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Japanese raised bogs: their special position within the Holarctic with respect to vegetation, nutrient status and development

Japanische Hochmoore: ihre spezielle Stellung in der Holarktik hinsichtlich Vegetationszusammensetzung, Nährstoffverhältnisse und Entwicklung

by

Antoni W.H. DAMMAN

1. INTRODUCTION

Climatic conditions suitable for the development of ombrogenous peatlands occur primarily in the boreal and cold temperate zones. In Japan, such conditions are found only on Hokkaido and in the mountains of Honshu (SUZUKI 1977, WOLEJKO and ITO 1986). The vegetation of several of these bogs has been studied in detail, e.g., YOSHIOKA (1977), MIYAWAKI and FUJIWARA (1970), ITO and IMEZAWA (1970), MIYAWAKI et al. (1977), TA-

CHIBANA and ITO (1980, 1981), SUZUKI et al. (1981), HOGETSU and OSHIMA (1982), KASHIMURA and TACHIBANA (1982) and TACHIBANA (1982).

The structure and floristic composition of the vegetation of Sphagnum bogs is remarkably similar throughout the Holarctic (TUEXEN et al. 1972). This applies especially to ombrotrophic bogs, although, of course, the geographical differences in the evolutionary history of the flora are also reflected in this vegetation. Aside from these differences, the Japanese raised bogs contain species that do not occur on ombrotrophic peat elsewhere. Very little attention has been paid to this in the literature. JENSEN (1977) referred to the rare occurrence of "Hochmoor" vegetation in Japan, and recently WOLEJKO and ITO (1986) drew attention to the unique conditions in these peatlands and the ecological significance of tephra deposits. The 18th International Phytogeographic Excursion provided a welcome opportunity to observe first hand the conditions in two raised bogs, the Yashimagahara and the Ozegahara mires, in the mountains of Honshu. Subsequently, Prof. K. Ito and Mr. L. Wolejko showed me a variety of peatlands on the island of Hokkaido.

The purpose of this paper is to point out the unusual conditions in the Japanese raised bogs and to compare them with raised bogs in other parts of the world. In addition, the effect of volcanic ash on the ionic composition of the bog water and the chemistry of the peat will be discussed, as well as its implications for peat bog development.

ACKNOWLEDGEMENTS

The research on Tasmania and Newfoundland reported here was supported by U.S. National Science Foundation Grants DEB-8109913 and DEB-7905194. The University of Connecticut Research Foundation provided part of the funds for travel to and in Japan. This paper would not have been possible without the help of many colleagues in Japan. I am grateful to Prof. Akira Miyawaki for all his efforts in organizing the International Phytogeographical Excursion and for including the Ozegahara and Yashimagahara mires in the program. Dr. Kazae Fujiwara's familiarity with the flora and vegetation of Japan was invaluable. Prof. Hyoji Suzuki led the trip through the Yashimagahara mire and provided much information on this raised bog. I am much indebted to Prof. Koji Ito for discussions and for the excellent and detailed arrangements for my trip through Hokkaido. Mr. Leslaw Wolejko was instrumental in guiding me through the mires of Hokkaido. I benefited much from his knowledge about the bogs on the island, both in the field and in discussions. Several other people helped in one way or another: Mr. Tsunehiko Nishikawa accompanied us to the Ukijima bog and Tennyogahara fen, Dr. Hisako Tachibana with helpful discussions on her mire studies, and Messrs. Akira Senda and Hidenari Tsubaki with transportation to the mires in northeastern Hokkaido. Thanks are also due to Mrs. Elna DeCarli for typing the manuscript and Ms. Mary Jane Spring for preparing the illustrations.

2. STUDY AREA

2.1. GEOGRAPHIC FRAMEWORK

Most of Hokkaido is located within the northern part of the temperate zone with hemiboreal conditions occurring at sea level along the north shore and at middle elevations farther south. True boreal forests are restricted to the higher elevations (HAEMET-AHTI et al. 1974). In northern Honshu, the hemiboreal subzone occurs at over 900 m and true boreal forests at over 1200 m (HAEMET-AHTI et al. 1974). The hemiboreal and boreal zones correspond roughly to the nemorial *Acer mono* zone and the montane *Abies sacchalinensis* zone of KOJIMA (1970).

The climate of Japan is greatly influenced by the Asian continent. In the areas where ombrogenous peat bogs occur in Japan, the winters are much colder, the summers warmer and the precipitation higher than in the comparable zones of western Europe. However, the climate is rather similar to that of eastern North America. That of Hokkaido is comparable to that of the northern half of Maine and southern Nova Scotia, although snowfall is higher in western Hokkaido.

2.2. MIRES VISITED

Yashimagahara mire, Kirigamine Highlands, Honshu (36°05'N, 138°10'E); altitude 1630 m. Raised bog with 2 complex domes separated by a water track. This is the southernmost high moor in Japan. Vegetation described by SUZUKI et al. (1981).

Ozegahara mire, Nikko National Park, Honshu (36°56'N, 139°15'E); altitude 1400 m. The largest mountain mire in Japan with several raised parts and extensive fen areas. Detailed descriptions in HARA et al. (1982) and MIYAWAKI and FUJIWARA (1970).

Ukijima mire, central Hokkaido (43^o42'N, 142^o43'E); altitude 868 m. A plateau bog with irregular pools, the plateau is raised over 4 m above the lagg. Vegetation described by ITO and UMEZAWA (1970).

Tennyogahara mire, central Hokkaido (43^o39'N, 142^o49'E); altitude 1210-1320 m. A soligenous fen on the slope of the Asahidake volcano. Vegetation described by TACHIBANA and SATO (1981).

Kushiro mire, eastern Hokkaido (43^o05'N, 144^o25'E); altitude about 10 m. An extensive fen area including very oligotrophic parts, but apparently no raised bogs. This is the nesting area of the Japanese crane (Grus japonensis).

