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Holocene development of mountain wetlands within and outside of landslide in the Hachimantai volcanic group, northeastern Japan

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A B S T R A C T

In warm and humid, tectonically active regions like Japan, landslides are an important influence on the development of mountain wetlands, but data bearing upon the relationship of Quaternary landslides to wetland development are scarce. We used lithological analysis, ^{14}C dating, tephra age data, and carbon contents of wetland cores to compare the evolution of four wetlands, one (the Oyachi wetland) within a landslide area transformed by mass movement and three (the Appi Highland wetlands) outside of a landslide area, in the heavy snowfall region of the Hachimantai Mountains of northeastern Japan. Evidence from the Oyachi wetland shows that its transition from peatland to forest was interrupted at about 5500 cal BP by slope movement leading to the development of a lake that was drained by streams at about 3300 cal BP, after which a peatland environment has persisted until the present. We suggest that the evolution of this type of wetland is primarily influenced by landslide movements and stream dissection rather than climate change. In the Appi Highland wetlands, peatlands appeared much later, around the time of the To-a tephra fall in 915 AD, during the Medieval Warm Period, and have persisted with little change until the present. We suggest that the development of mountain wetlands outside of landslide areas is primarily related to climate changes rather than topographic changes. Sediment analyses of mountain wetlands within landslide areas may be useful for tracing the development of Quaternary landslides and subsequent topographic changes that may have implications for biodiversity in mountainous regions.

1. Introduction

Mountain wetlands, defined in this paper as natural peatlands or lakes in mountainous areas, are important reservoirs of biodiversity. Topographic depressions with an abundant supply of water are necessary for their formation. Glacial lakes (e.g., Ashraf et al., 2017) and volcanic crater lakes (e.g., Tantau et al., 2003) are typical examples of mountain wetlands. Landslides have been cited as one of the most important influences on the formation of mountain wetlands (Takaoka et al., 2012; Łajczak, 2013; Sasaki and Sugai, 2015; Takaoka, 2015). Wetlands caused by landslide activities are formed mainly in depressions, especially at the foot of main scarps on landslide areas and within inter-colluvial depressions (Margielewski, 2006), if there is abundant groundwater and meteoric water available to fill those depressions. Lakes formed by landslide damming of rivers are also common in areas of abundant landslides. Landslides have recently attracted the attention of ecological researchers because of their contribution to the mosaic landscapes that favor biodiversity (Geertsema and Pojar, 2007; Alexandrowicz and Margielewski, 2010; Walker and Shiels, 2013; Kariya et al., 2013; Takaoka, 2013).

In the Japanese island arc, mountain wetlands are common in regions of heavy snowfall that are susceptible to landslides, particularly in the Ou Mountains in northeastern Japan (Fig. 1). The Ou Mountains receive heavy snowfall supplied by the winter monsoon, and large landslides are densely distributed in the range (Sasaki and Sugai, 2015). Our study area in the Hachimantai area lies in the northern part of the Ou Mountains, where wetlands occupy various types of depression including volcanic craters, nivation hollows on original volcanic surfaces, and depressions formed by landslide activities, as well as the edges of lava flows (Sasaki and Sugai, 2015).

Wetlands can be affected by terrestrialization and hydroseral succession, thus evolving from lakes to peatlands and finally to forest (Tansley, 1939), or by paludification with no distinct aquatic phase (Charman, 2002). Wetlands on slopes, like those of landslide

