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Ecosystems and Monitoring of Miyatoko, Akaiyachi and Kushiro Mires

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Errata

Page ii, line 8 (contents):
For "17. Selection of Effective Spectral Bands with" read "17. Selection of Effective Spectral Bands from".

Page 63, line 13:
For "8.0°C" read "ca. 4°C" and for "ca. 4°C" read "8.0°C".

Pages 73-74:
Although the numbering of the captions in Figs. 2 and 3 on pages 73 and 74 are correct, the figures themselves were inadvertently switched.

Contents

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Preface

Mires, also known as peatlands, had long been considered as worthless areas which could not be used for housing, agriculture or other productive purposes. Extensive drainage of groundwater, peat extraction and land reclamation have fragmented or completely destroyed many mires in the past. Consequently, extant mires have become threatened landscapes.

Mires are classified according to their hydrological conditions as either bogs, fed only by precipitation, or fens, fed by surface and/or ground waters from their watersheds as well as by precipitation. Many of the previous studies on the classification of Japanese mires have been conducted based on vegetation, largely ignoring hydrology. A re-inventory of mires is therefore necessary for the conservation of these threatened landscapes.

The ecosystem approach is now widely applied to studies of lakes and forests or forest watersheds. Such an approach, however, has not been common in mire research. When, in 1991, we started a 5-year research project on the characteristics of wetland ecosystems and their resilience in the face of environmental change, we set as our research goal understanding of the structure and function of mire ecosystems. We firmly believed then, and remain convinced, that integrated information on mire ecosystems is essential for their conservation.

The present report deals with 3 Japanese mires of different scales, ecosystem structures, landscapes, geographical locations and levels of human impacts, studied between 1991 and 1995. Miyatoko Mire, the smallest of the 3 and located in a pass between mountains, seemed to be the least disturbed by human activities. This mire is a complex of bog and fen ecosystems. Akaiyachi Mire is located near a lake. This mire is now surrounded by irrigation ditches and rice paddies created by conversion of peatlands. Despite conversion of some of its land to agricultural uses, Akaiyachi Mire maintains its largely bog ecosystem intact. Kushiro Mire, located in the lowlands of Hokkaido, is the largest mire in Japan. This mire is mostly fen, having a vast watershed area. The human impact on Kushiro Mire seems to be highest among the 3 mires we studied.

We tried to develop methods for monitoring mire plants at different structure levels with various equipment, ranging from a conventional camera with interval operation capabilities and an airborne compact spectrum imager to Landsat data, according to the extent of mires. As mires are physically and chemically nourished by water, hydrological factors were studied intensively in the present study.

Our research on mires is continuing. Yet the present report may give some perspective on Japanese mires and the state-of-the-art of the monitoring methods we have developed and used. We would welcome critical comments from readers, which would surely improve our research and contribute to better understanding of mire ecosystems.

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Acknowledgements

All the mires which we surveyed are legally protected. We express our gratitude to the following organizations for permission to conduct the research presented here: the Cultural Properties Protection Department of the Agency for Cultural Affairs, the Fukushima Prefectural Department of Education, the Aizuwakamatsu City Board of Education and the Wakamatsu Forestry Office for the study of Akaiyachi Mire, the Fukushima Prefectural Department of Environmental Conservation, the South Aizu District Office of Fukushima Prefecture, the Tourism Division of Nango Village and the Tajima Forest Office of Fukushima Prefecture for the study of Miyatoko Mire, the Kushiro-Shitsugen National Park Office, and the Nature Conservation Bureau of the Environment Agency for the study of Kushiro Mire.

We thank the National Space Development Agency of Japan for providing Landsat and multispectral scanner (MSS) data on Kushiro Mire. The research on Akaiyachi Mire was performed partly as a project conducted by the Research Group on the Natural Monument-Akaiyachi Mire and was supported by the Aizuwakamatsu City Board of Education under the auspices of the Agency for Cultural Affairs and the Fukushima Prefectural Department of Education. Thanks are also due to Prof. Toshimichi Kashimura, Faculty of Education, Fukushima University, Prof. Tatsuichi Tsujii, Faculty of Agriculture, Hokkaido University and Prof. Hiroaki Sumida, College of Agriculture and Veterinary Medicine, Nihon University, for their critical comments and discussion of the present study.

PART I.   MIYATOKO MIRE

1
Environment of Miyatoko Mire

Toshio Iwakuma

A number of small- to medium-sized mires of several hectares to several tens of hectares in extent are located at altitudes of 600—1100 m in the Minami Aizu district of Fukushima Prefecture, central Honshu, Japan. Specifically these are Miyatoko (area 6.5 ha, altitude 830 m), Komado (area 27.3 ha, altitude 1100 m), Takashimizu (area 3 ha, altitude 660 m) and Yanohara (area 20.6 ha, altitude 660 m) Mires.

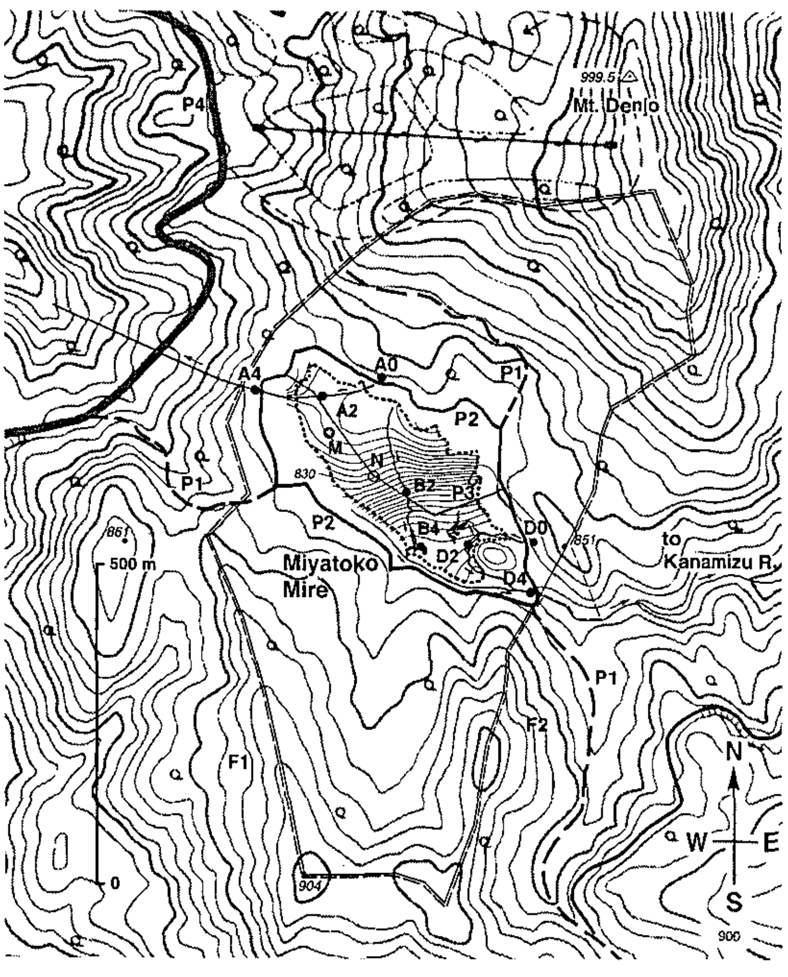

Fig. 1. Topographic map of Miyatoko Mire made by combining 1:25,000 scale maps (Aizuyamaguchi and Izumida, Geographical Survey Institute, 1990) with the results of a topographic survey in the mire. Contour lines in the mire are at 0.1 m intervals. M: meteorological monitoring tower; A0, A2, A4, B2, B4, C2, D0, D2, D4: sites of limnological and biological surveys. —: boundary of watershed; P1—P4: boardwalk, promenades or roads; •••: boundary of mire; - - -: boundary of Fukushima Prefectural Nature Conservation Area. (Redrawn from Iwakuma 1995).

Location and geological features of Miyatoko Mire

Miyatoko Mire (lat 37°14'48"N long 139°34'6"E, altitude 830 m) is located on a pass between Mount Denjo (altitude 999.5 m) and another mountain of 904 m altitude. Slopes of these mountains, which form the watershed of the mire, are covered with secondary deciduous forests dominated by *Quercus serrata* Thunb. ex Murray, *Q. crispula* Blume, *Magnolia obovata* Thumb. and *Alnus japonica* (Thumb.) Steud. (Takehara, 1995). The total area of the mire watershed is 54.1 ha.

The mire is elliptical in shape, measuring ca. 400 m along its longitudinal northwest to southeast axis and ca. 170 m across from northeast to southwest. The highest site is near the northeast tip of the short axis from where the ground slopes toward the southern tip of the mire. The height difference between the highest and lowest sites is 2.5 m (Nohara and Iwakuma, 1995a).

Several studies have been conducted in this mire since 1967 (Baba, 1969; Suzuki and Nishida, 1973). Flora and vegetation have been studied by Baba (1969), Kubota (1973), Higuchi (1975), Igarashi (1975) and Takehara (1995). No obvious change in vegetation has been detected during the past 30 years. Aerial photographs of these areas were taken in 1947 by the U.S. Army and after 1962 by either the Forestry Agency or the Geographical Survey Institute. Based on these photographs, forests within the watershed of the mire seemed to have remained unchanged during this period. The mire and its watershed areas have been designated by Fukushima Prefecture as a prefectural nature conservation area since 1975. A 40 cm wide boardwalk was built along the long axis of the mire in 1979 (Fig. 1).

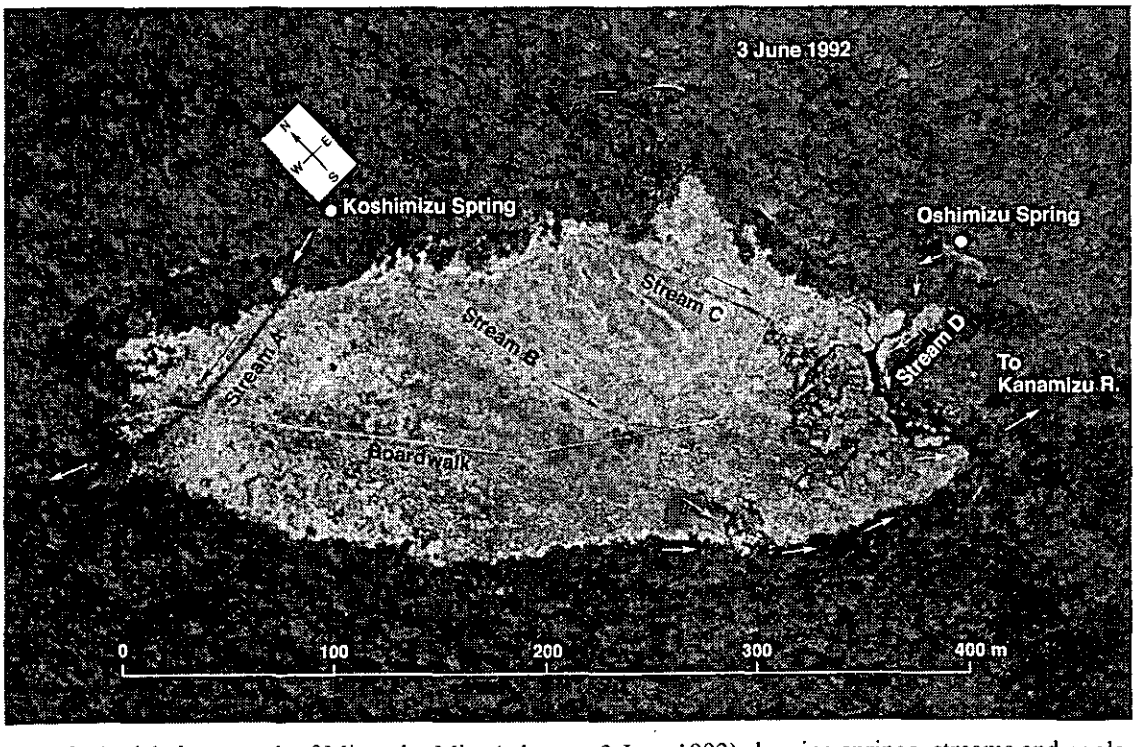

Fig. 2. Aerial photograph of Miyatoko Mire (taken on 3 June 1992) showing springs, streams and pools.

The bedrock of the mire is concave, like a lake basin (Suzuki and Nishida, 1973). The maximum peat depth is 6 m near the center of the mire based on cores taken at 20 locations (Suzuki and Nishida, 1973). The ^{14}C ages determined for the peat were 7000 BP for the 2.75—3.00 m depth interval (Choi and Hibino, 1985) and 11990 ± 250 BP for the 5.5—5.59 m depth interval (Kanouchi, 1991).

The mire is mostly covered with *Sphagnum fuscum* (Schimp.) Klinggr., *S. magellanicum* Brid, *S. palustre* L. and *S. papillosum* Lindb. and along the margin with a shrub, *Ilex crenata* Thumb. var. *paludosa* (Nakai) Hara (Takehara, 1995). There are four streams crossing the mire (streams A, B, C and D, Fig. 2). Streams A and D originate from springs at the foot of the slope of Mt. Denjo, flow into the mire and out of the northwest and southeast ends of the mire, respectively (sites A4 and D4, Fig. 1). Stream D flows through the lower southeast part of the mire. Stream B flows down the gentle slope in the mire, through a channel along the southwestern periphery of the mire, and finally out at site D4 (see Fig. 1). Site D4 is a headwater of the Kanamizu River, a tributary of the Tadami River.

Meteorology

A meteorological monitoring tower was set up near the northwest end of the mire in August 1991 (site M, Fig. 1). Air temperature, soil temperature at 10 cm depth, solar radiation, wind speed, and precipitation were recorded every 10 or 20 min (Nohara and Iwakuma, 1995b). Daily mean air temperature ranged from ca. -7°C to ca. 24°C and daily minimum and maximum air temperatures recorded during the period from August 1991 to November 1993 were -16°C and 30°C (Fig. 3a). Snowfall events were observed between November and April, and the mire surface was entirely covered with snow between December and March. Under the snow, soil temperature at 10 cm depth was a constant 0.4°C. Daily maximum soil temperature increased rapidly after snow thaw from 0.4°C to 7.3°C during the period from 16 to 18 April 1992 and from 0.4°C to 9.2°C during the period from 2-4 May 1993 (Fig. 3b). There was no indication of freezing in the peat soil. Solar radiation (Fig. 3c) was highest in May (20 MJ m^{-2} day^{-1} or 464 MJ m^{-2} $month^{-1}$). Daily mean wind speed fluctuated between 1 and 8 m s^{-1} throughout the year but the maximum wind speed often exceeded 20 m s-1 (Fig. 3e).

Annual mean (and minimum and maximum) air temperatures recorded at Nango Meteorological Observatory, 2.8 km northwest of the mire (lat 37°15'42"N long 139°32'42"E, altitude 540 m until February 1991 and lat 37°15'48"N long 139°32'24"E, altitude 494 m after March 1991), were: 10.5 (-15.6—35.5) in 1990, 9.7 (-13.7—32.5) in 1991, 9.4 (-15.6—33.1) in 1992 and 9.1 (-10.8—30.9°C) in 1993 (Table 1). Annual duration of sunshine was 1342, 1239, 1389 and 928 h in 1990, 1991, 1992 and 1993, respectively. Annual precipitation was 1217, 1487, 1310 and 1440 mm in 1990, 1991,

The annual average air temperature for the year from July 1992 to June 1993 in the mire (7.9°C) was 1.5°C lower than that at the Nango Observatory (9.4°C). The precipitation for the June—November 1992 period in the mire (635 mm) was higher than that at the Nango Observatory (551 mm). The maximum snow depth recorded at

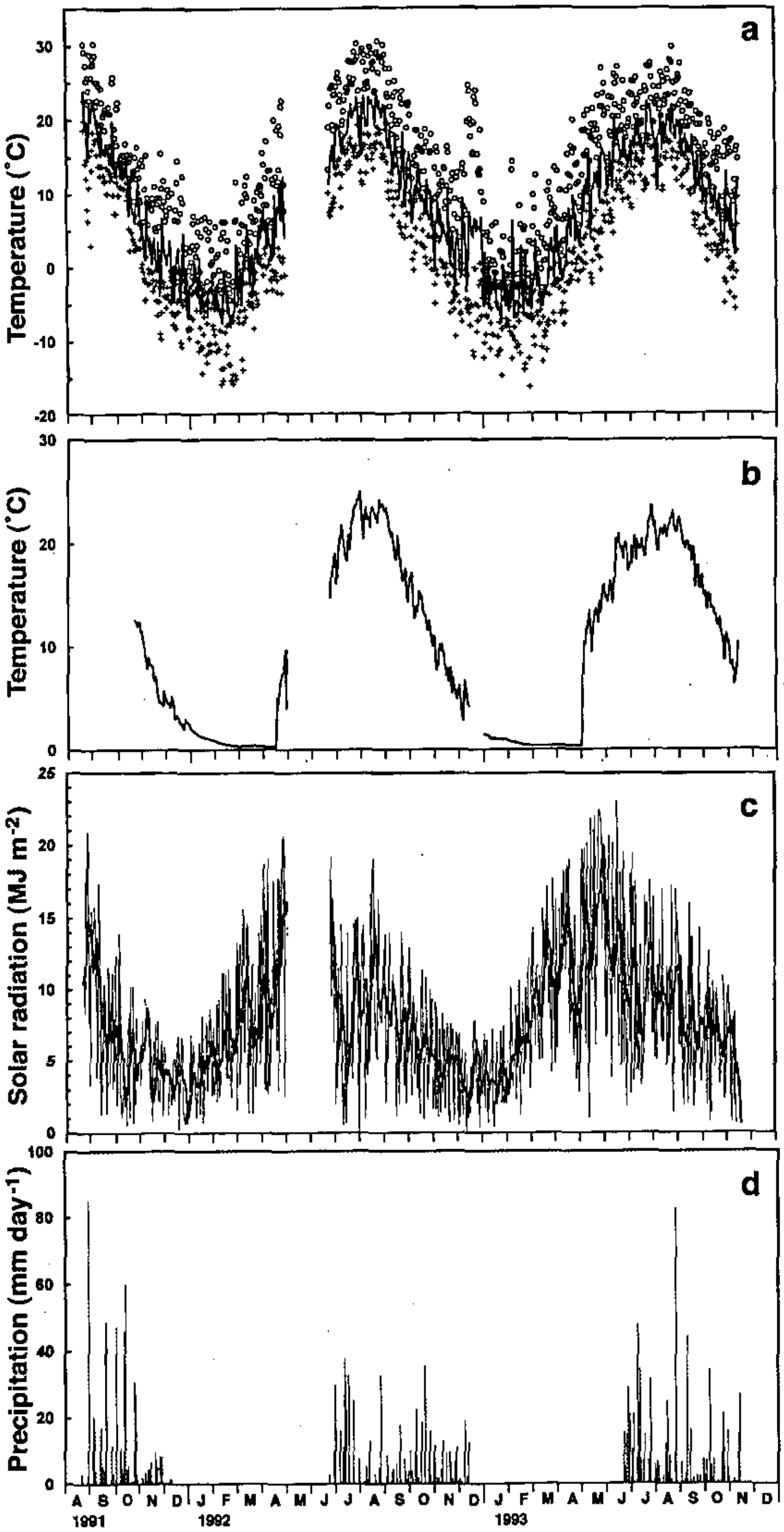

Fig. 3. Weather recorded at the monitoring tower in Miyatoko Mire. a: daily maximum (°), minimum (+) and mean (-) air temperatures; b: daily mean soil temperature; c: daily (—) and 7-day moving average (-) solar radiation; d: daily precipitation; e: daily maximum (—) and mean (-) wind velocity.

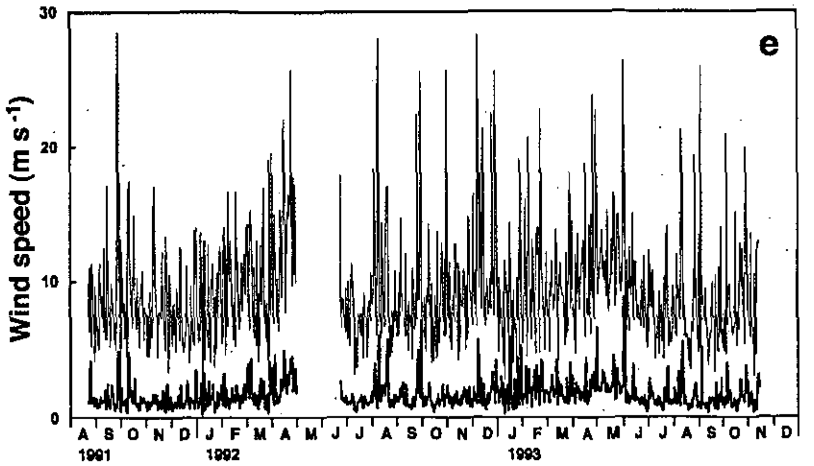

Fig. 3. continued.

Table 1. Comparison of monthly meteorological data at Miyatoko Mire with those at Nango Observatory (Iwakuma, 1995). * July 1992—June 1993; Ha.s.l. = above mean sea level.

Month	Miyatoko Mire (830 m Ha.s.l.)										Nango Observatory (494 m Ha.s.l.)						
	Air temperature			Wind speed		Solar radiation	Precipitation	Soil temperature			Air temperature			Wind speed		Sunshine duration	Precipitation
	Mean °C	Max. °C	Min. °C	Mean $m\ s^{-1}$	Max. $m\ s^{-1}$	$MJ\ m^{-2}$	mm	Mean °C	Max. °C	Min. °C	Mean °C	Max. °C	Min. °C	Mean $m\ s^{-1}$	Max. $m\ s^{-1}$	h	mm
1991																	
Aug											21.7	32.1	9.1	2.0	6.0	137.1	205.0
Sep	17.6	30.3	7.4	1.5	28.5	262.2	155.0				19.4	31.0	10.5	1.8	12.0	98.9	146.0
Oct	10.7	22.4	2.4	1.5	17.5	120.2	289.0				12.7	22.9	4.7	1.8	7.0	67.7	256.0
Nov	2.7	15.6	-9.6	1.2	17.1	104.0	77.5	7.2	11.4	1.1	4.6	16.8	-4.6	2.1	8.0	97.0	71.0
Dec	-0.6	14.5	-10.7	1.4	14.1	92.6		3.4	5.6	1.1	1.3	13.4	-6.5	2.3	8.0	87.6	54.0
1992																	
Jan	-3.1	7.1	-14.3	1.4	13.7	142.3		1.3	2.1	0.8	-1.4	5.6	-10.4	2.2	10.0	90.3	87.0
Feb	-4.7	11.7	-15.8	1.7	16.7	180.8		0.5	0.9	0.3	-2.9	9.7	-15.6	2.6	9.0	93.6	89.0
Mar	0.5	12.4	-13.9	1.9	19.1	270.2		0.4	0.5	0.1	1.8	12.3	-8.2	2.6	10.0	106.8	72.0
Apr	6.0	22.5	-3.5	2.6	25.8	342.3		3.0	12.0	0.2	7.7	24.3	-2.2	3.3	11.0	155.4	107.0
May											11.7	23.7	-0.8	2.8	10.0	109.0	123.0
Jun											16.7	28.4	8.4	2.4	9.0	107.5	138.0
Jul	19.1	30.2	8.2	1.1	11.3	197.4	227.5	21.1	26.9	13.9	20.9	32.2	10.0	1.9	7.0	128.1	186.0
Aug	20.9	30.4	11.3	2.1	28.3	304.7	74.0	22.9	26.4	18.8	22.9	33.1	13.2	2.3	8.0	175.9	68.0
Sep	15.2	30.0	3.9	1.8	25.6	216.8	74.0	19.1	25.5	13.5	17.2	31.7	6.2	2.3	10.0	137.5	65.0
Oct	9.8	22.2	-0.4	1.4	25.7	199.5	171.0	13.6	19.1	8.4	11.7	24.6	0.8	1.9	8.0	110.8	165.0
Nov	4.1	16.2	-9.5	1.4	14.8	145.0	88.5	7.8	10.9	4.4	5.6	17.9	-5.3	2.2	8.0	116.7	67.0
Dec	3.9		-12.2	2.0	28.3	114.4		4.9	7.5	2.4	1.1	16.3	-12.4	2.3	10.0	57.1	143.0
1993																	
Jan	-3.2	8.8	-14.8	1.9	19.1	117.4		1.2	1.6	0.9	-1.5	8.0	-10.8	2.5	14.0	60.7	110.0
Feb	-3.2	14.2	-16.3	2.3	22.8	173.7		0.6	0.9	0.4	-1.4	8.4	-10.1	3.3	11.0	74.2	100.0
Mar	-1.3	13.4	-12.9	2.0	18.1	328.7		0.4	0.5	0.4	0.5	12.9	-8.2	2.9	10.0	137.9	33.0
Apr	3.4	19.8	-7.9	2.1	23.9	342.4		0.4	0.5	0.1	5.6	21.5	-3.6	3.0	12.0	129.7	56.0
May	10.3	26.8	-2.3	2.5	22.8	463.7		11.1	18.3	0.3	12.4	28.3	0.2	3.1	9.0	191.3	99.0
Jun	15.1	27.0	4.6	1.8	26.4	363.7		17.7	24.1	12.2	17.3	28.5	8.2	2.5	10.0	95.0	190.0
Jul	17.8	27.5	8.0	1.4	14.2	329.4	218.0	20.2	25.9	15.2	19.9	29.2	11.1	2.1	6.0	71.4	188.0
Aug	18.3	29.8	-3.0	1.7	21.4	297.4	213.5	21.0	25.1	18.5	20.7	30.9	12.8	2.0	8.0	91.5	200.0
Sep	15.5	27.5	4.3	1.3	26.0	235.8	118.0	19.1	24.3	13.8	17.4	28.8	6.5	1.8	8.0	82.0	80.0
Oct	8.5	19.9	-5.0	1.5	21.0	205.8	151.5	13.0	17.0	7.0	10.6	21.6	-2.2	2.0	9.0	112.1	164.0
Nov											6.4	22.7	-5.9	2.3	9.0	106.6	103.0
Dec											0.3	14.7	-8.2	2.7	10.0	75.6	117.0
Annual*	7.8	30.4	-16.3	1.9	28.3	2967		10.1	26.9	0.1	9.4	33.1	-12.4	2.5	14.0	1414	1282

Fig. 4. Location of pools in Miyatoko Mire based on an aerial photograph taken on 3 June 1992. Pool numbers in italics. B2, B4, C2, D1, D2, E1, E2: Observation sites.

1992 and 1993, respectively.
the mire by serial photography for the 1992 winter, 160 cm, was twice that recorded at the Nango Observatory.

Distribution of pools and streams

Stream A had been excavated during the Edo era for paddy irrigation. This stream starts from spring A0, crosses the northwestern part of the mire, where the peat surface elevation is higher than that in the southeastern part, and flows out from the northwestern tip of the mire.

About 50 pools are distributed in the southeastern part of the mire where the elevation is low (Fig. 4). Pools 1 to 3 are distributed along stream B and pool 50 is in the midst of stream D. Many smaller pools near Pool 50 are connected with it after rains. Most of the pools are distributed between streams B and D. This area is inundated after rains or snow thaw in late spring and the pools are connected with each other making stream D into a broad tributary stream (Fig. 5).

Snow melt water flows into the mire supplying nutrients to the soils and pools. The effects of nutrient supply from the watershed should be considered because the watershed area is much larger than the mire area. Miyatoko Mire is a complex of fen and bog ecosystems.