Ochiishi mire, northeastern Hokkaido (43^o04'N, 145^o30'E); at low elevation along the coast. An extremely poor fen with locally well-developed hummocks.

Furen mire, northeastern Hokkaido (43^o15'N, 145^o21'E); altitude below 10 m. A large coastal mire with several low raised domes covered with a poor fen vegetation with high hummocks up to over 50 cm.

3. SPECIAL FEATURES OF JAPANESE BOGS

The surface of several bogs is raised above the water level in the lagg fens. This was most obvious in the Yashimagahara mire in the Kirigamine highlands, the Ozegahara mire in Nikko National Park, and the Ukijima mire in central Hokkaido. The Furen mire in northeastern Hokkaido is only slightly raised in its central parts. The Ukijima mire is a plateau bog with a flat central plateau, whereas all the others have one or more convex raised domes. Such raised areas appear to occur also in other Japanese bogs, e.g. the Sarabetso mire (MIYAWAKI et al. 1977, TACHIBANA and ITO 1980), the Matsuyama mire (TACHIBANA 1982), and perhaps the Takadayachi mire (Yoshioka 1963). The raised nature of the latter is uncertain, because peat depths rather than elevations are plotted for this mire.

Topographically and hydrogically these are raised bogs, as one would expect to find under the climatic conditions prevailing in this part of Japan. Therefore, the center ought to be ombrotrophic. However, the vegetation of the raised, and presumably ombrotrophic, central parts differs in several respects from that of ombrotrophic bogs elsewhere. Physiognomically most striking are: 1) the luxuriant vegetation with herbs and grasses playing a dominant role, and 2) the very subordinate role of upright and wintergreen ericaceous dwarf shrubs. Such species do occur in the Japanese flora, but they do not dominate the driest parts of bogs as they do in the corresponding North American and western European mires. The topography of the Yashimagahara is typical for a convex raised bog in the southern part of the raised bog zone. In north-eastern North America, such a bog would have been covered with a dwarf shrub vegetation dominated by Kalmia angustifolia and Gaylussacia baccata (DAMMAN 1977, 1979).

The Ozegahara mire is much wetter, and lawn communities occur over much of its surface, but here dwarf shrubs also do not occupy the ridges and hummocks. Similarly, the bog slope ("Randgehang") and marginal parts of the plateau of the Ukijima mire are not covered by an ericaceous dwarf shrub vegetation (ITO and UMEZAWA 1970) or heath forest as they are in Europe (OSVALD 1925) or North America (DAMMAN 1977, DAMMAN and DOWHAN 1981).

Chamaedaphne calyculata was the only ericaceous dwarf shrub observed as a genuine dominant, but this was always on weakly minerotrophic peats comparable to sites dominated by this species in eastern North America.

Floristically, these bogs are also peculiar. Several species not found in ombrotrophic bogs elsewhere occur on the raised bogs in Japan, e.g., Parnassia palustris, Carex michauxiana, and Osmunda cinnamomea. I am not familiar with the synecological amplitude of strictly eastern Asiatic vascular plants commonly occurring in these bogs. However, several of them have almost certainly nutrient demands that cannot be satisfied in genuinely ombrotrophic bogs, e.g., Heloniopsis orientalis, Hosta albo-marginata, H. rectifolia, Pogonia japonica, Hemerocallis middendorfii and Tofieldia japonica. Menyanthes trifoliata occurs commonly in bog pools. Admittedly, this species can also be found in bog pools in western Ireland, but only in blanket bogs of doubtful ombrotrophy and never in raised bogs. Similarly, Myrica gale occurs in the Ozegahara mire and is common in the Ukijima bog. This is a minerotrophic species that occurs on ombrotrophic bogs in the coastal zone; its occurrence on ombrotrophic peat is limited to areas geographically near salt water rather than to oceanic areas (DAMMAN 1977, 1978b). Its occurrence in the raised

parts of the Ozegahara and Ukijima mires is surprising.
Extensive carpets of Sphagnum papillosum make up the moss layer of the lawn communities of most of the raised bogs visited, and S. fuscum occurs only on hummocks and is never carpet-forming. Moreover, Sphagnum fallax and S. flexuosum occur frequently in these bogs, as is also reported by ITO and UMEZAWA (1970), MIYAWAKI and FUJIWARA (1970), and SUZUKI (1972).
The microtopography characteristic for raised bogs is very poorly developed in the Ozegahara, Yashimagahara and Ukijima mires. The vegetation varies mostly from lawn to mud bottom communities with hummocks virtually absent, especially in the first two bogs. Well-developed hummocks occurred in the Furen and Ochiishi mires in northeastern Hokkaido, but only as isolated hummocks in a wet, poor fen vegetation with Carex lasiocarpa, Sphagnum papillosum and S. flexuosum and with Moliniopsis japonica and S. papillosum, respectively.
This all suggests more nutrient-rich conditions than normally encountered in raised bogs. Ombrotrophic bogs can be locally enriched by fire, disturbance, or drainage. Evidence of fire was visible in the Yashimagahara mire in the Kirigamine highlands but not in the other peatlands. Obviously, the luxuriance of the Japanese bog vegetation cannot be attributed to either fire or other disturbances.
Volcanic ash layers are common in Japanese bogs, as pointed out by WOLEJKO and ITO (1986), who coined the name tephratrophic for these bogs. The Ozegahara mire has 12 tephra layers in the young peat that accumulated during the last 7000 years (SAKAGUCHI et al. 1982a), and YOSHIOKA (1963) and YAMANAKA (1963) report several tephra layers in the Takadayachi mire. Tephra was also clearly visible in several of the mires visited in Hokkaido, such as the Ukijima bog, Furen bog, and the Tennyogahara fen. These tephra layers occur often at shallow depth in the peat. That of the 1783 eruption of the Maekake-yama is found at 18-20 cm and 31-34 cm below the surface in 2 cores of the Ozegahara mire (SAKAGUCHI et al. 1982a). A tephra layer about 200 years old is at 17 cm below a Sphagnum papillosum carpet in Ukijima bog; and the latest tephra layer is at 22-25 cm below the hollows of the raised part of the Furen mire. The layer of surface peat overlying the tephra in the Ozegahara and Ukijima mires is rather thin compared to 200 years of accumulation in hummocks of ombrotrophic bogs in Fennoscancia (PAKARINEN and TOLONEN 1977, MALMER and HOLM 1984) or eastern North America (DAMMAN 1988).

