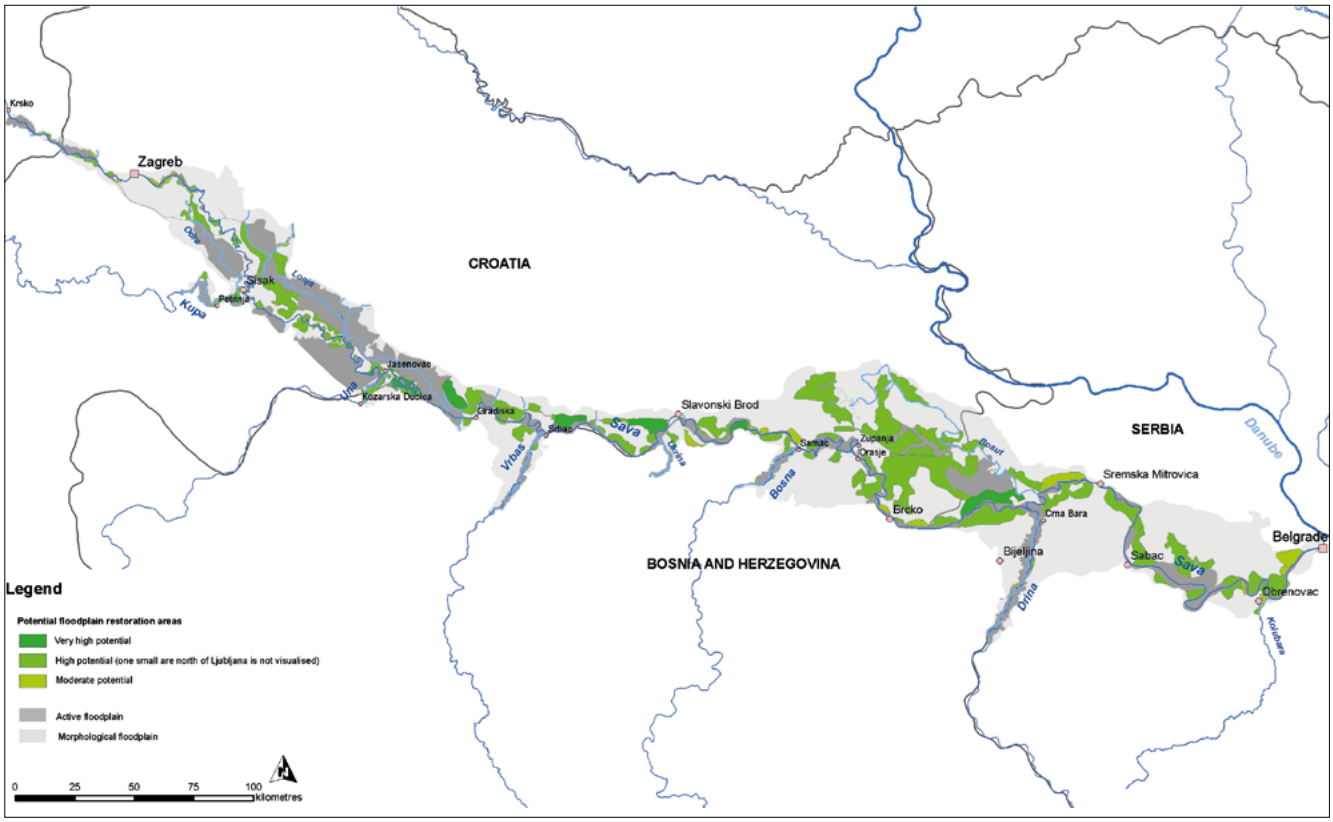

Figure 9. Potential river restoration stretches and their prioritisation. 41 river stretches with a total length of 251 km could be restored.

priority and 26 with *moderate* priority. The study also includes detailed proposals for several pilot restoration sites and areas.

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Wood resources in dynamic Danube floodplains – historical reconstruction and implications for management and restoration

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What do we know about the natural productivity of riparian forests prior to river regulation and about their function as a source of raw materials and renewable energy? Can we draw conclusions for today´s sustainable resource management using historical vegetation models?

