Ecohydrology & Hydrobiology 14 (2014) 285–295

Contents lists available at ScienceDirect

Ecohydrology & Hydrobiology

journal homepage: www.elsevier.com/locate/ecohyd

Original Research Article

Hydrological influences on the distribution of vegetation and tree height of *Alnus japonica* (Thunb.) Steud. in the Kushiro Mire, Japan

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ARTICLE INFO

Article history:
Received 29 December 2013
Accepted 17 September 2014
Available online 7 October 2014

Keywords:
Hydrology
Flooding
Alder forest
Tree height
Waterlogging
Peak water level

ABSTRACT

The relationship between the hydrology and plant communities assessed by continuous measurement of water, soil environment and vegetation, mainly in an alder forest, was studied in Kushiro Mire, Hokkaido, Japan. Seasonal changes in the water level were not detected, except in the willow forest located in the Kuchoro River, which showed a drawdown of the water level in summer. The height of the alder trees correlated with the mean and lowest water levels which would supply oxygen. The peak water level also affected the height of the alder forest, suggesting that waterlogging (reduction and lack of oxygen) inhibited the height of the alder trees. An overflow was only observed during the strong low pressure, typhoon or snowmelt flooding, as a result of the high peak water level. In snowmelt season, alder did not foliation stage. This suggests that the river water may only overflow the natural levee during a such large rain event, which supports the establishment of alder forests in the inflow area. Furthermore, the height of alder trees weakly negatively correlated with the carbon/nitrogen ratio of the soil, suggesting a difference in the deposition of peat. Reed-sedge community showed a large fluctuation of the water level, and resistant to drawdown of the water level, which would inhibit the invasion of alder.

1. Introduction

Changes in species composition and loss of ecological diversity threaten the mires in many countries. In addition, Japanese lowland mires are subject to alder tree invasion, which may be linked to hydrological disturbances. The Kushiro Mire, the largest mire in Japan, is mainly covered by reeds. However, alder (*Alnus japonica*) forests have invaded the area, indicating a desiccation of the mire has occurred. The quality of the habitat has declined, and the wildlife diversity of waterfowl and crane is now under threat. Changes in the water level and movements within a wetland habitat can be brought about in several ways, and these changes result from a modification of the surface topography or hydrological patterns (Tallis, 1983). Such phenomena have been reported previously for the Kushiro Mire (Ogawa et al., 1992; Mizugaki and Nakamura, 1999; Nakamura et al., 2004; Negishi, 2009).

Furthermore, it has been suggested that changes in the landscape, such as a change to a closed canopy forest from a thicket, can contribute to the spread of alder forests in the Kushiro Mire (Shinsho, 1983, 1997). It is important to understand the environmental factors that control the distribution and size of alder trees to preserve the Kushiro Mire.

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http://dx.doi.org/10.1016/j.ecohyd.2014.09.001
1642-3593/

In general, it can be said that flooding inhibits both plant growth and their biomass (Kozlowski, 1982, 1985; Hook, 1984; Ewing, 1996; Megonigal et al., 1997; Nakamura et al., 2002*b*). The growth of alder seedlings is inhibited by a flood treatment *in vitro*, altering the trees' size and morphological features (Terazawa and Kikuzawa, 1994; Yamamoto et al., 1995; Nagasaka, 2001), and mature alder forests are also affected *in situ* (Negishi, 2008). For the *in situ* case particularly, it is clear that a tree's size is determined by environmental factors and not by its age (Shinsho, 1982).

It is known that the alder forest is distributed toward the less flooded areas compared with the reed community (Nakamura et al., 2004; Negishi, 2009; Negishi unpublished). It is well known that hydrochemistry is a key factor for controlling the distribution of vegetation in mires (Bridgham et al., 1996; Wheeler and Proctor, 2000). In particular, for Japanese floodplain mires, which are waterlogged throughout the year, hydrological factors, such as the oscillation of the water level, are extremely important (Yabe and Onimaru, 1997; Nakamura et al., 2002a, 2002c; Negishi, 2009). From these results, waterlogging is a key factor for controlling the distribution of alders and their morphology, such as the height of a tree.