In the Ukijima and Furen mires, the peat above the tephra was well-decomposed and amorphous whereas that below the tephra was much less decayed. The peat of the Tennyogahara mire, a slope fen, was highly humified and the tephra layer hat little effect on the degree of decomposition. There was no opportunity to look at the peat of the Ozegahara and Yashimagahara mires because of National Park regulations.

4. PEAT AND WATER CHEMISTRY OF JAPANESE BOGS

The Ozegahara mire is the best studied raised bog in Japan, and excellent data on peat and water chemistry have been published (HARA et al. 1982). To illustrate the effect of the tephra deposits on the conditions in these bogs, I will draw heavily on data in this volume and compare them with data from ombrotrophic bogs elsewhere, both from my own research and the literature.

4.1. IONIC COMPOSITION OF BOG WATER

SAKAMOTO (1982), in a very interesting study on the water chemistry of the Ozegahara mire, concludes that these waters are truly ombrotrophic. He bases this mainly on the low ionic concentrations in the water of bog pools on the raised parts of the mire and on the K, P, and N deficiency of the water judging by the high plant/pool and plant/precipitation ratios for these elements. However, the analysis below will show that the Ozegahara bog water differs in several respects from that of ombrotrophic bogs.

The Na concentration in the bog pools is remarkably low (Table 1) as is that of the precipitation (KAKAMOTO 1982, YAMAGATA 1982). This indicates that the oceanic influence is weak in these mountain bogs, at least from a biogeochemical point of view. Ionic concentrations of the water in ombrotrophic bog pools differ from those in the precipitation before it reaches the bog surface. Evaporation increases ionic concentrations, but not ionic ratios. On the other hand, uptake by plants and adsorption on peat selectively remove ions, whereas decay and leaching of ions from

Table 1. Ionic composition ($mg.l^{-1}$) and pH of pool waters in Ozegahara and other ombrotrophic bogs. The data for Newfoundland and Tasmania are means ± S.E., based on 2-weekly measurements in 7 and 3 pools, respectively.

Tab. 1. Ionengehalt ($mg.l^{-1}$) und pH des Wassers einer Moor-Schlenke in Ozegahara und anderen ombrotrophen Mooren. Die Angaben für Neufundland (7 Tümpel) und Tasmanien (3 Tümpel) basieren auf zweiwöchigen Messungen während der Vegetationsperiode.

(1) SAKAMOTO 1982, (2) DAMMAN 1986, (3) GORHAM 1958, (4) DAMMAN unpubl.; this includes most of the vegetative season.

	Na	K	Ca	Mg	Fe	SO_4	Cl	pH
Ozegahara, Japan (1)								
Naka-tashiro VI/'78	0.38	0.034	0.16	0.072	0.12	0.62		
IX/'78	0.213	0.041	0.15	0.062	-	1.11	0.402	4.8
Kami-tashiro VI/'78	0.29	0.035	0.11	0.089	0.09	0.50		
Stephenville Crossing, Newfoundland (2) Plateau pools (May-Sept)	3.89±0.10	0.10±0.017	0.25±0.018	0.46±0.017	0.124±0.017	-	6.84±0.35	4.49
Coom Rigg Bog Great Britain (3)	5.29	0.39	1.00	1.08	-	11.04	9.22	3.88
Lake Pedder blanket bog Tasmania (Nov.-May) (4)	7.84±0.35	0.54±0.09	0.70±0.05	1.22±0.05	-	1.88±0.24	13.76±0.62	4.38

Table 2. Ionic ratios (based on $mg.l^{-1}$) in water of bog pools and percentage of ocean-derived ions for a Japanese raised bog (Ozegahara) and three ombrotrophic bogs.
Values in table are calculated from data in SAKAMOTO (1982) for Ozegahara, DAMMAN (1986) for Stephenville Crossing, GORHAM (1958) for Coom Rigg Bog and DAMMAN (unpublished) for pools in a Gymnoschoenus blanket bog, Lake Pedder. Sea water ratios are based on WEAST (1968).

Tab. 2. Die Elektrolyten-Quotienten ($mg.l^{-1}$) in Moor-Schlenken und der Prozentanteil der aus dem Meer stammenden Ionen im japanischen Hochmoor Ozegahara und in drei ombrotrophen Mooren.
Die Werte in der Tabelle sind berechnet nach Angaben von SAKAMOTO 1982 (für Ozegahara), DAMMAN 1986 (für Stephenville Crossing), GORHAM 1958 (für Coom Rigg Bog), DAMMAN, unveröff. (für Moor-Schlenken in einem Gymnoschoenus-Deckenmoor, Lake Pedder). Der Elektrolyten-Gehalt des Meerwassers basiert auf Daten in WEAST (1968).

	Ratios				
	Na/Cl	K/Cl	Ca/Cl	Mg/Cl	SO_4/Cl
Naka-tashiro Ozegahara, Japan	0.530	0.102	0.373	0.157	2.76
Stephenvillle Crossing, Newfoundland	0.570	0.015	0.037	0.067	-
Coom Rigg Bog Great Britain	0.574	0.042	0.108	0.117	1.197
Lake Pedder Tasmania	0.569	0.039	0.051	0.089	0.137
Sea water	0.556	0.020	0.021	0.067	0.140

	Percentage derived from ocean				
	Na	K	Ca	Mg	SO_4
Naka-tashiro, Ozegahara, Japan	105	20	6	43	5
Stephenville Crossing Newfoundland	98	137	58	100	-
Coom Rigg Bog Great Britain	97	47	19	57	12
Lake Pedder Tasmania	98	51	41	76	102

decaying organic matter increase the ionic concentrations in the bog water. This can also cause strong seasonal changes, especially of mobile ions for which the biological demand is high, such as K (MALMER 1962, DAMMAN 1986). All these processes also change the ionic ratios.

