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Peaty hummocks as an environmental indicator: a case of Japanese upland mire

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Abstract

Hummocky microforms are formed in Japanese high latitude and altitude regions under seasonal frost environments. The Senjogahara mire, a representative upland mire in Japan, provides shallow water table, adequate snow depth and frost penetration, which have promoted the formation of peaty hummocks. These hummocks are classified into active and inactive types in terms of the vegetation characteristics. The active forms occur on the seasonally waterlogged mire surface, whereas the inactive forms are located on the surface with perennial underground water. This suggests the environmental significance of hummocks as a hydrological indicator.

Key words: hummocks, mire, seasonal frost, snow depth, water table

1. Introduction

Hummocky microforms, commonly referred to as "earth hummocks", "thúfur" and "pounus", are often distributed in continuous and discontinuous permafrost and seasonal frost zones. Although the hummocks must be termed by internal and external morphology and thermal characteristics controlling the hummock formation, Grab (2005) described that diverse morphological and sedimentological features of the hummocks have produced various academic terms. Such a situation has resulted in typological and terminological confusions.

Similar hummocks are also formed in Japanese high altitude and latitude regions under cold environments, where they are locally called "Yachi-bozu" or "Tokachi-bozu". These two types are distinguished by vegetation and soil characteristics. The former generally includes a peat core and is covered with tussock grass such as sedge, whereas the latter mainly consists of volcanic ash and non-tussock grass. Few scientific investigations, however, have been conducted to evaluate environmental controls on the formation of these hummocks. This leads to the typological and terminological problems of the Japanese hummocks, and prevents the study on palaeoenvironmental reconstructions using the hummocks.

This paper classifies peaty hummocks called "Yachi-bozu" in terms of vegetation types and discusses the environmental significance of hummocks, based on data on climatic and hydrological conditions influencing the hummock formation in a Japanese upland mire (Senjogahara mire, shown in Fig. 1) located in a seasonal frost environment.

2. Study area and methods

The Senjogahara mire (about 1400 m in elevation), which has a peat layer about 4 m in depth, stretches over an area about 1.5 km in length and 1 km in width surrounded by volcanic mountains (highest peak, 2484 m in elevation) in the Nikko National Park. The mire has been drying and shrinking in recent decades. Yamakawa *et al.* (1999) reported that the extent of the mire decreased by 34.6 % from 1918 to 1997, and that the decreasing rate is one of the highest values in Japanese mires.

Climatic conditions in the study area are estimated from meteorological data at the Oku-Nikko station (1292 m in elevation, 7 km southeast of the study area) since no climatic data are available in the mire. The mean annual air temperature was 6.7˚C and the total mean annual precipitation was 2102.9 mm at the station between 1971 and 2000 (Table 1). In the study area, however, a cold air lake and higher altitude are likely to produce slightly lower temperature and larger snow amount.

Peaty hummocks, 20-40 cm in both height and diameter and composed of tussock grass (sedge: *e.g. Carex thunbergii, Eriophorum vaginatum*), are extensively distributed over the Senjogahara mire. Transect A-A' 50 m in length and 5 m in width was established at the margin of the mire (Fig. 1), where pioneering trees (*e.g.* birch: *Betula platyphylla*; larch: *Larix kaempferi*) have invaded on sandy deposits above the peat layer (Ogata, 2003). Along the transect, longitudinal profile was measured with a transit and laser distance meter. The transect was divided into ten quadrates (Q1-Q10, 5 m × 5 m), in which the total number and height were measured for the hummocks over 20 cm in height. Snow depth and water table were investigated at half-month

