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Evaluating climate change impacts on Alpine floodplain vegetation

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ABSTRACT. Over the last decades several studies highlighted the climatic changes induced by human activities. Climate change affects river hydrology by changing temperature, spatial and temporal distribution of precipitation. As floodplain vegetation is strongly related, dependent and adapted to flood occurrence and river stage variations, it is subject to these climate change effects. The presented study aims to evaluate the long term impacts of climate change on the Alpine riparian vegetation with a special focus on the hydrology-driven factors which influence the establishment, development and recycling of riparian vegetation. This work is part of an international initiative, which aims to quantify the climate change impacts on riparian vegetation in the Alpine and Mediterranean climates. The presented study has been carried out at the upper course of the Drau River (Austria). The site has been restored in 2002 and since then, it is subject to constant post project appraisal monitoring. To evaluate the long term effects of the climate change on the local riparian vegetation, a dynamic vegetation model was applied, allowing the simulation of the spatial and quantitative distribution of the vegetation over time. The model accounts for the effects of the river stage on vegetation recruitment and succession. Disturbance is considered based on experiences in field observations and hydrodynamic modeling. The successful establishment (recruitment) or recycling of the vegetation is evaluated in yearly time steps. Model outputs in the form of raster grids allow the quantification and visualization of the simulated results over time. The climate change impacts have been evaluated by performing three scenarios: reference period, optimistic and pessimistic. First replicates the reference period 1960-1990, second scenario (optimistic) was based on the climate change model scenario GCM ECHAM5 B1, time reference 2070-2100, while the third (pessimistic) was based on the climate change model scenario

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GCM ECHAM5 A2, time reference 2070-2100. The final landscape simulated in the three scenarios did not highlight large differences among the scenarios. In all three cases the restored side channel section of the ecosystem seems not able of self sustain its ecological functionality over a long time period and shows a low biodiversity. However, the scenarios development paths which lead to the final results show some degree of difference which affords topics for discussion. A further discussion point is given by the fact that the model results were obtained using a static topography, thereby neglecting morphological changes (bank erosion, bar accretion) which play a key role in shaping the riparian vegetation. Suggestions for implementation of morphodynamics in vegetation modeling are discussed.

Keywords: *riparian ecosystem modeling, climate change, alpine floodplain vegetation.*

1. Introduction

Riparian Vegetation and Climate Change

The fourth report of the Intergovernmental Panel on Climate Change clearly affirms that earth's climate is changing (IPCC, 2007). Climate variations include temperature, type, quantity and timing of precipitation, which in turn affect river hydrology (Kundzewicz, 2008). River hydrology is a determinant leading force for the evolution of the riparian vegetation community (Bendix & Hupp, 2000; Edwards *et al.*, 1999; Ward *et al.*, 2002; Whited *et al.*, 2007). In fact, riparian vegetation lifecycle is adapted to the magnitude, timing and frequency of floods (Karrenberg *et al.*, 2002) and their physiology has evolved to withstand the floods disturbances.

Given the relationships climate-hydrology and hydrology-riparian vegetation is legitimate to argue that climate change is affecting also the wealth of riparian vegetation. However, although the syllogism appears to be correct, the quantification of these climate change induced impacts can not proceed in a speculative fashion and requires means of assessment. The quantification of these affections is the main objective of this paper which aims to measure the impacts of climate change on the Alpine riparian vegetation. The findings of this research are part of a broader, trans-national initiative which involved Austria, Portugal and Spain. The project is addressed as Ripflow ("RIPFLOW Project") and its objectives where the modeling of riparian vegetation for the assessment of environmental flow regimes and climate change impacts within the EU Water Framework Directive.

2. Materials and methods

2.1. Study site

The presented study has been carried out at the upper course of the Drau River (Austria), nearby the village of Kleblach-Lind (Figure 1). The site has been restored

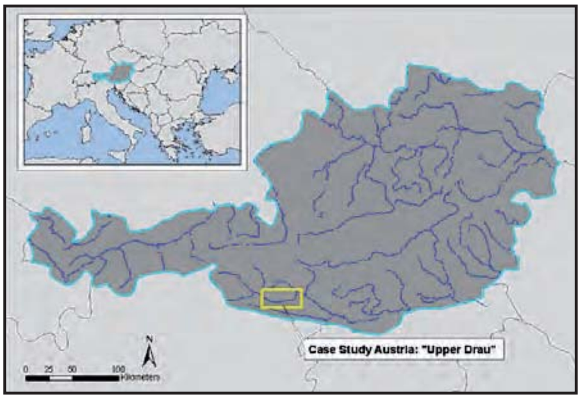

Figure 1. Case study location.

in 2002 and since then, it is subject to constant post project appraisal monitoring. One of the restoration objectives was to re-establish habitats suitable for the maintenance of typical and endangered Alpine riparian species like *Myricaria germanica* which are indicators of ecological functionality.