Biological processes remove virtually no chloride from the water, and, as an anion, it is not adsorbed on the peat substrate. The former appears to be true for Na also, since Na/Cl ratios of water in ombrotrophic bog pools is close to that of sea water (Table 2). In the Ozegahara mire the Na/Cl ratio is 0.530 (on a weight basis), and thus only slightly lower than in sea water. Therefore, the Cl and Na concentrations of the pools compared to that of the precipitation will indicate the increase in ionic concentrations resulting from evaporation at the bog surface.

In Fig. 1, the Ca ion concentrations of raised bog pools studied by SAKAMOTO (1982) are plotted against their Na concentrations. If the changes in concentration after the precipitation reached the bog surface were caused only by evaporation, then the Ca/Na ratio would remain unchanged and all points would fall on the line drawn through the point for the Ca and Na concentration of the precipitation. In ombrotrophic bogs, the Ca/Na ratio of the pool water is much lower than that of the precipitation, primarily because of adsorption of Ca on the peat (DAMMAN 1986). However in the Ozegahara mire, the Ca/Na ratio is higher in the pools than in the precipitation (Fig. 1). This shows that Ca is added from another source to the pool water.

The SO_4 concentration of the pool water varies greatly on the Ozegahara mire (SAKAMOTO 1982). Fig. 2 shows this variation in SO_4 concentration among pools as well its independence of the Na concentration. This is especially clear for the September samples. Weather conditions affect the SO_4 concentration of pool water (GORHAM 1956) due to oxidation of sulfides to sulfides to sulphates during dry periods and flushing of SO_4 ions from the peat with the subsequent rain. At any one time, one would expect some variation in SO_4 concentrations among pools because of differences in pool dimensions and their position on the bog. However, the large differences in SO_4 concentration of the pool waters of the Ozegahara mire cannot be explained simply by differences in the size of the pools. The amount of sulfur that bog pools receive from the volcanic ash layers will vary, and this could account for the differences observed.

The Na/Cl ratios of the bog pools at Ozegahara are similar to those of ombrotrophic bogs (Table 2) and also approach that of seawater. This shows that these ions are almost completely derived from the ocean. The K/Cl, Ca/Cl, Mg/Cl and SO_4/Cl ratios are all much higher in the Ozegahara mire than in oceanic ombrotrophic bogs; this applies especially to the ratios for Ca, K, and SO_4 (Table 2). This means that the Ozegahara mire is enriched in these elements from non-marine sources. The marine contribution for each element can be calculated from its chloride ratio in pools and sea water, by expressing the sea water ratio as a percent

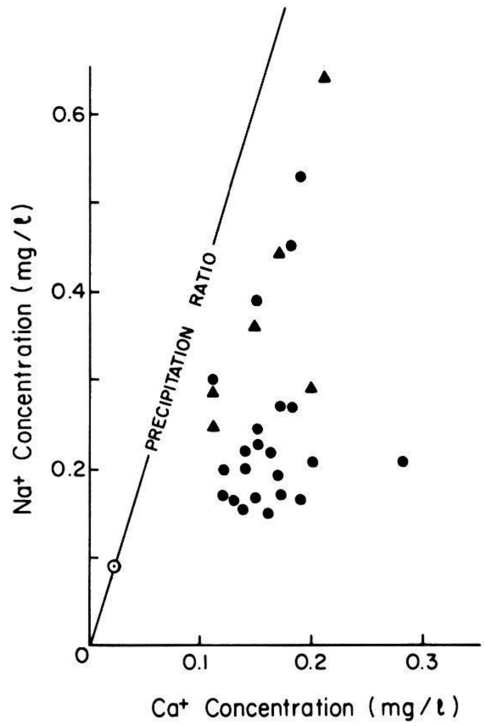

Fig. 1. Na and Ca ion concentration in pool water (triangles = June, dots = September, 1978) of Naka-tashiro, a raised part of the Ozegahara mire, in relation to that in the precipitation for June 1978 (circled dot). The line indicates the Na/Ca ratio in the precipitation; ion concentrations would remain on this line if concentration changes were caused only by evaporation. Graph plotted from data in SAKAMOTO (1982).

Abb. 1. Na- und Ca-Gehalt im Schlenken-Wasser von Naka-tashiro, einem höher gelegenen Teil des Ozegahara-Moores (Dreiecke = Juni, Punkte = September 1978) und im Niederschlag im Juni 1978 (Punkt im Kreis). Die Linie ist der Na/Ca-Quotient des Niederschlages. Die Ionen- Konzentration würde auf dieser Linie bleiben, wenn die Konzentrations-Schwankungen nur durch Verdampfung verursacht würden. Nach Daten von SAKAMOTO (1982).

of that in bog water (GORHAM 1957). At Ozegahara, the oceanic contribution of all elements, except Na, is much lower than in the other bogs (Table 2). Consequently, inputs from other sources account for a much larger part of the total input of these elements than in the other bogs. Removal of ions from the bog water lowers its ionic concentration. Thus, a larger part of the amount present can be explained by contributions from the ocean than is actually derived from this source. This means that the values in Table 2 tend to overestimate the oceanic contribution for elements actively taken up by the vegetation or adsorbed on the peat. For these elements inputs from other sources are even greater at Ozegahara than Table 2 suggests. This also explains oceanic contribution over 100% for K in the Stephenville Crossing bog.