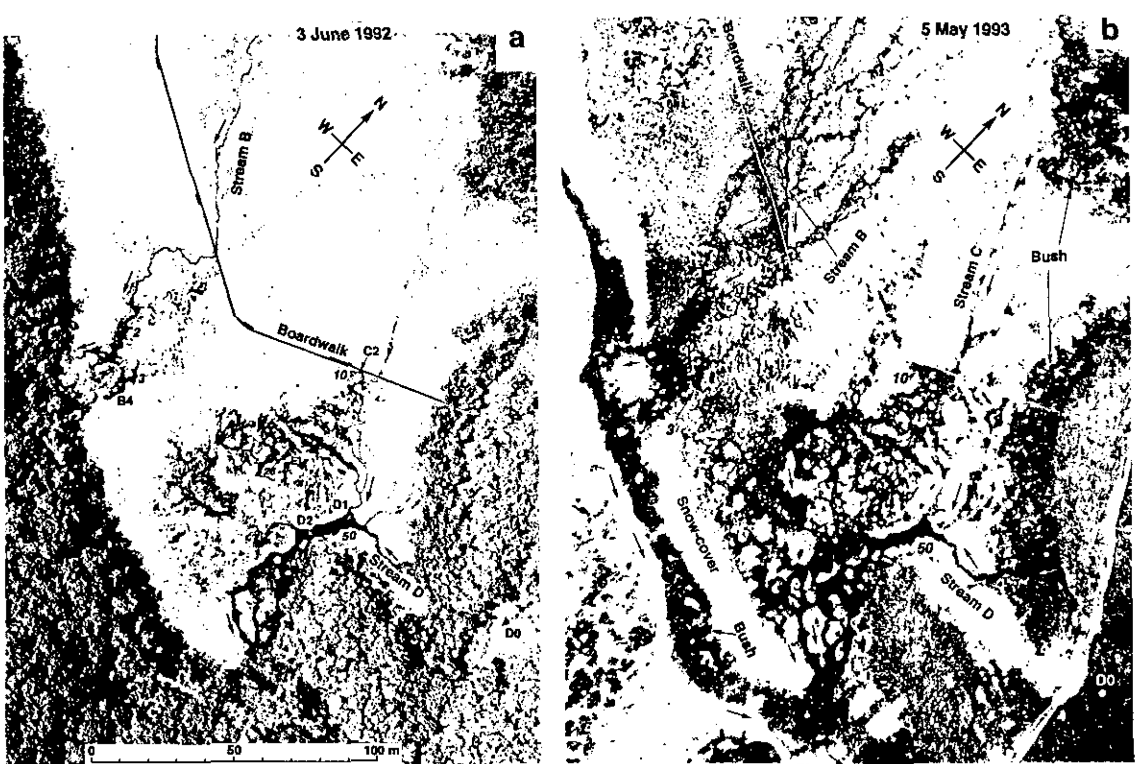

Fig. 5. Pool inundation in early summer and during snow melt in Miyatoko Mire. a: map drawn based on an aerial photograph taken on 3 June 1992; b: map drawn based on an aerial photograph taken on 5 May 1993.

In the present study of Miyatoko Mire, samples of water, algae and zoobenthos were collected along these streams or in the pools shown in Table 2. The results of studies of surface and groundwater chemistry, groundwater table variations and aquatic organisms are presented in Chapters 2, 3, 7, 8 and 9. Chapters 4, 5, 6 and 10 deal with the vegetation, pollinator insects and soil microbes.

Table 2. Physicochemical features and vegetation of the sampling sites in waters of Miyatoko Mire. Minimum and maximum values are shown for water temperature, pH and specific conductivity (Iwakuma, 1995).

Site		Depth (cm)	Width (m)	Current speed ($m\ s^{-1}$)	Vegetation	Sediment	Water temperature (°C)	pH	Specific conductivity ($\mu S\ cm^{-1}$)
A0	Koshimizu Spring	10	1.5	0.0	none	clay, litter	7.5—11.1	5.38—6.71	15.0—24.1
A2	Stream A, upstream of boardwalk	20	0.5	0.5	*Carex*	litter	5.5—14.8	5.49—7.05	12.8—25.7
A4	Stream A, outlet	20	1.5	0.5	*Potamogeton*	silt, litter	3.6—17.8	5.45—6.35	10.7—22.0
B2	Stream B, upstream of boardwalk	15	0.3	0.1	*Phragmites, Sphagnum*	litter	2.6—31.9	4.08—6.03	7.6—22.7
C2	Pool 10	20	3.0	0.0	*Nymphaea, Sphagnum*	litter	2.4—17.0	4.81—5.35	11.5—18.7
E1	Pool 26	20	3.0	0.0	*Nymphaea, Menyanthes*	litter	2.5—28.4	4.69—5.18	9.8—16.3
D0	Oshimizu Spring	20	2.0	0.0	none	clay, litter	8.0—10.8	5.39—6.63	16.6—29.3
D1	Pool 50	20	1.5	0.0	*Menyanthes*	litter	4.0—25.6	4.50—6.39	6.4—20.6
D2	Pool 50	30	5.0	0.0	*Menyanthes, Nymphaea*	litter	5.9—20.6	4.92—6.83	11.0—25.0
D4	Stream D, outlet	40	5.0	0.0	*Lysichiton*	clay, litter	1.1—21.4	5.25—6.28	7.9—18.6

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2
Ground and Surface Waters of Miyatoko Mire

Tatemasa Hirata, Seiichi Nohara and Toshio Iwakuma

The topography of Miyatoko Mire generally inclines from the northwest towards the southeast. Along the 400 m of the mire's longitudinal axis, there is an elevation decline of 2.2 m. A total of 5 stations were established along this slope to study groundwater flow in the mire (W1—W5, Fig. 1). Site W5 was taken as being representative of the sources of groundwater seepage to stream D. Observations at site W1 were carried out in a PVC sampling well (2 cm inner diameter) at 2 depths, 55 and 150 cm from the ground surface. At the other 4 sites, W2, W3, W4 and W5, the measurements took place in similar wells from 3 depths, 50, 150 and 250 cm. Apart from these 5 observation sites spaced out along the longitudinal axis, we also sampled from 9 measurement sites, denominated A through J, along a transect normal to the the mire's longitudinal axis to examine groundwater flow in the lateral direction (see Fig. 1). To supplement the measurements performed in the longitudinal direction, 3 further measurement points, denominated L, M, and N, were added. These 12 additional sampling wells were 100 cm deep (Hirata et al., 1995).

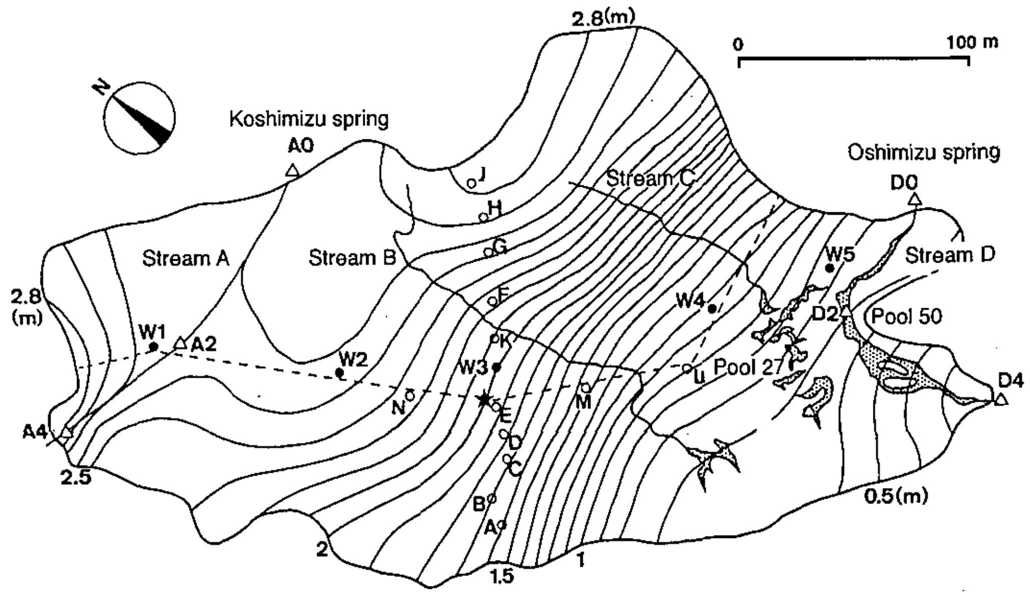

Fig. 1. Location of sampling wells in Miyatoko Mire. Contour lines show the relative differences in elevation with respect to a reference point in the mire. - - -: boardwalk; ★:center of the mire (altitude 830 m) where relative height is set as 2.0 m.

Groundwater table

Groundwater does effuse into the mire from the mountains surrounding its periphery. The Koshimizu (A0) and Oshimizu (D0) springs, both of which release water into the mire, are the most prominent of such water sources. These two springs flow from opposite ends of the mire. In addition to the 2 streams flowing from these springs, there are 2 more streams in the mire, which we call B and C. Stream C carries water from spring thaw in April or May through the wet seasons in July and September.

Comparison of the total water head (cm) at W1 and W2 revealed practically no potential difference at the 50 cm depth in 1991 (Fig. 2). In 1992, however, the potential at W2 was higher. At 150 cm, the potential at W2 was higher in 1991, though only by a very small margin. In 1992, the potential at that depth at W1 was higher. The groundwater at W1 and W2 near the surface flows generally towards the northwestern edge of the mire.

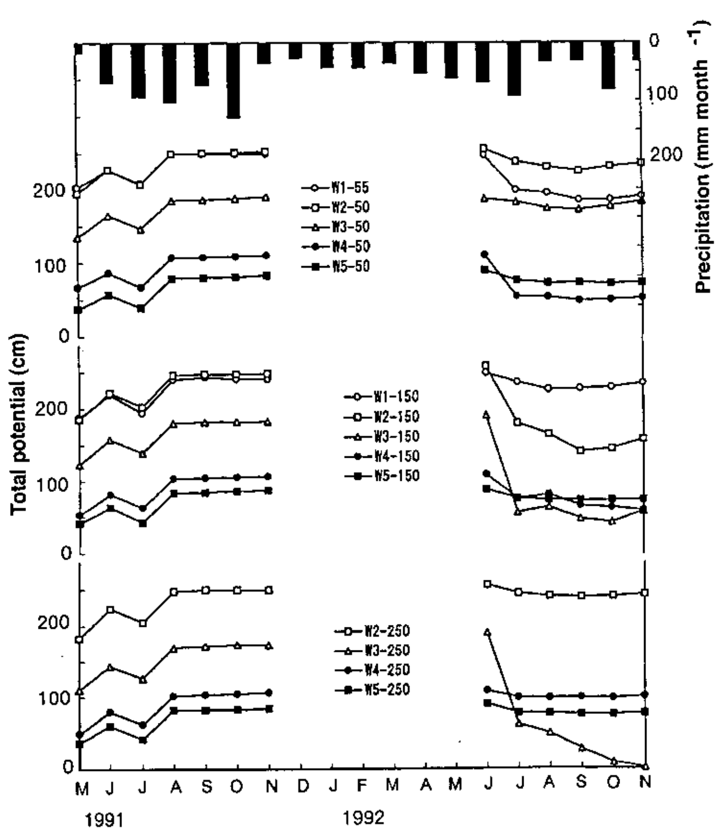

Fig. 2. Monthly changes in total potential of groundwater along the longitudinal axis of Miyatoko Mire. The values following the well numbers (W1—W5) denote the sampling depth in cm.

The total potential at the 150 and 250 cm depths decreased from W2 through W3 and W4 to W5 in 1991. The groundwater in these locations is believed to flow towards the southeastern rim of the mire along the slope of the land surface in the longitudinal direction. In 1992, however, a significant drop in total water head was measured at the 150 and 250 cm depths at W3. At the measurement depth of 50 cm at wells W4 and W5, the total potential actually increased. The predominant flow pattern was along the slope of the land surface.

Groundwater chemistry

The groundwater pH in the Miyatoko Mire tends to peak in the summer and decline from autumn to winter (Fig. 3). A similar pattern is followed by groundwater Na+, which tends to increase from spring into summer and decrease in winter. However, other systematic patterns of seasonal change for other chemical substances could be discerned in our results for the period from 1991 through 1992 (Table 1).

Although sampling wells W1 through W5 do not necessarily lie in the same groundwater flow, this system might be adequate to reveal some of the specific features of the mire. First, it has been found that the groundwater has a significantly lower NO_3^-

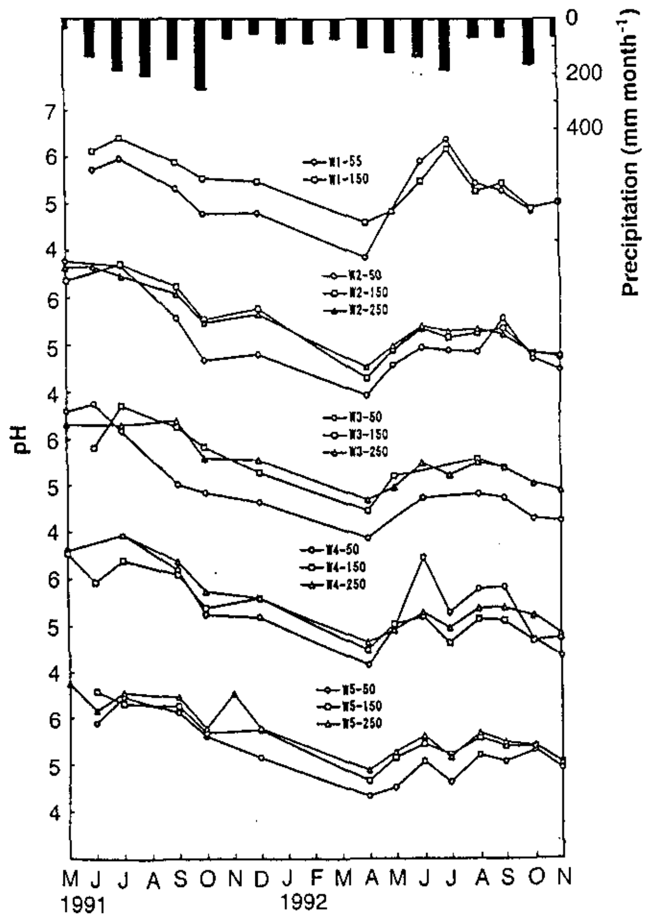

Fig. 3. Monthly changes of groundwater pH in Miyatoko Mire

Table 1. Annual mean groundwater solute concentrations in Miyatoko Mire during a 2-year period from 1991 to 1992. SC=specific conductivity.

Well	Depth cm	NH_4^+ mg l^{-1}	NO_3^- mg l^{-1}	PO_4^{2-} mg l^{-1}	SiO_2 mg l^{-1}	Cl^- mg l^{-1}	SO_4^{2-} mg l^{-1}	Na^+ mg l^{-1}	K^+ mg l^{-1}	Ca^{2+} mg l^{-1}	Mg^{2+} mg l^{-1}	pH	SC µS cm^{-1}
April—December 1991													
W1	55	0.33	0.008	0.110	9.9	5.70	5.65	2.04	3.95	2.07	0.95	5.32	29.2
	150	0.28	0.005	0.027	21.1	11.20	4.18	2.29	8.14	2.15	1.44	5.90	68.7
W2	50	1.32	0.005	0.140	28.1	12.40	9.67	1.87	9.63	4.67	2.50	5.71	92.1
	150	2.28	0.003	0.067	30.6	4.62	7.03	1.68	2.43	5.32	2.97	6.13	60.4
	250	2.93	0.008	0.044	32.5	3.85	5.53	1.77	2.25	4.68	2.39	6.17	65.5
W3	50	1.49	0.001	0.065	14.6	5.32	9.60	1.79	2.23	4.07	2.05	5.68	45.4
	150	4.00	0.011	0.130	37.8	5.34	13.10	2.34	1.71	5.70	3.45	6.00	66.6
	250	4.21	0.005	0.075	42.9	4.05	9.07	2.35	1.97	5.38	2.96	6.05	66.2
W4	50	1.01	0.006	0.056	23.8	4.15	7.02	3.00	3.11	4.57	2.19	6.06	44.8
	150	2.07	0.001	0.092	37.0	4.43	5.34	2.86	3.18	2.70	1.49	6.01	47.0
	250	2.70	0.008	0.064	37.1	3.82	2.94	2.71	2.68	2.32	1.46	6.20	38.9
W5	50	0.51	0.008	0.157	30.6	4.10	6.12	4.04	2.47	2.97	1.55	5.89	27.6
	150	0.34	0.009	0.026	32.3	2.80	2.68	4.09	2.03	2.77	1.51	6.16	31.2
	250	0.26	0.005	0.035	30.3	3.20	3.30	4.29	1.98	3.69	2.05	6.33	45.5
April—December 1992													
W1	55	3.50	0.026	0.593	10.1	6.22	6.33	2.47	4.02	1.88	0.57	5.30	27.6
	150	0.45	0.025	0.022	22.3	2.06	4.24	1.74	0.73	1.79	1.18	5.25	21.7
W2	50	2.90	0.007	0.132	22.8	3.83	7.26	1.66	1.30	1.06	0.75	4.81	23.2
	150	3.43	0.005	0.075	25.2	4.10	7.10	1.94	1.55	0.70	0.50	5.07	26.8
	250	3.76	0.005	0.047	27.8	3.04	7.17	1.70	0.97	0.97	0.65	5.11	29.8
W3	50	2.43	0.005	0.059	13.8	5.10	10.40	1.76	0.89	1.38	0.84	4.56	20.9
	150	5.23	0.018	0.185	37.1	6.80	14.80	2.75	2.03	1.33	0.86	5.22	40.1
	250	6.20	0.007	0.160	42.2	4.44	9.99	2.80	2.30	1.03	0.62	5.23	41.4
W4	50	1.97	0.012	0.039	24.0	2.37	5.50	2.12	0.89	0.73	0.52	4.72	22.4
	150	2.73	0.004	0.038	37.1	1.81	4.94	2.48	0.87	0.79	0.49	5.04	26.5
	250	3.28	0.010	0.011	35.8	1.60	2.29	2.19	0.73	0.74	0.59	5.25	30.1
W5	50	0.57	0.006	0.048	35.8	2.09	4.84	2.90	0.87	1.31	0.78	5.06	19.7
	150	0.67	0.008	0.006	32.8	1.94	1.93	3.44	0.58	2.47	1.45	5.42	27.9
	250	0.54	0.004	0.007	30.5	1.94	2.33	3.36	0.64	2.79	1.59	5.52	28.5

concentration than ordinary surface water (Hirata and Muraoka, 1993). In contrast, however, its NH_4^+ and SiO_2 concentrations tend to be higher than those in surface water. The NH_4^+ concentration was monitored for 2 years at the wells from W2 through W4, with the annual mean concentration being in excess of 1 mg l-1. Similarly, annual mean levels of SiO_2 exceeded 30 mg l^{-1} at many of the observation points. SiO_2 originates from the soil, so the concentration in the groundwater will increase with increasing contact time between the water and the soil. Thus these relatively high SiO_2 levels lead to the inference that the groundwater in the mire has a fairly long residence time. Nitrate was practically absent while the concentration of ammonium was elevated, suggesting that the groundwater in Miyatoko Mire is anaerobic as is typical of a peatlands.

We evaluated the horizontal distributions of NH_4^+ and SiO_2 in the Miyatoko groundwater with 1991 data (Fig. 4). At most sites, the NH_4^+ and SiO_2 concentrations were higher in deeper groundwater. This result was expected because the contact time between water and soil is generally longer at deeper levels. The SiO_2 concentration at W1 was lower than those at the other 4 wells, suggesting that the groundwater there has a shorter residence time. The NH_4^+ concentration at W1 was also lower than those at wells W2 through W4. These features and the fact that the groundwater in the western part of the mire flows along the path of stream A may be taken as evidence of different flow dynamics and residence behavior of this groundwater compared with most of the other groundwater which flows in the longitudinal direction.

Surface water chemistry

Annual mean pH values of spring A0 were 6.35 for 1991 and 6.09 for 1992 and those at Stream A's outlet, A4, were 6.22 for 1991 and 6.11 for 1992. Annual mean pH values at the other spring, D0, were 6.52 for 1991 and 5.97 for 1992 and that at Stream D's outlet, D4, was 6.11 for both 1991 and 1992 (Table 2).

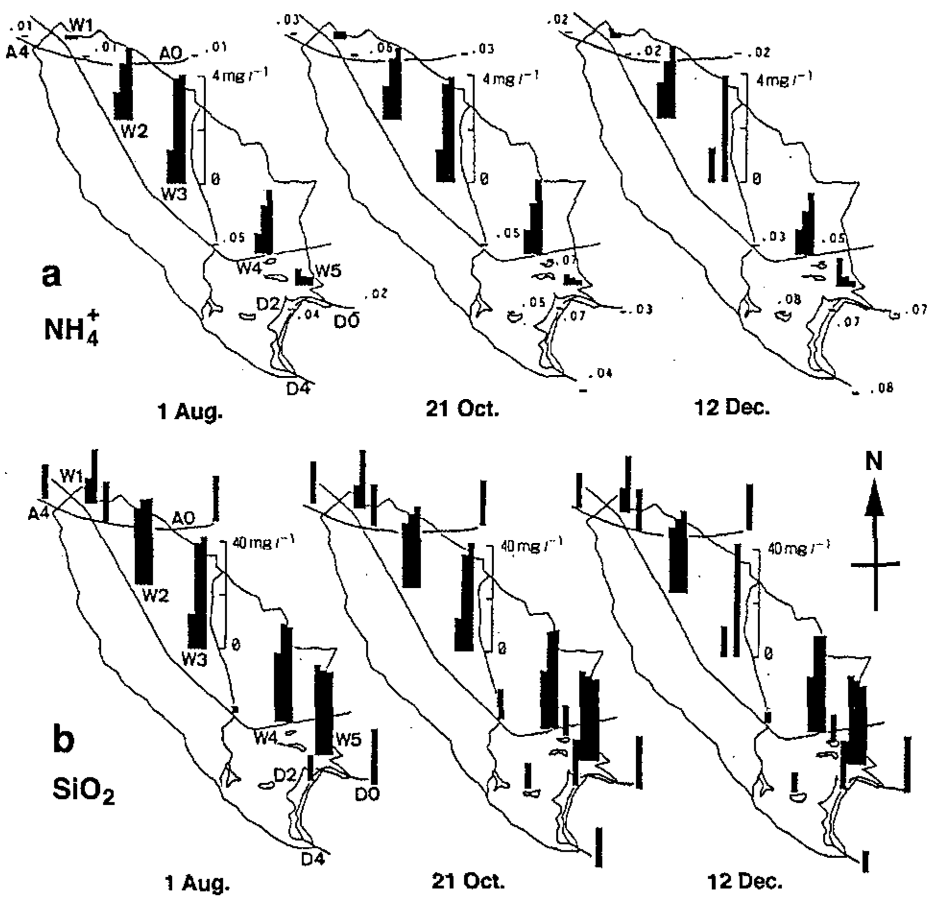

Fig. 4. Horizontal distributions of NH_4^+ (a) and SiO_2 (b) in ground and surface waters during 1991. The concentrations at sites W1—W5 are from samples obtained from well depths of 50, 150 and 250 cm, from left to right.

Table 2. Annual mean surface water solute concentrations in Miyatoko Mire during a 2 year period from 1991 to 1992. SC=specific conductivity.

Site	NH_4^+ mg l^{-1}	NO_3^- mg l^{-1}	PO_4^{2-} mg l^{-1}	SiO_2 mg l^{-1}	Cl^- mg l^{-1}	SO_4^{2-} mg l^{-1}	Na^+ mg l^{-1}	K^+ mg l^{-1}	Ca^{2+} mg l^{-1}	Mg^{2+} mg l^{-1}	pH	SC µS cm^{-1}
April—December 1991												
A0	0.036	0.006	0.009	16.9	2.81	1.08	2.33	1.71	0.53	0.27	6.35	32.3
A4	0.033	0.012	0.009	14.0	3.25	1.31	2.15	2.23	0.50	0.33	6.22	27.8
D0	0.034	0.006	0.008	20.5	2.91	0.86	2.56	2.03	0.62	0.28	6.52	37.8
D2	0.070	0.002	0.028	14.7	3.11	1.80	2.15	2.11	0.64	0.32	6.25	28.1
D4	0.077	0.009	0.028	12.7	4.33	2.05	1.95	2.61	0.68	0.39	6.11	36.8
April—December 1992												
A0	0.026	0.008	0.002	17.1	2.31	2.69	2.13	0.95	0.56	0.27	6.09	14.6
A4	0.017	0.013	0.002	14.4	2.61	1.37	1.85	0.73	0.53	0.29	6.11	16.0
D0	0.015	0.005	0.001	20.7	2.18	0.86	2.36	1.21	0.55	0.29	5.97	16.3
D2	0.045	0.006	0.001	18.3	2.39	1.33	2.12	1.04	0.61	0.28	6.10	15.1
D4	0.077	0.009	0.028	12.7	4.33	2.05	1.95	2.61	0.68	0.39	6.11	36.8
Pool 27	0.072	0.002	0.006	8.5	3.88	2.78	0.88	0.46	0.43	0.33	5.20	25.9

The SiO_2 concentrations in Koshimizu and Oshimizu springs were monitored monthly. The annual mean concentration was 20.5 mg l^{-1} in 1991 and 20.7 mg l^{-1} in 1992 at Oshimizu spring, D0. These values are not substantially different from the mean concentration levels for rivers from the Kanto to Tohoku regions, which are in the range from 21.5 to 23.1 mg l^{-1} (Hanya and Otake, 1978). The SiO_2 concentration in Koshimizu spring, A0, is lower than that at Oshimizu spring, D0, and showed no seasonal variation. The SiO_2 concentrations at the mire outlets were lower than those at either of the springs. The pattern of seasonal changes of SiO_2 was similar to that for pH. Both at the springs and the mire outlets, the concentrations of the solutes Na^+ and K^+ varied in patterns similar to that of SiO_2 (Fig. 5)

Low nitrate concentration emerged as a characteristic feature of Miyatoko Mire. As for the mire groundwater, there was practically no nitrate in the spring water or the spring outlets. The NH_4^+, Ca^{2+} and Mg^{2+} concentrations in stream D showed a minor increase at the outlets as compared to their concentrations in the spring water (Table 2).

The seasonal changes in pH and SiO_2 concentarations of surface water may be attributed to the effects of groundwater and rainwater runoff. The runoff of groundwater was examined by a survey of groundwater chemistry in the mire at depths below 0.5 m for 5 measurement points located essentially along the longitudinal axis. Of these 5 points, the water from W5 is closest in composition to that from stream A, yet the outlet of the Oshimizu spring, D0, has a height of about 0.4 m and the pool depth on the downgradient is also 0.75m. Moreover, the relative elevation of well W5 is 0.85 m, significantly downstream of pool 50 (site D2) and outlet D4 even though the groundwater at the depths of 1.5 m and 2.5 m in sampling well W5 does flow out. This observation suggests that the groundwater runoff from W5 has no direct impact on the solute concentrations in the pool and outlet for stream D. At the depth of 0.5 m in W5, the annual mean concentrations of NH4+-N and SiO2 exceed 0.5 mg l-1 and 30 mg l-1, respectively. Both of these concentrations are higher than those at Oshimizu spring, D0. Sodium and potassium concentrations are generally higher at the springs than in the wells, suggesting that seasonal changes in solute concentrations cannot be explained in terms of the runoff of groundwater with these properties.

Flow of surface and ground waters

The seasonal changes in SiO_2 and Na^+ measured in the surface water can be explained, however, if some portion of the outflowing water comes into contact with the soil for very short periods. Silicate, in particular, is a substance practically absent from rain water. The runoff of rain water into surface waters would therefore lower the SiO_2 concentration in the surface water by dilution. This process could also explain the fall in pH and SiO_2 concentration measured at the spring outlets during the period from the winter to the spring thaw season.