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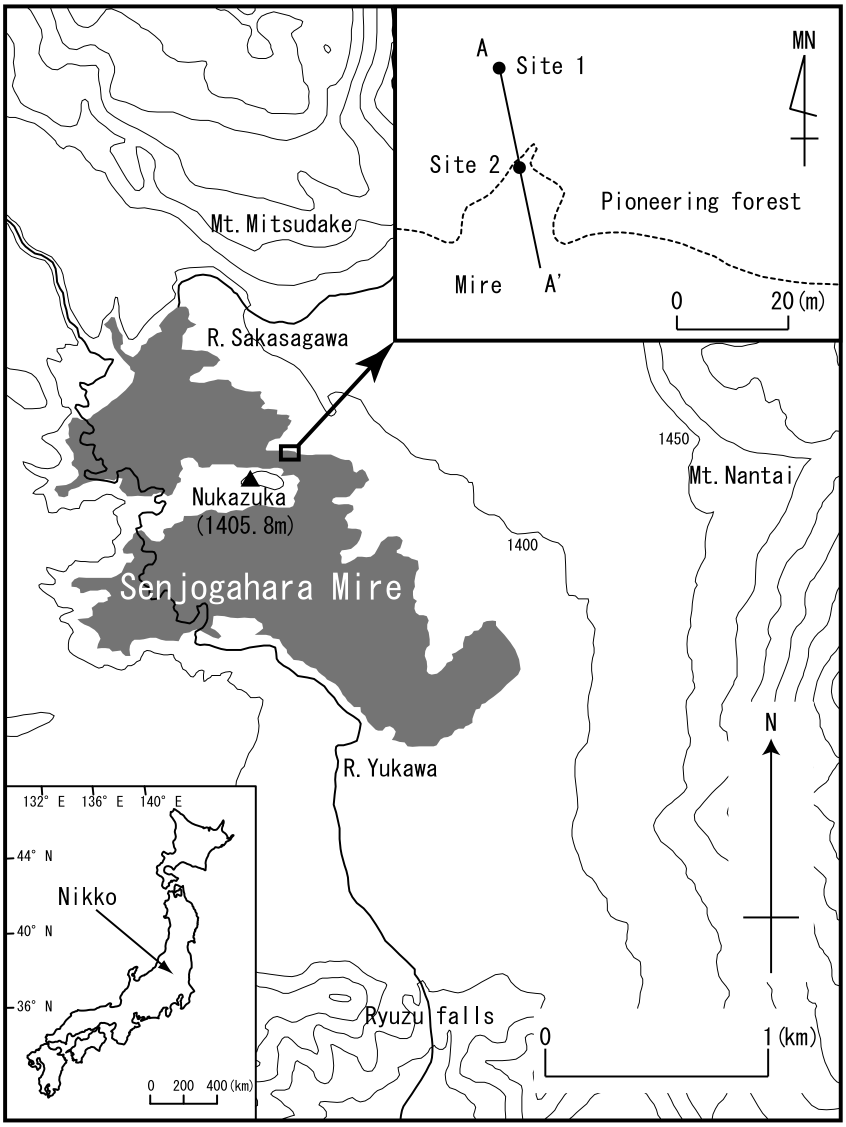

Fig. 1 Study area.

Table 1 Mean monthly and annual temperature (T) and precipitation (P) at Oku-Nikko station in 1971-2000.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
T (℃)	−4.1	−4.2	−1.1	4.9	9.7	13.6	17.4	18.5	14.6	8.9	3.9	−1.1	6.7
P (mm)	42.2	66.9	104.4	159.6	172.4	233.9	259.7	393.9	355.5	169.0	109.5	36.0	2102.9

intervals between December 2001 and March 2003 at two sites (Sites 1 and 2), where snow scales and wells were installed with a hand auger.

3. Classification

Figure 2 displays the number of hummocks in each quadrate with the landform cross section. The longitudinal profile shows that the mean gradient is 1/93, and that relative height between points A and A' is 53.5 cm (Fig. 2a). The hummocks are classified into "tree-invasion type" (with tree species), "shrub-invasion type" (with shrub but without tree species), "herb-invasion type" (with non-tussock herb but without tree nor shrub species) and "no-invasion type" (with only tussock herb) based on the invading plant species. The last type hummocks are formed only in the lower area, whereas the upper area allows the formation of the other hummocks (Fig. 2b).