The location of the pools on the raised parts of the Ozegahara mire appears to preclude the influence of mineral soil water. SAKOMOTO (1982), on the basis of differences in the ionic composition between the mineral

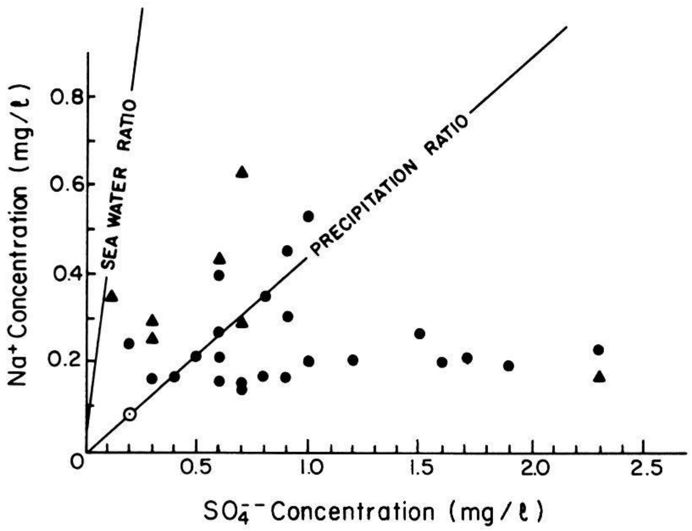

Fig. 2. Na und SO_4 ion concentration in pool waters of Naka-tashiro, a raised part of the Ozagahara mire, in relation to their ratios in precipitation for June 1978 (circled dot) and sea water. Symbols as in Fig. 1. Graph plotted from data in SAKAMOTO (1982).

Abb. 2. Vergleich zwischen dem Na- und SO_4-Gehalt im Schlenken-Wasser eines höher gelegenen Teils des Ozegahara-Moores (Naka-tashiro), dem Na/SO_4- Quotient im Niederschlag im Juni 1978 (Punkt im Kreis) und im Meerwasser. Nach Daten von SAKAMOTO (1982). Symbole wie in Abb. 1.

soil water and the water in bog pools, also concludes that these pools are never affected by mineral soil water. The Ozegahara mire is located in a forested mountain region far removed from the agricultural fields in the coastal parts of Japan. Therefore, enrichment of the mire by K, Ca and Mg in atmospheric dust of agricultural origin is unlikely. This would also have shown up in the precipitation data. This suggests strongly that the anomalous ionic composition of the bog pool water is caused by the tephra layers in the peat.

4.2. CHEMICAL COMPOSITION OF THE PEAT

The chemical composition of the peat provides a further insight into the differences between the Ozegahara mire and ombrotrophic bogs elsewhere. The ash content of the peat is much higher than in ombrotrophic bogs (Table 3). This can be the result of a higher input of mineral elements, a more rapid decomposition of the peat, or a combination of both. The elemental content of the upper 10 cm of the Ozegahara peat is also much higher than in an ombrotrophic bog (Table 4), especially that of Al (100x), Fe (> 16x) and Mg (> 12x). YAMAGATA (1982) does not indicate the surface vegetation in which the samples were taken. This was most likely

Table 3. Ash content (% oven-dry weight) of peat of a raised bog in Japan (Naka-tashiro, Ozegahara mire) and of ombrotrophic bogs.
Tab. 3. Aschengehalt (% Trockengewicht) im Torf eines Hochmoores in Japan (Naka-tashiro, Ozegahara) und in zwei ombrotrophen Hochmooren

Location	Mean	Range	Source
Ozegahara, Japan (8-68 cm)	7.14	4.52 - 9.86	YAMAGATA (1982)
Stephenville Crossing, Newfoundland (0-75 cm)	1.88	1.31 - 2.77	DAMMAN (1988)
Traneröds Mosse Sweden (0-100 cm)	2.68	1.66 - 3.83	DAMMAN (1978a)

Table 4. Comparison elemental content ($g.m^{-2}$) of surface peat (0-10 cm) of raised bogs in Japan and Newfoundland.
Data for Ozegahara are from YAMAGATA (1982) and for Stephenville Crossing from DAMMAN (unpublished).

Tab. 4. Die Elementmenge ($g.m^{-2}$) im Oberflächentorf (0-10 cm) japanischer und neufundländischer Hochmoore.
Daten für Ozegahara nach YAMAGATA (1982) und für Stephenville Crossing nach DAMMAN (unveröff.).

(1) Kalmio-Sphagnetum fuscae, (2) Scirpo-Sphagnetum tenelli, (3) Rhynchosporetum albae (DAMMAN 1977)

Location	Na	K	Mg	Al	Fe	Mn
OZEGAHARA, JAPAN						
Naka-tashiro	13.3	18.4	23.6	129	23.8	0.88
Kami-tashiro	7.2	10.9	12.0	91	16.1	0.47
STEPHENVILLE CROSSING NEWFOUNDLAND						
Ericaceous dwarf-shrub heath (1)	1.1	3.9	2.4	1.0	1.1	0.19
Scirpus caespitosus lawn (2)	1.1	3.8	4.1	2.3	2.8	0.32
Mud bottom (3)	1.4	1.9	4.4	3.9	4.6	0.06

a lawn vegetation belonging to the Moliniopsio-Sphagnetum papillosi (MIYAWAKI and FUJIWARA 1970). In any case, the elemental content is higher than in any of the three major plant communities of the Stephenville Crossing bog.

The nitrogen concentrations of ombrotrophic peat are very low and usually remain beween 0.6 and 1.3%. Characteristic is the initial leaching phase with decreasing N and increasing C/N ratio (DAMMAN 1986), followed by a very slow increase in N concentration that continues into the upper part of the catotelm (MALMER and HOLM 1984, DAMMAN 1988). During this accumulation phase, the C/N quotient decreases but rarely drops below 40. Figure 3 shows the distribution of N and C/N in an ombrotrophic bog (Stephenville Crossing) and that in a raised part of the Ozegahara mire. The latter shows a very different pattern; nitrogen concentrations increase with depth and C/N quotients decrease from 68 at the surface to 28 at 30 cm. C/N quotients as low as 8-11 occur from 48-150 cm, and at several depth below this (YAMAGATA 1982). This change in N concentration and C/N ratio with depth is typical for minerotrophic peat where N immobilization in the microbial biomass is not limited by the deficiency of other elements. In ombrotrophic bogs, this pattern occurs only in extremely oceanic bogs with very high marine-derived nutrient inputs, such as those in Southern Hemisphere peatlands on Macquarie Island and parts of New Zealand (DAMMAN 1988).

