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Effect of hydrologic regime and forest age on Collembola in riparian forests

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ABSTRACT

The principal objective of the study was to assess factors of primary importance for collembolan community variability measured in riparian forest stands of different age after traditional clear cutting within natural and altered hydrologic regimes. The study was conducted in the Ukrainian part of the Latorica river floodplain where the largest stands of the highly protected medio-European *Querco—Ulmetum minoris* fluvial forests can be found. Six oak forest stands were investigated on the river floodplain: three in a natural section (inside levee) of the floodplain, which have their original features preserved with periodical inundation, and three in a section separated by a flood control embankment (outside levee) and subjected to serious damage by drainage. In each section the three stands sampled were represented by different ages regenerated with clear-cutting (>3 years, >8 years and >112 years).

Differences in hydrologic regimes were central to identification of a predictable and explainable percentage of variation in species composition of Collembola communities in fluvial forests. The hydrologic regime factor was correlated with the basic structural attributes of collembolan communities, such as abundance, species richness and some ecological traits. Season accounted for a higher degree of variation in collembolan communities than did the age of forest stands. We conclude that differences in hydrologic regime are of much higher importance in structuring collembolan communities in riparian forests than are the ages of stands.

1. Introduction

Understanding the processes that shape biological communities influenced by multiple disturbances is a key challenge in ecology and conservation science (Mouillot et al., 2012). Disturbances have a considerable effect on species diversity in any community (Buckling et al., 2000; Murphy and Romanuk, 2012). Studies of disturbances have a long tradition in ecology, including the development of the concept of succession or community response (see White and Jentsch, 2001 for a review), but most of them have focused on the ecological effect of one form of disturbance, and very few have examined the impact of more than one disturbance factor (Cobb et al., 2007; Ross et al., 2004; Vepakomma et al., 2010). The response of Collembola communities to multiple simultaneous disturbances is poorly understood (Malmström, 2012), and little is known about the influence of natural and anthropogenic factors such as hydrological regimes and forest management on their variability in riparian forests.

Riparian forest habitats, covering soils of alluvial terraces, levees and floodplains of wide river valleys (Malanson, 1993; Stanford et al., 1996), are complex and dynamic ecosystems (Décamps et al., 1988; European Environment Agency (EEA), 2006; Strasser et al., 2012). Their high ecological value in the landscape has been widely recognized, especially its roles in controlling nutrient flux (Gregory et al., 1991) providing environmental services such as water protection, buffering the impact from clear-cutting of upland forests, and maintaining terrestrial biodiversity (Gundersen et al., 2010). Forest biotopes of river floodplains experience strong pressures from natural disturbances associated with seasonal inundations (Flood Pulse Concept: Junk et al., 1989), changes in surface water below the bankfull and river-induced ground-water movements (Flow Pulse Concept: Tockner et al., 2000). On the other hand, humans have extensively altered natural river dynamic, which causes changes in functions and services of riverine forests (Poff, 2002; Steiger et al., 2005; Wei et al., 2011).

Soils and soil animal communities in riparian forests are influenced by natural hydrodynamic conditions that permanently modify the substrate for plant growth and animal colonization.

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These modifications inhibit or promote successful establishment of certain species (Junk and Welcomme, 1990; Naiman et al., 1998; Steiger et al., 2005). Natural hydrological regimes can be directly altered and degraded by construction of levees, dams and channels, which leads to a limitation on fluvial processes (Steiger et al., 2005) and damage to the ecological integrity of riparian ecosystems (Jungwirth et al., 2002). Ecological processes such as production, decomposition and consumption driven by the flood pulse are changed (Naiman et al., 1998; Nilsson and Svedmark, 2002; Pinay et al., 2002).

Forest biotopes of river floodplain are highly vulnerable not only to flow regulation, but also to forest management practices (Piégay and Landon, 1997; Russel, 2009; Villarin et al., 2009) that lead to alteration of energy fluxes, microclimate and changes in material budgets, e.g. nutrient loss through leaching (Naiman et al., 1998). Forest management practices have an influence on soil animal communities and may significantly affect their distribution, composition and activity (Bengtsson, 2002; Bengtsson et al., 2000; Marshall, 2000; Setälä et al., 2000). However, the response of soil animal communities to forest management practices in riparian forests has not been examined. The effect of water level variation and nutrients on spatial distribution of soil mesofauna has been investigated only in peatland habitats drained for forestry (Laiho et al., 2001). Collembola, as a dominant group of soil mesofauna, are a convenient model to study the formation and dynamics of their communities as they are impacted by natural and human-induced disturbances (Greenslade, 2007; Rusek, 1998; Kopeszki, 1988). Research on soil Collembola communities in riparian forests of major European river valleys has been scarce (Kolesnikova et al., 2013; Rusek et al., 2009; Russell, 2008; Russell and Griegel, 2006; Russell et al., 2002, 2004; Sterzyńska, 2001, 2009; Tsalan and Shrubovych, 2008). Effects of disturbances caused by inundation and ecological response of soil collembolan communities to inundation, such as spatio-temporal dynamic, metacommunity response, also have been documented (i.e. Deharveng and Lek, 1995; Gauer, 1997; Griegel, 1999; Lek-Ang and Deharveng, 2002; Lek-Ang et al., 1999; Rusek, 1984; Russell et al., 2002, 2004; Russell and Griegel, 2006; Russell, 2008; Tamm, 1984, 1986; Weigmann and Wohlgemuth-Von Reiche, 1999). Few studies have focused on the influence of different river floodplain hydrologic regimes on variability of soil collembolan communities (Russell, 2008; Russell and Griegel, 2006; Russell et al., 2002, 2004). Thus, it is of considerable value to investigate the effects of combined disturbance factors associated with regeneration practices after traditional clear-cutting harvesting in riparian forests, in both natural and altered hydrologic regimes.

