella *et al.* 2006). Thus, considering that the disturbance regime is the mediator of riparian vegetation dynamics (Shafroth *et al.* 2002; Lovell *et al.* 2009), this study intended to determine the disturbance requirements of riparian vegetation in Mediterranean rivers using a novel approach based on riparian vegetation modeling. By these means we intended to forecast the structural response of this ecological indicator facing different disturbance regimes and evaluate its responses benchmarked by the natural riparian patch disposal.

Methodology/approach

Study sites

The assessment of the riparian vegetation disturbance requirements was performed in two study sites located in different Portuguese free flowing rivers, namely, Alvito and Ocreza. The Alvito River is a small-sized stream draining a 186 km^2 river basin throughout approximately 34 km and ending at the Ocreza River. The Ocreza River is a medium-sized stream that runs for 94 km and drains a 1429 km^2 watershed. The flow regime in both rivers is typically Mediterranean with a low flow period interrupted by flash floods in winter and a very low flow, even null, during summer (Gasith and Resh 1999).

In each river, one study site was selected to be representative of the respective overall river course in the riparian vegetation modeling. The Alvito's study site (hereafter named AVTO) is located near the river mouth, approximately 4 km upstream of where Alvito meets the Ocreza (39^o 45' 42.03'' N; 7^o 45' 03.62'' W). The Ocreza's study site (hereafter named OCRZ) is located immediately upstream of the Alvito confluence with the Ocreza (39^o 44' 09.78'' N; 7^o 44' 24.75'' W). Both study sites encompass a surveyed area corresponding to the 100-year flooded area, in river lengths of 300 and 500 m, respectively for the AVTO and OCRZ. In both case studies, riparian vegetation is typically Mediterranean, inhabited mostly by willows (*Salix salviifolia* Brot. and *Salix atrocinerea* Brot.) and ashes (*Fraxinus angustifolia* Vahl).

Field data

A field survey was performed during 2013 in both case studies to collect data about the habitat traits of the existing riparian communities. Field survey included a topographic assessment, vegetation patch georeferencing and habitat features recording. The topographic assessment was performed using a combination of a Nikon DTM330 total station and a Global Positioning System (GPS) (Ashtech, model Pro Mark2) with an effort to record all elevation changes greater than 20 cm. The vegetation and habitat assessment considered homogeneous vegetation patches, each corresponding to one succession phase. During these surveys five succession phases were identified: Initial phase (IP), Pioneer phase (PP), Early Successional Woodland phase (ES), Established Forest phase (EF), and Mature Forest phase (MF). Whenever patches were dominated by open sand or gravel bars, sometimes covered by herbaceous vegetation but without woody arboreal species, the classification of IP was attributed. PP was considered for all the patches dominated by woody arboreal species recruitment. Patches with a high standing biomass and well established individuals, dominated by pioneer watertable-dependent species like willows and alders were classified as ES. Older patches presenting moderate to high canopy cover and dominated by macrophanerophytes like ashes were considered as EF. The Mature Forest phase was considered at patches where terrestrial vegetation was also present, determining the transition phase to the upland vegetation communities. Field data was used to calibrate the riparian vegetation model. Moreover, the observed vegetation maps were used as reference for model accuracy evaluation purposes and as benchmark during the disturbance regime analysis.

Hydrological data

Hydrological data of the study sites, namely, maximum annual discharges for different recurrence intervals, were gathered from previous hydrological studies in the context of a dam construction project in the location of the OCRZ study site (Table 1).

Based in this information, several disturbance regimes were created to rule the riparian vegetation model runs. The disturbance regimes accounted for two different recurrence interval floods, recreating large and intermediate floods, and embraced all the possible combinations between the 2, 5 and 10-year recurrence interval floods.

Table 1: Considered discharges (m^3/s) for different recurrence intervals in the study sites.