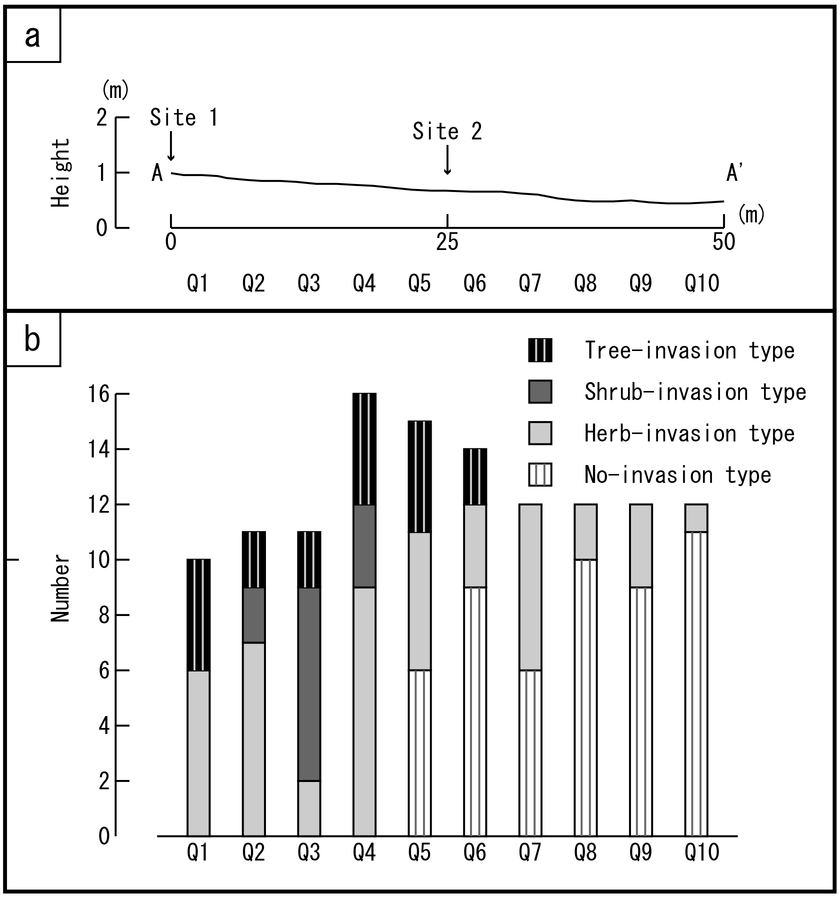

Fig. 2 Landform cross section and the number of peaty hummocks over 20 cm in height along Transect A-A'. (a) Landform cross section. (b) The number of hummocks.