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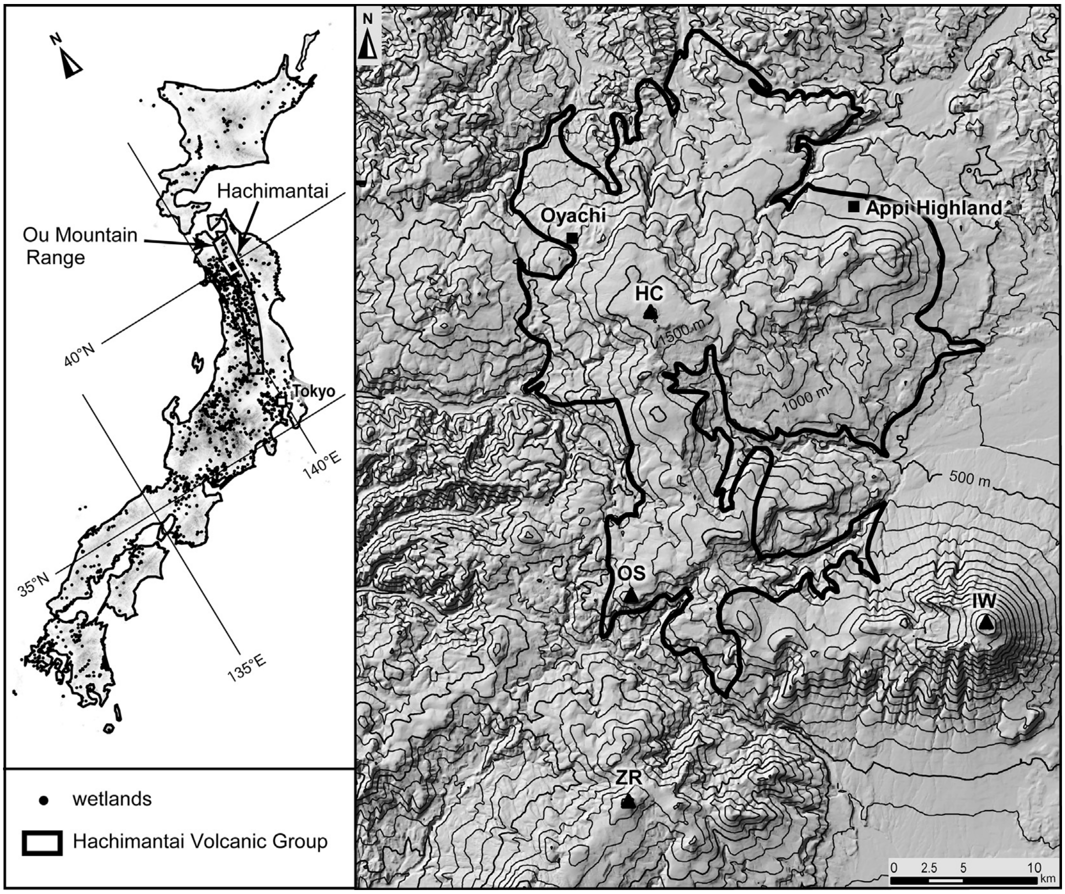

Fig. 1. Location maps showing the regional setting of this study. Wetland distribution is from Environment Agency (1993), outline of the Hachimantai volcanic group is from Geological Survey of Japan (2015), and detailed topographic map of the Hachimantai area is based on the 10-m digital elevation model published by the Geospatial Information Authority of Japan. HC, Hachimantai volcano; OS, Oshiromori Mountain; IW, Iwate volcano; ZR, Zarumori Mountain.

areas, are also influenced by the surrounding topography. Sasaki and Sugai (2015) compared various types of coexisting wetlands on a large landslide area in the Hachimantai volcanic group. They reported that wetlands within river channels draining the area had become peatlands, whereas those in higher areas not dissected by river channels remained as lakes. They suggested that the extent of dissection of landslide areas by drainage channels can control the pace of wetland development, with wetlands that are breached by such channels evolving rapidly from lakes to peatlands in response to a decrease in recharge water to the depression and increased aggradation of channel sediments.

Wetlands in nivation hollows on original volcanic surfaces, found mainly along ridgelines outside of landslide areas and recharged from precipitation, may differ in type (lake, lake with peatland, or peatland) depending on the amount of available recharge water, which suggests that the history of peat accumulation may provide a record of past climate changes. Previous studies of nivation hollows (e.g., Koizumi, 1982; Daimaru et al., 2002; Kariya, 2005) and kettle-hole bogs (Booth et al., 2006) have considered the relationship between peat accumulation and climate change. Koizumi (1982) reported that the initial formation of peat in nivation hollows in Japan occurred in two distinct periods, the first (12,000–7000 yr BP) related to the commencement of a period of heavier snowfall and the second (4100–3300 yr BP) related to cooler temperatures.

Given the differences in the factors influencing their development, wetlands in landslide depressions and wetlands in nivation hollows may differ in the timing and duration of their stages of evolution. Many previous studies have used analyses of peatland sediments within landslide areas to reconstruct the history of landslide activity (e.g., Alexandrowicz, 2013), paleovegetation (e.g., Morita, 1985), and paleoclimate and related human activity (Margielewski et al., 2011). Igarashi and Takahashi (1985) showed that the timing of initial peat formation in wetlands on two landslides was controlled by the timing of the landslides, but they did not consider the development of these wetlands that preceded the initial formation of peat. Sasaki and Sugai (2015) investigated the influence of topography on the distribution of wetlands within landslide areas, but they did not attempt to reconstruct the temporal changes in wetland conditions.

This study used sediment analyses to reconstruct the development histories of mountain wetlands within and outside of landslide areas and to assess the geomorphological and climatic influences on wetlands. We studied two wetland areas, the Oyachi wetland in a landslide area and the Appi Highland wetlands on an original volcanic surface. We then considered and compared the effects of landslide activity, local topography, and climate variability on these wetlands. The formal mass movement terminology in this paper follows WP/WLI UNESCO; see Dikau et al., 1996. If the triggers of wetland formation and evolution differ for wetlands within and outside of landslide areas, then the timing and pace of wetland evolution should also differ. Because changes of habitat during the evolution of wetlands influence local ecosystems, the existence and the evolution of wetlands have implications for the richness of local biodiversity. The results of this study improve our understanding of Quaternary wetland development and may have