Clearly, high marine inputs can be ruled out as a cause of the anomalous N distribution in the Ozegahara mire, as shown by the very low Na and Cl inputs (SAKAMOTO 1982, YAMAGATA 1982). Since mineral soil water does not enrich this peat, volcanic ash is the most likely source of additional nutrients, and the cause of the high mineral element content and the anomalous pattern of N distribution in this raised bog peat.

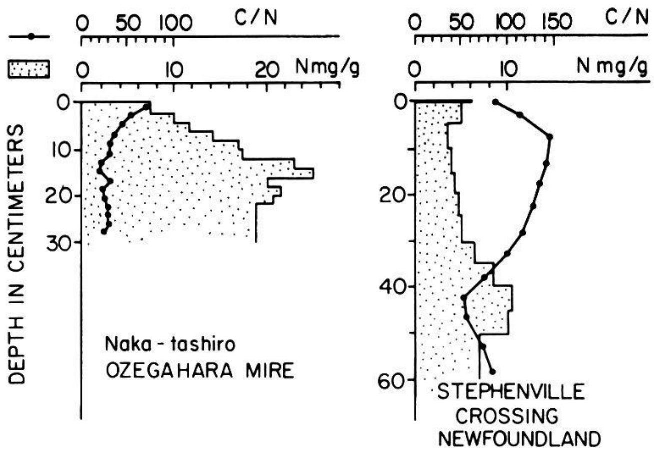

Fig. 3. Changes in N concentration and C/N quotient in the surface peat of a Japanese raised bog (Naka-tashiro) and a clearly ombrotrophic raised bog (Stephenville Crossing). The graph for Nakatashiro is based on N data in HOGETSU et al. (1982); organic carbon is calculated as 58% of the loss-on-ignition using ash contents for the same peat from YAMAGATA (1982). The graph for the Stephenville Crossing is based on data in DAMMAN (1988).

Abb. 3. Stickstoff-Gehalt und C/N-Quotient im Oberflächentorf eines japanischen Hochmoores (Naka-tashiro) und eines echten ombrotrophen Hochmoores (Stephenville Crossing). Die Graphik basiert auf Daten für N in HOGETSU et al. (1982) und für organische Stoffe in YAMAGATA (1982). Der organische Kohlenstoff ist berechnet als 58% des Verbrennungsverlustes berechnet aus dem Aschengehalt des gleichen Torfes. Die Daten für Stephenville sind aus DAMMAN (1988).

5. EFFECT OF VOLCANIC ASH ON THE VEGETATION AND DEVELOPMENT OF BOGS

Tephra deposition fertilizes the bog, and this will have an immediate impact on the floristic composition of the vegetation. In the bogs visited, the youngest tephra was deposited over 200 years ago, so that the direct effect could not be observed. With the passage of time, the effect of the tephra becomes less pronounced because of removal of nutrients with the drainage water and the accumulation of peat on top of the tephra. The rate of accumulation will determine how rapidly the bog surface will outgrow the effect of the volcanic ash. This rate itself will depend on the chemical composition and amount of tephra deposited. Obviously, the effect is longlasting. This is caused by the incorporation of nutrients in the detritus cycle and the acceleration of peat decay by the tephra deposition.

The lowest parts of the bog surface, the hollows and pools, show the effect longest. They receive nutrients leached out of the higher parts and the tephra occurs at shallower depth. Therefore, the hummock vegetation will express the enrichment less clearly than the hollows, especially in its moss carpet. The deep root systems of several of the bog plants will reach into the tephra layer, even if this is buried under 40 or 50 cm of the peat. Their litter and leachates will enrich the moss carpet. This is probably the cause of the abundance of Sphagnum papillosum on many of these bogs, and the frequent occurrence of other somewhat more nutrient-demanding species, such as S. flexuosum and S. fallax.

Peat accumulation is caused by slow decomposition rather than fast growth (CLYMO 1984). Accumulation of peat above the anaerobic level results primarily from the extreme nutrient-deficiency of the substrate (DAMMAN 1979b, 1986). Volcanic ash will decrease accumulation by accelerating decomposition. This can increase decay within the aerobic acrotelm to the extent that it equals or exceeds production. Therefore, peat accumulation will be slow, or may not occur for a period of time, following the deposition of volcanic ash. Moreover, peat already on the site will decay more rapidly.

This increased decay will also affect bog development. Under the climatic conditions of northern Japan, ombrogenous bogs will develop as convex raised bogs (Fig. 4) or as plateau bogs. The former if precipitation eventually limits their development, and the latter if precipita-