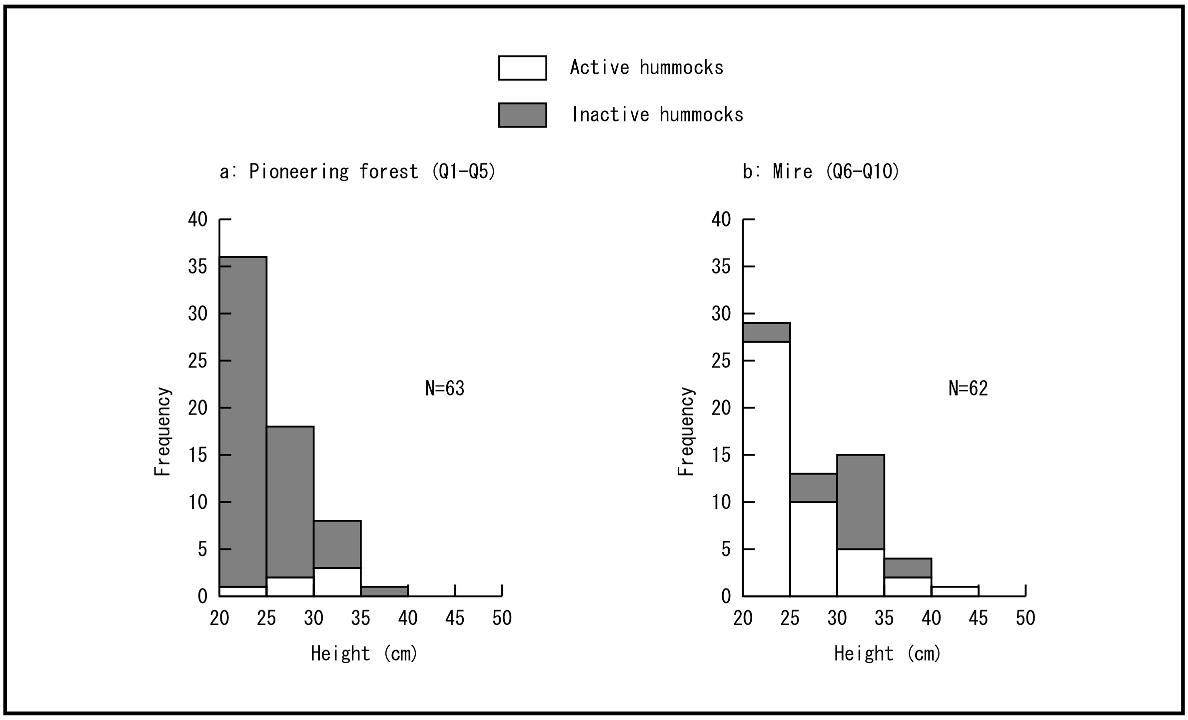

Fig. 3 Histograms for the height of peaty hummocks over 20 cm in height along Transect A-A'.

Table 2 The number and height of peaty hummocks over 20 cm in height in each quadrate.

Quadrate	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Number	10	11	11	16	15	14	12	12	12	12
Average height (cm)	21.6	24.5	23.7	25.9	27.9	26.2	26.5	25.6	26.3	28.8
Maximum height (cm)	25	28	29	32	35	39	35	32	38	43
Range of height (cm)	5	8	8	11	14	18	15	12	18	21

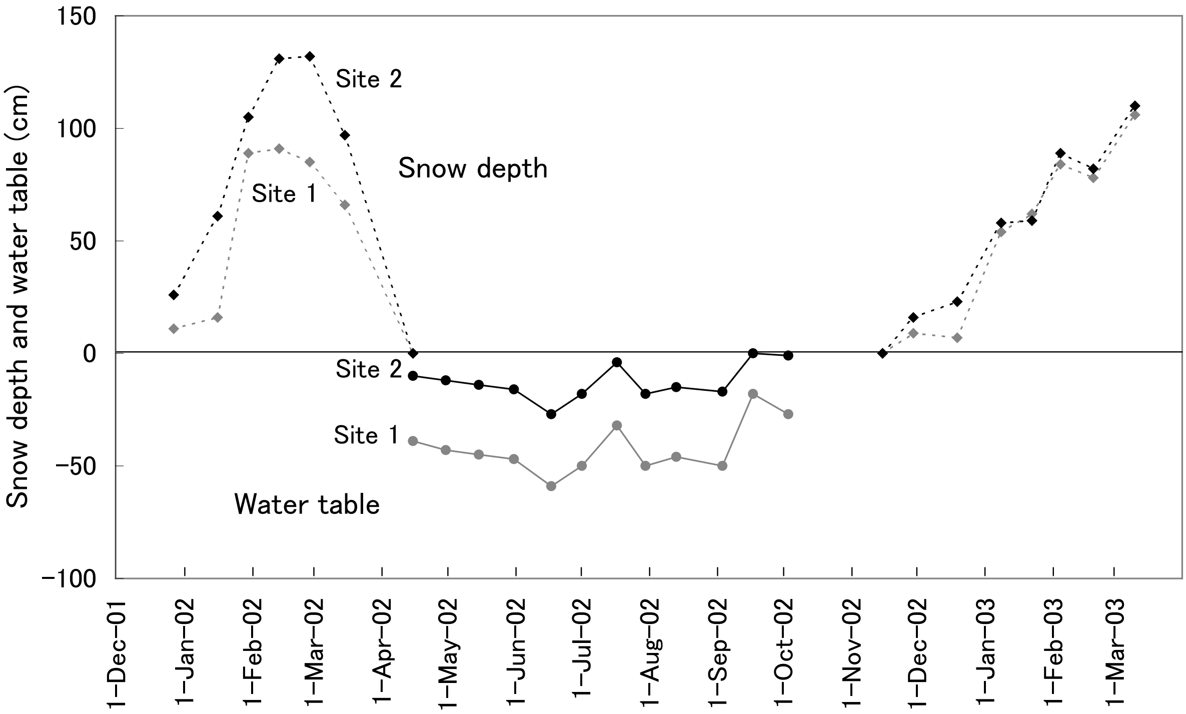

Fig. 4 Changes in snow depth and water table (depth below the surface) at Sites 1 and 2 between December 2001 and March 2003.