However, the influence of flooding depends on the timing, duration, and hydrological energy of a flood event. These different flooding characteristics may have positive or negative effects on plant growth (Mitsch et al., 1979; Odum, 1979; Brinson et al., 1981; Taylor et al., 1990; Odum et al., 1995; Megonigal et al., 1997), causing various physiological changes in plants, such as the closure of the stomatal aperture, the formation of injurious substances, root dieback, and inhibition of nutrient uptake (Grandil, 1972; Kozlowski, 1982; Hook, 1984). Since the 1940s, numerous studies have indicated that the distribution of vegetation in a mire depends not only on the mean water stage, but also on fluctuations in the stage (Ingram, 1983). Various attempts have been made to explain the distribution of mires in terms of precipitation in many countries (Ingram, 1983), and to discuss these influences, we need to survey these details of hydrological characteristics.

Although periodical field measurements of the water level at specific times carried out *in situ* is one way of representing major trends in hydrological oscillations, such as the maximum, minimum, or the range, this method does not allow us to obtain the flood index, which has a very large impact on mire vegetation, such as the peak level of swelling or the duration of waterlogging. Consequently, it is important to examine the water fluctuation characteristics using continuous measurements employing water-stage recorders. Previous studies have surveyed these indices in specific, small, local areas (Nakamura et al., 2004) or in few rivers (Fujimura et al., 2006; Nakayama, 2008b). However, because the results from these areas were influenced by the characteristics of the river discharge and topography, it is difficult to determine major hydrological trends that would influence the distribution of vegetation in the Kushiro Mire as a whole. With regard to the Kushiro Mire acting as a floodplain, it is necessary to use a quantitative approach to elucidate the relationships of the patterns of precipitation that determine a flood's characteristics. Therefore, in this study, we aimed to attempt new index for impacts on plants to determine quantitative differences in a hydrological event of flooding using continuous measurements that have a high impact, such as the peak water level, range of fluctuations, duration of waterlogging among plant communities, and the height of alder trees in the Kushiro Mire, especially at the more broad sites.

2. Material and methods

2.1. Study site

Kushiro Mire is the largest mire in Japan (18,290 ha), and is located in eastern Hokkaido on the Pacific coast (43°06′ N, 144°24′ E), 1.5–20 m above sea level. Weather reports from 1971 to 2000 for Tsurui (43°13.8′ N, 144°9.7′ E), located in the hilly area situated north of the mire, indicate that the annual mean air temperature in this period was 5.3 °C, and the mean precipitation level was 1085 mm (Japan Meteorological Agency, 2001). In the 2001, survey year, the annual precipitation was 932 mm, an average rainfall (Japan Meteorological Agency, 2010). Most of the precipitation occurred between spring and autumn, and little snowfall occurred during winter. Based on this climate information, the mire has been classified as a shallow-snow lowland wetland zone (Yabe, 1993a,b) with the peat being frozen in the winter.

The vegetation community is divided into the following four types (Tsujii et al., 1993): sphagnum bog, sedge fen, reed swamp, and alder forest. Most of the area is a floodplain mire composed of a reed community, but some of the area has been altered by an alder forest. This alder forest is categorized into low thicket or closed canopy forest from the height, or as bog, fen, or swamp from the floor vegetation (Shinsho, 1978; Nakamura et al., 2004; Negishi, 2009). Moreover, along the sides of the inflow rivers, willow has replaced the alder trees because of heavy sedimentation (Nakamura et al., 1997).

The inflow rivers are mostly channelized and the meanders have been removed at the upper sites: the Kuchoro, Setsuri, and Hororo rivers. The Chiruwatsunai River has not been channelized, but had a small catchment area. Agricultural development occurs along each river. In the Hororo area particularly, many ditches have been constructed, and the main flow of the Hororo River is connected to the Setsuri River. The Onnenai site is a large bog area, and has a large levee constructed on it.

2.2. Methods

Continuous data were obtained from 14 water-stage recorders installed across a wide area in the Kushiro Mire (Fig. 1). Four types of communities were surveyed: willow (one site), alder (forest and thicket type, seven sites), reed–sedge (three sites), and bog (sphagnum and *Chamaedaphne calyculata*-type, three sites). Several sites were selected to avoid any effect from the elevation of these communities. The recorders were set near to the river as well as in areas far from the river. Although the water level survey was conducted for the complete through year from 1999 to