2.2. Dynamic vegetation model

The applied model is expert rule based and accounts for the major riparian ecosystem processes, namely recruitment, morphodynamic disturbance and succession. It makes use of hydraulic and morphological inputs in form of raster grids. The time step is one year and the outputs are one raster grid per simulated year and an area balance table (Benjankar, 2009; Benjankar *et al.*, 2010). In order to allow an efficient, portable and comparable classification of the vegetation, the vegetation along the site is classified in succession series and succession phases accordingly to their development stage.

2.3. Hydrodynamic model

Hydrodynamics were simulated using the two dimensional numerical flow model RSim-2D, a part of the RSim river modeling framework (Tritthart, 2005). The applied integrated hydrodynamic-numerical model is based on the Finite Element method, a triangular mesh and the Smagorinsky turbulence closure and delivers depth-averaged flow velocities. Several discharge classes between mean discharge and the discharge of a 300-year-flood were modeled. The resulting flow variables as flow velocity, water surface elevation, water depth and bed shear stress during peak flow, as well as the maximum shear stress during the entire hydrograph of corresponding flood discharge class were calculated in every computation point. The groundwater level was approximated from the calculated water surface elevation. These data were prepared as raster maps to be included into the Dynamic Vegetation Model.

2.4. Climate change scenarios

Temperature and precipitation outcomes of several regional climate change models (*i.e.* REMO-UBA (Jacob *et al.*, 2008)) for "Special Report on Emission Scenarios" SRES (Nakicenovic *et al.*, 2000) scenario A2, pessimistic, and B1, optimistic, were used for modeling the impact of climate change on riparian vegetation. Temperature is expected to increase for both scenarios. In contrast, the changes in precipitation vary highly and no clear trends are visible for the next century (Nachtnebel & Stanzel, 2010). For scenario B1 a higher annual precipitation is expected in 2100 than today. On the contrary the annual precipitation is predicted to be lower for scenario A2 (Nachtnebel & Stanzel, 2010). The winter precipitation will increase and the summer precipitation will decline for both scenarios.

Beside changes in temperature and precipitation, alterations of hydrology will occur. Modeled hydrological variables are annual runoff, floods, low flow periods and hydrological regime.

2.5. Boundary conditions of simulated scenarios

Three scenarios were simulated, namely scenario 1: reference period, scenario 2: optimistic and scenario 3: pessimistic scenario. The reference period replicated the time span 1960-1990 and was based on hydraulic data measured at the study site. The hydrographs for the climate change scenarios (scenario 2 and scenario 3) have been yield by applying the monthly discharge variations, estimated by the climate change scenarios A2 and B1, to the reference period hydrograph. The analysis of the results focused solely on the bank zone, neglecting the rest of the site. The initial simulation point for all the scenarios was the vegetation mapped back in 2002, right after the restoration works conclusion, when all the bank zone was occupied by initial phase (gravel). The topography measured in 2008 was used for all scenarios and kept constant throughout the whole modeling period.

3. Results and discussion

Simulated scenarios are discussed by means of relative area balance charts (Figure 2) which portray the relative area balance of the vegetation succession phases in the bank zone over time.

3.1. Scenario 1: reference period

The first part of the simulated scenario 1 (Figure 2, top) maintains large areas open (initial phase) until the 10th year, when a massive colonization starts to steadily occupy the bank zone. Beyond this year, the vegetation dynamics are led by successional processes and the turnover of the succession phases is very limited. Observing the whole period, the tendency of the simulated system is to constantly reduce the youngest succession phases (initial, pioneer and pioneer shrub phases) in favor of the most mature ones.

3.2. Scenario 2: optimistic

The global tendency of this simulated scenario shows (Figure 2, middle) a fair dynamic system in the first eight years of simulation. In this period, there is an active turnover of succession phases driven by disturbance. This situation applies, but with a consistent reduction, also in the second part of the simulation, more or less until the 16th -17th year. On the other hand, the final simulated period, from the 15th-16th year, portrays an ecosystem where the vegetation dynamics are time driven.