The no-invasion type is considered to be active and the other types are thought to be inactive, because the hummock growth requires the tussock grass. The inactive hummocks suggest the vegetation succession to drier meadow or pioneering forest.

Figure 3 presents histograms of the height of active and inactive hummocks in the pioneering forest (Q1-Q5, 63 hummocks in total) and in the mire (Q6-Q10, 62 hummocks in total). The inactive hummocks account for 90.5 % in the pioneering forest and 27.4 % in the mire. The percentage of hummocks higher than 30 cm occupies 14.3 % in the pioneering forest and 32.3 % in the mire. In addition, the range of height increases with the occurrence of active hummocks (Table 2). These facts indicate that various ages of hummocks coexist in the mire, and that the hummocks are growing in the mire and influenced by succession in the forest.

4. Environmental conditions

Figure 4 shows changes in snow depth and water table at Sites 1 and 2 between December 2001 and March 2003. In the study area, continuous snow covered the ground for about four months from December to March. The maximum annual snow depth reached 91 cm (2002) and 106 cm (2003) at Site 1, and 132 cm (2002) and 110 cm (2003) at Site 2. Such a snow cover insulates the ground surface from diurnal variation in air temperature, while the meteorological data (at Oku-Nikko station) on air temperature suggest that diurnal freeze-thaw cycles occur at the study sites in autumn (September to November) and in spring (April to May) when snow cover is absent. In fact, in the observation period, the freeze-thaw cycles occurred 25 times in autumn, 2001, 9 times in spring, 2002, 27 times in autumn, 2002 and 15 times in spring, 2003. This suggests that freeze-thaw action affects the snow-free ground at

