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Springtails of flooded meadows along Matsalu Bay and the Kasari River, Estonia

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ABSTRACT

The brackish conditions of the Baltic Sea create special habitats in coastal meadow soils surrounding Matsalu Bay. The floodplains of the Kasari River are periodically flooded by fresh water. In the eastern part of Matsalu Bay and in the delta of the river, brackish and fresh water can be mixed due to strong winds from the west or due to exceptionally large amounts of fresh water flowing from the river in the spring. The aim of this study was to find out how flood and habitat soil salinity influence the abundance and diversity of springtail communities on flooded meadows. The studied meadows were grouped to four types by distance of study sites from the open sea and by soil electroconductivity: fresh floodplain, wet floodplain, transitional and coastal grasslands. Springtail communities on temporarily flooded meadows along Matsalu Bay and the Kasari River consist of 20 − 30 species per meadow type, species *Metaphorura affinis, Willemia anophthalma, Brachystomella parvula, Folsomia quadrioculata* were abundant in soil of all types of meadows. Our results confirmed that flooding is an important factor in shaping soil communities. Long-term flood had strong negative effect on springtail communities' abundance and diversity. However, there was no such negative effect of flood on meadows with shorter flooding period, for several species the flood was positive factor increasing the abundance. Flooding brackish sea water is the reason for higher electroconductivity of meadow soils negatively influencing the diversity of springtail communities. The abundance of several species was the highest in soil of coastal grasslands (*Agrenia bidenticulata, Folsomia sexoculata, Podura aquatica, Sminthurides schoetti*) despite the higher salinity of soil. The impact of flood duration on the composition of communities by life forms seemed to be less important than the impact of soil salinity, saline soil was not a suitable habitat for euedaphic springtails.

1. Introduction

Springtails have high importance in grassland ecosystem altering microbial activity and thereby influencing the processes of nutrient turnover (Filser (2002), Chauvat et al., (2003), Turnbull and Lindo (2015)). Abiotic factors, mainly temperature and soil moisture content, directly affect the activity, fecundity and mortality of springtails, they compete for organic resources with diverse invertebrate fauna in soil (mites, enchytraeids, diptera larvae, millipeds, ants, earthworms etc.) (Filser, 2002). Despite their poor ability to move, springtails inhabit different soil habitats and are flexible in responding to habitat disturbances (Rusek (1998); Sousa et al., (2004); Russell et al., (2010), Marx et al., (2012); Urbanovičová et al., (2013)). They are able to develop populations relatively quickly after recession of inundation (Russell (2008), Russell et al., (2010)). The dispersal behaviour, lifespan and reproductive strategies of springtails as well as all other groups of microarthropods are evaluated as the key factors regulating survival and colonisation after disturbances (Petersen, 1995; Shaw, 1997; Barbercheck et al., 2009). The responses of springtails after disturbances are species-specific as the result of differences in life-history (Lindberg and Bengtsson, 2005; Song et al., 2016; Rzeszowski et al., 2017).

Soil moisture is supposed to be one of the most important factors regulating the decomposition processes as well as the composition of soil fauna (Irmler, 2004). In inundated habitats the spatial distribution and abundance of soil fauna are mainly affected by parameters associated with periodic floods (Marx et al., 2012). There are numerous adaptations of springtails to live on or in water during the flooding period. Several authors (Cloudsley-Thompson 1988; Marx et al., 2012) have concluded that these adaptations include morphological (special structures on the surface cuticle that inhibit descent below the water surface), physiological (a metabolic shift under anaerobic conditions)

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and behavioural (small scale escape strategies like vertical trunk migration during a flood or remigration from non-flooded refugia after the flood) traits. Surviving submergence in the egg stage seems to be a successful strategy of several terrestrial arthropods including springtails for occupying the long-term flooded areas studied (Tamm, 1984).

The salinity of flooding water is an environmental factor affecting springtail communities on coastal meadows. Soil invertebrates are sensitive to saline substrates caused by the immersion of saline sea water into soils during seasonal floods (Pereira et al., 2015). The different salinity level of soil dependent upon the longevity of inundation period of the sea water would favour species which are adapted for these particular conditions (Widenfalk et al., 2015). Unfortunately, there is little published data about springtail species tolerance to soil salinity.

Flooded semi-natural meadows are endangered all over the world, thus it is important to have good knowledge of their biological diversity and understand the factors influencing their community assembly (Joyce et al., 2016; Meriste et al., 2016). Flood disturbance and seasonally changing climatic conditions are keys to maintaining floodplain taxonomical and functional diversity (Samaritani et al., 2017). The floodplain and coastal meadows in northern Europe have semi-natural origin i.e. they have developed as a result of extensive agricultural activities (mostly mowing and grazing), and the composition of soil invertebrate fauna is characterized by tolerance to flooding and management (Plum, 2005; Meriste et al., 2016). The continuum of Matsalu Bay and the Kasari River in the eastern part of the Baltic Sea represents a complex mosaic of marine, coastal and inland wetlands, an inland delta and flooded meadows. Temporary floods in Matsalu are natural altering significantly the surrounding habitats of soil biota because of high moisture. The flat floodplains of the Kasari River are periodically flooded by fresh water. The brackish conditions of the Baltic Sea create saline habitats in the coastal meadow soils surrounding Matsalu Bay. In the eastern part of Matsalu Bay and in the delta of the river, brackish and fresh water can be mixed due to strong winds from the west or due to exceptionally large amounts of fresh water flowing from the river on coastal meadows in the spring (Kumari, 1985; Ivask et al., 2012). The habitat conditions on meadows around Matsalu Bay and the Kasari River differ mainly by two factors. Firstly, the annual (or biannual in some years) flooding of meadows causes high soil moisture periodically fluctuating on a large scale. Secondly, the different salinity of floodwater causes differences in salt ion levels in soils flooded by seawater.