3.3. Scenario 3: pessimistic

Throughout the early years of simulation (Figure 2 bottom) a large decrease of initial phase in favor of the pioneer phase occurs. In the 3rd year the herb phase is established and covers approximately 25-30% of the total area. At the same time, 10% of the area is covered with pioneer shrub which then turns into shrub phase.
In the following years these phases progressively turn into early succesional woodland. The overall indication given by this scenario is a marked lack of diversity in the final result. Only two succession phases with stable area balance are present and therefore depicting a very static situation.

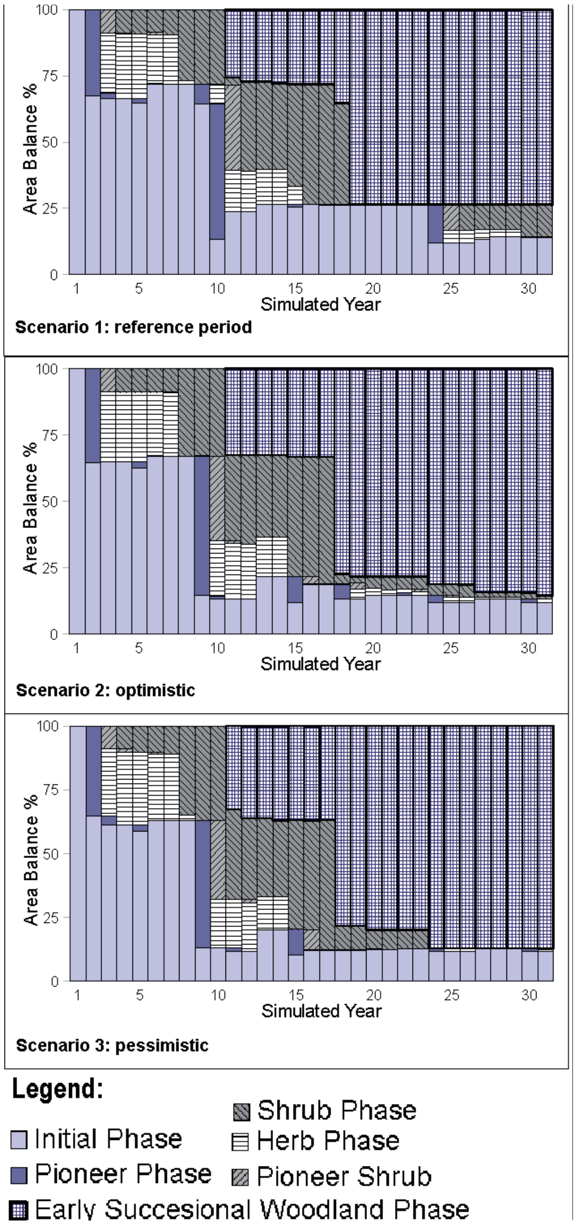

Figure 2. Relative area balance scenario 1 (top), scenario 2 (middle) and scenario 3 (bottom).

3.4. Comparison of scenarios

All the climate change scenarios show a similar pattern: the initial phase is progressively replaced by more mature phases until the simulated riparian ecosystem reaches a stable situation in which the succession phases' turnover is nearly or totally absent and the quantitative distribution of the succession phases is constant. Then, in last instance, all scenarios return a quite static picture of the simulated ecosystem. However there are some differences among the reference period and the climate change scenarios. In the reference period, the percentage of initial phase and the young succession phases (pioneer shrub and shrub) is larger, likely due to the larger magnitude of the peak events.

3.5. Discussion

The small differences observed in the area balances of the three scenarios suggest that the impact of climate change on floodplain vegetation is not very large. In all three cases, the restoration objective of maintaining a riparian environment suitable for long term survival of *Myricaria germanica* would not be reached since it requires open areas for its recruitment. This condition is met only in the first simulated part of every scenario. Climatic variations seem not to represent the major impacting factor on this riparian vegetation community of the restored side channel which, in spite of climate change, on the long run would not be able of self-maintaining its ecological functionality. In fact in all three cases, there is a loss of the youngest succession phases, a reduction of the sites suitable for typical riparian habitat and ultimately a reduction of biodiversity and compromised ecological functionality. However, it has to be highlighted that in the current model version, morphodynamic changes are not considered. Such changes are pivotal elements for the vegetation evolution dynamics for their role in creating new seedling safe sites (Polzin & Rood, 2006) and destruction of established vegetation stands through bank erosion (Dykaar & Wigington, 2000). Morphodynamic has as well a tight link to hydrology and in second instance climate. Therefore the morphodynamic turnover rates in response to climate change should be investigated to obtain a more complete picture of the climate change induced impacts on Alpine riparian vegetation.

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