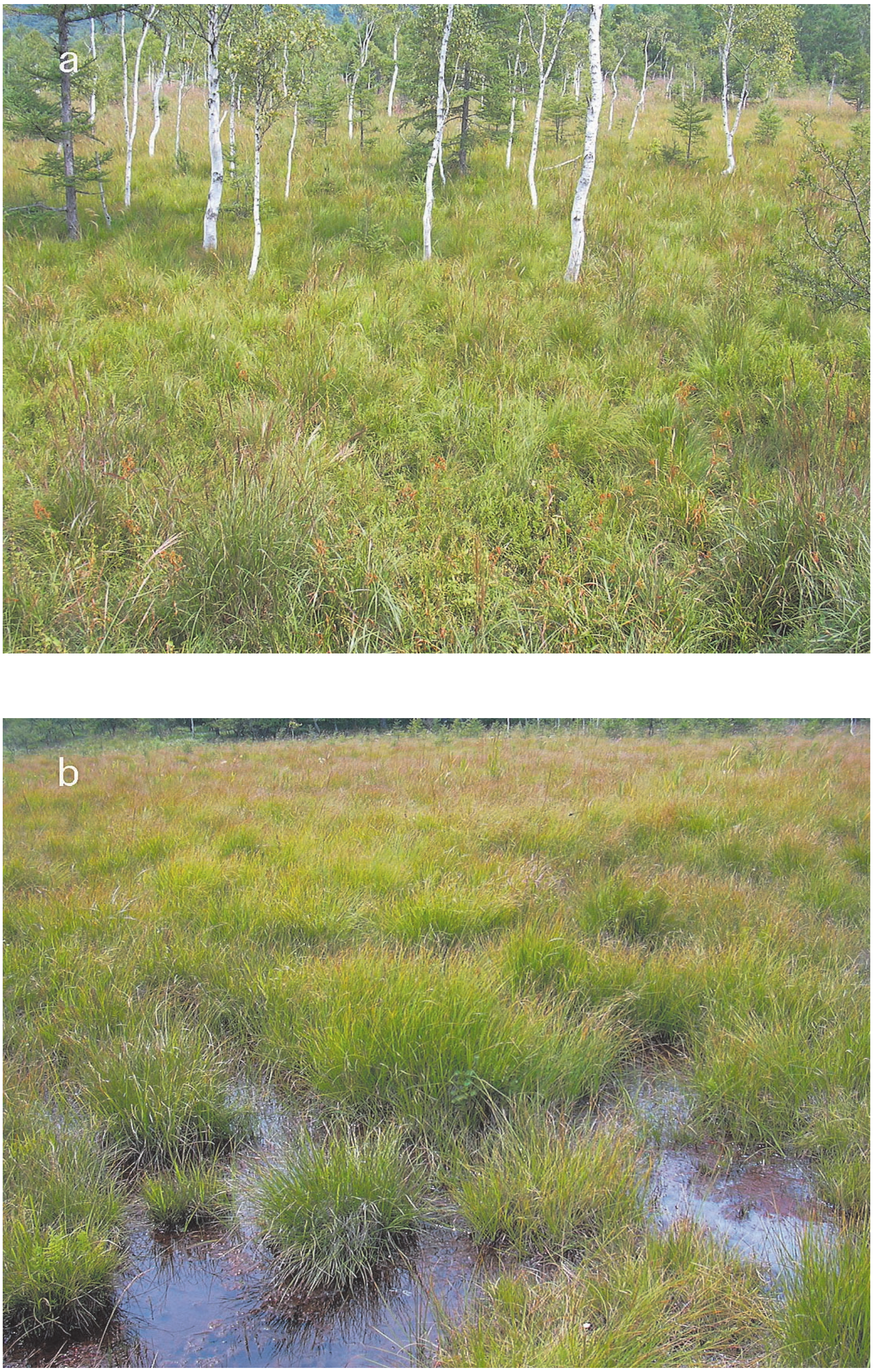

Fig. 5 (a) Inactive peaty hummocks in the pioneering forest (3 September 2005). Water table lies below the ground surface. Pioneering trees invaded on slightly higher ground result in a drier condition. (b) Active peaty hummocks in the mire (3 September 2005). Water table lies above the mire surface.

the study sites.

Groundwater data indicate a significant difference in the water table between the two sites throughout a year. The water table rises above the surface seasonally at Site 2 located at the boundary between the pioneering forest and the mire, while it never rises above the surface at Site 1 located in the forest. The hydrological condition seems to influence the hummock growth, because the inactive hummocks are distributed where the water table always lies below the ground surface. This suggests that drying in the pioneering forest is likely to have promoted the vegetation succession, which in turn has inactivated the hummocks (Fig. 5a). In contrast, the active hummocks are considered to have grown under the environment where the water table fluctuates across the ground surface (Fig. 5b).

Thus, the hummock formation requires both a high water table and paucity of snow which favor frost action. The peaty hummocks in Japan are distributed mostly in the mires under cold environments located in the Pacific Ocean side, such as eastern Hokkaido (*e.g.* Kushiro, Kiritappu and Nemuro) and central Honshu (*e.g.* Kirigamine and Senjogahara), lacking deep snow. This strongly supports that peaty hummocks favor the mires with winter frost action.

These climatic and hydrological conditions probably control the morphology of hummocks. In Finnish Lapland, pond ice excavates a notch at the foot of hummocks which are located in a waterlogged condition (Van Vliet-Lanoë and Seppälä, 2002). Active peaty hummocks in the Senjogahara mire often have a notch which is considered to be formed by frequent freeze-thaw alternations of surface water.

5. Environmental significance

Some recent studies have pointed out the significance of earth hummocks as an environmental indicator. For instance, in Finnish Lapland, Van Vliet-Lanoë and Seppälä (2002) suggested that earth hummocks indicate a general cooling trend associated with progressive depletion of summer insolation. Luoto and Seppälä (2002) also described that earth hummocks react quickly to variations in temperature, snow depth and precipitation. In the high Drakensberg, southern Africa, relict earth hummocks are indicative of hydrological changes which are caused by a gradual lowering of the water table due to desiccation along wetland peripheries (Grab, 2005).

Field data in the Senjogahara mire also suggest the environmental significance, especially for hydrology. The close relation between the hummock growth and the seasonal groundwater level change permits the estimation of past hydrological environments around the hummocks. Especially, the inactive hummocks with perennial underground water suggest the groundwater deepening, because the hummock formation is considered to require the seasonally waterlogged ground.

Future studies on the Japanese hummocks have to undertake terminological redefinition based on the mechanism of hummock formation, which will enhance the environmental significance of hummocks called “Tokachi-bozu” and “Yachi-bozu”.

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