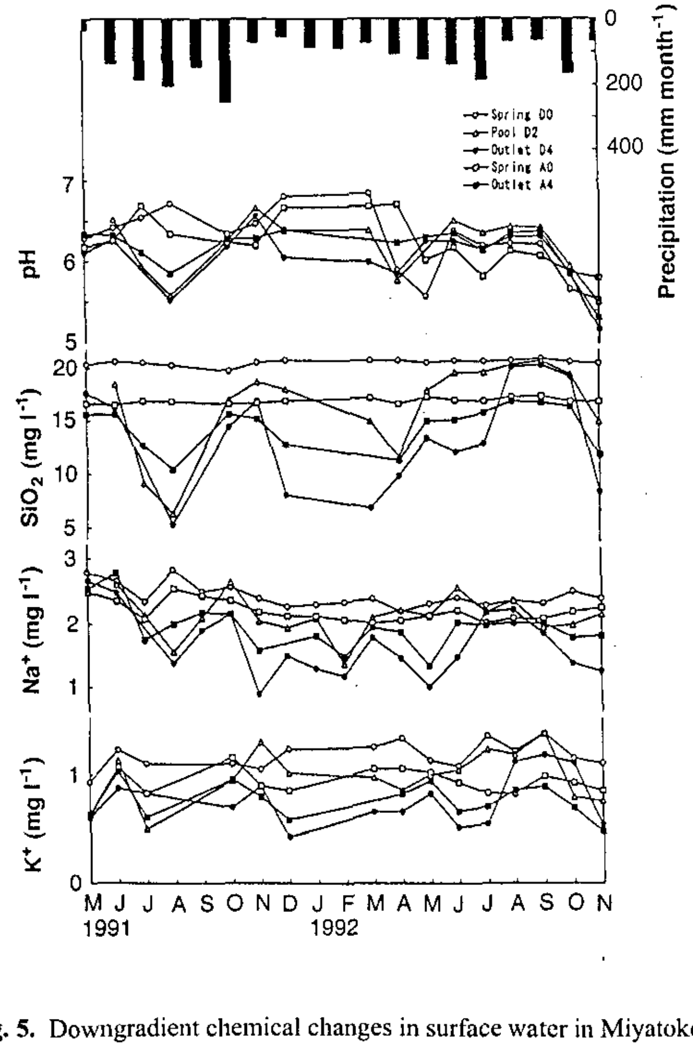

Fig. 5. Downgradient chemical changes in surface water in Miyatoko Mire

Some of the other results suggest the same possibility. The flow of groundwater in the direction of the lateral axis of the mire is accompanied by water accumulation at points B or C on the A-J section. As a result, the end points of streams B and C are located not in the center of the mire but more to the west, with the pool having developed in this area. Water samples were taken from the pool 27, situated at the end point of stream C, on a total of four occasions from August through December 1991 (see bottom part of Table 2). The annual mean pH, SiO_2, Na^+ and K^+ values for the pool are lower than those for Oshimizu spring, D0. However, mean levels of NH_4^+ and Mg^{2+} in the pool were higher than those in Oshimizu spring. Thus, it may be concluded that the seasonal changes in water chemistry (see Fig. 5) are due to the runoff of groundwater very close to the ground surface after having come into contact with the soil and plants only briefly.

The Miyatoko Mire groundwater at a depth of 50 cm and below has a long residence time, as evidenced by its water chemistry. It flows to the surface downstream of the mire's outlets, and thus it does not significantly influence the surface water in the mire zone. In contrast, the groundwater near the surface has been found to exhibit very clear seasonal changes in pH, raising the possibility that it may be very rapidly replaced through rainwater infiltration and outflow.

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3
Micro-topography and the Hydrological Environment of Miyatoko Mire

Seiichi Nohara and Toshio Iwakuma

Topographic variations may be correlated with differences in climate, water source, and water movement. The abundance of water is one of most important characteristics of mire ecosystems. Mire plant species vary with micro-topographic variations in habitats such as hollows and hummocks (Sakaguchi, 1974). The groundwater table is one of main

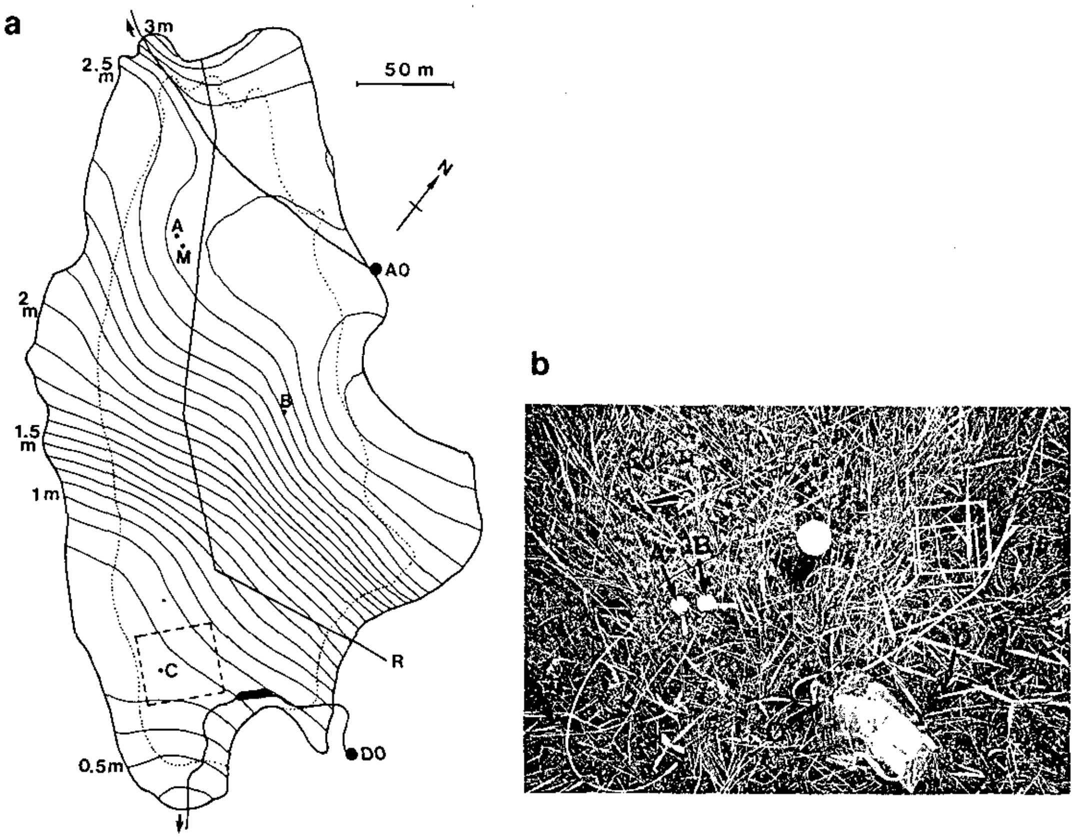

Fig. 1. (a) Topographic map of study site in Miyatoko Mire. Contour lines are drawn at 0.1 m intervals. Heights are relative to a point on the 2.0 m contour in the center of the mire (830 m above mean sea level). A, B, and C: sites of groundwater level monitoring wells. M: meteorological monitoring tower. A0 and D0: springs; R: boardwalk; Rectangular area surrounded by a broken line: area for monitoring soil moisture; Dotted line: boundary between marginal shrub and inner *Sphagnum* vegetation. (b) Monitoring system for water level, soil moisture and soil temperature. Data were taken at 10 min intervals from rainy season to summer. A and B: soil moisture sensors for deployment at 10 and 30 cm depths, respectively; C: soil moisture sensor for continuous monitoring; D: soil temperature sensor for continuous monitoring.

factors regulating plant biomass and distributions (Hogetsu and Oshima, 1982). The present study was carried out in Miyatoko Mire from 1991 to 1992 (Nohara and Iwakuma, 1995) in order to clarify the relationship between the hydrological environment and the micro-topography.

Miyatoko Mire (6.5 ha, altitude 830 m) is a small mire located 170 km north of Tokyo. The watershed area is about 54.1 ha in the vicinity of Mt. Denjo (altitude 999.5 m) and other mountains. Eight hectares of the mire is a special reserve area of Fukushima Prefecture and 46.1 ha of the watershed area has been an ordinary reserve area of the prefecture since 1975. A micro-topographic map (Fig. 1a) was made from 3-dimensional data obtained for about 560 sites with a laser theodolite (a surveying instrument; model DM-13, Nikon, Japan). The northwestern tip of the mire was approximately 2.5 m higher than the southeastern lowland. Twenty permanent quadrats (1 × 1 m) were established on mire hollows and hummocks (Fig. 1b).

The groundwater table in each of the quadrats, monitored by piezometers deployed 1.5 m deep in wells, varied among the sites but were essentially constant at each site from May through October, 1991 (Fig. 2a).

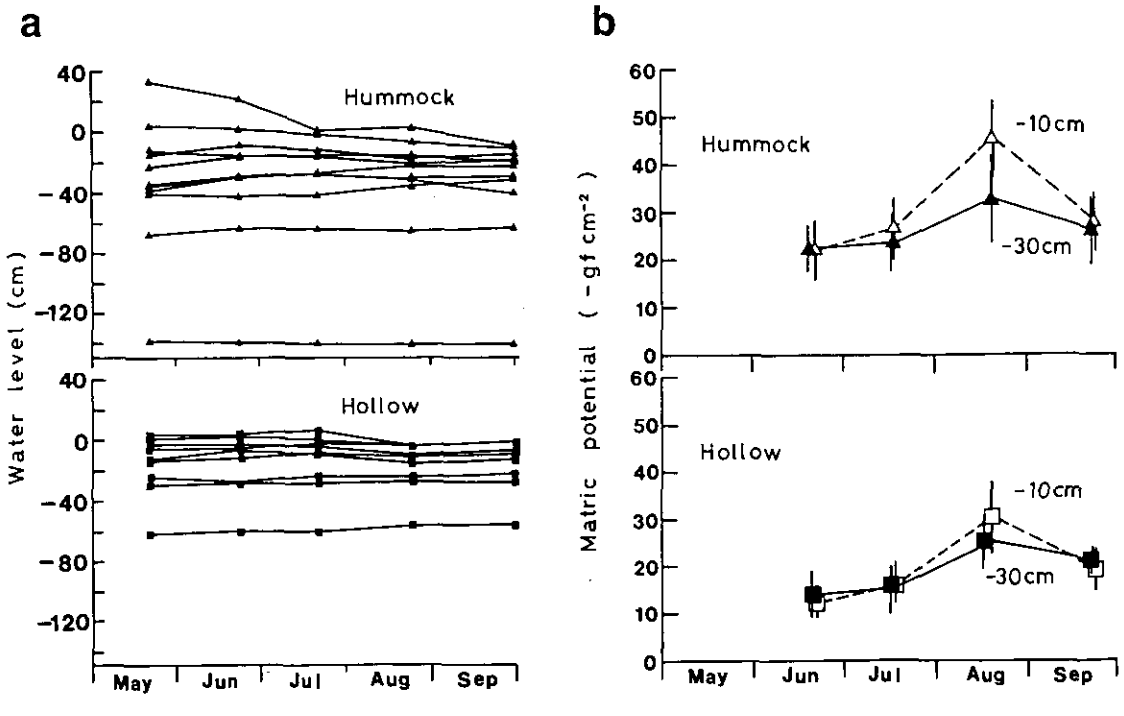

Fig. 2. (a) Monthly changes in water levels at the eastern-most study site in Miyatoko Mire. (b) Monthly changes in soil moisture at the eastern-most study site in Miyatoko Mire. Open triangles: 10 cm deep in hummocks; solid triangles: 30 cm deep in hummocks; open squares: 10 cm deep in hollows; solid squares: 30 cm deep in hollows. Bars indicate standard deviations (n=10).

Soil moisture at 10 and 30 cm depths was monitored in each quadrat with tensiometers (DIK-3130, Daikirika Co., Ltd., Japan). During summer, the absolute value of soil matric potential in hummocks was larger than that in hollows (Fig. 2b).

Changes in soil moisture and meteorological factors were monitored at 10 min intervals from late July to September. The daily changes in soil matric potential in hummocks was larger than that in hollows (Fig. 3). Decreases in the absolute value of soil matric potential were correlated with the amount of rainfall during rainfall events. The rates of increase in soil matric potential in hummocks after the end of rainfall events were -3.6 to -7.1 kPa day^{-1}. These values did not change much from August to September.

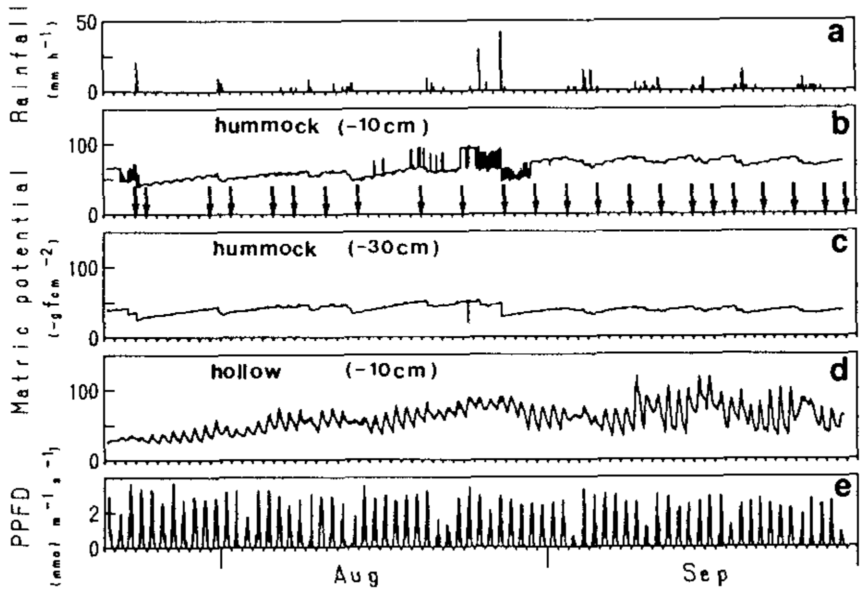

Fig. 3. Changes in soil moistures and meteorological factors in summer. a: rainfall; b, c, d: Matric potential; e: photosynthetic photon flux density (PPFD); Arrows indicate the beginning and cessation of rainfall events.

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4
Plant Phenology in Mire Pools

Seiichi Nohara and Toshio Iwakuma

We used a simple remote sensing approach of serial photography to study the phenology of the flowering rhythms of 2 aquatic plants, *Menyanthes trifoliata* L. and *Nymphaea tetragona* George, both growing mostly in shallow acidic waters (Nohara and Iwakuma, in revision). *Menyanthes trifoliata* is distributed in ponds and bog pools in northern Japan, and in southern Japan as a relict community of the glacial period (Kadono, 1994). *Nymphaea tetragona* is one of the predominant species in shallow irrigation ponds (Kunii, 1991) and bogs (Kanai, 1982) and is distributed throughout Japan (Kadono, 1994).

Aerial and serial photographs

Vertical aerial photographs were taken with 4 × 5 or 6 × 9 cm format cameras on real color film from an airplane flying at an altitude of about 2000 m on 6 November 1991, 3 June 1992, 22 November 1992 and 5 May 1993. A measurement pole for water level monitoring was set in a mire pool (B4, 20 cm mean depth, 3 m in width, about 15 m in length) in the southern part of Miyatoko Mire. A simple photographic system with interval function used at the B4 site is presented in Fig. 1. The scale on the measurement pole was used to monitor the water level in this mire pool. The camera (Samurai, Kyosera, Japan) in a water resistant, polyvinyl chloride (PVC) housing could take pictures on schedule at intervals from once per second to once per day. The PVC

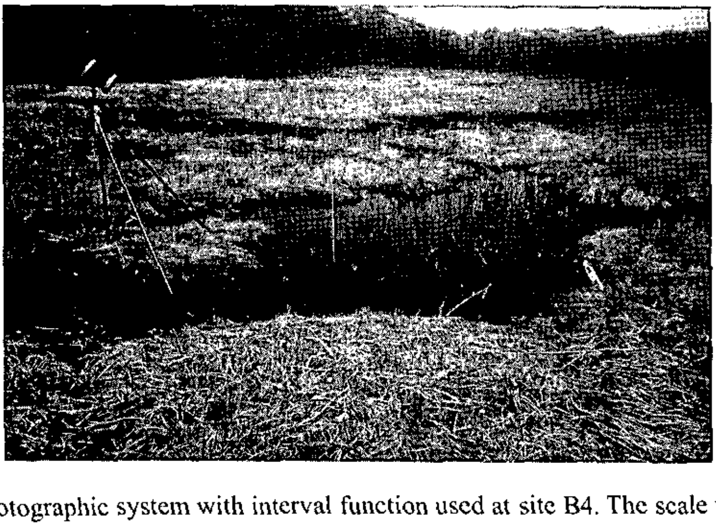

Fig. 1. Photographic system with interval function used at site B4. The scale was used as a reference for measurements of water level in the mire pool. The photographic system is mounted on a tripod. The camera in the PVC housing can take pictures at scheduled times.

housed camera was fixed at a height of about 150 cm above the ground on a tripod. The exposure size of the real color film was half that of normal 35 mm film. Therefore, a maximum of about 70 scenes could be taken on each roll. Serial photographs were taken daily from late May 1991 to August 1992 except during the snow cover period in winter. The number of individual *M. trifoliata* L. inflorescences and fruits, *N. tetragona* George flowers, and *Phragmites australis* (Cav.) Trin. Ex. Steud shoots in a 6 m^2 area in each daily photograph were counted.

Description of the mire

Aerial photographs of the pools of Miyatoko Mire were taken during snow melt, in early summer, middle autumn, and late autumn (Fig. 2). The many mire pools in the southern part of the mire were connected by flooding during the snow melt season. A comparison of the levels of inundation of pools during spring thaw with those in early summer suggests that the mire was supplied with water and nutrients from the surrounding watershed in spring. During summer, water at phenological monitoring site B4 flowed in from a groundwater spring.

Landscape of a mire pool

The aquatic plant community in the mire changed from month to month during the period from May to December, 1991 (Fig. 3). *Menyanthes trifoliata*, *N. tetragona*, *P. australis* and *Scirpus juncoides* Roxb. predominated in a mire pool (site B4). Monthly changes in phenology were apparent from the daily photographs. Beginning in late May, *M. trifoliata* was the earliest among these plants to put forth leaves. In August, the above-ground parts of *M. trifoliata* died naturally. *Nymphaea tetragona*, in contrast, put forth leaves from June. The surface was primarily covered by *N. tetragona* from summer until October. The water surface covered by *P. australis* and *S. juncoides* was small.

Analysis of flowering rhythm

The numbers of individual *M. trifoliata*, *N. tetragona* and *P. australis* plants in an approximately 6 m2 area of the mire pool in the daily photographs through the seasons were counted (Fig. 4). The flowering period of *M. trifoliata* lasted for about 20 days from late May 1991. The number of flowering *M. trifoliata* shoots in 1991 was larger than that in 1992. Seeds of *M. trifoliata* matured about 40 days after flowering, and floated for a few weeks after falling. The flowering period of *N. tetragona* in the pool lasted for about 50 days from late June 1991. Flowering of *N. tetragona* began about 10 days earlier in 1991 than in 1992. Based on photographs taken at 20 minute intervals, each *N. tetragona* flower blossomed for about one week, opening at about 14:00 and closing at evening in all seasons and in all weather conditions.

Haraguchi (1993) observed that at the southern extremity of its geographical distribution in Japan (Kokawa, 1961), at Mizorogaike Pond in central Japan, the development of *M. trifoliata* foliage began in early April and its density peaked in early

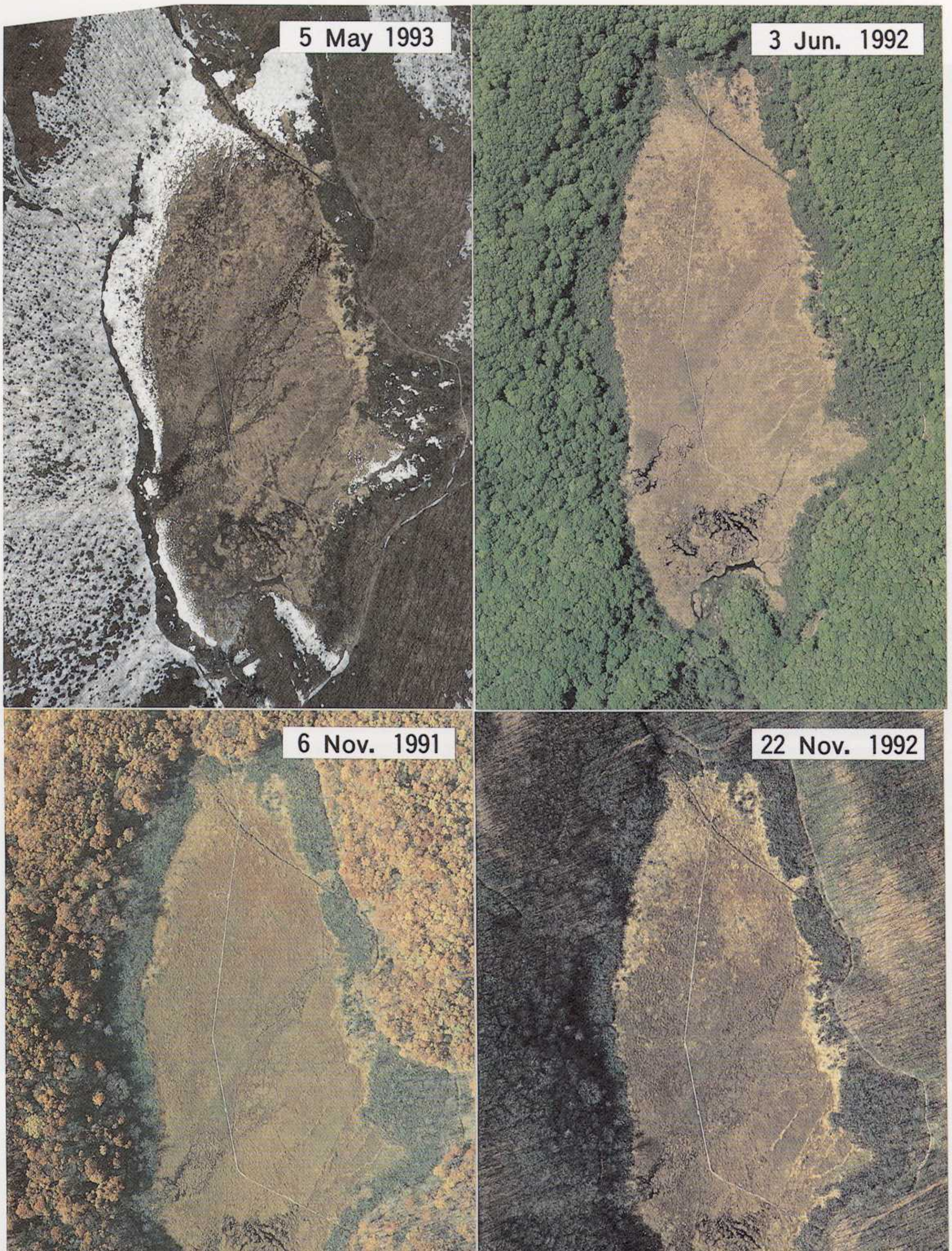

Fig. 2. Aerial photographs of mire pools of Miyatoko Mire taken during snow melt (top left, 5 May 1993), early summer (top right, 3 June 1992), mid-autumn (bottom left, 6 November 1991) and late autumn (bottom right, 22 November 1992).

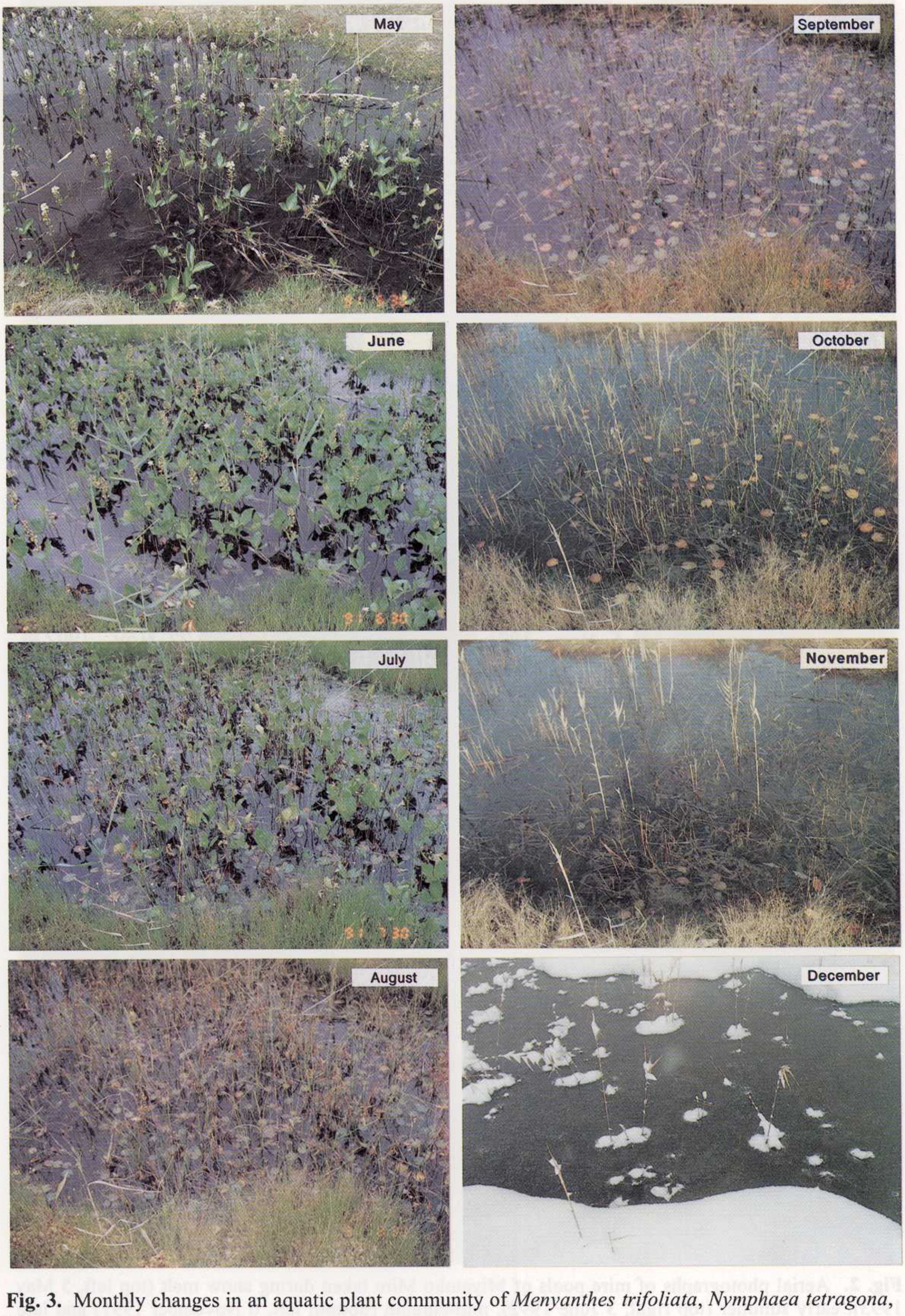

Fig. 3. Monthly changes in an aquatic plant community of *Menyanthes trifoliata*, *Nymphaea tetragona*, *Phragmites australis* and *Scirpus juncoides* in a Miyatoko Mire pool.

June. The foliage then began to senescence and reached its minimum density in late July. Leaf expansion began in August and foliage became crowded in autumn, although foliage density was lower than it had been in June. In the present study, the timing of foliage opening was later than that observed at Mizorogaike Pond, and the timing of foliage death was earlier than that at Mizorogaike Pond.

Fukuhara (1990) reported that the flowering rate in shoots of *M. trifoliata*, determined by counting the flowering scars on the rhizomes over 15 years fluctuated from 26.7 to 60.9%. The flowering rate was highly correlated with the cumulative daily temperature and total solar radiation in July. Nishimura (1983) found that *M. trifoliata* reproduces mainly vegetatively and that large shoots had many offspring by frequently producing larger branches. In the present study, the flowering and fruit shoot densities were higher in 1991 than in 1992 (Fig. 4). These differences seemed to be caused by the difference in cumulative daily June temperatures between 1991 and 1992.

The initiation and duration of flowering by *M. trifoliata* differs among habitats. Seed setting rate increases with delays in the initiation of flowering in Mizorogaike Pond (Haraguchi, 1991). Haraguchi suggested that air temperature and anthophilous insects influenced the seed setting rate of *M. trifoliata*. The average number of anthophilous insect species per flowering plant was 0.9 in the present mire surrounded by forest compared to 46 species in Mizorogaike Pond surrounded by an open area of secondary forest and city (Ueno, 1995).