The main goal of our study was to measure differences in Collembola communities in riparian forest stands of different age after traditional clear cutting within natural and altered hydrologic regimes. The principal objectives of the study were to assess: (i) factors of primary importance for variability: forest age, hydrologic regimes (natural versus altered) and season; (ii) whether the effect of forest age on variability of collembolan communities is different in natural and altered hydrologic regimes.

2. Material and methods

2.1. Study area

Our study was carried out on the floodplain of the Latorica River, which supports the largest refuge of the ancient Transcarpathian *Querco—Ulmetum minoris* riverine forests (habitat code 91F0) in Central and Eastern Europe (Prots et al., 2003). These ecosystems are in danger of vanishing as or of becoming seriously reduced in distribution ("Habitat" Council Directive 92/43/EEC).

Table 1
Soil properties at the different hydrologic regimes in the Latorica river floodplain. Each values are means ± standard deviation (SD) of three replicates of the soil properties; inundated section indicates natural hydrologic regime; non-inundated section indicates altered hydrologic regime.

Soil properties	Inundated section	Non-inundated section
pH*	5.26 ± 0.22	3.59 ± 0.12
CEC meg/100 g	26.93 ± 3.58	23.33 ± 4.23
Organic carbon C org. (%)*	4.01 ± 0.73	5.95 ± 0.45
Fractions (%)		
Sand 1–0.05	19.57 ± 6.37	21.93 ± 7.16
Silt 0.05–0.01	43.73 ± 3.66	47.93 ± 3.87
Clay <0.01	36.70 ± 2.97	40.13 ± 9.96

* Significant differences at the 0.05 probability level.

The major part of the catchment area of the Latorica River is located at the southeastern edge of the Central Danubian Lowland in the Mukachevska depression, in the Ukrainian part of the Transcarpathian Lowland. Despite considerable adjustment of the river – rectification and canalization of its bed and bounding of the floodplain with dikes – this part of the floodplain has preserved its natural hydrological regime with periodic inundation. The study area is situated in the temperate zone of the European continental climate. However, the orographic barrier of the Carpathian Arc ridges shielding the Transcarpathian Lowland territory from the north and northeast influence the climate of the region and make it milder. The annual mean temperature in this area is 9.8 °C (maximum temperature of warmest month 25.9 °C, minimum temperature of coldest month 5.8 °C, mean temperature of warmest quarter 19.4 °C, mean temperature of coldest quarter 0.9 °C) and annual precipitation is 688 mm. The climatic data were generated from WorldClim – Global Climate Data, version 1.4 (Hijmans et al., 2005; http://www.worldclim.org) for years 1950–2000. Yearly stream flow has a typical pattern, with low flows from late summer to the next spring, and with flood waves triggered by rapid snowmelt or storms. The mean annual runoff for the study territory is 100–300 mm/year (ICPDR, 2009). In 2007 year the area was inundated several times: 12–14 and 23–29 January, 23–28 February, 7–19 March, 25–26 November and 3–5 December (data source: Transcarpathian Regional Centre for Hydrometeorology, Ukraine Ministry of Emergencies).

2.2. Study sites

Study sites were established in the central part of the floodplain (48°27′–48°29′N, 22°28′–22°29′E) where the oak-elm-ash habitats are found and the tree overstorey is formed by *Quercus robur*, *Fraxinus angustifolia*, *Ulmus laevis* and *U. minor*. In both sections, the three stands each represented a different age since regeneration by clear-cutting: the old-growth stage (>112 years) and two younger regeneration stages (>3 years and >8 years) planted after clear-cutting (Fig. 1, Table 1).

2.3. Experimental design

Three factors were assessed in this study: hydrologic regime, age of oak stands, and seasonality. Two hydrologic regimes influencing Collembola communities were examined within the river floodplain: a natural regime preserved in the floodplain exposed to regular, periodical inundation "pulses" by river water (inside levee), and an altered regime in a section protected from flooding by an embankment, limiting fluvial processes (outside levee). Within each section of the floodplain, three fluvial oak stands in different phases of improvement were selected based on forest regeneration stages: old growth stage (>112 years) and two younger regeneration stages (>3 years and >8 years) after clear-cutting (Fig. 1,