An interdisciplinary research team consisting of river morphologists, vegetation/forest ecologists, and environmental historians investigated the Viennese Danube river landscape around 1825. The main research goal was to reconstruct the potential annual timber yield prior to river channelization. The riparian vegetation models and the historical research show that the natural wood productivity in the pre-channelization Danube floodplain was higher than in comparable near-natural riparian forests today. In comparison, current commercial forests with hybrid poplars yield higher amounts of wood. However, they do not meet sustainable forestry standards because of nature conservation concerns. Our study results call for the partial re-dynamization of embanked river reaches. This would also comply with the requirements of the EU Habitat Directive, EU Water Framework Directive and the EU Directive for Renewable Energy Sources.

Introduction

Forests in general and riparian forests in particular face an area of conflict – that between forestry revenue maximization and ecological, nature conservation-oriented forest management. Many of the remaining riparian forests along large European rivers were designated as protected areas according to the Flora-Fauna-Habitat Directive (NATURA 2000, 92/43/EWG). In addition, consideration must

be given to the requirements of the EU Water Framework Directive (WFD, 2000/60/EC), which aims at achieving a good ecological status of river systems. Recently, the potential role of renewable energy sources to cover Europe's energy demand at least partially is gaining increasing public and political awareness (see Renewables Directive 2009/28/EC). Today, the fragments of the former riparian forests are heavily impaired by river regulation, construction of reservoirs and dikes, and drawdown of the groundwater table due to channel incision. Moreover, native tree species have been exchanged by other species or by alien species in order to maximize wood productivity. On the other side, current restoration projects aim at the partial re-dynamization of stabilized and degraded river-floodplain systems.

Against this background the project "Enough wood for city and river? Vienna's wood resources in dynamic Danube floodplains" was designed to model the natural productivity of riparian forests on the Danube River prior to regulation and to estimate their potential function as a source of raw materials and renewable energy. Based on preceding research projects, we selected an 11.8-km-long Danube section in Vienna prior to regulation around 1825 as a study site. It comprises the up to 8.5-km-wide postglacial valley floor (recent floodplain) close to the historical city center.

Method

The design of the research project required an interdisciplinary, nature-humanity oriented team consisting of river morphologists, vegetation/forest ecologists, and environmental historians who focused on three central topics: (1) The river morphological and forest ecological site conditions and natural productivity potential for wood resources in dynamic Danube floodplains before channelization; (2) the historical use of locally available wood resources in a biomass-based society; and (3) the development options of Danube riparian forests against the background of ecological and nature conservation requirements and the objectives for a sustainable management of renewable resources.

A new model for estimating the former wood productivity under dynamic hydromorphological conditions provided the basis for answering the research questions. Because site age is a key factor for the development of the riparian vegetation, emphasis was put on the detailed reconstruction of the fluvial dynamics and the persistence of the floodplain terrain since the 16th century (compare Hohensinner et al., 2013a, 2013b). Generally, two scenarios were distinguished: Scenario 1 ("total natural wood potential"), assuming that the entire Viennese floodplain in 1825 showed riparian forests without any direct human influences; and Scenario 2, taking into account the actual historical land uses and forest management. The resulting values for the wood productivity in the dynamic river landscape were then compared with sample data from different types of stabilized riparian forests along the Danube River today.

Results

Due to the high fluvial dynamics the potential natural riparian vegetation in 1825 (omitting human land uses) was primarily characterized by vegetation types that generally develop on gravel/sand deposits along active river arms. Accordingly, 87 % of the floodplain terrain featured communities referring to "mineral sedimentation series" *(compare figure 1).* Communities that evolve in abandoned river arms as a consequence of terrestrialization processes ("organic/mineral sedimentation series") amounted only to 13 % of the study site.

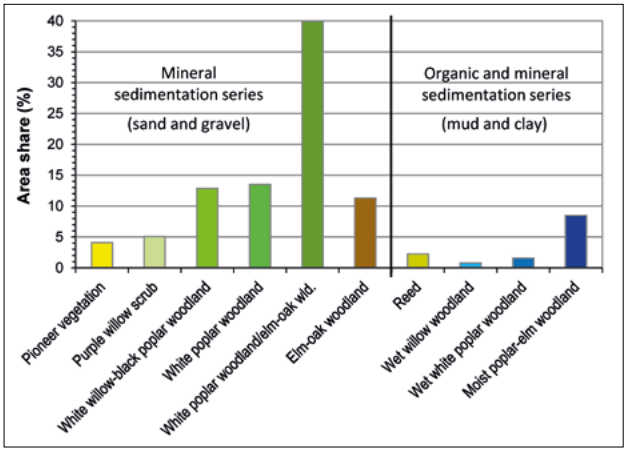

Figure 1. Modelled area shares of the potential natural floodplain vegetation types of the Viennese Danube River in 1825 (left side: mineral sedimentation series due to aggradation along active river arms, right side: organic/mineral sedimentation series due to terrestrialization in abandoned arms).