Study site	Recurrence interval (years)		
	2	**5**	**10**
OCRZ	167	284	372
AVTO	49	83	109

Riparian vegetation modeling

The dynamic floodplain vegetation model CASiMiR – vegetation (Benjankar *et al.* 2011) was used to determine the disturbance requirements of riparian vegetation communities in different case studies. This tool is a physically based, numerical distributed model that simulates the existing relationships between relevant hydrological characteristics (Poff *et al.* 1997) and the riparian responses to permanent hydrologic regime changes at a guild level (Merritt *et al.* 2010). There are several advantages in using this model: it incorporates the historical patch dynamics into every simulation, together with observed data information and expert knowledge; it works at a response guild level thus allowing regional calibration and application in both individual streams and catchments (Merritt *et al.* 2010); easily adapts to the environmental specificities of each case study; and its outputs are spatially-explicit vegetation maps of the riparian vegetation patches. The response guilds are portrayed by riparian succession phases associated with different hydromorphological attributes that result from a dynamic interplay between flow variation and its extreme events, and the annual area development sequence of the woody patches.

The CASiMiR-vegetation model was calibrated based on the surveyed data using the methodology described by (García-Arias *et al.* 2013; Rivaes *et al.* 2013). After calibration, model accuracy was evaluated by comparison of the observed vegetation map with its coetaneous expected riparian vegetation map. Model accuracy was evaluated using Cohen's Kappa (Cohen 1960), which is considered to be a valuable tool to assess the accuracy of this model (Benjankar *et al.* 2010). Then, the disturbance regimes were simulated for a period of 11 years and the resulting expected vegetation maps were compared with the expected natural vegetation map of the study sites. Differences were assessed in term of categorical agreement and mean succession phase area balance with, respectively, Cohen's kappa (Cohen 1960), fuzzy kappa (Visser and de Nijs 2006) and Root Mean Squared Error (RMSE). Kappa and fuzzy kapa are most appropriate to directly account a pixel by pixel comparison between natural and simulated vegetation maps, attaining higher scores for more overlapping predictions and observations. On the other hand, RMSE measures the existing error between predicted and observed succession phases areas during the entire modeling period, presenting lower values for more accurate classifications. Lastly, the disturbance regime generating the riparian vegetation map with the best results regarding these statistics was considered to be the most efficient flooding regime to preserve the riparian patch mosaic as close as possible to the reference condition.

Results

After calibration, the riparian vegetation model achieved a quadratic weighted kappa of 0.61 in OCRZ and 0.66 in AVTO. This accuracy measures are considered to be a good agreement classification between modeled and observed vegetation maps (Altman 1991; Viera and Garrett 2005).

The expected vegetation maps of the OCRZ study site are presented in Figure 1. From an initial visual analysis, when expected vegetation maps are compared with the expected natural vegetation map, is evident that floods with recurrence intervals smaller than 10 years are incapable of preventing vegetation encroachment.