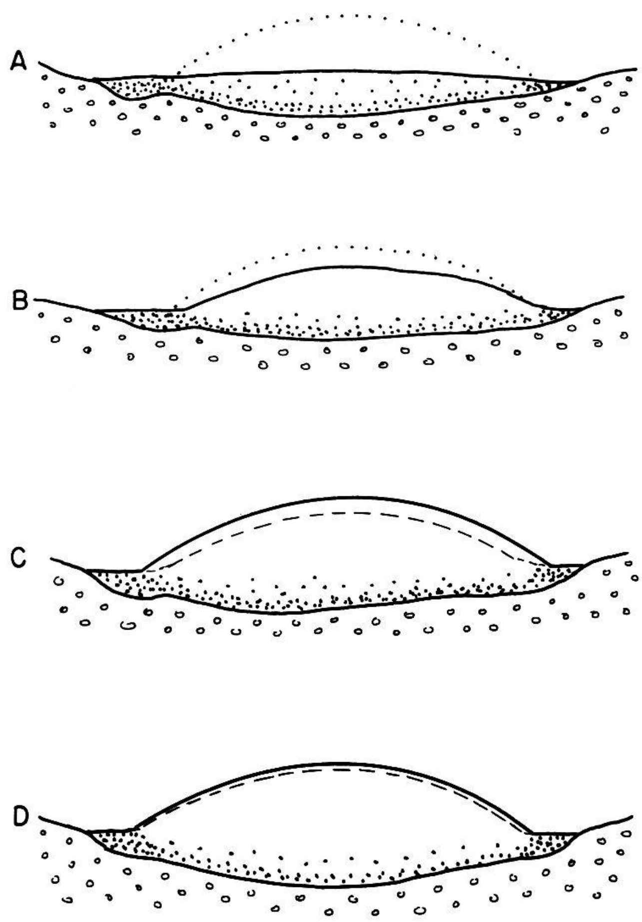

Fig. 4. Development of a raised bog (A-C) with a maximum elevation limited by precipitation. It is assumed that climatic conditions do not change during bog development. Mineral soil water influence is shown by stippling; the density of stippling indicates differences in density. The dotted line shows the potential critical level of the water mound in this peat deposit under the existing climatic conditions; the broken line is its actual level. The water table will be near the bog surface if it is below the critical level of the water mound. Volcanic ash will accelerate decay, reduce the thickness of the acrotelm, and result in a wetter bog surface (D), except during the early stage of bog development.

Abb. 4. Entwicklung eines Hochmoores (A-C), dessen Höhenwachstum durch Niederschlag beschränkt ist, vorausgesetzt, dass das Klima unverändert bleibt. Der Einfluss des Mineralbodenwassers ist durch Punktierung angegeben; die Dichte der Punktierung zeigt die Unterschiede im Elektrolytengehalt. Die punktierte Linie stellt das potentielle kritische Wasserniveau dar, die gebrochene Linie die aktuelle Höhe. Der Wasserspiegel ist der Mooroberfläche am nächsten, wenn diese unter dem kritischen Niveau liegt. Vulkanische Asche beschleunigt die Zersetzung, vermindert die Dicke des Akrotelm und verursacht daher eine nässere Mooroberfläche (D), ausgenommen am Anfang der Moorentwicklung.

tion is ample and other factors limit their development, such as length of the vegetative season or atmospheric nutrient supply (DAMMAN 1979b, 1986). Tephra deposition on a bog in equilibrium with the climate (Fig. 4C) will accelerate decay and reduce the thickness of the acrotelm. The level of the water mound in the peat (IVANOV 1981, INGRAM 1982) depends on the climate and the permeability of the peat above the water level in the lagg. Decay in the anaerobic peat of the catotelm is exceedingly slow (CLYMO 1984) and presumably not affected to any significant extent by volcanic ash. The level of the water mound, and the perched water table above it, should also remain virtually unchanged. Consequently, the reduction in the depth of the acrotelm will bring the water table closer to the surface (Fig. 4D). This increased wetness of the bog surface favours the predominance of lawn and mud bottom communities. This and the enrichment of the bog surface by the volcanic ash appear to be the main reasons for the very limited occurrence of heath communities with ericaceous dwarf-shrubs on the Japanese bogs, even on those in Hokkaido.

The acrotelm is very thin during the early stages of bog development (Fig. 4A, B) or on the plateau of plateau bogs. Volcanic ash will minimally increase the wetness of these bogs, because the water table is already close to the surface. Of course, it will fertilize the bog surface and reduce peat accumulation, so that further bog development is arrested here too.

Tephra layers are widespread in Japanese bogs (WOLEJKO and ITO 1986), and many bogs have several layers. This repeated interruption of normal peat accumulation will increase the time required for bogs to reach an equilibrium with the climate. In the Norhern Hemisphere, most raised bogs seem to be in equilibrium (GRANLUND 1932, DAMMAN 1979b), but this may not be true in Japan. Most of the bogs visited appeared to be raised less than one would expect under these climatic conditions.

No genuine ombrotrophic vegetation was seen in any of the bogs visited. The vegetation of the hummocks locally approaches ombrotrophy, especially in its moss layer, but more nutrient-demanding vascular plants are always present. Thus, these hummocks are comparable to those developing in minerotrophic fens. This is obvious in the field to anyone familiar with ombrotrophic bogs elsewhere, but this is not clear from the literature. Mainly, because very small sample plots (1-2 m^2, or less) are used in all studies. These plots refer to conditions in individual hummocks and cover areas well below the minimal area of these hummock communities. Therefore, they do not provide a realistic impression of the species composition of these communities. They also do not indicate that these hummock communities cover only very small areas of the bog as a whole.

The hummock and lawn communities described from the Japanese raised bogs belong, without doubt, to the Oxycocco-Sphagnetea Br.-Bl. et Tx. 1943. This class includes both minerotrophic peatland vegetation (poor and extremely poor fens) and ombrotrophic bog vegetation. The major subdivisions of this class by TUEXEN et al. (1972) appear to provide a reasonable breakdown of the Japanese peatland vegetation, but the ecological and geographic comparisons misrepresent the actual conditions. The hummock vegetation, the Myrica tomentosae-Sphagnion fusci Tx., MIYAWAKI et FUJIWARA 1972, is nutrient-enriched and comparable to hummocks in minerotrophic peatlands. It is not the East Asian counterpart of the Kalmio-Sphagnion fusci or Calluno-Sphagnion of the ombrotrophic peatlands of eastern North America and northwestern Europe, respectively. Similarly, the Moliniopsio-Sphagnion papillosi (Tx. 1964) Tx., MIYAWAKI et FUJIWARA 1970, is not the counterpart of the lawn vegetations of the ombrotrophic bogs elsewhere but comparable to plant communities of the European Calluno-Sphagnion papillosi (Schwick. 1940) Tx. 1970 occurring in laggs and on other minerotrophic sites.