We studied the springtail communities' abundance and diversity in temporarily flooded meadows soil. The aim of this study was to find out how flood and habitat soil conditions (moisture, salinity) influence the abundance and diversity of springtail communities on Estonian flooded meadows. It was hypothesized that the annual temporary flooding by fresh water from the river and brackish water from the sea is an important factor shaping springtail communities abundance and species abundances as well as the ecomorphological diversity of communities.

2. Material and methods

2.1. Study area

The study area is located on the eastern coast of the Baltic Sea and covers Matsalu Bay, delta of the Kasari River and the surrounding grasslands (Fig. 1.). The climate of study area is characterized by mean temperatures of −5 °C in February and 16.5 °C in July. The average annual precipitation is 700 mm and the number of days with snow cover ranges from 100 to 105. The description of the study area has been published earlier in several articles (Ivask et al., 2006; Ivask et al., 2012; Leito et al., 2014; Meriste et al., 2016).

Matsalu Bay is shallow, brackish and rich in nutrients, it is 18 km long (from west to east) and 6 km wide (from north to south). The average depth of the bay is 1.5 m, with a maximum depth of 3.5 m. The water salinity varies from 7‰ in the bay mouth to 0.2‰ in the estuary of the Kasari River. There are no significant tidal variations in the Baltic Sea and the fluctuations of water normally less than two meters are mostly due to winds. The shoreline of the bay lacks high banks, there are mostly shingle shores and muddy flats with extensive reed stands in the innermost sheltered part (Kumari, 1985).

The Kasari River is the largest of several rivers that enter the bay, and the alluvial meadow of its delta is one of the largest (4000 ha) open wet meadows in Europe, 2500 ha of which is mown once per year. The bedrock is formed of limestone, the relief is mostly flat, loamy till and laminated clay plains dominate. The delta plain is low, less than 1.5 m above the sea level. The annual freshwater inflow to Matsalu Bay from the Kasari River exceeds the amount of water in the bay itself by about 10–11 times. This allows extensive periodic floods in spring during the snowmelt period and the floodplain meadow also can be flooded in summer and autumn during heavy rains and westerly storms (Meriste and Kirsimäe, 2015). Spring floods last for one to two months. The duration of flooding period differs on meadows, mainly caused by the relief − inundation does not recess from the huge flat area of the river delta but recedes from the areas with higher altitude or coastal areas. Grasslands closer to the sea are influenced by shorter brackish floods from the sea, more distant grasslands, on the other hand, are influenced by long term fresh water floods. The transition zone at intermediate distances from the open sea can be influenced by both fresh water from rivers and brackish water from the sea (Meriste et al., 2016). 2014 was an average year with one flooding period when the maximum flood water level was observed on March 26 on wet floodplain and transitional meadows, and on 28 March on fresh and coastal meadows. The duration of flooding period on studied meadows is presented in Table 1.

The soils of West Estonian coastal meadows are saline littoral soils (Kumari, 1985). Floodplains are characterized by nutrient-rich alluvial soils, typical for flooded meadows soils are Fluvisols. The plant cover is high, lush and relatively species-poor with dominating species of families Cyperaceae and Gramineae (Kumari, 1985; Reintam et al., 2006).

2.2. Sampling sites

The sites for study were selected to represent grasslands temporarily flooded with freshwater, brackish water, or both. Twelve sampling sites were chosen to represent a gradient of habitats from a typical floodplain meadow flooded with freshwater to a typical low coastal meadow flooded with brackish water (Porgassaar and Simm, 1985) including intermediate transitional meadows where fresh or brackish water extent is indistinct (Table 1).

There were two sampling points on the flooded part of each grassland site: 1. One point (A) on flooded part of grassland not far from the flood upper line; 2. The second sampling point (B) on the flooded part of the same grassland in the same distance from the open sea, with a similar duration of flood as in the first sample point and as far as possible from floodwater line. In each studied meadow we additionally studied soil and springtail community parameters in the sample point over the flood line where the soil was never flooded (C).

In sampling points the parameters of habitat, soil and soil biota were measured:

1 Habitat: distance of sample point A from the open sea measured from the top of Saastna peninsula (location 58.738154, 23.524918) (Fig. 1, Table 1). Habitat characteristics were determined by botanical (height of plant cover, bare ground proportion, coverage and abundance of Gramineae) and ecological field studies.
2 Flood characteristics (duration of flooding period, depth of flooding water) were measured in 2014 using 14 automatic sensors Solinst Levelloger Junior 3001 which were installed at the study sites. The sensors recorded the level of water table from the depth of 95 cm with an interval of one hour. The term "flood duration" refers to the number of days when the water level was above of 15 cm below the