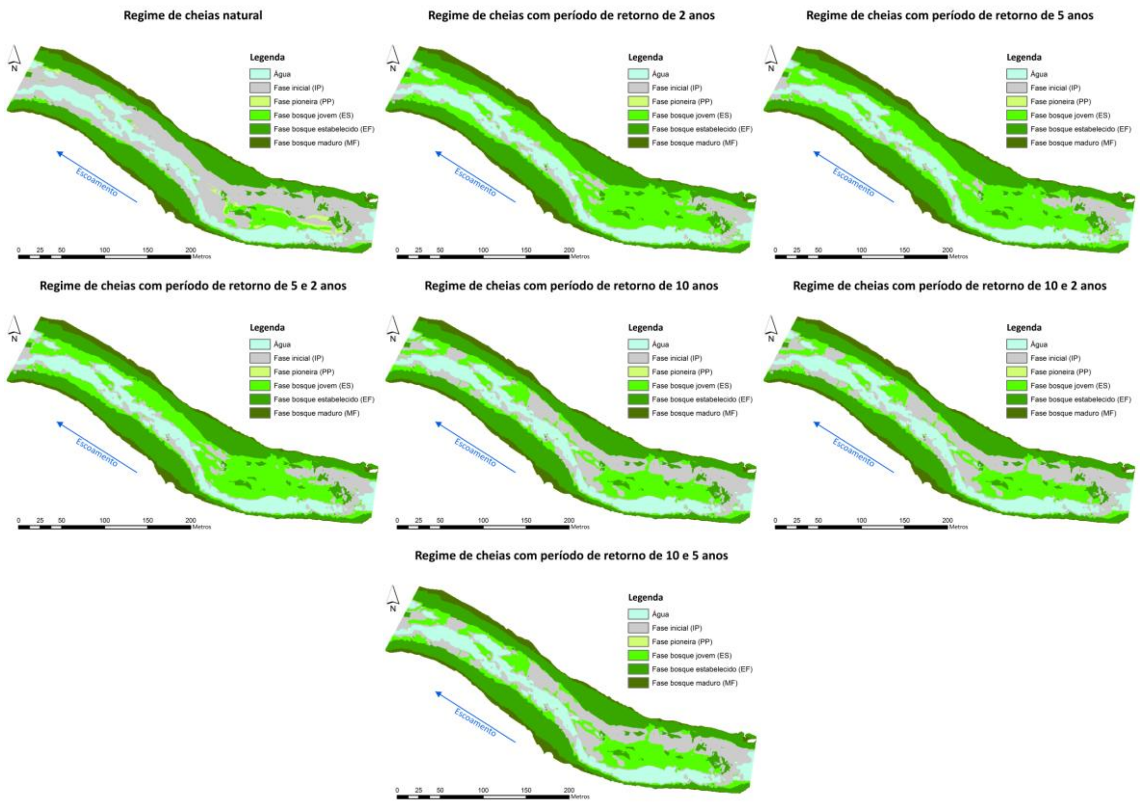

Figure 1: OCRZ expected vegetation maps according to the considered disturbance regimes.

A detailed analysis of the considered statistics show unanimously that the best disturbance regime is composed by 10-year floods interspersed by 2-year floods (Figure 2).

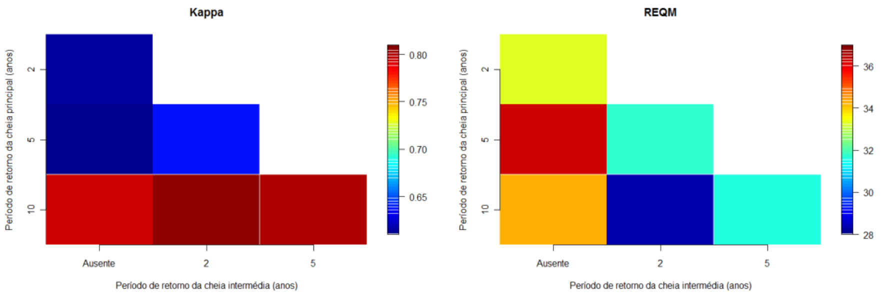

Figure 2: Agreement evaluation of the expected vegetation maps with the expected natural vegetation map in OCRZ study site.

The expected vegetation maps of the AVTO study site are presented in Figure 3. The direct visualization of the disturbance regime effects on the riparian patch mosaic is somewhat harder to observe in this case due to the greater slope of the valley and consequent narrowing of the succession phases according to the lateral gradient of the river. Notwithstanding, in the river channel, the same tendency is observed as in the previous case study.