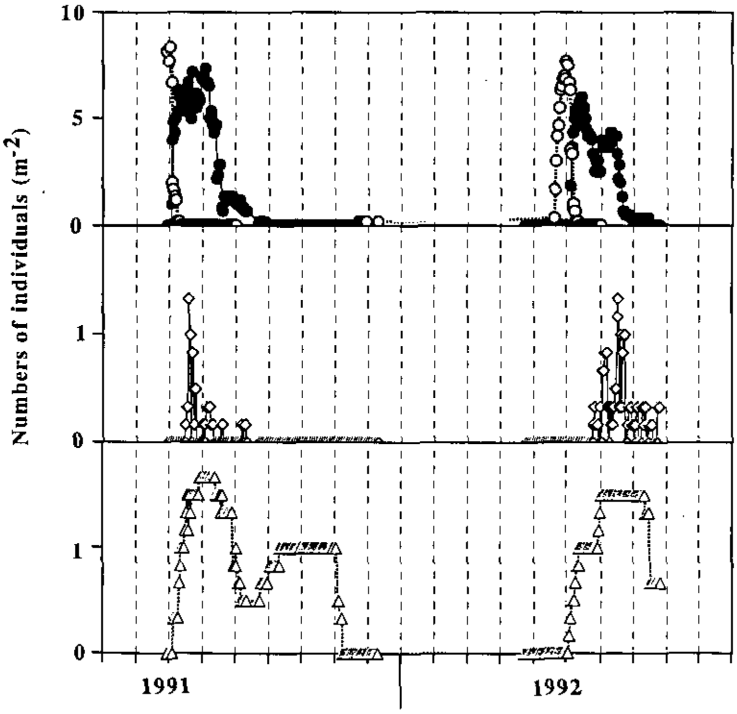

Fig. 4. The numbers of individual plants in the mire pool through the seasons. Numbers of individuals in a 6 m2 area in the daily photographs were counted. Open circles: *Menyanthes trifoliata* inflorescences ; solid circles: *M. trifoliata* fruit shoots; open diamonds: *Nymphaea tetragona* flowers; open triangles: *Phragmites australis* shoots.

Kunii and Aramaki (1992) observed that flowering of *N. tetragona* in an irrigation pond in southern Japan began in early June and ceased in the middle of October. The length of the vegetative period, beginning with first leaf appearance and ending on the day when the last leaves disappeared, was 207 days (late May to mid-December). The flowering and vegetative periods there were longer than those observed in the present study (flowering period: mid-June—late August, vegetative period: early June—mid-October), because the site of the present study was in a colder region of northern Japan having characteristics such as deep snow (maximum depth: 1.4 m) and higher altitude (830 m).

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5
Flora and Vegetation of Miyatoko Mire

Akihide Takehara

The flora of Miyatoko Mire (lat 37°15'N, long 139°34'E, ca. 830 m alt., Fukushima Prefecture, northern Honshu) and the surrounding area was studied. A total of 371 species of Musci and vascular plants, that is 47 species of Bryopsida belonging to 17 families, 19 species of pteridophytes belonging to 9 families, and 305 species of spermatophytes belonging to 71 families, were recorded (Table 1). Of the 8 *Sphagnum* species observed in the mire, all except *Sphagnum flexuosum* are phytosociologically remarkable.

Table 1. A list of Musci (cf. Higuchi, 1975) and vascular plants of Miyatoko Mire and its surrounding area. An asterisk indicates that the species was not been recorded by Baba (1969).
Nomenclature: Iwatsuki (1991), Iwatsuki (1992), and Satake (1981, 1982, 1989).

BRYOPSIDA (Musci)
SPHAGNIDAE

Sphagnaceae
Sphagnum cuspidatum Ehrh. ex Hoffm.
Sphagnum flexuosum Dozy et Molk.
Sphagnum fuscum (Schimp.) Klinggr.
Sphagnum magellanicum Brid.
Sphagnum nemoresum Scop.
Sphagnum palustre L.
Sphagnum papillosum Lindb.
Sphagnum tenellum Ehrh. ex Hoffm.

BRYIDAE

Polytrichaceae
Atrichum undulatum (Hedw.) P.Beauv.
Pogonatum inflexum (Lindb.) Lac.

Fissidentaceae
Fissidens taxifolius Hedw.

Ditrichaceae
Ceratodon purpureus (Hedw.) Brid.
Ditrichum pallidum (Hedw.) Hampe

Dicranaceae
Brothera leana (Sull.) C.Müll.
Dicranella heteromalla (Hedw.) Schimp.
Dicranum nipponense Besch.
Dicranum viride (Sull. et Lesq.) Lindb. var. *hakkodense* (Card.) Tak.
Trematodon longicollis Michx.

Leucobryaceae
Leucobryum bowringii Mitt.

Pottiaceae
Weissia controversa Hedw.

Grimmiaceae
Racomitrium canescens (Hedw.) Brid. subsp. *latifolium* (C.Jens.) Frisvoll
Schistidium apocarpum (Hedw.) Bruch et Schimp.

Bryaceae
Bryum caespiticium Hedw.
Bryum capillare Hedw.
Pohlia wahlenbergii (Web. et Mohr) Andr.

Neckeraceae
Thamnobryum subseriatum (Mitt. ex Lac.) Tan

Theliaceae
Fauriella tenuis (Mitt.) Card.

Thuidiaceae
Anomodon rugelii (C.Müll.) Keissl.
Haplocladium angustifolium (Hampe et C.Müll.) Broth.

Table 1. continued.

Thuidium kanedae Sak.
Thuidium recognitum (Hedw.) Lindb. var. *delicatulum* (Hedw.) Warnst.

Amblystegiaceae
Campyliadelphus chrysophyllus (Brid.) R.S.Chopra

Brachytheciaceae
Brachythecium brotheri Par.
Brachythecium helminthocladum Broth. et Par.
Brachythecium populeum (Hedw.) Bruch et Schimp.
Eurhynchium eustegium (Besch.) Dix.
Myuroclada maximowiczii (Borosz. ex Maxim.) Steere et Schof.

Plagiotheciaceae
Plagiothecium denticulatum (Hedw.) Bruch et Schimp.
Plagiothecium nemorale (Mitt.) Jaeg.

Hypnaceae
Callicladium haldanianum (Grev.) Crum
Ctenidium capillifolium (Mitt.) Broth.
Gollania ruginosa (Mitt.) Broth.
Hypnum lindbergii Mitt.
Hypnum plumaeforme Wils.
Taxiphyllum aomoriense (Besch.) Iwats.
Taxiphyllum taxirameum (Mitt.) Fleisch.

Hylocomiaceae
Loeskeobryum cavifolium (Lac.) Fleisch.

PTERIDOPHYTA

Lycopodiaceae
Lycopodium clavatum L.
Lycopodium inundatum L.
Lycopodium serratum Thunb.

Equisetaceae
**Equisetum arvense* L.

Osmundaceae
Osmunda cinnamomea L.
Osmunda japonica Thunb.

Dennstaedtiaceae
Pteridium aquilinum (L.) Kuhn var. *latiusculum* (Desv.) Underw. ex Hall.

Blechnaceae
Blechnum niponicum (Kunze) Makino

Dryopteridaceae
Arachniodes standishii (Moore) Ohwi
**Dryopteris monticola* (Makino) C.Chr.
**Polystichum retroso-paleaceum* (Kodama) Tagawa

Thelypteridaceae
Stegnogramma pozoi (lagasca) K.Iwats. subsp. *mollissima* (Fischer ex Kunze) K.Iwats.
**Thelypteris japonica* (Bak.) Ching
**Thelypteris nipponica* (Fr. et Sav.) Ching
Thelypteris palustris (Salisb.) Schott

Woodsiaceae
**Athyrium deltoidofrons* Makino
Matteuccia struthiopteris (L.) Todaro
**Onoclea orientalis* (Hook.) Hook.

Polypodiaceae
**Polypodium fauriei* Christ

SPERMATOPYTA
GYMNOSPERMAE

Pinaceae
**Larix kaempferi* (Lamb.) Carr.
Pinus densiflora Sieb. et Zucc.
Pinus parviflora Sieb. et Zucc.

Taxodiaceae
**Cryptomeria japonica* (L.fil.) D.Don

Cephalotaxaceae
Cephalotaxus harringtonia (Knight) K.Koch var. *nana* (Nakai) Rehder

ANGIOSPERMAE
DICOTYLEDONEAE
CHORIPETALAE

Juglandaceae
Pterocarya rhoifolia Sieb. et Zucc.

Salicaceae
Salix bakko Kimura
**Salix futura* Seemen
**Salix gracilistyla* Miq.
Salix integra Thunb.
**Salix jessoensis* Seemen
**Salix sachalinensis* Fr.Schm.

Betulaceae
**Alnus hirsuta* Turcz.

Table 1. continued.

**Alnus inokumae* Murai et Kusaka
Alnus japonica (Thunb.) Steud.
Alnus pendula Matsum.
**Betula grossa* Sieb. et Zucc.
**Betula platyphylla* Sukatchev var. *japonica* (Miq.) Hara
Carpinus laxiflora (Sieb. et Zucc.) Blume
Corylus sieboldiana Blume

Fagaceae
Castanea crenata Sieb. et Zucc.
Fagus crenata Blume
Quercus crispula Blume
**Quercus serrata* Thunb. ex Murray

Urticaceae
Boehmeria tricuspis (Hance) Makino

Loranthaceae
**Hyphear tanakae* (Franch. et Savat.) Hosokawa
Viscum album L. subsp. *coloratum* Komarov

Polygonaceae
Persicaria thunbergii (Sieb. et Zucc.) H.Gross
Reynoutria japonica Houtt. var. *uzensis* Honda
**Reynoutria sachalinensis* (Fr.Schm.) Nakai
**Rumex acetosa* L.
**Rumex acetosella* L.
**Rumex japonicus* Houtt.

Magnoliaceae
Magnolia obovata Thunb.
**Magnolia praecocissima* Koidz. var. *borealis* Sarg.
Magnolia salicifolia (Sieb. et Zucc.) Maxim.

Lauraceae
Lindera praecox (Sieb. et Zucc.) Blume
Lindera umbellata Thunb. var. *membranacea* (Maxim.) Momiyama

Ranunculaceae
Anemone debilis Fisch.
**Aquilegia buergeriana* Sieb. et Zucc.
**Clematis japonica* Thunb.
**Coptis trifolia* (L.) Salisb.
**Ranunculus silerifolius* Lev.
Thalictrum minus L. var. *hypoleucum* (Sieb. et Zucc.) Miq.

Lardizabalaceae
Akebia trifoliata (Thunb.) Koidz.

Nymphaeaceae
**Nymphaea tetragona* Georgi

Actinidiaceae
Actinidia arguta (Sieb. et Zucc.) Planch.ex Miq.
Actinidia polygama (Sieb. et Zucc.) Planch. ex Maxim.

Guttiferae
Hypericum erectum Thunb.
Sarothra laxa (Blume) Y.Kimura
Triadenum japonicum Makino

Droseraceae
Drosera rotundifolia L.

Hamamelidaceae
**Hamamelis japonica* Sieb. et Zucc. var. *megalophylla* (Koidz.) Kitam.

Saxifragaceae
Astilbe thunbergii (Sieb. et Zucc.) Miq. var. *congesta* H.Boiss.
Hydrangea paniculata Sieb. et Zucc.
Hydrangea petiolaris Sieb. et Zucc.
Parnassia palustris L. var. *multiseta* Ledeb.
Schizophragma hydrangeoides Sieb. et Zucc.

Rosaceae
**Agrimonia nipponica* Koidz.
**Aruncus dioicus* (Walt.) Fern. var. *tenuifolius* (Nakai) Hara
**Duchesnea chrysantha* (Zoll. et Mor.) Miq.
**Geum japonicum* Thunb.
Malus toringo (Sieb.) Sieb. ex Vriese
**Potentilla centigrana* Maxim.
Potentilla freyniana Bornm.
**Prunus apetala* (Sieb. et Zucc.) Franch. et Savat. subsp. *pilosa* (Koidz.) H.Ohba
Prunus grayana Maxim.
Prunus sargentii Rehder
Prunus verecunda (Koidz.) Koehne
**Rubus crataegifolius* Bunge
Rubus microphyllus L.fil.
Rubus palmatus Thunb. var. *coptophyllus* A.Gray
Rubus parvifolius L.
Sorbus alnifolia (Sieb. et Zucc.) C.Koch
Sorbus commixta Hedl.

Leguminosae
**Amphicarpaea bracteata* (L.) Fernald subsp. *edge-worthii* (Benth.) Ohashi var. *japonica* (Oliver) Ohashi
Lespedeza bicolor Turcz.
**Lespedeza juncea* (L.fil.) Pers. var. *subsessilis* Miq.
**Lotus corniculatus* L. var. *japonicus* Regel
**Maackia amurensis* Rupr. et Maxim. subsp. *buergeri* (Maxim.) Kitamura
Pueraria lobata (Willd.) Ohwi
**Robinia pseudoacacia* L.

Table 1. continued.

**Trifolium pratense* L.
**Trifolium repens* L.
Wisteria floribunda (Willd.) DC.

Daphniphyllaceae
Daphniphyllum macropodum Miq. var. *humile* (Maxim.) Rosenthal

Rutaceae
Phellodendron amurense Rupr.
**Skimmia japonica* Thunb. var. *intermedia* Komatsu f. *repens* (Nakai) Hara

Polygalaceae
**Polygala japonica* Houtt.

Anacardiaceae
Rhus ambigua Lavall. ex Dipp.
Rhus javanica L. var. *roxburgii* (DC.) Rehd. et Wils.
Rhus trichocarpa Miq.

Aceraceae
Acer amoenum Carr. var. *matsumurae* (Koidz.) Ogata
**Acer crataegifolium* Sieb. et Zucc.
**Acer distylum* Sieb. et Zucc.
Acer japonicum Thunb.
**Acer micranthum* Sieb. et Zucc.
**Acer mono* Maxim. var. *ambiguum* (Pax) Rehder
**Acer mono* Maxim. var. *mayrii* (Schwerin) Sugimoto
Acer rufinerve Sieb. et Zucc.
Acer sieboldianum Miq.

Hippocastanaceae
Aesculus turbinata Blume

Aquifoliaceae
Ilex crenata Thunb. var. *paludosa* (Nakai) Hara
**Ilex leucoclada* (Maxim.) Makino
Ilex macropoda Miq.

Celastraceae
Celastrus orbiculatus Thunb.
**Celastrus orbiculatus* Thunb. var. *strigillosus* (Nakai) Makino
Euonymus alatus (Thunb.) Sieb. f. *striatus* (Thunb.) Makino

Rhamnaceae
Berchemia longeracemosa Okuyama
**Berchemia racemosa* Sieb. et Zucc.
Rhamnus crenata Sieb. et Zucc.

Vitaceae
Ampelopsis brevipedunculata (Maxim.) Trautv. var. *heterophylla* (Thunb.) Hara
Vitis coignetiae Pulliat ex Planch.

Tiliaceae
Tilia maximowicziana Shirasawa

Violaceae
Viola grypoceras A.Gray
**Viola grypoceras* A.Gray var. *pubescens* Nakai
**Viola kusanoana* Makino
Viola verecunda A.Gray
**Viola violacea* Makino var. *makinoi* (H.Boiss.) Hiyama

Stachyuraceae
Stachyurus praecox Sieb. et Zucc.

Onagraceae
**Oenothera biennis* L.

Cornaceae
Aucuba japonica Thunb. var. *borealis* Miyabe et Kudo
**Benthamidia japonica* (Sieb. et Zucc.) Hara
Swida controversa (Hemsl.) Sojak

Araliaceae
Acanthopanax sciadophylloides Franch. et Savat.
Aralia cordata Thunb.
Aralia elata (Miq.) Seemann
Kalopanax pictus (Thunb.) Nakai

Umbelliferae
**Hydrocotyle ramiflora* Maxim.

GAMOPETALAE

Clethraceae
Clethra barbinervis Sieb. et Zucc.

Pyrolaceae
**Chimaphila japonica* Miq.
**Monotropastrum humile* (D.Don) Hara
Pyrola japonica Klenze

Ericaceae
Gaultheria adenothrix (Miq.) Maxim.
Leucothoe grayana Maxim.
**Lyonia ovalifolia* (Wall.) Drude var. *elliptica* (Sieb. et Zucc.) Hand.-Mazz.
Menziesia multiflora Maxim.
Rhododendron albrechtii Maxim.
Rhododendron japonicum (A.Gray) Suringer

Table 1. continued.

Rhododendron obtusum (Lindl.) Planch. var. *kaempferi* (Planch.) Wilson
**Rhododendron semibarbatum* Maxim.
**Vaccinium hirtum* Thunb.
Vaccinium japonicum Maxim.
Vaccinium oldhamii Miq.
Vaccinium oxycoccus L.

Primulaceae
**Lysimachia clethroides* Duby
**Lysimachia japonica* Thunb.
**Lysimachia thyrsiflora* L.
Lysimachia vulgaris L. var. *davurica* (Ledeb.) R.Kunth

Styracaceae
Styrax obassia Sieb. et Zucc.

Symplocaceae
Symplocos chinensis (Lour.) Druce var. *leucocarpa* (Nakai) Ohwi f. *pilosa* (Nakai) Ohwi

Oleaceae
**Fraxinus lanuginosa* Koidz. f. *serrata* (Nakai) Murata
Fraxinus mandshurica Rupr. var. *japonica* Maxim.
**Ligustrum tschonoskii* Decne.

Gentianaceae
**Gentiana thunbergii* (G.Don) Griseb. var. *minor* Maxim.
Gentiana triflora Pallas var. *japonica* (Kusnez.) Hara
**Gentiana zollingeri* Fawcett
Swertia bimaculata (Sieb. et Zucc.) Hook. et Thoms.
Tripterospermum japonicum (Sieb. et Zucc.) Maxim.

Menyanthaceae
Menyanthes trifoliata L.

Asclepiadaceae
**Cynanchum sublanceolatum* (Miq.) Matsum. var. *albiflorum* (Franch. et Savat.) Hara
**Tylophora aristolochioides* Miq.

Rubiaceae
**Galium trifidum* L. var. *brevipedunculatum* Regel
**Galium trifloriforme* Komar. var. *nipponicum* (Makino) Nakai
**Mitchella undulata* Sieb. et Zucc.

Verbenaceae
Callicarpa japonica Thunb.

Labiatae
**Ajuga nipponensis* Makino
**Clinopodium gracile* (Benth.) O.Kuntze
**Lycopus maackianus* (Maxim.) Makino
**Lycopus uniflorus* Michx.
Rabdosia umbrosa (Maxim.) Hara var. *leucantha* (Murai) Hara

Scrophulariaceae
Melampyrum roseum Maxim. var. *japonicum* Franch. et Savat.

Lentibulariaceae
Utricularia bifida L.
Utricularia yakusimensis Masam.

Plantaginaceae
Plantago asiatica L.

Caprifoliaceae
Viburnum dilatatum Thunb.
Viburnum furcatum Blume ex Maxim.
**Viburnum plicatum* Thunb. f. *glabrum* (Koidz. ex Nakai) Rehder
Viburnum wrightii Miq.
Weigela hortensis (Sieb. et Zucc.) K.Koch

Valerianaceae
Patrinia villosa (Thunb.) Juss.

Campanulaceae
**Adenophora triphylla* (Thunb.) A.DC. var. *japonica* (Regel) Hara
**Codonopsis lanceolata* (Sieb. et Zucc.) Trautv.

Compositae
**Artemisia montana* (Nakai) Pamp.
**Artemisia japonica* Thunb.
Artemisia princeps Pamp.
**Aster ageratoides* Turcz. subsp. *leiophyllus* (Franch. et Savat.) Kitam.
**Aster ageratoides* Turcz. subsp. *ovatus* (Franch. et Savat.) Kitam.
Aster glehnii Fr.Schm. var. *hondoensis* Kitam.
**Carpesium glossophyllum* Maxim.
**Chrysanthemum leucanthemum* L.
**Cirsium amplexifolium* Kitam.
**Cirsium borealinipponense* Kitam.
Cirsium inundatum Makino
**Cirsium japonicum* DC.
**Cirsium nipponicum* (Maxim.) Makino
Eupatorium chinense L.
**Eupatorium chinense* L. subsp. *sachalinense* (Fr.Schm.) Kitam.
**Eupatorium lindleyanum* DC.
**Hypochoeris radicata* L.

Table 1. continued.

Inula ciliaris (Miq.) Maxim.
Ixeris dentata (Thunb.) Nakai
**Lactuca indica* L.
**Lactuca raddeana* Maxim. var. *elata* (Hemsl.) Kitam.
**Pertya rigidula* (Miq.) Makino
Petasites japonicus (Sieb. et Zucc.) Maxim.
**Picris hieracioides* L. subsp. *japonica* (Thunb.) Krylov
Senecio cannabifolius Less.
**Solidago gigantea* Ait. var. *leiophylla* Fernald
**Solidago virgaurea* L. subsp. *asiatica* Kitam.
Stenactis annuus (L.) Cass.
**Synurus pungens* (Franch. et Savat.) Kitam.

MONOCOTYLEDONEAE

Alismataceae
**Alisma canaliculatum* A.Br. et Bouche
Sagittaria natans (Lour.) Hara

Potamogetonaceae
**Potamogeton fryeri* A.Bennett

Liliaceae
Disporum smilacinum A.Gray
Heloniopsis orientalis (Thunb.) C.Tanaka
Hemerocallis dumortieri Morr. var. *esculenta* (Koidz.) Kitam.
**Hosta albo-marginata* (Hook.) Ohwi
**Hosta sieboldiana* (Lodd.) Engler
Lilium auratum Lindl.
**Lilium rubellum* Baker
Metanarthecium luteo-viride Maxim.
**Paris tetraphylla* A.Gray
**Polygonatum falcatum* A.Gray
Polygonatum lasianthum Maxim.
**Smilax china* L.
**Smilax nipponica* Miq.
Smilax riparia A.DC. var. *ussuriensis* (Regel) Hara et T.Koyama
Tricyrtis affinis Makino
**Veratrum album* L. subsp. *oxysepalum* Hulten

Dioscoreaceae
Dioscorea gracillima Miq.
**Dioscorea nipponica* Makino
**Dioscorea tokoro* Makino

Iridaceae
Iris ensata Thunb. var. *spontanea* (Makino) Nakai

Juncaceae
**Juncus effusus* L. var. *decipiens* Buchen.
**Juncus leschenaultii* Gay
**Juncus tenuis* Willd.
**Luzula capitata* (Miq.) Miq.
Luzula plumosa E.Meyer var. *macrocarpa* (Buchen.) Ohwi

Eriocaulaceae
Eriocaulon monococcon Nakai

Gramineae
**Agrostis alba* L.
**Agrostis clavata* Trin. subsp. *nukabo* Ohwi
Arundinella hirta (Thunb.) C.Tanaka
Brachypodium sylvaticum (Huds.) Beauv.
**Calamagrostis hakonensis* Franch. et Savat.
**Dactylis glomerata* L.
**Festuca arundinacea* Schreb.
**Festuca parvigluma* Steud.
**Festuca rubra* L.
**Lolium multiflorum* Lamar.
**Lolium perenne* L.
**Microstegium vimineum* (Trin.) A.Camus
**Miscanthus intermedius* (Honda) Honda
Miscanthus sinensis Anderss.
Moliniopsis japonica (Hack.) Hayata
**Oplismenus undulatifolius* (Arduino) Roemer et Schultes
Phragmites australis (Cav.) Trin. et Steud.
**Poa annua* L.
**Sasa palmata* (Marliac) Nakai
**Sasa senanensis* (Franch. et Savat.) Rehder
**Zoysia japonica* Steud.

Araceae
**Arisaema serratum* (Thunb.) Schott
Lysichiton camtschatcense (L.) Schott
**Symplocarpus foetidus* Nutt. var. *latissimus* (Makino) Hara

Typhaceae
**Typha orientalis* Presl

Cyperaceae
Carex albata Boott
**Carex aphanolepis* Franch. et Savat.
**Carex blepharicarpa* Franch.
**Carex breviculmis* R.Br.
**Carex capillacea* Boott
Carex dispalata Boott
Carex dolichostachya Hayata var. *glaberrima* (Ohwi) T.Koyama
**Carex fedia* Nees var. *miyabei* (Franch.) T.Koyama
Carex foliosissima Fr.Schm.
**Carex hakonensis* Franch. et Savat.
Carex heterolepis Bunge
**Carex hondoensis* Ohwi
**Carex ischnostachya* Steud.
**Carex kiotensis* Franch. et Savat.

Table 1. continued.

Carex lanceolata Boott	*Scirpus juncoides* Roxb.
**Carex maximowiczii* Miq.	*Scirpus wichurae* Böcklr
**Carex mollicula* Boott	
**Carex omiana* Franch. et Savat.	**Orchidaceae**
**Carex parciflora* Boott var. *macroglossa* (Franch. et Savat.) Ohwi	**Cephalanthera longibracteata* Blume
	Cymbidium goeringii (Reichb.fil.) Reichb.fil.
**Carex sadoensis* Franch.	*Eleorchis japonica* (A.Gray) F.Maek.
Carex siderosticta Hance	*Epipactis thunbergii* A.Gray
**Eleocharis wichurae* Böcklr.	**Liparis kumokiri* F.Maek.
Eriophorum gracile Koch	*Platanthera hologlottis* Maxim.
Eriophorum vaginatum L.	*Platanthera nipponica* Makino
Rhynchospora alba (L.) Vahl	**Platanthera sachalinensis* Fr.Schm.
Rhynchospora fauriei Franch.	*Pogonia japonica* Reichb.fil.
**Rhynchospora yasudana* Makino	*Spiranthes sinensis* (Pers.) Ames var. *amoena* (M.Bieberson) Hara

The following vegetation units were recognized in and around the mire (Tables 2—5): 1) 2 hydrophyte communities, 2) 6 moss vegetation communities comprising 4 groups and 6 subgroups, 3) 3 transitional mire vegetation communities, 4) 1 thicket community, and 5) 5 forest vegetation communities comprising 4 groups and 2 subgroups.

The floating-leaf plant communities (hydrophytic communities) are observed in the streams and shallow ponds of the mire. The moss vegetation (high mire vegetation) is the most widely distributed plant community and is characteristic of Miyatoko Mire. The *Moliniopsis japonica-Sphagnum fuscum* and the *Moliniopsis japonica-Sphagnum papillosum* communities usually form thick carpets or hummocks, and the *Rhynchospora alba-Sphagnum cuspidatum* community occurs in the hollows among the hummocks. The transitional mire vegetation (intermediate mire vegetation; *Moiniopsis japonica* community or *Inula ciliaris* community) occupies drained marginal sloping areas and water-logged depressions. However, no fen vegetation (low mire vegetation) is found in the mire. Distributions of the main species in Miyatoko Mire are shown in Fig. 1.

The mire is besieged by the thicket -*Hydrangea paniculata-Rhamnus crenata* community and the swamp forest - *Alnus japonica* community. The summer-green broad leaf forests (e.g. *Fagus crenata-Aucuba japonica* var. *borealis* community, *Quercus serrata-Prunus apetala* subsp. *pilosa* community) are distributed widely around the mire.

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Table 2. Synthesis table for mire vegetation of Miyatoko Mire.
Roman numerals (or Arabic numerals below four investigative quadrats) and subscripts represent the constancy class and the range of Braun-Blanquet's dominance factor, respectively.