In particular, softwood communities, mostly located in the central river corridor and in silted up backwaters covered 34 % of the potential floodplain area. These were younger and up to 200 years old successional stages, as purple willows, and different forms of willow and poplar communities. Most of the older sites (> 200 years) featured transitional forms between hardwood and softwood forests due to the relatively small depth of the groundwater table and frequent flooding (48 % of the floodplain). Real hardwood forests, i.e. elm-oak woodland, could only develop on the highest and oldest sites of the floodplain (11 %). Most of them were located on more than 300 years old locations (Hohensinner et al., 2016).

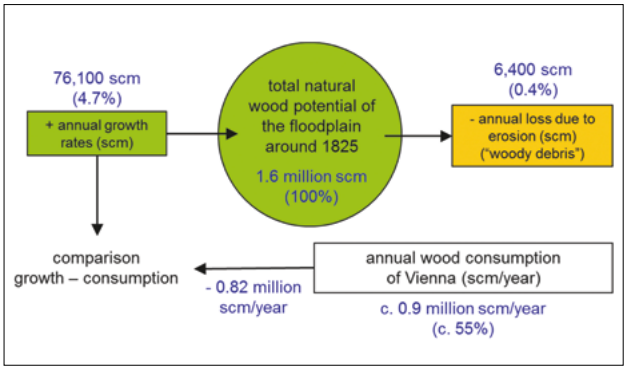

Figure 2. Synthesis of Scenario 1 ("total natural wood potential"; scm = solid cubic meter wood; percentages related to the total available wood in the floodplain).

Figure 3. Eroded riverbank with woody debris in the Austrian Danube Floodplain National Park (Christian Baumgartner, NP Donau-Auen GesmbH, 2009)

The main results for Scenario 1 are presented in figure 2. Accordingly, in 1825 the 77.07 km^2 large river landscape potentially featured approximately 1.6 million solid cubic meter (scm) of wood (c. 269 scm per hectare floodplain terrain). Productivity was highest in 45 – 100 years old willow stands and 160 – 200 years old poplar stands (both with more than 300 scm/ha). On average, c. 6,400 scm wood was released annually into the Danube River due to lateral erosion and avulsion processes ("woody debris" corresponding to 60 – 90 about 200 years old willows or poplars that were eroded annually per kilometer current river length). In comparison, the annual rate of wood growth was much bigger (c. 76,100 scm). Figure 2 also shows the annual wood consumption of the Viennese inhabitants at that time, which was more than 10 times higher than the annual growth rate. The riparian vegetation models show that the natural wood productivity in the dynamic pre-channelization Danube floodplain was higher than in comparable near-natural riparian forests that are used for timber production today.

On average, the annual growth rates of current near-natural floodplain forests are 25 % lower than in the historical reference state (standardized values per hectare forest). Even taking historical wood uses into account (Scenario 2), annual growth rates were slightly higher than in near-natural forests today. However, current commercial forests with hybrid poplars can yield much higher amounts of wood (44 % higher than the reference value). Nonetheless, such alien species are not an adequate choice because they do not meet the demands of modern sustainable forest management from the perspective of nature conservation (i.e. NATURA 2000).

Figure 4. Primary forest in the Austrian Danube Floodplain National Park (Werner Gamerith, 1992)

Conclusion

The results of the project show that a partial re-dynamization of embanked and stabilized river reaches would meet several legal specifications and socio-economic demands:

(1) According to the EU Flora-Fauna-Habitat Directive, originally typical softwood forests (priority habitats 91E0*) that are severely endangered today would benefit from the amplified fluvial dynamics.

(2) The restoration of riverbanks and floodplain water bodies supports the aim to achieve a good ecological status according to the EU Water Framework Directive. Here, the river-type-specific status functions as a reference.

(3) Given the high productivity of forest stands with intact fluvial dynamics it would provide new sources for ecological compatible and sustainable biomass energy as stipulated by the EU Directive for Renewable Energy Sources.

From the perspective of a modern management of riverine landscapes, this calls for a compromise between sustainable (commercial) forest uses, restoration of river-floodplain systems, and protection/promotion of dynamic riparian forests.

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