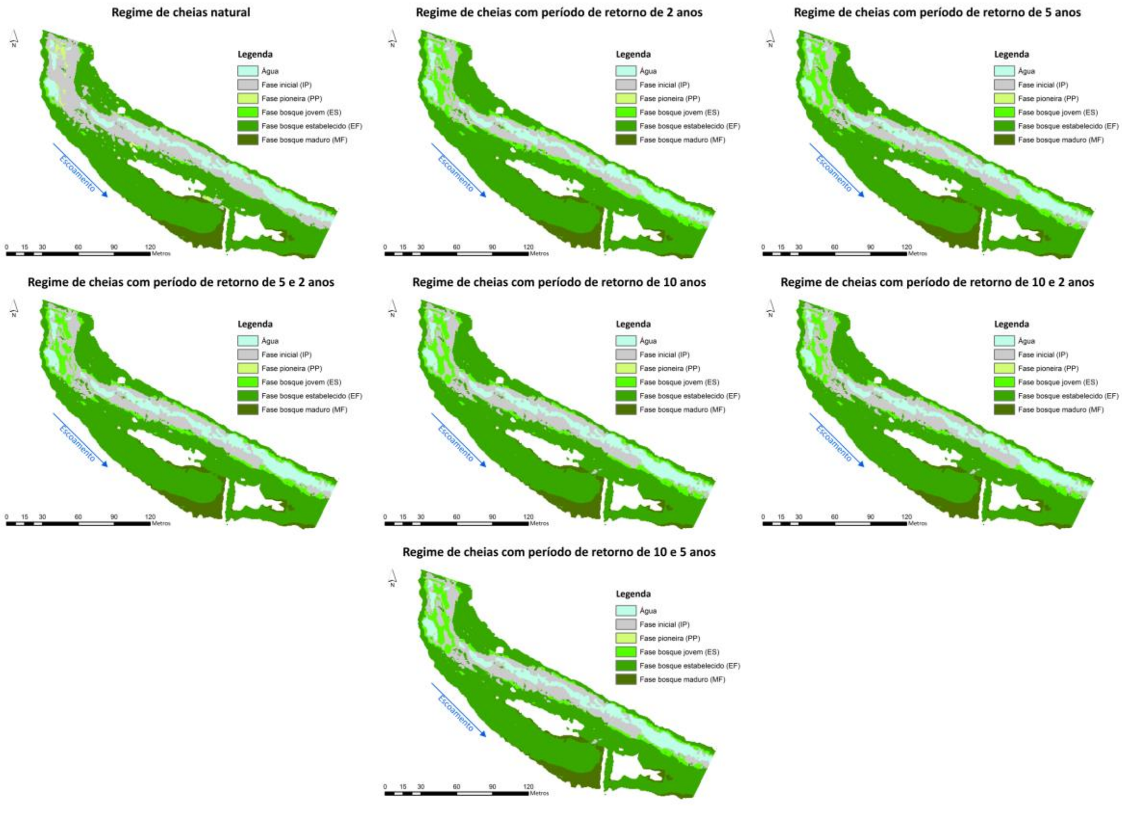

Figure 3: AVTO expected vegetation maps according to the considered disturbance regimes.

From the kappa and RMSE statistics analysis one can detect that, once again, the disturbance regime of 10-year floods interspersed by 2-year floods was the best classified according to kappa and the second best according to the RMSE (Figure 4).

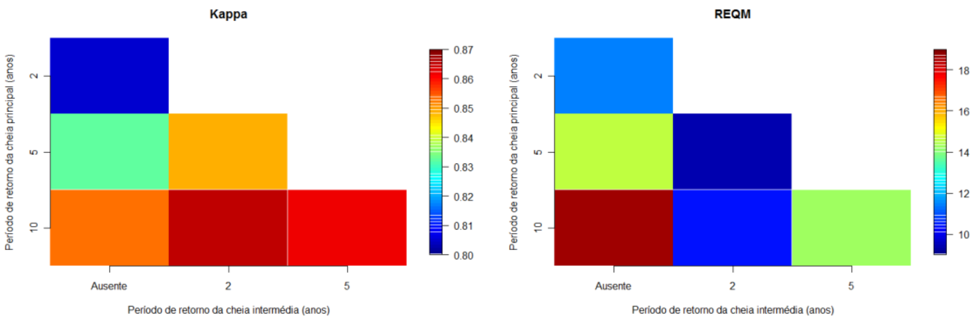

Figure 4: Agreement evaluation of the expected vegetation maps with the expected natural vegetation map in AVTO study site.

Discussion

In this study, the disturbance requirements of riparian vegetation were assessed by means of riparian vegetation modeling techniques. Results show the model robustness and its capacity to correctly reproduce the riparian vegetation dynamics facing the main aspects of river disturbance. In both case studies, results were consistent in selecting the best disturbance regime composed by 10-year recurrence intervals floods interspersed by 2-year recurrence interval floods. Riparian requirements seem to be identical within the same watershed despite the different characteristics of the rivers and such outcome may suggest the probable applicability of this approach to rivers in general. Similar results were also achieved in previous studies (Rivaes *et al.* 2015) showing an hydrological trend which must be more thoroughly investigated in subsequent studies. Moreover, the natural metastable oscillation state (Formann *et al.* 2013) to which riparian vegetation is forced can likely be preserved artificially in regulated rivers in order to maintain the viability and sustainability of the riparian communities.

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