1: *Potamogeton fryeri* community 2: *Nymphaea tetragona-Menyanthes trifoliata* community
3: *Carex omiana* community
4: *Inula ciliaris* community a. *Carex capillacea* group b. *Sphagnum cuspidatum* group
5: *Rhynchospora alba-Sphagnum cuspidatum* community a. *Rhynchospora yasudana* group
b. Typical group (1. *Eleocharis wichurae* subgroup, 2. typical subgroup)
6: *Rhynchospora alba-Sphagnum tenellum* community
7: *Moliniopsis japonica-Sphagnum papillosum* community
a. Typical group (1. typical subgroup, 2. *Sphagnum fuscum* subgroup)
b. *Osmunda cinnamomea* group (1. *Sphagnum fuscum* subgroup, 2. typical subgroup)
8: *Moliniopsis japonica-Sphagnum fuscum* community 9: *Sphagnum nemoreum community*
10: *Moliniopsis japonica-Sphagnum palustre* community 11: *Moliniopsis japonica* community

Community number:	1	2	3	4a	4b	5a1	5a2	5b	6	7a1	7a2	7b1	7b2	8	9	10	11
Number of quadrat:	1	7	1	2	6	6	26	23	3	13	22	13	20	14	3	15	13
Number of species:	1	5	10	16	25	24	30	19	14	23	20	25	29	24	15	38	35
Average number of species:	1	3	10	12	14	14	13	9	10	12	13	14	13	14	11	12	11
Potamogeton fryeri	1_{4}	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nymphaea tetragona	·	V_{2-3}	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Scirpus juncoides	·	III_{2-3}	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Carex omiana	·	·	1_{4}	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Inula ciliaris	·	·	·	2_{1-4}	V_{2-4}	II_{+}	·	·	·	·	·	·	·	·	·	·	·
Carex capillacea	·	·	·	2_{1}	·	·	·	·	·	·	·	·	·	·	·	·	·
Lycopus maackianus	·	·	·	2_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·
Alnus japonica	·	·	·	2_{+}	·	·	·	·	·	·	·	·	·	·	·	II_{+-1}	·
Sphagnum cuspidatum	·	·	·	·	V_{1-5}	V_{1-5}	V_{+-5}	V_{2-5}	2_{1-3}	·	·	·	·	·	·	·	·
Rhynchospora yasudana	·	·	·	·	V_{1-4}	V_{+-1}	III_{+-4}	·	·	·	·	·	·	·	·	·	·
Utricularia yakusimensis	·	·	·	·	IV_{1-4}	V_{+-3}	IV_{+-2}	·	·	·	·	·	·	·	·	·	·
Lycopodium inundatum	·	·	·	·	III_{1-4}	IV_{1-2}	III_{+-4}	·	·	·	·	·	·	·	·	·	·
Eleocharis wichurae	·	·	1_{1}	·	I_{+}	V_{+-1}	·	·	·	·	·	·	·	·	·	·	·
Sphagnum tenellum	·	·	·	·	·	·	·	·	3_{4-5}	·	·	·	·	·	·	·	·
Sphagnum magellanicum	·	·	·	·	·	·	I_{+-1}	II_{+-1}	·	V_{+-5}	IV_{+-5}	V_{+-5}	V_{4-5}	V_{+-2}	2_{+-2}	III_{+-1}	III_{1}
Osmunda cinnamomea	·	·	·	·	·	·	·	·	·	·	·	IV_{+-4}	V_{+-5}	III_{+-2}	3_{2-3}	II_{+-4}	IV_{+-5}
Rhododendron japonicum	·	·	·	·	·	·	·	·	·	·	·	III_{+}	IV_{+-2}	I_{+}	2_{+-2}	III_{+-2}	IV_{+-2}
Sphagnum fuscum	·	·	·	·	·	·	·	·	·	·	V_{+-3}	V_{+-3}	·	V_{4-5}	1_{2}	·	·
Sphagnum nemoreum	·	·	·	·	·	·	·	·	·	·	·	·	·	·	3_{4-5}	·	·
Sphagnum palustre	·	·	·	·	·	·	·	·	·	·	·	I_{1}	II_{1-3}	·	·	V_{4-5}	III_{+-3}
Moliniopsis japonica	·	·	I_{2}	2_{+-2}	V_{+-2}	V_{+-2}	V_{+-3}	V_{+-2}	3_{+-2}	V_{+-4}	V_{+-3}	V_{1-3}	V_{1-4}	V_{+-2}	3_{2-3}	V_{1-5}	V_{2-4}
Phragmites australis	·	V_{+-3}	1_{+}	1_{+}	V_{+-3}	IV_{+-1}	V_{+-3}	II_{+-2}	1_{+}	II_{+-2}	III_{+-3}	II_{+-2}	II_{+-1}	V_{+-2}	·	III_{+-3}	III_{1-3}
Drosera rotundifolia	·	·	1_{+}	2_{+-2}	IV_{+-1}	V_{+-1}	V_{+-2}	V_{+-2}	3_{+-1}	IV_{+}	IV_{+}	IV_{+}	III_{+}	IV_{+}	1_{+}	III_{+}	II_{+-1}
Rhynchospora alba	·	·	1_{+}	·	V_{+-4}	V_{2-4}	V_{+-4}	V_{2-4}	3_{3-4}	V_{+-4}	V_{+-4}	V_{+-4}	V_{+-4}	IV_{+-3}	1_{1}	I_{+-1}	I_{1-2}
Eriophorum vaginatum	·	·	·	1_{1}	III_{+-1}	II_{1}	V_{+-1}	V_{+-2}	3_{+-1}	V_{+-3}	V_{1-3}	V_{+-2}	V_{+-3}	V_{1-3}	3_{1-2}	V_{+-2}	IV_{+-2}
Parnassia palustris var. *multiseta*	·	·	·	1_{+}	II_{+}	IV_{+}	III_{+-1}	III_{+}	2_{+}	V_{+-1}	V_{+-1}	V_{+-2}	V_{+-2}	IV_{+-1}	3_{+}	IV_{+}	III_{+-2}
Hosta albo-marginata	·	·	·	1_{+}	V_{+-2}	I_{+}	III_{+-1}	IV_{+-2}	3_{1}	IV_{+-3}	V_{+-2}	V_{+-2}	V_{+-3}	V_{+-2}	3_{+-1}	III_{+-3}	V_{+-2}
Ilex crenata var. *paludosa*	·	·	·	1_{+}	I_{2}	·	·	·	·	IV_{1-3}	V_{+-4}	V_{+-3}	III_{+-3}	V_{1-3}	·	IV_{+-3}	II_{+-2}
Pogonia japonica	·	·	·	·	V_{+-1}	V_{+-1}	V_{+-2}	V_{+-1}	2_{+}	IV_{+-2}	III_{+-1}	IV_{+}	II_{+}	II_{+}	·	I_{+}	·
Gentiana thunbergii var. minor	·	·	·	·	II_{+}	II_{+}	III_{+-1}	II_{+}	1_{+}	II_{+}	II_{+}	III_{+}	III_{+}	II_{+}	1_{+}	II_{+}	III_{+-2}
Sphagnum papillosum	·	·	·	·	I_{+}	III_{+-1}	II_{+-2}	IV_{+-4}	3_{+-1}	V_{+-5}	V_{1-5}	V_{+-5}	IV_{+-4}	V_{1-3}	·	I_{+}	II_{+-2}
Gentiana triflora var. japonica	·	·	·	·	II_{+}	·	III_{+}	II_{+}	·	IV_{+-1}	IV_{+}	IV_{+-1}	IV_{+-1}	IV_{+}	3_{+}	II_{+}	IV_{+-1}
Vaccinium oxycoccus	·	·	·	·	I_{+}	·	I_{+}	II_{+}	·	IV_{+-1}	V_{+-2}	V_{+-1}	IV_{+-1}	V_{+-1}	1_{1}	IV_{+-5}	·
Epipactis thunbergii	·	·	·	·	III_{+}	·	·	·	·	I_{+-1}	I_{+-1}	I_{+-1}	I_{+}	III_{+-2}	·	III_{+-2}	·
Miscanthus intermedius	·	·	·	·	·	·	·	·	·	II_{+-2}	II_{+-2}	I_{1}	II_{+-3}	III_{+-1}	·	III_{+-1}	III_{+-1}
Menyanthes trifoliata	·	V_{1-4}	·	2_{2}	II_{2-3}	I_{+}	I_{+-1}	·	·	·	·	·	·	·	·	I_{+}	·
Rhynchospora fauriei	·	·	1_{+}	1_{+}	II_{1-2}	III_{+-4}	IV_{+-3}	·	·	·	·	·	·	·	·	·	·
Eriocaulon monococcon	·	·	1_{1}	1_{+}	III_{+-2}	IV_{+-1}	II_{+-2}	·	·	·	·	·	·	·	·	·	·
Eleorchis japonica	·	·	·	·	II_{+}	I_{+}	I_{+-1}	·	·	·	·	·	·	·	·	·	·
Pteridium aquilinum var. latiusculum	·	·	·	·	·	·	·	·	·	·	·	·	I_{+}	·	2_{+-1}	·	I_{+-1}
Platanthera nipponica	·	·	·	·	·	I_{+}	·	·	1_{+}	·	·	·	·	·	·	·	·
Hydrangea paniculata	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	II_{+-1}	II_{+}
Eriophorum gracile	·	I_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Platanthera hologlottis	·	·	1_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Juncus leschenaultii	·	·	1_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Cirsium inundatum	·	·	·	1_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·
Triadenum japonicum	·	·	·	1_{+}	·	·	·	·	·	·	·	·	·	·	·	·	·
Alisma canaliculatum	·	·	·	·	I_{+}	·	·	·	·	·	·	·	·	·	·	·	·
Utricularia bifida	·	·	·	·	·	I_{1}	·	·	·	·	·	·	·	·	·	·	·
Lycopus uniflorus	·	·	·	·	·	I_{+}	·	·	·	·	·	·	·	·	·	·	·
Hypnaceae sp.	·	·	·	·	·	I_{+}	·	·	·	·	·	·	·	·	·	·	·
Acer amoenum var. matumurae	·	·	·	·	·	·	·	·	I_{+}	·	·	·	·	·	·	·	·
Hemerocallis dumortieri var. esculenta	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	II_{+-2}	·
Carex dispalata	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	I_{+-1}	·

Table 3. Floristic composition of the thicket, *Hydrangea paniculata-Rhamnus crenata* community.
1: *Sphagnum palustre* group, 2: *Sphagnum nemoreum* group

Community type:		1				2
Running number:		1	2	3	4	1
Quadrat number:		165	226	105	181	227
Date:		'93 6.26	'93 9.28	'92 10.3	'93 9.27	'93 9.28
Quadrat size (m^2):		4	8	9	9	4
Height of shrub layer (S; m):		2.0	2.5	1.5	2.0	1.8
Cover degree of shrub layer (S; %):		80	80	60	50	90
Height of herb layer (H; m):		0.3	1.0	0.8	1.0	1.0
Cover degree of herb layer (H; %):		10	50	95	90	40
Cover degree of moss layer (M; %):		100	10	10	10	60
Number of species:		13	14	15	16	16
Differential species of community:						
Hydrangea paniculata	S	1·1	3·3	3·3	3·3	4·4
	H	·	+	+	+	·
Rhamnus crenata	S	2·3	2·2	3·3	·	·
	H	·	+·2	1·2	+	+
Differential species of under unit:						
Sphagnum palustre	M	5·5	1·1	1·1	1·2	·
Sphagnum nemoreum	M	·	·	·	·	4·4
Companion species:						
Rhododendron japonicum	S	1·1	·	·	·	1·1
	H	·	1·1	2·2	+·2	2·2
Ilex crenata var. *paludosa*	S	4·4	3·3	·	1·1	3·3
	H	1·2	+·2	·	2·2	+·2
Phragmites australis	S	+	2·3	·	2·3	1·2
Eriophorum vaginatum	H	+	·	+	+	1·1
Moliniopsis japonica	H	·	3·3	2·3	4·5	1·1
Osmunda cinnamomea	H	·	2·2	4·4	3·3	2·3
Hosta albo-marginata	H	·	+·2	1·2	3·3	+
Gentiana triflora var. *japonica*	H	·	+·2	+	·	1·2
Thelypteris japonica	H	·	+	·	+·2	+
Rhus trichocarpa	S	+	+	·	·	·
	H	+	+	·	·	·
Symplocarpus foetidus var. *latissimus*	H	1·2	·	+	·	·
Epipactis thunbergii	H	+	·	+	·	·
Alnus japonica	S	+	·	·	+	·
Gentiana thunbergii var. *minor*	H	·	+·2	+·2	·	·
Prunus grayana	S	+	·	·	·	·
	H	+	·	·	·	·
Castanea crenata	H	+	·	·	·	·
Miscanthus intermedius	H	·	1·1	·	·	·
Pogonia japonica	H	·	·	+	·	·
Sphagnum magellanicum	M	·	·	+	·	·
Disporum smilacinum	H	·	·	+	·	·
Cirsium inundatum	S	·	·	·	+·2	·
Carex dispalata	H	·	·	·	+·2	·
Lycopus uniflorus	H	·	·	·	+	·
Platanthera sachalinensis	H	·	·	·	+	·
Sphagnum papillosum	M	·	·	·	·	1·2
Scirpus wichurae	H	·	·	·	·	1·1
Drosera rotundifolia	H	·	·	·	·	+
Quercus serrata	H	·	·	·	·	+

Table 4. Floristic composition of the swamp forest, Alnus japonica community.
1: *Moliniopsis japonica* group; 2: *Carex capillacea* group (a. *Lysichiton camtschatcense* subgroup, b. *Symplocarpus foetidus* var. *latissimus* subgroup)

Community type:		1								2a								2b						
Running number:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Quadrat number:		223	100	220	222	113	101	99	50	114	133	72	80	146	110	143	109	108	15	172	6	147	170	128
Date:		'93	'92	'93	'93	'92	'92	'92	'92	'92	'92	'92	'92	'93	'92	'93	'92	'92	'92	'93	'92	'93	'93	'92
		9.28	10.3	9.28	9.28	10.4	10.3	10.3	10.2	10.4	10.4	10.3	10.3	6.25	10.4	6.25	10.4	10.4	6.24	6.26	6.24	6.25	6.26	10.4
Quadrat size (m²):		4	1	4	4	1	4	4	4	25	16	9	25	100	100	225	150	100	25	100	4	25	16	16
Height of tree layer-1 (T1; m):		-	-	-	-	-	-	-	-	-	-	-	-	12	10	18	14	12	-	12	-	-	-	-
Cover degree of tree layer-1 (T1; %):		-	-	-	-	-	-	-	-	-	-	-	-	70	70	80	60	50	-	70	-	-	-	-
Height of tree layer-2 (T2; m):		-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	-	-	-	-	-	-	-
Cover degree of tree layer-2 (T2; %):		-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	30	-	-	-	-	-	-	-
Height of shrub layer (S; m):		1.5	1.2	1.0	0.8	1.2	1.3	2.0	2.0	3.0	2.0	5.0	5.0	5.0	4.5	3.5	3.0	5.0	6.0	5.0	2.5	2.5	2.5	2.0
Cover degree of shrub layer (S; %):		80	30	70	60	70	30	90	90	100	100	90	100	90	95	60	50	90	50	90	95	90	100	100
Height of herb layer (H; m):		0.6	0.6	0.5	0.4	0.6	0.7	0.5	0.6	0.5	0.8	0.5	0.6	0.8	0.6	0.5	1.2	1.0	0.8	0.6	0.5	0.3	0.3	0.4
Cover degree of herb layer (H; %):		70	70	60	70	70	70	40	80	10	20	50	40	40	70	50	70	60	60	30	30	20	20	10
Cover degree of moss layer (M; %):		60	80	30	60	40	20	70	20	60	70	50	30	10	30	0	60	20	5	10	30	90	20	70
Number of species:		13	16	16	16	17	18	19	22	13	15	22	25	27	32	38	39	27	24	16	15	15	14	14
Differential species of community:																								
Alnus japonica	T1	·	·	·	·	·	·	·	·	·	·	·	·	4·4	4·4	3·3	4·4	3·3	·	4·4	·	·	·	·
	T2 , H	·	·	·	·	·	1·2	·	·	·	·	·	·	·	·	·	2·2	·	+·2	·	·	·	+	·
	S	4·4	2·2	4·4	4·4	3·3	3·3	3·3	4·4	4·4	3·3	4·4	4·4	+	2·2	·	·	1·1	2·2	·	+	2·2	3·3	1·1
Differential species of under unit:																								
Moliniopsis japonica	H	4·4	3·3	3·3	3·3	2·3	3·3	+·2	1·1	·	·	·	·	·	2·2	·	·	·	+	·	·	·	+	·
Eriophorum vaginatum	H	1·1	2·3	1·1	2·3	1·1	2·3	1·1	1·2	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Parnassia palustris var. *multiseta*	H	·	+·2	1·2	+·2	+	1·2	+	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Epipactis thunbergii	H	·	1·2	+	1·2	+	+·2	+	1·2	·	+	+	·	·	·	·	+	·	·	·	·	·	·	·
Drosera rotundifolia	H	·	+	·	+	+	·	+	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Hemerocallis dumortieri var. *esculenta*	H	+	+	·	+	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Malus toringo	S	·	·	·	·	·	·	·	·	·	·	·	·	·	+	1·2	·	·	·	1·1	·	·	·	1·1
	H	·	·	·	·	·	·	·	·	+	+	+	+	1·1	+	·	+·2	+	+	·	·	·	·	·
Rhus trichocarpa	T2 , S	·	·	·	·	·	·	·	·	1·2	+	·	1·1	·	1·1	1·2	+	1·2	·	1·1	+	+	+·2	·
	H	·	·	·	·	·	·	·	·	·	·	+	+	·	+	+	+	+·2	+	+·2	+	·	·	·
Prunus grayana	T2 , H	·	·	·	·	·	·	·	·	·	·	·	·	·	+	+	1·1	·	+	+	+	·	·	·
	S	·	·	·	·	·	·	·	·	·	·	+	·	2·2	2·2	2·3	1·1	2·2	+	3·3	2·2	+	+	·
Magnolia obovata	T1	·	·	·	·	·	·	·	·	·	·	·	·	·	·	3·3	+	·	·	·	·	·	·	·
	T2 , H	·	·	·	·	·	·	·	·	·	+	·	·	·	·	1·1	+	+	·	·	·	·	·	·
	S	·	·	·	·	·	·	·	·	·	·	·	+	+	+	+	·	+	·	+	·	·	·	+
Carex capillacea	H	·	·	·	·	·	·	+	·	1·2	·	+	1·2	+	2·3	·	1·1	·	+	·	1·1	·	·	·
Thelypteris palustris	H	·	·	·	·	·	·	·	·	+	·	·	·	+	1·2	+	1·1	·	·	·	·	+	+	+
Thelypteris nipponica	H	·	·	·	·	·	·	·	·	·	·	·	+	1·2	·	2·2	+	2·2	·	1·1	·	+	1·2	·
Cirsium inundatum	S	·	+·2	·	·	·	·	·	2·2	+·2	+	·	·	+	1·2	+	1·1	·	·	·	·	·	·	·
	H	+	·	·	·	·	+	+·2	·	+	+	·	+·2	·	+·2	·	1·2	·	·	·	·	·	·	·
Lycopus maackianus	H	·	1·1	+·2	·	1·2	·	·	3·3	·	+	1·1	+	+	+	·	+·2	·	·	·	·	·	·	·
Acer sieboldianum	S	·	·	·	·	·	·	·	·	·	+	+	·	+	1·1	1·1	·	·	·	·	·	·	·	·
	H	·	·	·	·	·	·	·	·	·	·	·	+	+	+	·	+	·	·	·	·	·	·	·
Lysichiton camtschatcense	H	·	·	·	·	·	·	·	·	·	·	1·1	+	+	2·2	+	+	·	·	·	·	·	·	·
Thuidium sp.	M	·	·	·	·	·	·	+·2	·	·	·	3·3	+	·	1·1	·	3·3	·	·	·	+	·	·	·
Symplocarpus foetidus var. *latissimus*	H	·	·	·	1·1	·	·	·	·	·	·	·	·	·	·	·	·	2·3	·	1·2	+	1·2	2·2	1·1
Companion species:																								
Rhododendron japonicum	S	·	·	·	·	·	·	·	·	1·1	1·1	·	·	·	·	·	·	·	·	+	·	1·2	2·2	+
	H	+	1·1	·	+	1·1	1·1	1·1	+	·	1·1	+·2	+·2	+	1·1	+	1·1	1·1	1·1	+	1·2	1·2	·	+
Ilex crenata var. *paludosa*	S	·	1·1	·	·	·	·	4·5	·	4·5	4·4	·	4·4	3·3	3·3	3·3	3·3	3·3	3·3	3·3	4·4	4·4	4·5	4·5
	H	1·1	·	·	·	3·3	·	1·2	1·1	1·2	1·2	2·2	1·2	2·3	2·3	1·2	2·3	2·3	2·3	1·2	1·2	1·2	1·1	·
Phragmites australis	S	+	·	·	+·2	3·3	1·2	1·2	2·3	1·2	1·2	2·3	+·2	+·2	1·2	+	2·3	1·2	+·2	+	·	+	·	3·3
Hydrangea paniculata	S	·	·	·	·	·	·	·	·	+	+	·	+	1·1	+	2·2	1·1	1·1	·	1·2	2·2	·	2·2	+
	H	+	+	+	1·1	·	+	+	·	·	+	+	+	·	·	+	+	·	+·2	+·2	+	+·2	·	·
Sphagnum palustre	M	4·4	4·4	2·2	4·4	·	2·2	4·4	·	4·4	4·4	2·2	3·3	1·1	2·2	·	1·1	2·2	·	1·1	3·3	5·5	2·2	4·4
Rhamnus crenata	S	1·1	·	·	·	·	·	+	·	2·2	1·1	1·1	2·2	3·3	1·1	1·1	1·1	3·3	1·1	3·3	3·3	2·2	+	1·1
	H	·	·	·	·	·	+	·	·	·	·	+	+·2	1·2	+·2	·	+·2	+·2	+	·	+·2	+	·	·
Osmunda cinnamomea	H	+·2	·	·	·	·	3·3	·	·	·	·	·	+	1·2	1·1	1·1	3·3	3·3	3·3	+	1·1	+	·	1·1
Carex maximowiczii	H	·	·	·	1·1	1·1	·	·	1·1	·	·	·	+	·	1·1	·	+	+	1·1	·	·	+	·	·
Magnolia praecocissima var. *borealis*	T2 , H	·	·	·	·	·	·	·	·	·	·	+	+	+	·	+	+	·	+	+	·	·	·	·
	S	·	·	·	·	·	·	·	·	·	·	·	·	+	+	+	+	·	·	·	·	·	·	·
Lycopus uniflorus	H	·	+	·	·	1·2	·	·	·	·	·	1·1	2·3	·	1·1	·	+	·	+	·	·	·	·	·
Hosta albo-marginata	H	·	·	1·1	·	1·1	·	·	·	·	·	·	·	·	·	·	1·1	1·1	1·2	·	·	+	·	+
Scirpus wichurae	H	·	·	·	1·1	·	+	·	+	·	·	·	·	·	+	·	+	+	+	·	·	·	·	·
Rhus ambigua	T1	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1·2	·	+	·	·	·	·	·	·
	H	·	·	·	·	·	·	·	·	·	·	·	·	1·2	·	2·3	1·2	1·2	1·1	·	·	·	·	·
Acer amoenum var. *matumurae*	T1	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1·1	·	·	·	·	·	·	·	·
	S , H	·	·	·	·	·	·	·	·	·	·	·	·	·	+	1·1	+	+	+	·	·	·	·	·
Triadenum japonicum	H	·	+·2	+	·	·	·	·	1·1	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·

Table 4. continued.

Community type:		1								2a								2b						
Running number:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Quadrat number:		223	100	220	222	113	101	99	50	114	133	72	80	146	110	143	109	108	15	172	6	147	170	128
Fraxinus mandshurica var. *japonica*	T1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1·1	1·1	+	.	.	.	.	.	.
	S	.	.	.	.	.	.	.	.	.	.	.	.	1·1	.	.	+	.	.	.	.	.	.	.
	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.
Gentiana triflora var. *japonica*	H	.	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Platanthera sachalinensis	H	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.
Thelypteris japonica	H	.	.	.	.	.	.	.	.	+	.	.	1·1	.	.	.	.	.	.	.	1·1	.	.	.
Lycopodium serratum	H	.	.	.	.	.	.	.	.	.	.	+	.	.	1·1	3·3	.	.	.	.	.	.	.	.
Sasa senanensis	H	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	1·1	.	.	.	.	.	.	.
Sphagnum squarrosum	M	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	+
Sorbus alnifolia	S, H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.
Osmunda japonica	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1·1	.	.	+	.	.	.
Sphagnum papillosum	M	2·2	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhynchospora alba	H	.	.	1·1	2·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sphagnum cuspidatum	M	.	.	+	.	2·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eriocaulon monococcon	H	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rhynchospora fauriei	H	.	.	1·1	.	.	.	.	+·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hepaticae sp.	M	.	.	.	.	2·2	.	.	1·1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Inula ciliaris	H	.	.	.	.	+	.	.	1·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gentiana thunbergii var. *minor*	H	.	.	.	.	.	+	.	+·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex dispalata	H	.	.	.	.	.	+	2·3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscanthus intermedius	H	.	.	.	.	.	.	1·1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Disporum smilacinum	H	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Hypnaceae sp.	M	.	.	.	.	.	.	.	2·2	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Menziesia multiflora	S, H	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	1·1	.
Sorbus commixta	S	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.
Acanthopanax sciadophylloides	S	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.
Schizophragma hydrangeoides	H	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.
Lindera umbellata var. *membranacea*	S	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.
	H	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Skimmia japonica var. *intermedia* f. *repens*	H	.	.	.	.	.	.	.	.	.	.	.	.	.	1·1	.	1·1	.	.	.	.	.	.	.
Acer rufinerve	S	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.
Viburnum plicatum f. *glabrum*	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1·1	+	.	.	.	.	.	.	.
Euonymus alatus f. *striatus*	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.
Symplocos chinensis var. *leucocarpa* f. *pilosa*	S, H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1·1	.	+	.	.	.	.	.	.
Magnolia salicifolia	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.
Sasa palmata	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.
Pteridium aquilinum var. *latiusculum*	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.
Sphagnum magellanicum	M	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sphagnum amblyphyllum	M	.	.	.	.	.	.	1·1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex omiana	H	.	.	.	.	.	.	+·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lysimachia vulgaris var. *davurica*	H	.	.	.	.	.	.	.	2·2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pogonia japonica	H	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Heloniopsis orientalis	H	.	.	.	.	.	.	.	.	.	2·3	.	.	.	.	.	.	.	.	.	.	.	.	.
Galium trifidum var. *brevipedunculatum*	H	.	.	.	.	.	.	.	.	.	.	1·2	.	.	.	.	.	.	.	.	.	.	.	.
Ilex leucoclada	H	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Carex ischnostachya	H	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Veratrum album subsp. *oxysepalum*	H	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Quercus crispula	H	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Hydrangea petiolaris	T1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2·2	.	.	.	.	.	.	.	.
	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+·2	.	.	.	.	.	.	.	.
Acer mono var. *mayrii*	T1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Wisteria floribunda	T2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Kalopanax pictus	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Rubus palmatus var. *coptophyllus*	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Celastrus orbiculatus var. *papillosus*	T2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Actinidia arguta	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Vitis coignetiae	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Castanea crenata	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Ligustrum tschonoskii	S	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Tripterospermum japonicum	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Athyrium deltoidofrons	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Solidago virgaurea subsp. *asiatica*	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Styrax obassia	H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.