The hollow communities fit well into the eastern Asian representative of the European Rhynchosporion albae (KOCH 1926) but, of course, they are also nutrient-enriched by the occurrence of tephra.

6. CONCLUSIONS

In spite of the clearly raised surface of many Japanese bogs, they are not covered with an ombrotrophic bog vegetation but rather with a poor or extremely poor fen vegetation, in the sense of the Scandinavian mire ecologists. Tephra layers are common in bogs, and this enrichment must be attributed to them. Therefore, the name tephratrophic, introduced by Wolejko and Ito, is very appropriate. None of the bogs visited was genuinely ombrotrophic, and apparently such bogs do not occur in Japan. The floristic composition of the bog vegetation has been well studied in Japan. However, their vegetation should not be considered representative for that of bogs in eastern Asia as a whole.

These tephratrophic bogs differ from ombrotrophic ones in their water chemistry, but the difference is most clearly reflected in the chemical composition and humification of the peat. The nature of the tephra and the time since the deposition of the youngest tephra layer will affect the surface vegetation. It still has a dominant effect after 200 years, e.g. Ozegahara mire, and thus is clearly long-lasting. The abundance of Sphagnum papillosum in these tephratrophic bogs is not an oceanic effect but primarily edaphically controlled. This is certainly true for the mountain bogs.

Volcanic ash also affects bog development by increasing decay and reducing accumulation. Many raised bogs do not appear to have reached a stable state yet, in contrast to those in other parts of the Northern Hemisphere. This effect of tephra deposition on bog development needs to be investigated. The Japanese bogs offer ideal conditions for such studies.

SUMMARY

This paper points out the unique features of the Japanese raised bogs and compares them with raised bogs in other parts of the world. The Japanese raised bogs differ from ombrotrophic bogs in the following respects: 1) the abundance of grasses and herbs, and the subordinate role of ericaceous dwarf-shrubs, 2) the presence of many species not found in ombrotrophic bogs elsewhere, such as Parnassia palustris, Carex michauxiana, or Sphagnum flexuosum, 3) the overrepresentation of Ca ions and the large spatial variation in SO_4 concentration in the bog pools, 4) the more highly humified peat, the higher ash percentage (3x), and the larger amounts of Al (100x), Fe (> 16x) and Mg (> 12x) than those in the surface peat of ombrotrophic bogs, 5) the rapid increase in N and decrease in C/N with peat depth; there is no indication that nutrient-deficiency of the peat limits N immobilization.

These raised bogs are not covered with an ombrotrophic bog vegetation but with a poor or extremely poor fen vegetation. This enrichment is caused by volcanic ash. Its effect on the surface vegetation remains very pronounced after over 200 years.

Tephra deposition increases decomposition, reduces peat accumulation, and slows bog development. It does not affect the water mound in the peat deposit. Since it can reduce the thickness of the acrotelm, it tends to increase the wetness of the bog surface. This may explain the dominance of lawn and mud bottom communities, even on convex raised bogs. The abundance of Sphagnum papillosum in the moss carpet appears to be due to the presence of the tephra; it cannot be explained by the oceanic conditions in these mires.

ZUSAMMENFASSUNG

Die japanischen Hochmoore sind nicht mit einer ombrotrophen Hochmoorvegetation bewachsen, sondern tragen eine minerotrophe Vegetation, die indessen mager bis sehr mager ausgebildet ist. Diese Moore haben eine deutliche hochmoorartige Form. Sie unterscheiden sich von den ombrotrophen Mooren insbesondere durch: 1) die Häufigkeit von Gräsern und Kräutern und die untergeordnete Rolle der Zwergsträucher (Ericaceae), 2) das Vorkommen von vielen Arten mit höherem Nahrungsbedarf wie Parnassia palustris, Carex michauxiana oder Sphagnum flexuosum, 3) den höheren Gehalt an Ca-Ionen und die breite Variation der SO_4-Konzentration in den Moor-Tümpeln, 4) den zersetzteren Torf, den höheren Aschengehalt (3x) und die viel grössere Menge Al (100x), Fe (>16x) und Mg (>12x) als im Oberflächentorf der ombrotrophen Moore, 4) die rasche Zunahme des N-Gehaltes und die Abnahme des C/N-Quotienten mit dem Alter (d.h. der Tiefe) des Torfes; die N-Immobilisierung wird hier nicht durch Nährstoffmangel beschränkt wie in eigentlichen ombrotrophen Hochmooren. Ausserdem gibt es verhältnismässig viel Ca im Moorwasser und grosse Unterschiede im SO_4-Gehalt der Schlenken.
Die Ablagerung von vulkanischer Asche ist die Ursache dieser Eigentümlichkeiten der japanischen Hochmoore. Auch mehr als zwei Jahrhunderte nach der Tephra-Ablagerung ist dieser Einfluss noch immer klar in der Vegetation zu beobachten. Die Tephra-Ablagerung beschleunigt die Zersetzung, verzögert die Torfanhäufung und verlangsamt die Moorentwicklung. Aber sie hat keinen Einfluss auf das kritische Niveau des Wasserstandes in der Torfablagerung. Daher ist die Akrotelm dünner und die Oberfläche des Moores nässer als in vergleichbaren Hochmooren ausserhalb Japans. Das erklärt wahrscheinlich die Dominanz von kurzhalmigen Weissmoor-, Schlenkenweissmoor- und Torfschlammgesellschaften, sogar auf gewölbten Hochmooren, anstatt Reisermoorgesellschaften. Die Häufigkeit von Sphagnum papillosum im Moosteppich dieser Moore scheint auch eine Folge der vulkanischen Ascheablagerung zu sein; es kann nicht durch das ozeanische Klima in diesen Mooren erklärt werden.

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