Table 5. Floristic composition of the summer-green broad leaf forests.
1: *Fagus crenata-Aucuba japonica* var. *borealis* community
2: *Quercus crispula-Rhododendron obtusum* var. *kaempferi* community
3: *Quercus serrata-Prunus apetala* subsp. pilosa community (a. typical group, b. *Sasa senanensis* group)

Community type:		1	2	3-1				3-2				
Running number:		1	1	1	2	3	4	5	6	7	8	9
Quadrat number:		31	32	34	40	145	39	42	33	144	36	41
Date:		'92	'92	'92	'92	'93	'92	'92	'92	'93	'92	'92
		6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Altitude (m):		760	830	860	835	930	900	855	855	910	840	830
Slope aspect (°):		N30E	N	N20W	N70E	S70W	SW	S	N10E	S20E	S70W	S60W
Slope degree (°):		20	55	10	15	5	25	10	5	15	15	5
Quadrat size (m²):		200	400	400	225	225	225	225	400	225	400	225
Height of tree layer-1 (T1; m):		20	20	16	16	21	16	18	16	20	18	18
Cover degree of tree layer-1 (T1; %):		90	90	90	90	90	80	90	85	90	90	90
Height of tree layer-2 (T2; m):		7	10	8	9	7	6	7	8	7	10	-
Cover degree of tree layer-2 (T2; %):		5	30	30	20	40	10	30	20	5	20	-
Height of shrub-1 layer (S1; m):		3.5	3.0	3.0	3.0	3.5	2.5	2.5	3.0	4.0	4.0	4.0
Cover degree of shrub-1 layer (S1; %):		40	60	50	80	40	50	20	20	30	40	20
Height of shrub-2 layer (S2; m):		-	-	-	-	-	-	1.2	1.0	0.8	1.0	1.5
Cover degree of shrub-2 layer (S2; %):		-	-	-	-	-	-	60	70	70	60	95
Height of herb layer (H; m):		0.6	0.5	0.8	0.5	0.6	0.6	0.3	0.3	0.3	0.6	0.3
Cover degree of herb layer (H; %):		50	20	40	50	50	30	20	20	10	20	5
Number of species:		41	41	43	40	40	46	36	27	26	25	19
Differential species of community:												
Fagus crenata	T1, T2	3·3	·	·	·	1·1	·	·	·	1·1	·	·
	S1	+	·	·	·	+	·	·	·	+	·	·
	H	+	·	·	·	·	·	·	·	+	·	·
Aucuba japonica var. *borealis*	H	2·2	·	·	·	·	·	·	·	·	·	·
Viburnum furcatum	S1	2·3	1·2	·	·	·	·	·	·	·	+	·
	H	3·3	·	·	·	·	·	·	·	·	·	·
Rhododendron obtusum var. *kaempferi*	S1	·	2·2	·	·	·	1·1	·	·	·	·	·
	H	·	·	+	·	·	+	·	·	·	·	·
Lyonia ovalifolia var. *elliptica*	T2	·	1·1	·	·	·	·	·	·	·	·	·
Quercus serrata	T1	·	+	5·5	5·4	5·5	5·5	5·5	5·5	5·4	4·4	5·5
	T2	·	·	+	1·1	·	1·1	·	·	+	·	·
	S1	·	·	·	·	·	2·3	·	·	+	·	1·1
	H	·	·	·	+	+·2	+	+	+	·	·	+
Pteridium aquilinum var. *latiusculum*	H	·	·	1·2	1·2	+	1·2	1·2	1·2	1·2	+	+·2
Weigela hortensis	S1	·	·	+	2·3	·	+·2	·	+	·	+	+·2
	H	·	·	·	·	+·2	+	·	+	·	·	+
Differential species of under unit:												
Sasa senanensis	S2, H	+·2	·	+	·	·	·	4·5	4·5	4·5	4·5	5·5
Companion species:												
Rhus trichocarpa	T2	·	·	2·2	1·2	·	·	+	1·2	·	1·1	·
	S1	·	·	2·3	1·1	2·3	2·3	1·2	·	+·2	2·3	+·2
	S2	·	·	·	·	·	·	+	+	+	·	·
	H	+	+	2·3	1·2	1·2	·	+·2	1·2	+·2	+	+
Acanthopanax sciadophylloides	T1, T2	·	+	1·1	·	1·1	·	+	·	+	·	·
	S1	·	·	·	+	1·2	+	·	·	·	·	·
	H	+	·	+	+	1·2	·	1·2	+	+	+	+
Prunus apetala subsp. *pilosa*	T2, S1	1·2	+	+	1·1	·	·	·	2·3	1·1	·	+
	H	·	+	1·1	+	+·2	+	1·1	1·2	·	·	·
Pertya rigidula	H	+	+	2·2	1·2	2·3	1·1	+	+	+	+·2	·
Castanea crenata	T1	+	2·2	·	1·1	1·1	·	+	+	·	·	·
	S1	·	·	+	+	+·2	+	·	·	·	·	·
	H	·	+	+	+	·	+	+	+	+	·	+
Acer sieboldianum	T2	1·1	+	+	·	1·1	·	1·2	·	·	2·3	·
	S1	·	·	+	1·1	·	1·1	1·2	·	2·3	1·1	+
	H	·	·	·	+·2	1·2	·	+·2	·	+	·	·
Schizophragma hydrangeoides	T2	·	·	·	·	·	·	+	·	·	+	·
	H	1·2	+·2	+	1·1	1·1	+	+·2	+	·	1·1	·
Prunus grayana	T2, S1	+	·	·	3·3	+	+	+	+	·	·	1·1
	H	·	+	+	1·1	+	·	1·2	+	·	·	+
Acer japonicum	T2	·	1·1	+	·	·	·	·	1·1	·	·	·
	S1	+	·	+	+	+	·	·	·	·	·	·
	H	+	+·2	·	·	1·1	+	+	+	·	·	+
Acer amoenum var. *matumurae*	S1, H	1·1	+	+	+	1·1	+	+	·	+	·	+
Sorbus alnifolia	T1, T2	·	+	·	+	+	·	1·1	+	·	·	·
	S1	·	+·2	1·1	+	·	·	+	1·2	+	·	1·1
	S2, H	+	·	1·2	+	+	·	·	+	+	·	·
Ilex crenata var. *paludosa*	S1	·	+	·	·	·	·	·	·	·	·	·
	H	2·2	+	+	+	1·1	·	+	+	·	1·1	+
Magnolia obovata	T1	3·3	·	+	·	·	·	+	1·1	·	+	·
	T2	·	1·1	·	·	+	·	·	·	·	+	·
	S1	·	·	·	·	·	·	+	·	+	+	·
	H	+	·	+	·	+	+	·	+	+	·	·
Acer rufinerve	T2, S1	·	·	+	+	+	+	·	·	·	·	·
	S2, H	+·2	+	+	+	·	·	+	+	+	·	·

Table 5. continued.

Community type:		1	2	3-1				3-2				
Running number:		1	1	1	2	3	4	5	6	7	8	9
Quadrat number:		31	32	34	40	145	39	42	33	144	36	41
Quercus crispula	T1	3·3	4·4	1·1	·	·	+	1·1	+	1·1	2·2	·
	T2	·	·	1·1	·	·	+	1·1	·	·	+	·
	S1 , H	1·2	+	+	·	·	+	·	+	+	+	·
Viburnum wrightii	S1 , S2	·	1·2	1·2	+	·	+	+	·	+	1·2	·
	H	·	+·2	1·2	·	+·2	+	·	·	+·2	+	·
Fraxinus lanuginosa f. *serrata*	T2 , S1	·	·	·	+	·	·	+	·	1·1	+	·
	H	·	+	+	+	+	·	·	+·2	·	+	·
Pyrola japonica	H	+	·	+	+	+	+	+	+	·	·	·
Tripterospermum japonicum	H	+	·	+	+	·	+	+	+	·	+	·
Rhododendron japonicum	S1	·	·	·	1·1	+	1·1	·	·	·	·	·
	H	·	+·2	1·1	2·2	+	2·2	1·1	·	·	·	+
Lindera umbellata var. *membranacea*	S1	2·3	1·2	1·2	+	+	·	·	+	·	·	·
	H	+·2	1·2	+·2	·	+	·	+	+	·	·	·
Acer mono var. *mayrii*	T1	2·2	·	·	·	·	·	·	·	·	·	·
	T2	+	·	·	·	·	·	+	·	·	·	·
	S1	·	·	+	·	+	·	+	·	·	+	·
	H	+	+	·	·	+	·	+	·	·	·	·
Styrax obassia	T2	·	1·1	1·1	·	·	·	·	·	·	+	·
	S1	1·1	1·1	+	·	+	·	·	·	+	·	·
	H	·	+	·	·	·	·	·	·	+	·	·
Vaccinium japonicum	H	+	1·1	·	·	·	+	·	+	+·2	1·2	·
Clethra barbinervis	S1	+	2·2	·	1·1	·	·	+	·	+	·	·
	S2 , H	+	·	·	·	·	·	+	·	·	+	·
Euonymus alatus f. *striatus*	S1	+	·	·	·	·	·	+	·	·	·	·
	H	+	·	·	+	·	·	+	+	+	·	+
Kalopanax pictus	T1 , T2	·	·	·	+	·	·	·	+	·	1·1	·
	S1	·	·	+	+	·	·	·	·	·	·	·
	H	·	·	+	+	+	+	·	·	·	·	·
Wisteria floribunda	T2	·	·	·	·	·	·	·	+	·	·	·
	H	·	·	·	+·2	+	·	+	+	+·2	+	·
Blechnum niponicum	H	1·2	+·2	+	+	·	+	·	·	·	·	·
Disporum smilacinum	H	1·1	·	+·2	+·2	·	+	1·1	·	·	·	·
Leucothoe grayana	S1	·	·	+	1·1	·	+·2	·	·	·	·	·
	H	·	·	+	·	·	1·1	·	·	1·2	+	·
Osmunda japonica	H	+	+	+	·	+	·	·	·	·	·	·
Corylus sieboldiana	S1	+	+	·	·	·	·	·	·	·	·	+
	H	+	·	·	·	·	·	+	·	·	·	·
Vitis coignetiae	H	+	·	·	+	+	+	·	·	·	·	·
Polygonatum lasianthum	H	·	·	+	+·2	+·2	+·2	·	·	·	·	·
Hydrangea paniculata	S1 , S2	·	·	+	+	·	·	·	·	·	·	+
	H	·	·	·	·	+	·	·	·	·	·	·
Hydrangea petiolaris	H	+	+	·	·	·	·	·	·	+	·	·
Menziesia multiflora	S1	+	1·1	·	·	·	·	·	·	·	+	·
Ilex macropoda	T2	·	+	·	·	·	·	·	+	·	·	·
	S1 , H	·	+	·	·	·	+	·	·	·	·	·
Monotropastrum humile	H	·	+	·	·	·	+	·	·	+	·	·
Rhus ambigua	T2	·	·	·	·	+	·	·	·	·	·	·
	H	·	·	+	·	+	+	·	·	·	·	·
Melampyrum roseum var. *japonicum*	H	·	·	+	·	·	1·1	+	·	·	·	·
Prunus verecunda	T1 , H	·	·	·	+	+	·	1·1	·	·	·	·
Astilbe thunbergii var. *congesta*	H	+	·	·	·	·	+	·	·	·	·	·
Vaccinium hirtum var. *pubescens*	H	·	1·2	1·1	·	·	·	·	·	·	·	·
Dioscorea nipponica	H	·	·	+	+	·	·	·	·	·	·	·
Smilax riparia var. *ussuriensis*	H	·	·	+	·	·	·	·	·	·	+·2	·
Solidago virgaurea subsp. *asiatica*	H	·	·	·	+	·	+·2	·	·	·	·	·
Miscanthus sinensis	H	·	·	·	+	·	+	·	·	·	·	·
Symplocos chinensis var. *leucocarpa f. pilosa*	S1	·	·	·	+	·	·	·	·	·	·	·
	H	·	·	·	+	·	·	+	·	·	·	·
Calamagrostis hakonensis	H	·	·	·	+	·	·	+	·	·	·	·
Reynoutria japonica var. *uzensis*	H	·	·	·	+	·	·	+	·	·	·	·
Miscanthus intermedius	H	·	·	·	·	+	2·3	·	·	·	·	·
Carex dolichostachya var. *glaberrima*	H	1·2	·	·	·	·	·	·	·	·	·	·
Daphniphyllum macropodum var. *humile*	S1	+	·	·	·	·	·	·	·	·	·	·
Mitchella undulata	H	+	·	·	·	·	·	·	·	·	·	·
Aesculus turbinata	H	+	·	·	·	·	·	·	·	·	·	·
Lindera praecox	H	+	·	·	·	·	·	·	·	·	·	·
Celastrus orbiculatus var. *papillosus*	H	+	·	·	·	·	·	·	·	·	·	·
Hamamelis japonica var. *megalophylla*	T2	·	+	·	·	·	·	·	·	·	·	·
	S1	·	+	·	·	·	·	·	·	·	·	·
Rhododendron semibarbatum	S1	·	+	·	·	·	·	·	·	·	·	·
Callicarpa japonica	S1	·	+	·	·	·	·	·	·	·	·	·
Rhododendron albrechtii	S1	·	+	·	·	·	·	·	·	·	·	·
Carex siderosticta	H	·	+	·	·	·	·	·	·	·	·	·
Acer distylum	H	·	+	·	·	·	·	·	·	·	·	·
Brachypodium sylvaticum	H	·	·	+·2	·	·	·	·	·	·	·	·
Lilium rubellum	H	·	·	+	·	·	·	·	·	·	·	·
Acer crataegifolium	H	·	·	+	·	·	·	·	·	·	·	·
Polygonatum falcatum	H	·	·	·	+	·	·	·	·	·	·	·
Smilax china	S1	·	·	·	·	+	·	·	·	·	·	·

Table 5. continued.

Community type:		1	2	3-1				3-2				
Running number:		1	1	1	2	3	4	5	6	7	8	9
Quadrat number:		31	32	34	40	145	39	42	33	144	36	41
Tilia maximowicziana	S1	·	·	·	·	+	·	·	·	·	·	·
Acer micranthum	S1	·	·	·	·	+	·	·	·	·	·	·
Cephalanthera longibracteata	H	·	·	·	·	+	·	·	·	·	·	·
Aralia cordata	H	·	·	·	·	+	·	·	·	·	·	·
Berchemia longeracemosa	H	·	·	·	·	+	·	·	·	·	·	·
Carex lanceolata	H	·	·	·	·	·	2·3	·	·	·	·	·
Benthamidia japonica	T2	·	·	·	·	·	+	·	·	·	·	·
Viola violacea var. *makinoi*	H	·	·	·	·	·	+	·	·	·	·	·
Potentilla freyniana	H	·	·	·	·	·	+	·	·	·	·	·
Lespedeza bicolor	H	·	·	·	·	·	+	·	·	·	·	·
Cirsium borealinipponense	H	·	·	·	·	·	+	·	·	·	·	·
Eupatorium chinense	H	·	·	·	·	·	+	·	·	·	·	·
Viola kusanoana	H	·	·	·	·	·	+	·	·	·	·	·
Synurus pungens	H	·	·	·	·	·	+	·	·	·	·	·
Tylophora aristolochioides	H	·	·	·	·	·	+	·	·	·	·	·
Maackia amurensis subsp. *buergeri*	S1	·	·	·	·	·	·	+	·	·	·	·
Magnolia salicifolia	S1	·	·	·	·	·	·	·	·	+	·	·
Dioscorea tokoro	H	·	·	·	·	·	·	·	·	·	·	+

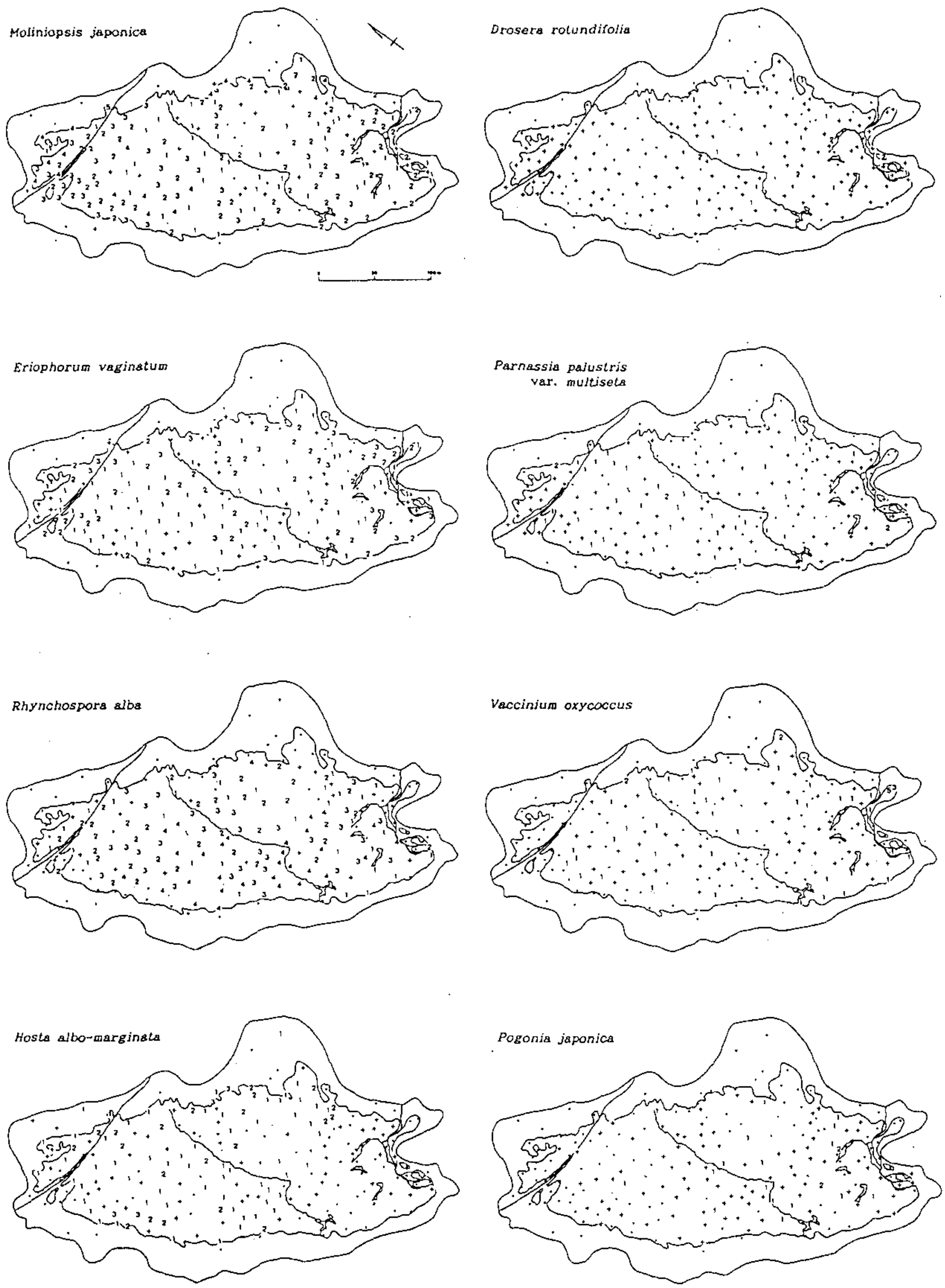

Fig. 1. Distributions of the main plant species in Miyatoko Mire.
A numeral indicates Braun-Blanquet's dominance factor.

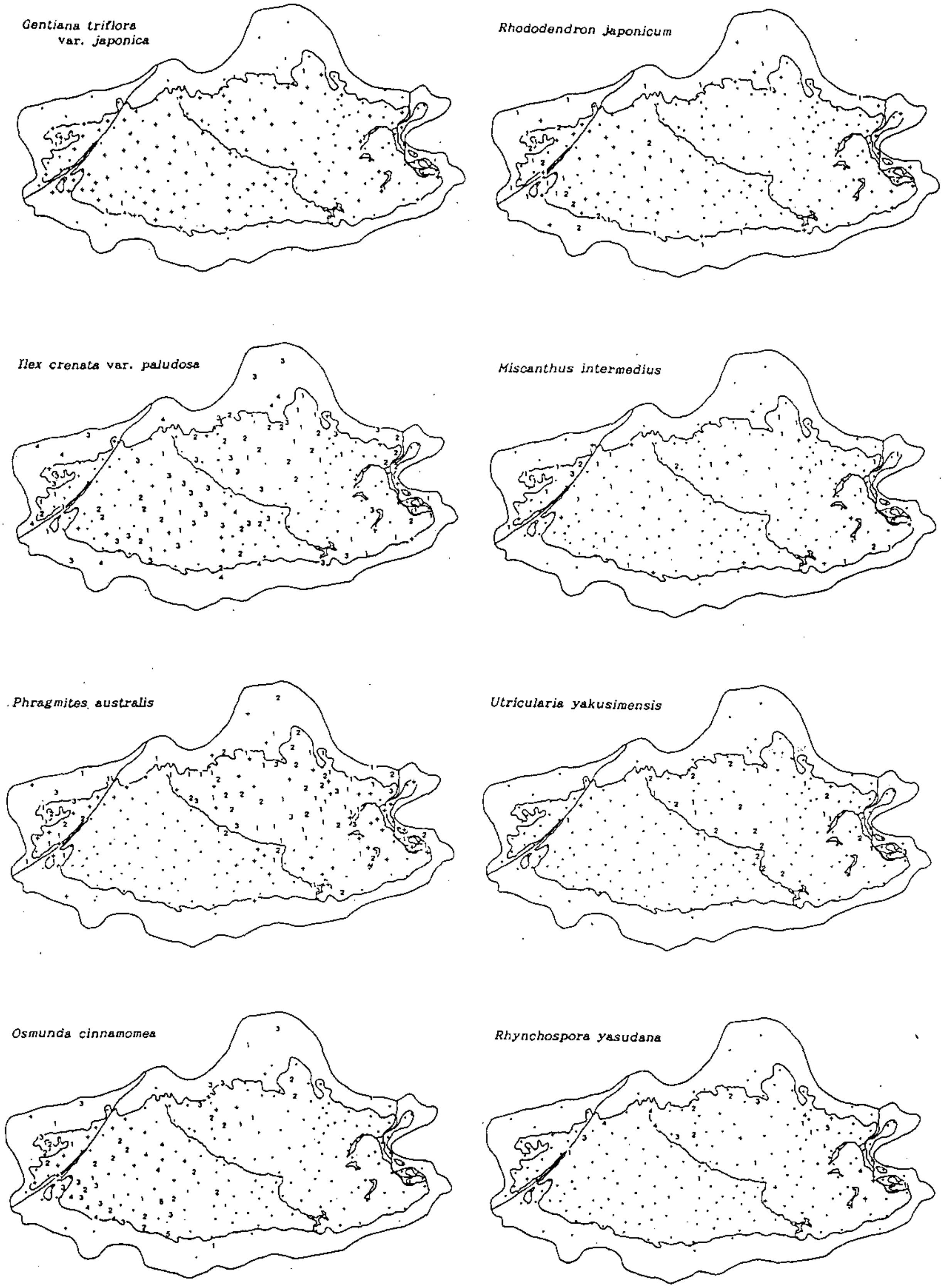

Fig. 1. continued.

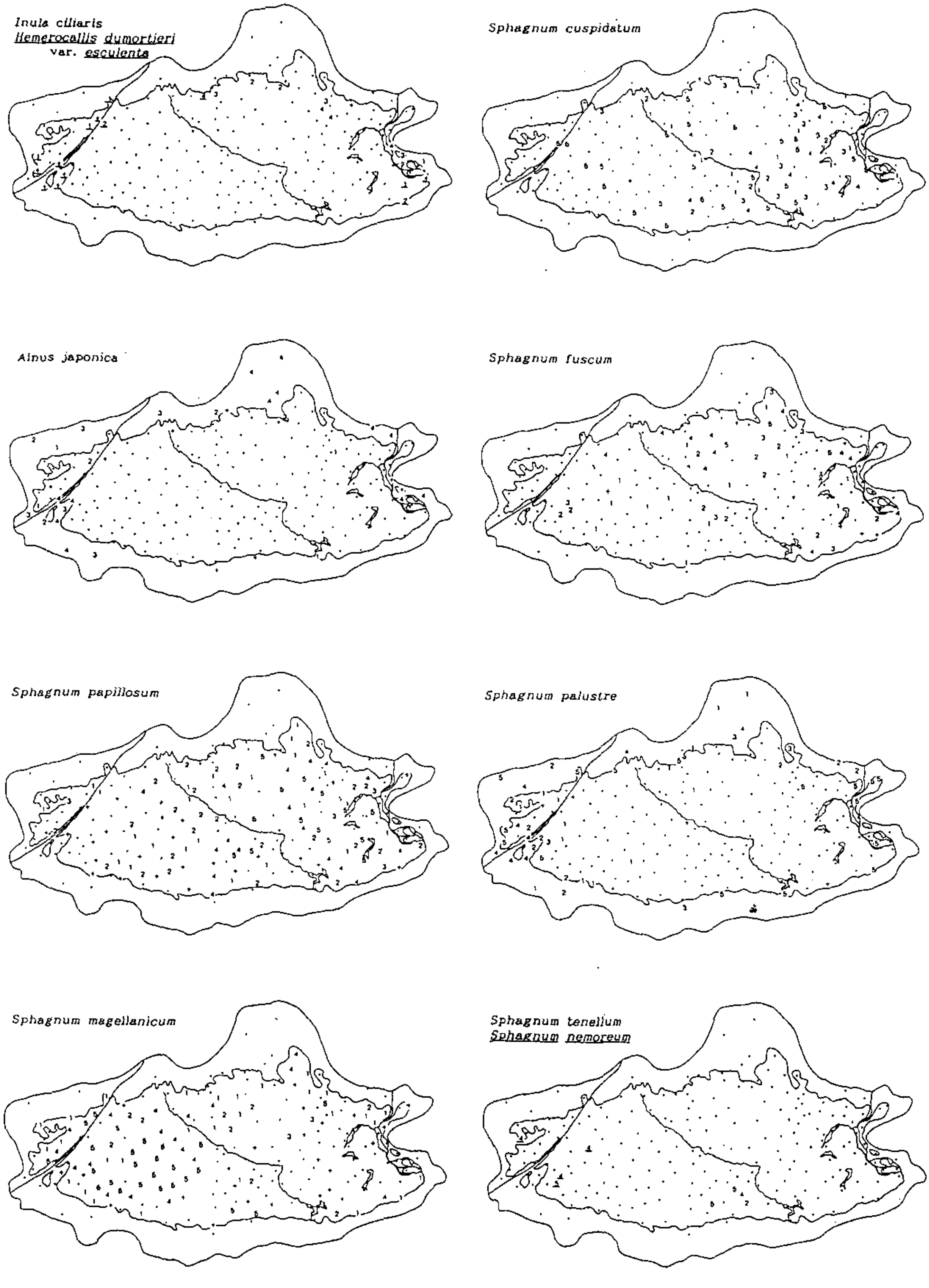

Fig. 1. continued.

6
Anthophilous Insects in Miyatoko Mire

Ryuhei Ueno

The phenology of anthophilous insects (flower-visiting insects) in Miyatoko Mire was studied monthly from June to October 1992 and from May to September 1993 except for July 1993. Among the 23 flower species which appeared, the following species were abundant in both years: *Gentiana aquatica* var. *laeviuscula* in May, *Hemerocallis esculenta* and *Pogonia japonica* in June, *Hosta sieboldii* f. *lancifolia* in August and *Gentiana triflora* in September. A total of 124 insects belonging to 21 taxa visited the mire flowers (Table 1).

The anthophilous entomofauna of this mire had less species richness than other comparable regions reported previously (Endo, 1981, 1982). I evaluated the relationships between flower and insect species on the basis of "visiting" with or without pollen transport (Fig. 1). Hymenopterans made the most frequent visits followed by dipterans. *Apis mellifera* was observed most frequently, although they primarily visited only one flower species, *Rhamnus crenata*.

Bombus diversus frequently visited many kinds of flowers, and SEM micrography (Fig. 2) showed that they received pollen loads on their body surfaces during close approaches to stigmas. Thus, they seemed to be a very important pollinator in this mire.

Competition for pollinators among plants was uncommon and was observed for only one combination of two plants. *Weigela hortensis* was a competitor with *H. esculenta* for *B. diversus*. *Weigela hortensis* suffered specific nectar-robbing by *Bombus hypocrita* at high frequency and lost rewards for B. diversus to some extent. Thus, *B. hypocrita* potentially contributes to pollination by *B. diversus* of *H. esculenta*.

Fine net exclosures were applied to two abundant plants, *H. esculenta* and *H. sieboldii* f. *lancifolia* in order to estimate their selfing rates. None of 9 *H. esculenta* flower buds from which insects had been excluded bore fruit, while the exposed buds achieved 65% fructification. Two adjacent clumps of the same species bore fruits on 60% and 68% of their flowers. Thirtysix percent of *H. sieboldii* inflorescences in exclosures bore fruits. This value was comparable to the rate of the flowers (41%), which had already bloomed before the experiment. Thus, reproduction in these plants seemed to depend on insect pollination. Except for *Plateumaris sericea*, all the anthophilous insects I studied seemed to grow outside of the mire (e.g. forests, sewage,

Table 1. List of flowering plants and anthophilous insects in Miyatoko Mire.
* Plants in the marginal zone. † No visiting insects observed.

	Plant	Insect
May	*Magnolia salicifolia* (Sieb. et Zucc.) Maxim	Staphylinidae sp. 1
	Viola sp.*	Chrysomelidae sp.
	Prunus sp.*	*Plateumaris sericea* (L.)
	Gentiana aquatica L. var. *laeviuscula* Ohwi	*Bombylius major* L.
	Lysichiton camtschatcense (L.) Schott	Diptera sp. 1
	Heloniopsis orientalis (Thunb.) C. Tanaka var. *orientalis*†	
June	*Nymphaea tetragona* Georgi	Orthoptera sp.
	Menziesia multiflora Maxim.	Syrphidae sp.
	Rhododendron japonicum (A. Gray) Suring	Diptera sp. 2
	Weigela hortensis Sieb. et Zucc.*	*Papilio machaon hippocrates* C. et R. Felder
	Menyanthes trifoliata L.†	*Papilio maackii tutanus* Fenton
	Hemerocallis esculenta Koidz.	*Ochlodes venata* Bremer et Grey
	Eleorchis japonica (A. Gray) F. Maekawa	*Bombus diversus* Smith
	Pogonia japonica Reichb. fil.	*Bombus hypocrita* Perez
July	*Nymphaea tetragona*	Mordellidae sp.
	Drosera rotundifolia L.†	Syrphidae sp.
	Ilex crenata Thunb. var. *paludosa* (Nakai) Hara	Diptera sp. 3
	Rhamnus crenata Sieb. et Zucc.	*Ochlodes venata*
	Inula ciliarid (Miq.) Maxim. var. *ciliaris*	*Bombus diversus*
	Iris ensata Thunb.	*Apis mellifera* L.
	Epipactis thunbergii A. Gray	Hymenoptera sp. 1
	Platanthera hologlottis Maxim.	
	Platanthera tipuloides Lindl. var. *nipponica* (Makino) Ohwi†	
	Pogonia japonica	
	Rhynchospora alba (L.) Vahl	
August	*Nymphaea tetragona*	Thripidae sp.
	Parnassia palustris L. var. *multiseta* Ledeb.	Staphylinidae sp. 2
	Utricularia sp.†	*Papilio machaon hippocrates*
	Cirsium sp.	*Bombus diversus*
	Inula ciliarid	
	Hosta sieboldii (Paxton) J. Ingram f. *lancifolia* (Miq.) Hara	
	Epipactis thunbergii	
	Platanthera tipuloides var. *nipponica*†	
	Spiranthes sinensis (Pers.) Ames var. *amoena* (M. Bieberson) Hara†	
September		Hesperiidae sp. (?*Ochlodes venata*)
	Parnassia palustris var. *multiseta*	Syrphidae sp.
	Gentiana triflora Pall. var. *japonica* (Kusnez.) Hara	Diptera sp.4
	Cirsium sp.	*Bombus diversus*
		Hymenoptera sp. 2

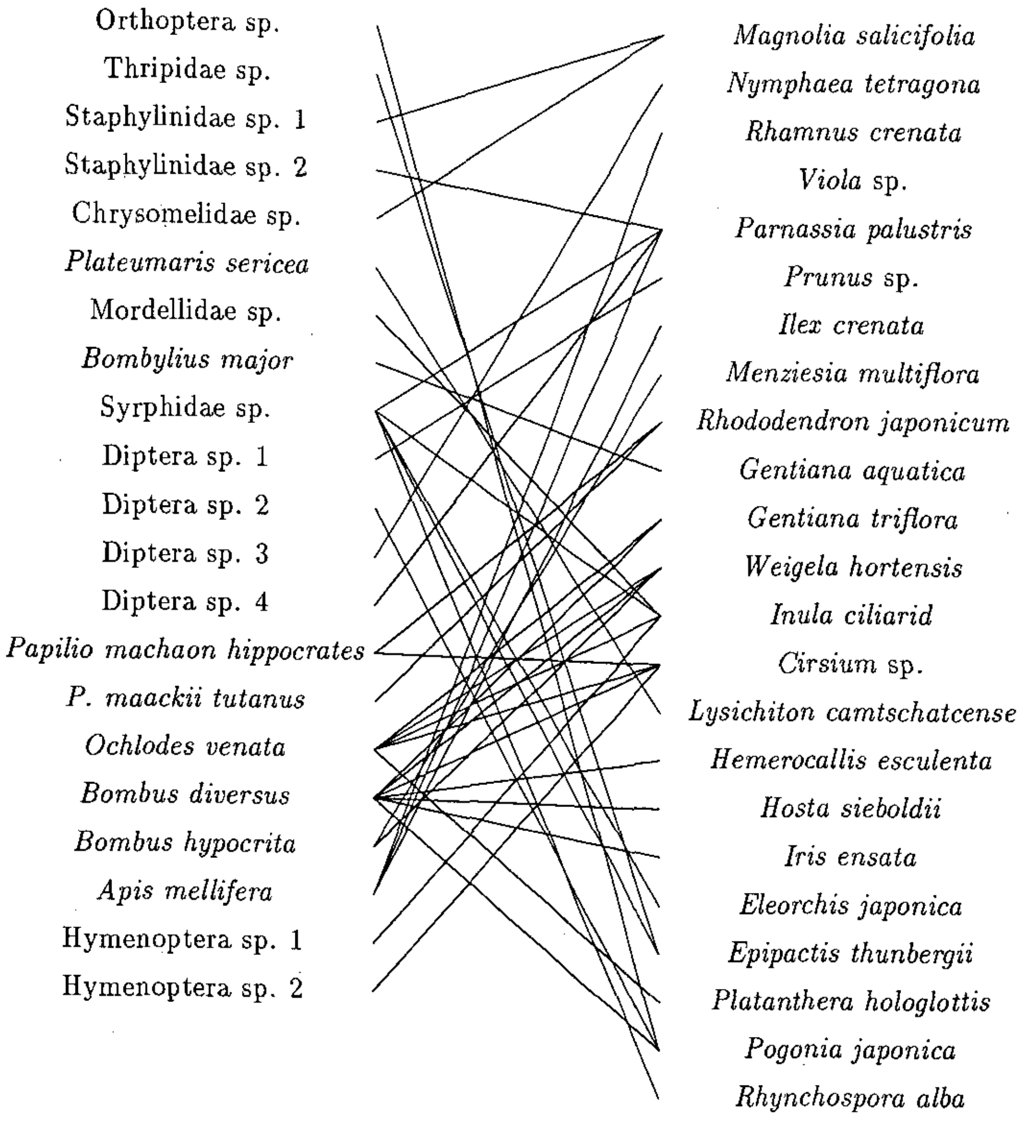

Fig. 1. Relationship between flowers and anthophilous insects in Miyatioko Mire.

etc.). Clearly interaction of a mire ecosystem with its neighboring environments is important for sustainability.

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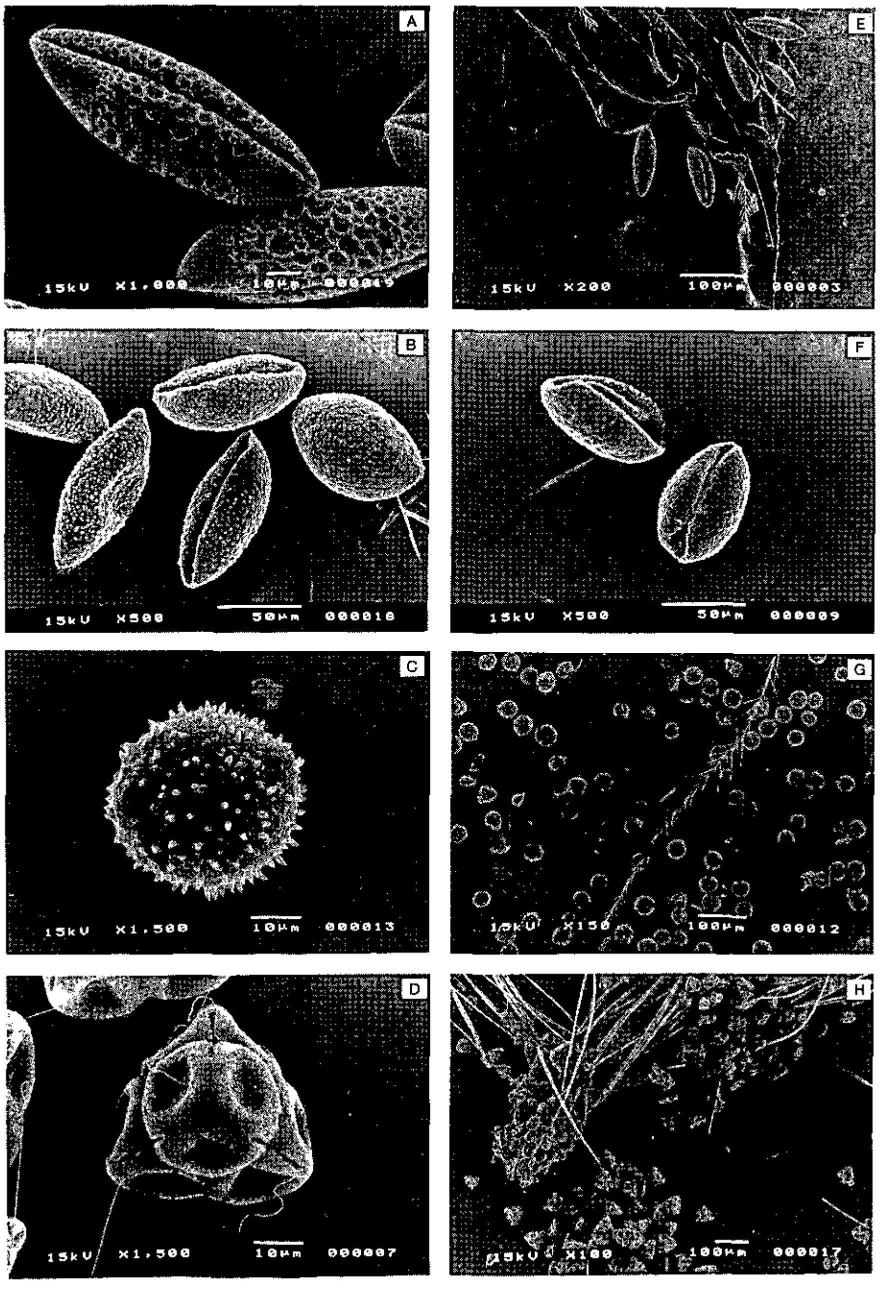

Fig. 2. Pollen grains taken from fresh flowers or from the surfaces of anthophilous insects.
A: *Hemerochallis esculenta*; B: *Hosta sieboldii* f. *lancifolia*; C: *Weigela hortensis*; D: *Rhododendron japonicum*; E: *Bombus diversus* on *H. esculenta*; F: *B. diversus* on *H. sieboldii* f. *lancifolia*; G: *B. diversus* on *W. hortensis*; H: *Papilio machaon hippocrates*.

7
Biomass, Species Composition and Diversity of Epipelic Algae in Mire Pools

Makoto M. Watanabe, Shigeki Mayama and Hisayoshi Nozaki

It is generally recognized that algal species diversity in mires is very high and that there are many algal species endemic to mires (Hirose and Yamagishi 1977). Mires encompass running water system, including pools of various sizes and physicochemical characteristics. The spatial and temporal heterogeneity of mire pools may powerfully influence algal community structure and diversity. However, there has been little quantitative study of algal community structure and environmental heterogeneity of pools in mires. The biomass, species composition and diversity of the epipelic algae in 2 Miyatoko Mire pools of contrasting physicochemical characteristics were studied in 1992. Pool 3 (site B4) is 40 m^2 in area and 20 cm deep. Pool 50 (site D2) is 109 m^2 in area and 40 cm deep. The results reveal quantitative characteristics of algal community structure and provide insights into the factors controlling the species diversity of epipelic algae in the mire.

Seasonal changes of biomass of epipelic algae

A total of 67 species of epipelic algae, specifically 40 species of diatoms, 18 species of desmids and 9 species of the other algae, occurred at site B4 (Table 1). The biomass of epipelic algae was highest in April, 4115 ng C mm^{-2} and then gradually decreased from

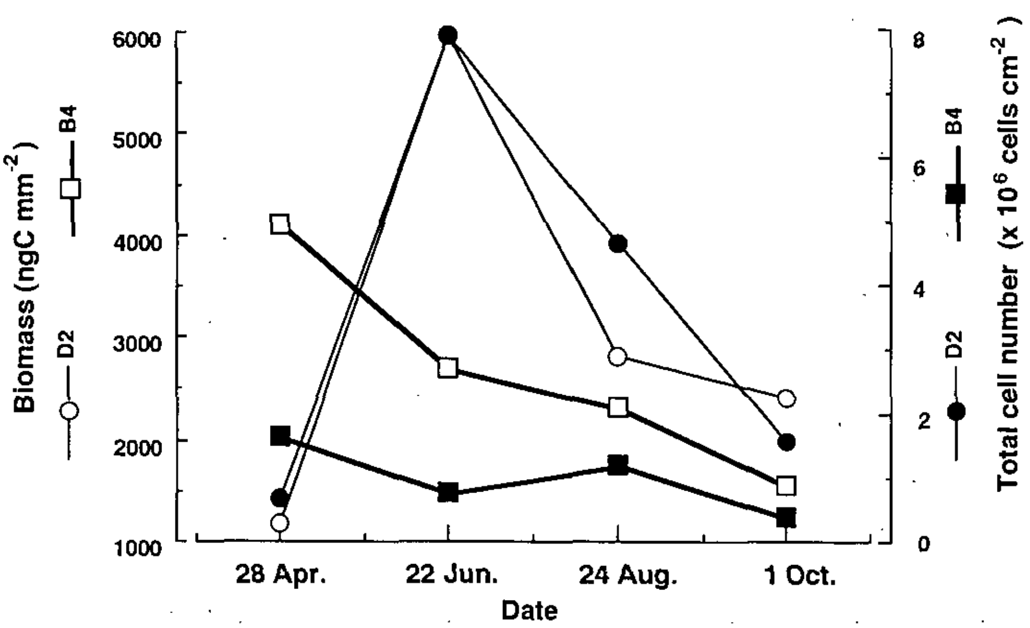

Fig. 1. Seasonal changes of biomass and total cell number of algae at sites D2 and B4.

Table 1. Algal speices in Miyatoko Mire.

Species	D2	B4	Volume (μm^3)	Carbon content ($pgC\ cell^{-1}$)
Diatoms				
Achnanthes helvetica	+		692	54
A. minutissima	+	+	70	10
A. nodosa	+		84	11
A. pusilla	+	+	188	20
A. subatomoides	+		94	12
Actinella punctata	+	+	3815	196
Anomoeoneis brachysira	+	+	218	22
A. serians var. *acuta*	+	+	1620	103
Aulacoseira alpigena	+	+	500	42
A. canadensis	+		921	67
A. laevissima	+		1177	80
A. valida	+		2849	157
Cymbella gracilis	+	+	500	42
C. minuta	+	+	302	29
C. naviculiformis	+		3327	177
C. sinuata		+	150	17
Eunotia curvata	+	+	367	33
E. curvata var. *linearis*	+	+	2500	142
E. diadema	+		12716	489
E. exigua	+	+	506	42
E. incisa	+		384	34
E. naegeli	+	+	262	26
E. nipponica	+	+	7000	311
E. parallela		+	3240	173
E. pectinalis var. *minor*	+	+	595	48
E. perminuta	+		113	14
E. rhomboidea		+	153	17
E. serra	+	+	28138	892
E. tenelloides	+	+	100	12
Fragilaria capucina var. *gracilis*	+	+	100	13
F. construens var. *venter*	+		137	16
F. elliptica	+		69	9
F. exigia	+		132	15
F. nitzschioides	+		435	38
Fragilaria sp.	+		1377	91
Frustulia rhomboides	+	+	35332	1061
F. rhomboides var. *saxonica*	+	+	5070	243
Gomphonema accuminatum	+		2301	134
G. gracile	+		425	37
G. parvulum	+	+	287	28
Meridion circulare	+	+	750	57
Navicula mediocris	+	+	75	10
N. minima	+		138	16
N. minuscula	+		126	15
N. notha	+		537	44
N. okadae	+	+	1012	72
N. parasubtilissima	+	+	303	29
N. pseudosctiformis	+		699	54
N. seminulum	+		157	17
N. subtilissima	+	+	522	43
Neidium iridis	+		95062	2246
Nitzschia amphibia	+	+	225	23
N. fontinalis		+	76	10
N. hantzschiana	+		153	17
N. palea	+	+	450	39
Peronia fibula	+	+	400	36
Pinnularia bogotensis	+		35840	1072
P. hilseana var. *japonica*	+	+	4096	207
P. microstauron	+		28977	913

Table 1. continued.

Species	D2	B4	Volume (μm^3)	Carbon content (pgC $cell^{-1}$)
P. subgibba	+		14400	537
P. transversa		+	64000	1664
P. viridis	+	+	53802	·1459
Stauroneis phoenicenteron	+		77824	1930
Stenopterobia curvula	+	+	5112	245
S. delicatissima	+	+	1600	102
Surirella linearis	+		39865	1162
Synedra acus	+		2238	131
S. ulna	+	+	2767	154
Tabellaria fenestrata	+	+	2615	147
T. flocculosa	+	+	808	61
Green Algae:Desmids				
Bambusina brebissonii var. *brebissonii*	+	+	8079	832
Closterium acerosum	+		34605	2951
C. acutum var. *acutum*		+	1415	186
C. costatum	+		196250	13291
C. gracile	+		1695	219
C. intermedium	+	+	15272	1445
C. lunula	+		847800	46774
C. parvulum var. *maius*	+		32708	2818
C. peracerosum	+		5652	617
Cosmarium angulare var. *angulare*		+	5128	566
Cylindrocystis crassa	+		12560	1230
Euastrum crassum var. *tumidum*	+	+	524160	31121
E. didelta var. *didelta*		+	62694	4948
Gloenbladia neglecta var. *neglecta*	+	+	2653	320
Mesotaenium degreyi var. *breve*		+	7771	811
Micrasterias apiculata var. *apiculata*		+	296503	19001
M. denticulata		+	318396	20210
M. truncata		+	63842	5026
Netrium digitus var. *digitus*	+	+	77507	5945
Netrium digitus var. *naegeli*		+	9272	945
Pleurotaenium minutum var. *crassum*		+	105855	7788
Pleurotaenium minutum var. *minutum*	+	+	15045	1438
P. undulatum var. *undulatum*	+	+	19040	1763
Staurastrum geminatum	+	+	5333	586
S. micron var. *micron*		+	533	78
Green Algae:Others				
Bulbochaete sp.		+	12560	1229
Gloeotila turfosa	+		78	15
Klebsormidium klebsii	+	+	769	109
Microspora willeana	+		1177	158
Oedogonium sp.		+	35325	3011
Pediastrum boryanum	+		1766	225
Scenedesmus acutus	+	+	98	18
Blue-green Algae				
Anabaena sp.	+	+	523	78
Chroococcus turgidus	+	+	1766	225
Merismopedia glaucum	+		65	13
Oscillatoria sp.	+	+	12	3
Stigonema ocellatum f. *ocellatum*		+	523	78
Other Algae				
Dinobryon serturalia	+		3532	410
Gymnodinium sp.	+		6280	675
Synula sphagnicola	+		3532	410
Trachelomonas sp.	+	+	523	78

June to October, when the population was at its smallest value, 1562 ng C mm-2 (Fig. 1). A similar pattern of seasonal change was observed for total cell number. Diatoms and desmids comprised 33% to 82% and 15% to 63% of total algal biomass, respectively (Fig. 2). A diatom, *Frustulia rhomboides*, together with one or two desmid species comprised 70% to 90% of total algal biomass throughout the season. A total of 93 species of epipelic algae, comprised of 65 species of diatoms, 15 species of desmids and 13 species of other algae, occurred at site D2 (Table 1). The biomass of epipelic algae was 1190 ng C mm-2 in April and had increased greatly by June, peaking at 5970 ng C mm-2. Biomass decreased during the August to October period (see Fig. 2). The same pattern of seasonal change was observed in total cell number. Except for April, algal biomass at site D2 was larger than that at site B4. Diatoms predominated in every season and occupied 90%—98% of total algal biomass (see Fig. 2). No marked predominance of any species was observed in April and October. A Centralean diatom, *Aulacoseira laevissima,* predominated and comprised 40% and 32 % of total algal biomass in June and August, respectively.

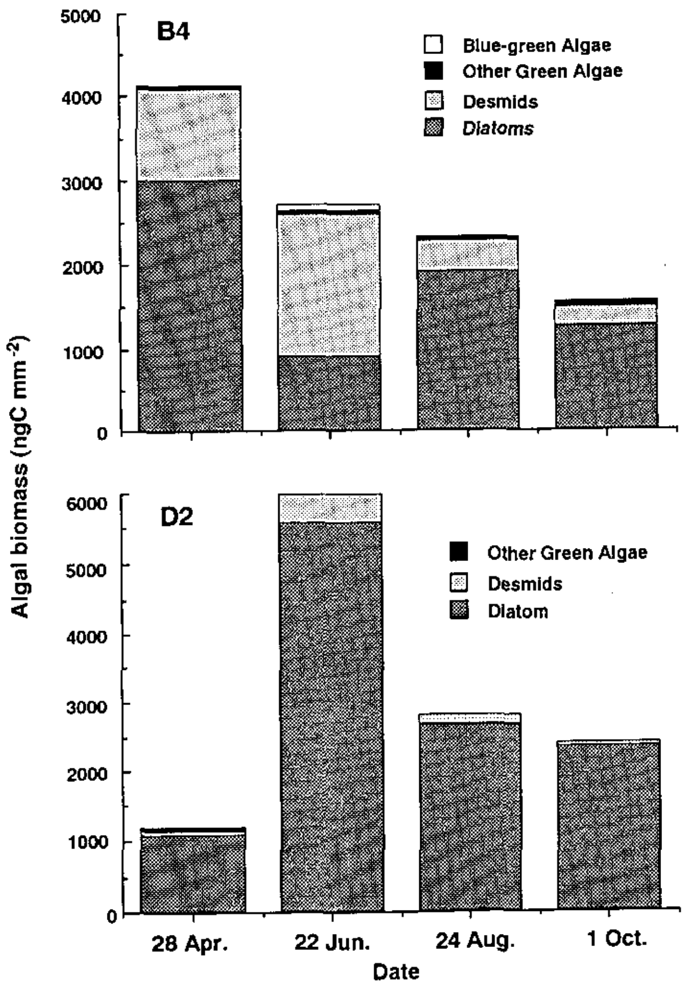

Fig. 2. Seasonal changes of biomass of diatoms, desmids and other algae at sites B4 and D2.

Species richness and diversity

Species diversity was estimated with Simpson's Diversity Index *(D)* as follows.

$$D = 1 / [\sum_{i=1}^{s} n_i (n_i - 1) / N (N - 1)]$$

where s is total species number, n_i is the number of individuals in the i-th species and N is the total number of individuals. Also, the modified diversity index, D', was estimated based on biomass. In this case, ni is the biomass of the i-th species and N is the total biomass of epipelic algae. At site B4, species numbers were 29 to 32 in April and August and increased to 43 at October (Fig. 3). This pattern did not correspond to that of biomass (Fig. 1). The diversity index, D, was high in April, low in June and August, and reached its maximum in October. However, the other index, D', did not change much throughout the season, because 70%—90% of total algal biomass was occupied by a diatom, *Frustulia rhomboides* and 1 or 2 desmid species throughout the season.

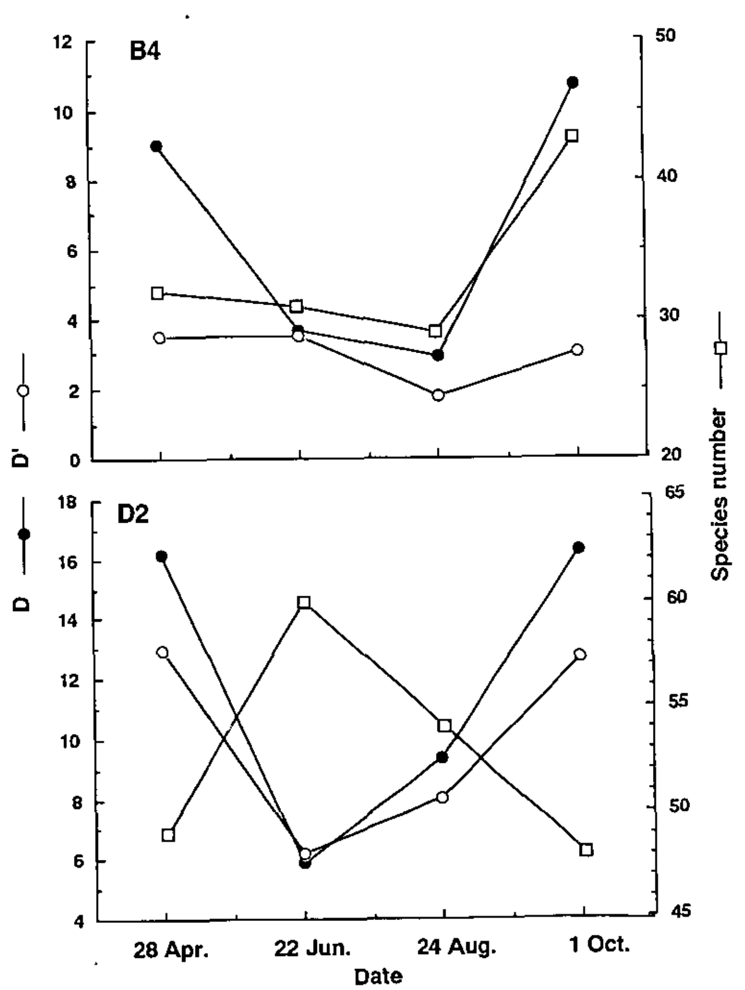

Fig. 3. Seasonal changes of sepcies number and diversity indices at sites B4 and D2.

At site D2, species number was 49 in April, increased to 60 in June and decreased to 54 in August and to 48 in October (Fig. 3). This pattern corresponded to that of biomass (Fig. 1). However, both diversity indices, *D* and *D'*, showed patterns of seasonal change inverse to those of species number and biomass (see Figs. 1 and 3), implying that species evenness greatly decreased with increasing algal community size. The decrease in the diversity indices in June and August was caused by high degree of dominance of total algal biomass by *Aulacoseira laevissima*. The species number and the diversity indices of the epipelic algae were higher at site D2 than at site B4 throughout the season, that is, the algal community at site D2 showed higher species richness and evenness than those at site B4. According to Hirata et al. (1995), there were large differences in water temperature and chemistry between the two pools (Table 2). In particular, the concentrations of silicate were much lower in stream B than in stream D. Silicate is practically absent from rain water. Stream B is fed by surface water flow which is strongly influenced by rain water (Hirata et al., 1995). From the *F*-test for differences in variances of water temperature and chemistry between the two pools, it seems that pool 3 (site B4) experiences higher disturbance frequency than does pool 50 (site D2) (Table 2).

Table 2. Water chemistry summary statistics for sites D2 and B2 and a test of differences between sample variances based on the *F*-test. Mean *(X)*, standard deviation *(SD)*, sample variance *(V)* and degree of freedom *(df)*

	B2				D2				F_0 [1]	F [2]
	X	*SD*	*V*	*df*	*X*	*SD*	*V*	*df*		
Temp.	20.36	8.24	8.49	8	12.90	3.32	1.38	8	6.15	4.43
pH	5.21	0.42	0.02	8	6.08	0.41	0.02	8	1.00	4.43
NH_4^+ [3]	0.09	0.06	0.0004	9	0.05	0.04	0.0002	9	2.00	4.03
Cl^-	2.10	0.90	0.09	9	2.39	0.44	0.02	9	4.50	4.03
SiO_2	2.56	1.83	0.37	9	18.25	2.67	0.79	9	2.13	4.03
SO_4^{--}	2.81	0.55	0.033	9	1.33	0.63	0.044	9	1.30	4.03
Na^+	1.00	0.23	0.0059	9	2.11	0.29	0.0093	9	1.58	4.03
K^+	0.31	0.19	0.004	9	1.05	0.19	0.004	9	1.00	4.03
Mg^{++}	0.46	0.15	0.0025	9	0.28	0.05	0.0003	9	8.33	4.03
Ca^{++}	0.82	0.33	0.012	9	0.61	0.22	0.0054	9	2.22	4.03

1) $F_0 = V_B/V_D$ or V_D/V_B
2) The value from *F* distirbution table of $F(F_D, F_B; 0.025)$ or $F(F_B, F_D; 0.025)$
3) Each ion concentration in mg l^{-1}

Higher biodiversity in low-disturbance habitat

There were great differences between the two pools, 3 (B4) and 50 (D2), not only in biomass, species composition, species diversity, but also in physicochemical characteristics. Biomass and species diversity at D2 were higher than those at B4. Site B4 experiences higher disturbance frequency than does site D2. Our result supports the hypothesis proposed by Scarsbrook and Townsend (1993): "Biomass and species diversity are predicted to decrease as disturbance frequency increases".

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8
Chironomid Fauna of Miyatoko Mire

Ryuhei Ueno and Toshio Iwakuma

Very little is known of the chironomid fauna of mires (Rosenberg et al., 1988). Here, we present the faunal composition of pools and channels in Miyatoko Mire and discuss trends of habitat preferences.

We recovered 320 chironomid adults belonging to 32 species from Miyatoko Mire (Fig. 1) by rearing larvae, net-sweeping and light-trapping. The species composition of animals captured in light-traps was somewhat different from those of animals collected by the other 2 methods (Table 1).

Several species (e.g. *Cricotopus sylvestris* and *Polypedilum unifascium*) were captured only by the light trap method. These species are known as typical members of the faunae of eutrophic water bodies. It is unlikely that these species breed in an oligotrophic mire. Thus the striking light trap results might have been caused by individuals actively attracted by light from outside of the mire. This finding implies that non-mire chironomids have access to the mire and might predominate if the mire water were to become eutrophic.

Site specific distribution of mire midges were clarified by rearing of larvae collected from various sites in the mire (see Fig. 1). Seventeen species were collected and successfully reared. Among them, each of eight species was recovered from a specific site. No species were common to all three channel systems (A, B and D). No species were common to channels A and B. Five species were common to channels A and D, and most of them were collected from standing waters (A0, D0 and D2). Two

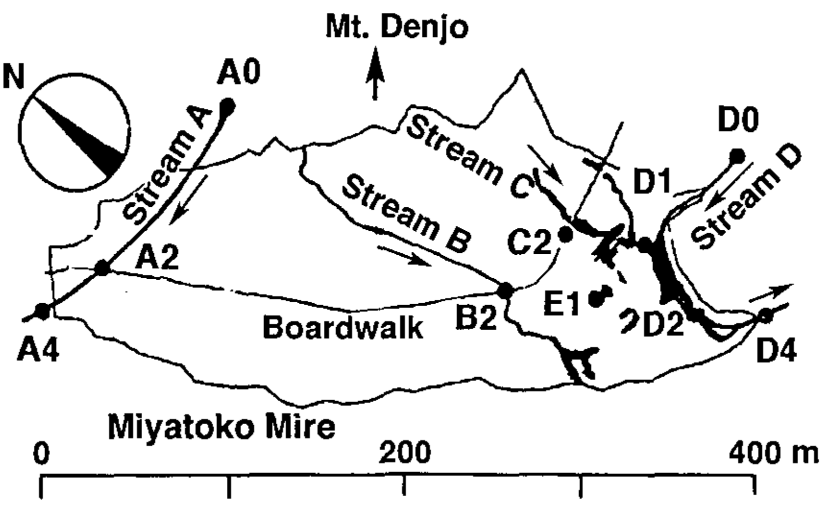

Fig. 1. Sampling locations.

species were common to channels B and D and all of them were collected from flowing waters (B2 and D4). Abundant species were *Procladius culiciformis* in bog pools, *Micropsectra* sp. in springs and *Stictochironomus akizukii* in various types of waters.

The Tanypodinae-rich fauna of this mire is comparable to the "bog" faunae reported from Canada (Wrubleski, 1987), although the sampling sites there are classified as "fens" based on geological characteristics. Though the chironomid species richness of Miyatoko Mire was not very high, this fauna is distinct from previously reported chironomid faunae, primarily researched in lowland lakes and rivers or alpine lakes. *Alotanypus ?venustus* (Fig. 2), *Compteromesa* sp. and *Doithrix villosa* (Fig. 3) were new to the Palaearctic subregion.

Table 1. Chironomids collected in Miyatoko Mire.

Species	Rearing								Sweeping	Light
Site	A0	A2	A4	B2	D0	D1	D2	D4		
Tanypodinae										
Ablabesmyia monilis (Linnaeus)								1		1
Alotanypus ?venustus (Coquillett)									2	
Apsectrotanypus sp.				1						
Conchapelopia quatuormaculata Fittkau									11	
Macropelopia sp.	1	1					1			
Natarsia punctata (Fabricius)					1			3	1	
Procladius culiciformis (Linnaeus)							14			
Procladius sp. *										4
Rheopelopia ?maculipennis (Zetterstedt) *										3
Tanypodinae sp.	1					1				
Prodiamesinae										
Compteromesa sp.					1					
Orthocladiinae										
Brillia modesta (Meigen)									2	
Cricotopus sylvestris (Fabricius) *										6
Cricotopus sp. *tremulus* gp.						2				
Doithrix villosa Saether and Sublette									1	
Heterotrissocladius marcidus (Walker)	2					1				
Limnophyes sp.									2	
Parametriocnemus nr. *togadigitalis* Sasa et Okazawa									13	
Psectrocladius yunoquartus Sasa				2				3		
Chironominae: Chironomini										
?*Chaetolabis* sp. *										74
Chironomus ?yoshimatsui Martin et Sublette *										5
?*Dicrotendipes* sp. *	1									
Polypedilum kasumiense Sasa				4				1	1	
Polypedilum unifascium Tokunaga *										1
Polypedilum sp.	1		1							
Stictochironomus akizukii Tokunaga	14	2			1		4		3	
Chironominae: Tanytarsini										
Micropsectra yunoprima Sasa					1					
Micropsectra sp.	16	1			6				62	
Tanytarsus sp. 1									6	
Tanytarsus sp. 2									21	
Tanytarsus sp. 3		11								
Tanytarsini sp.									1	
unidentified*										74

*No males were collected.

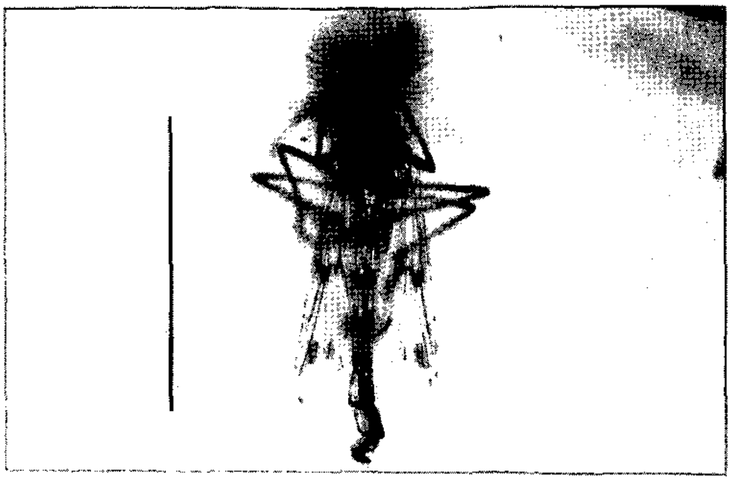

Fig. 2. A chironomid adult (*Alotanypus ?venustus*). Scale=5 mm.

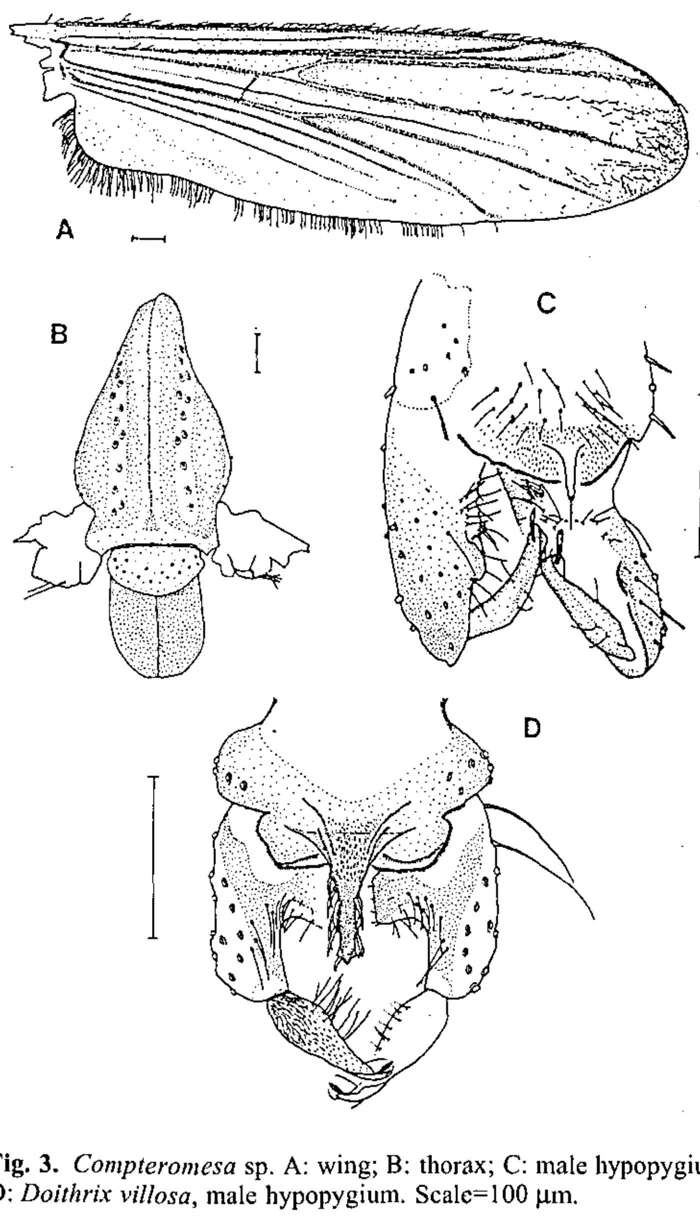

Fig. 3. *Compteromesa* sp. A: wing; B: thorax; C: male hypopygium; D: *Doithrix villosa*, male hypopygium. Scale=100 μm.

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9

Ecology and Production of Chironomidae in a Mire Pool

Toshio Iwakuma

Two chironomids, *Stictochironomus akizukii* (Tokunaga) and *Procladius culiciformis* (L.) dominated the zoobenthos of a pool (pool 50, area: 110 m^2, maximum depth: 40 cm) in the midst of stream D that flows through the lower southeast part of the mire (Fig. 1, Table 1). The population dynamics and production of these two chironomids were studied (Iwakuma, 1995). The pond is covered with aquatic macrophytes, *Menyanthes trifoliata* L., *Nymphaea tetragona* Georgi and *Phragmites australis* (Cav.) Trin. ex Steud. Bottom samples were taken at a site downstream from the *M. trifoliata* vegetation (site D2, 40 cm depth).

Since the pool receives water from a spring in which the winter water temperature was a constant 8.0°C, the daily mean water temperature in the pool was ca. 4°C from

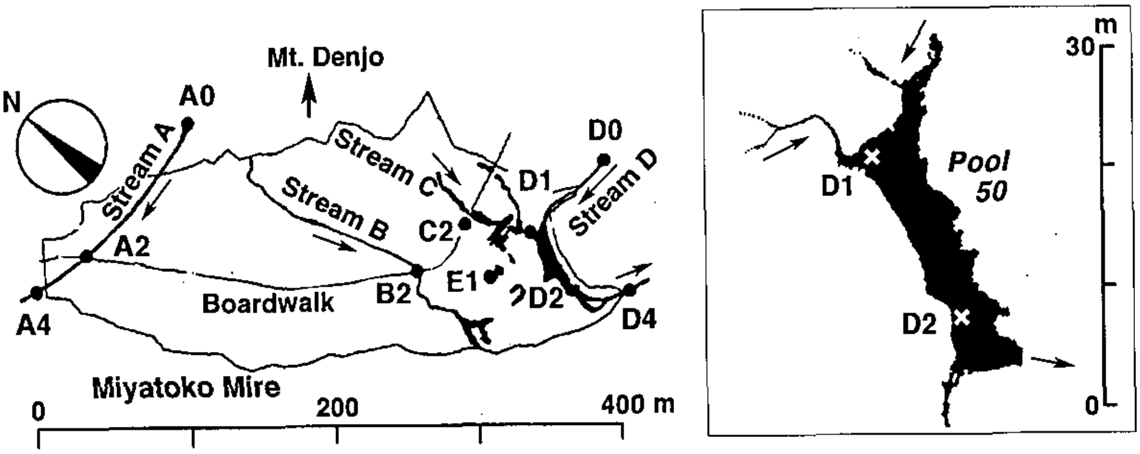

Fig. 1. Sampling locations in Miyatoko Mire.

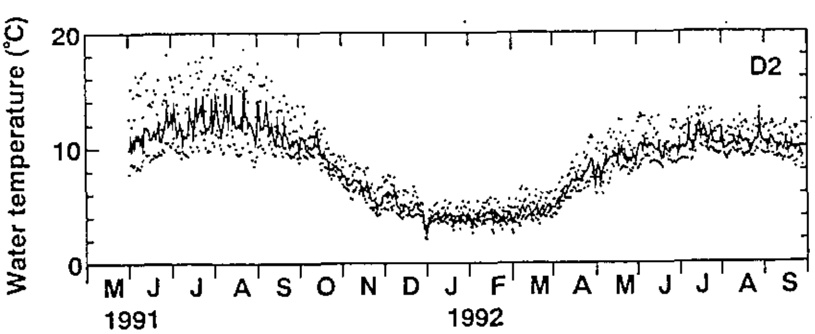

Fig. 2. Seasonal changes in bottom water temperature in pool 50 in Miyatoko Mire (site D2). Solid line shows the daily mean temperatures calculated from hourly data and dots show the daily maximum and minimum hourly values.

January to March (Fig. 2) while the other mire sites were completely covered with snow. Summer daily mean temperatures in the pool were between 10 and 14°C. Daily

Table 1. Zoobenthos collected from pool 50 (sites D1 and D2) in Miyatoko Mire (Iwakuma, 1995)
* classification of larvae; + classification of adults obtained by rearing of larvae

	D1	D2
Arthropoda		
Insecta		
Ephemeroptera		
Baetidae sp.	*	
Odonata		
Suborder Zygoptera		
Coenagrion lanceolatum (Selys)	*	
Mortonagrion selenion (Ris)		*
Suborder Anisoptera		
Davidius moiwanus moiwanus (Okumura)	*	
Davidius nanus (Selys)	*	
Davidius sp.	*	
Gomphidae spp.	*	
Nannophya pygmaea Rambur	*	
Anax parthenope julius Brauer		*
Libellula quadrimaculata asahinai Schmidt	*	
Sympetrum pedemontanum elatum (Selys)	*	
Plecoptera		
Nemouridae	*	*
Hemiptera		
Corixidae sp.	*	
Ilyocoris exclamationis Scott.	*	
Neuroptera		
Sialis sp.	*	*
Coleoptera		
Luciola lateralis Motchulsky	*	*
Diptera		
Chironomidae	*	*
Subfamily Tanypodinae		
Ablabesmyia sp.		+
Macropelopias sp.	+	
Procladius culiciformis (L.)		+
Tanypodinae sp.	+	
Subfamily Orthocladiinae		
Cricitopus sp. *tremulus* gp.	+	
Heterotrissocladius marcidus (Walker)	+	
Subfamily Chironominae		
Stictochironomus akizukii Tokunaga		+
Micropsectra sp.		+
Ceratopogonidae		
Ceratopogoninae sp.1	*	*
Trichoptera		
Goerodes sp. (Tsuda)	*	
Oligotricha sp.(Matsumura)	*	*
Psychomyiidae sp.	*	*
Trichoptera spp.	*	
Crustacea		
Chydoridae sp.		*
Asellus hilgendorfii Bovallius	*	*
Annelida		
Oligochaeta spp.	*	*
Alachinoidea		
Water mite	*	
Mollusca		*
Psidium sp.	*	
Others	*	

temperature range was ca. 2°C in winter and ca. 10°C in summer.

Pool 50's specific conductivity ranged between 11.0 and 25.0 μS cm^{-1} and its pH between 4.92 and 6.83.

Density of larvae

Both species were semivoltine, with two overlapping cohorts. Larval density ranged between 2400 and 10,640 m^{-2} for *S. akizukii* and between 3100 and 18,500 m^{-2} for *P. culiciformis*. Both species emerged between May and August. The densities of 4th-instar larvae of both species exceeded 4000 m^{-2} before emergence (Fig. 3). Larvae of *Ablabesmyia* sp., *Micropsectra* sp. and Orthocladiinae spp. were also collected from pool 50. The total density of these minor species was less than 1000 m^{-2}.

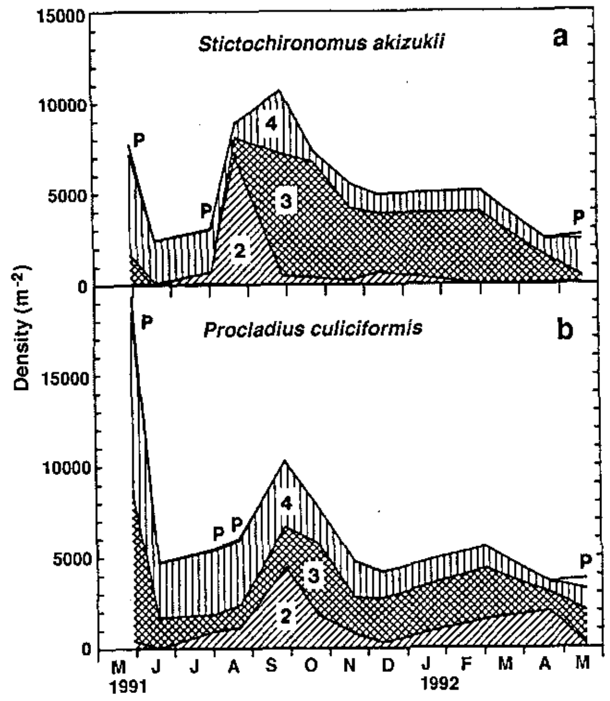

Fig. 3. Seasonal changes in larval and pupal densities of *Stictochironomus akizukii* (a) and *Procladius culiciformis* (b) in pool 50. Numerals in the figure indicate larval instars and the letter "P" indicates pupae for *S. akizukii* or mature 4th-instar larvae before pupation for *P. culiciformis*.

Growth of larvae

Fitting of the normal distribution curve to the body lengths of *S. akizukii* and *P. culiciformis* larvae revealed that the populations of both of these chironomids usually consisted of 2 cohorts (Fig. 4). However 3 *P. culiciformis* cohorts might have existed between May and August 1991. Both *S. akizukii* and *P. culiciformis* were semivoltine or partly univoltine, but the growth of *P. culiciformis* started about 1 month later than that of *S. akizukii*.

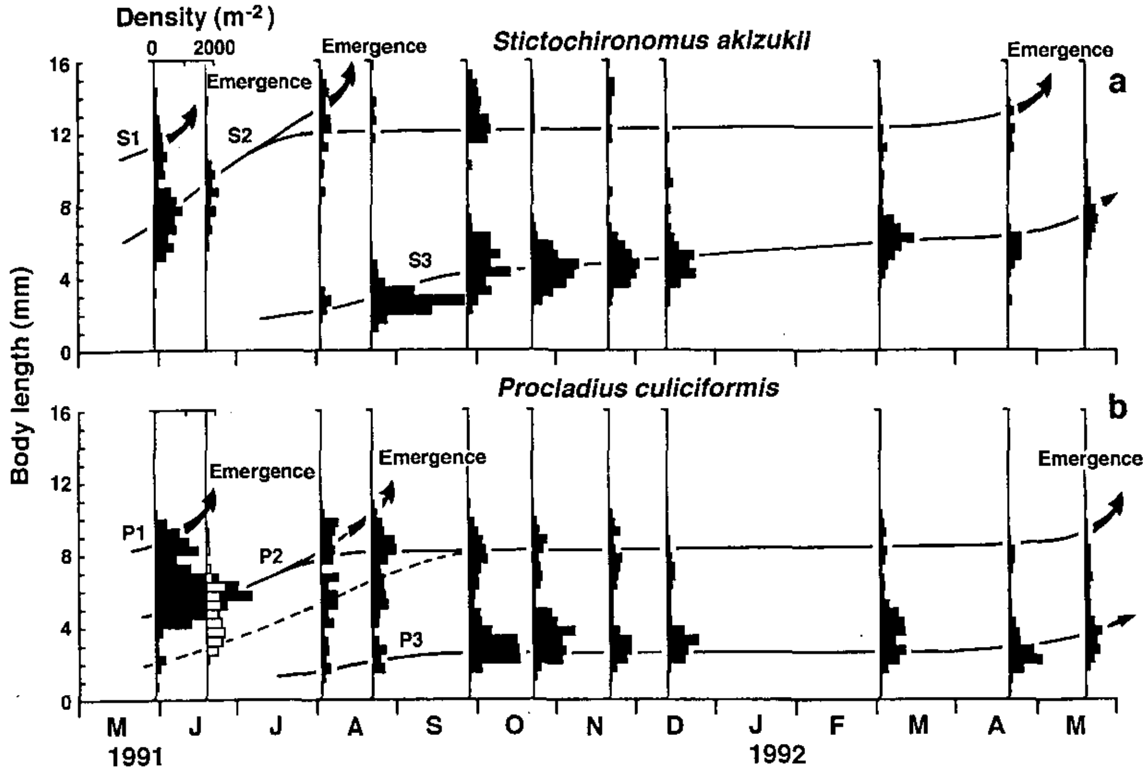

Fig. 4. Seasonal changes in the frequency distributions of body lengths for *Stictochironomus akizukii* (a) and *Procladius culiciformis* (b) in Pool 50. Usually two cohorts were recognized in the frequency distribution diagrams and these cohorts were traced by solid lines as growth curves.

In 1991 there were 2950 degree-days above 0°C or 1563 above the threshold temperature of 3.8°C, which was sufficient for *S. akizukii* to complete its development in this mire pool within 1 year. Some nutritional defect might have caused the delay in the development of *S. akizukii.*

Biomass of chironomid larvae

Seasonal changes in the biomass of chironomid larvae (Fig. 5) were calculated from body length (see Fig. 4) and length-weight relationship equations. The annual mean biomass was 1.46 g m^{-2} for *S. akizukii* and 0.44 g m^{-2} for *P. culiciformis.*

Temperature dependence of larval growth

Instantaneous larval growth rates were calculated for each interval between sampling occasions for each cohort shown in Fig. 4 and were plotted against mean water temperature calculated for these intervals based on the temperature record (see Fig. 2). The instantaneous growth rate of *S. akizukii* larvae was significantly dependent ($P<0.05$) on mean water temperature. The threshold temperature for growth was estimated to be 3.8°C.

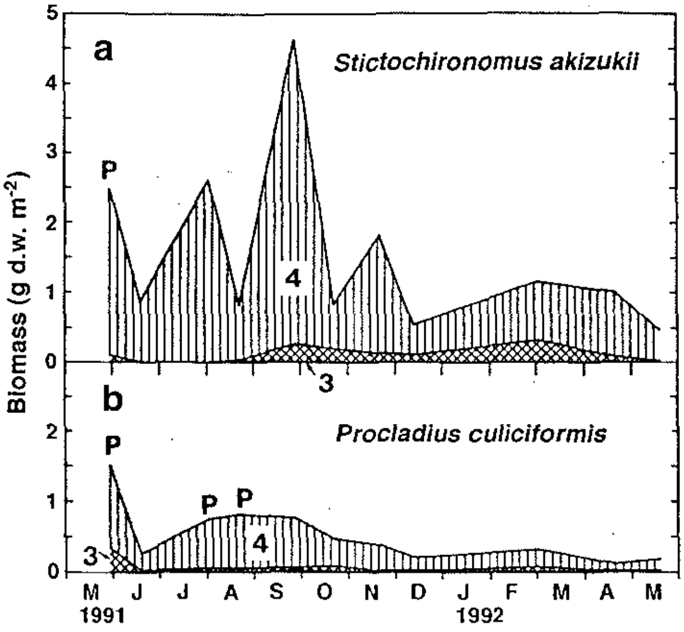

Fig. 5. Seasonal changes in larval biomass of *Stictochironomus akizukii* (a) and *Procladius culiciformis* (b) pool 50. Numerals in the figure indicate larval instars.

Production of chironomid larvae

The maximum production rate of *S. akizukii* was 63 mg m^{-2} day^{-1} during the June—August 1991 period which corresponded with the growth season for the larvae of cohort S2 that had overwintered from the preceding year. Another peak of production (26 mg m^{-2} day^{-1}) was observed during the August—September 1991 period in which the larvae that hatched in June (cohort S3) grew to the 4th instar. The annual production and P/B ratio of *S. akizukii* larvae during the period from 30 May 1991 to 29 May 1992 were 4.36 g m^{-2} year^{-1} and 3.0, respectively. No significant production was observed during winter, i.e., from November to March (Fig 6a).

The maximum production rate of *P. culiciformis* larvae was 64 mg m^{-2} day^{-1} during the May—June period and this peak declined until the end of July 1991 (11 g m^{-2} day^{-1}). This production peak corresponded with the growth of the larvae of cohort P2 that had overwintered from the preceding year. Another small production peak (11 mg m^{-2} day^{-1}) was observed during the September—October 1991 period when the larvae hatched from June to August (cohort P3) grew. The annual production and P/B ratio of *P. culiciformis* larvae during the period from 30 May 1991 to 29 May 1992 were 2.06 g m^{-2} year^{-1} and 4.7, respectively. Some slight production was observed (2.0 mg m^{-2} day^{-1}) during the December to March period (Fig 6b).

Digestive tract contents of chironomid larvae

Third- and 4th-instar larvae of *P. culiciformis* preyed on 1st and 2nd-instar larvae of *S. akizukii* between August and September when early-instar larvae of *S. akizukii* were abundant in the sediments (Table 2). Between September and October, 4th-instar

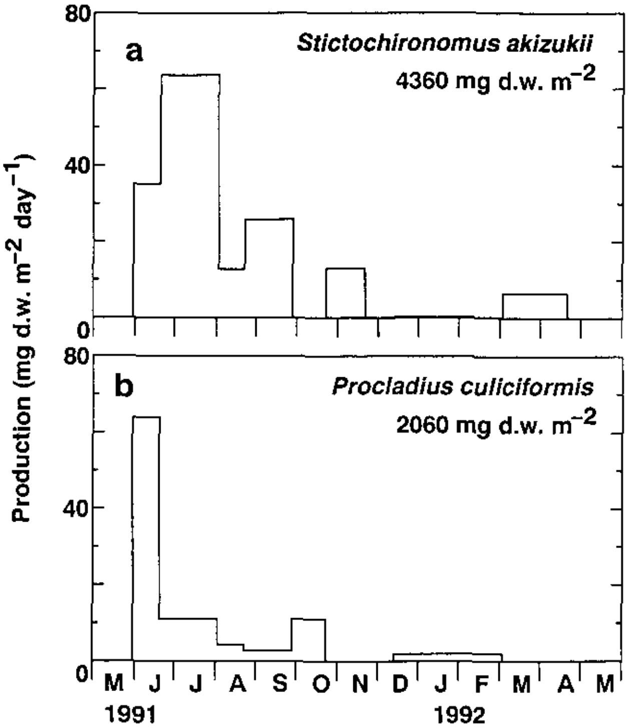

Fig. 6. Monthly changes in production rate of *Stictochironomus akizukii* (a) and *Procladius culiciformis* (b) larvae in Pool 50 (site D2). Numerals below the species name indicates annual production during the period from late May 1991 to late May 1992.

Table 2. Digestive tract contents of *Procladius culiciformis* larvae. N: Number of *P. culiciformis* larvae examined; n_k: Number of *P. culiciformis* larvae with respective food items in their digestive tract.

Date	Instar	N	n_k								Percentage occurrence (n_k/N, %)		
			Stictochironomus			*Procladius*		*Ablabesmyia*		Algae	*Stictochironomus*	*Procladius*	Chironomid total
			Instar 1	2	3	1	2	1	2				
30.May	4	15	0	0	0	0	2	0	0	13	0	13	13
	3	29	0	0	0	0	0	0	0	29	0	0	0
	2	1	0	0	0	0	0	0	0	1	0	0	0
1.Aug	4	17	0	1	0	1	1	0	1	15	12	6	18
	3	15	0	2	0	1	0	0	0	13	20	0	20
21.Aug	4	14	0	4	0	0	1	1	0	8	29	14	43
	3	14	0	3	0	1	0	0	0	10	29	0	29
	2	3	0	0	0	0	0	0	0	3	0	0	0
26.Sep	4	20	1	1	1	0	1	0	0	15	10	5	15
	3	17	0	0	0	1	0	0	0	13	6	0	6
	2	1	0	0	0	0	0	0	0	0	0	0	0
21.Oct	4	19	1	1	1	0	1	0	0	16	11	5	16
	3	20	0	1	0	0	0	0	0	19	5	0	5
	2	1	0	0	0	0	0	0	0	1	0	0	0
11.Dec	4	20	0	0	0	0	0	0	0	18	0	0	0

larvae of *P. culiciformis* preyed on the 3nd instars of *S. akizukii*. Although 3rd-instar larvae of *S. akizukii* were also present in August, the 3rd and 4th instars of *P. culiciformis* seemed to feed on the 2nd instar more frequently.

Fourth-instar larvae of *P. culiciformis* preyed on the 2nd instar of the same species although the frequency was low. They also fed on the larvae of *Ablabesmyia* belonging to the subfamily Tanypodinae. Prey larvae were all found in the digestive tracts with their head capsules positioning apically and abdomens downwards (Fig. 7).

S. akizukii larvae fed on small algae, such as *Aulacoseira* spp., and detritus while 3rd- and 4th-instar larvae of *P. culiciformis* fed on the 1st to 3rd instars *of S. akizukii* as

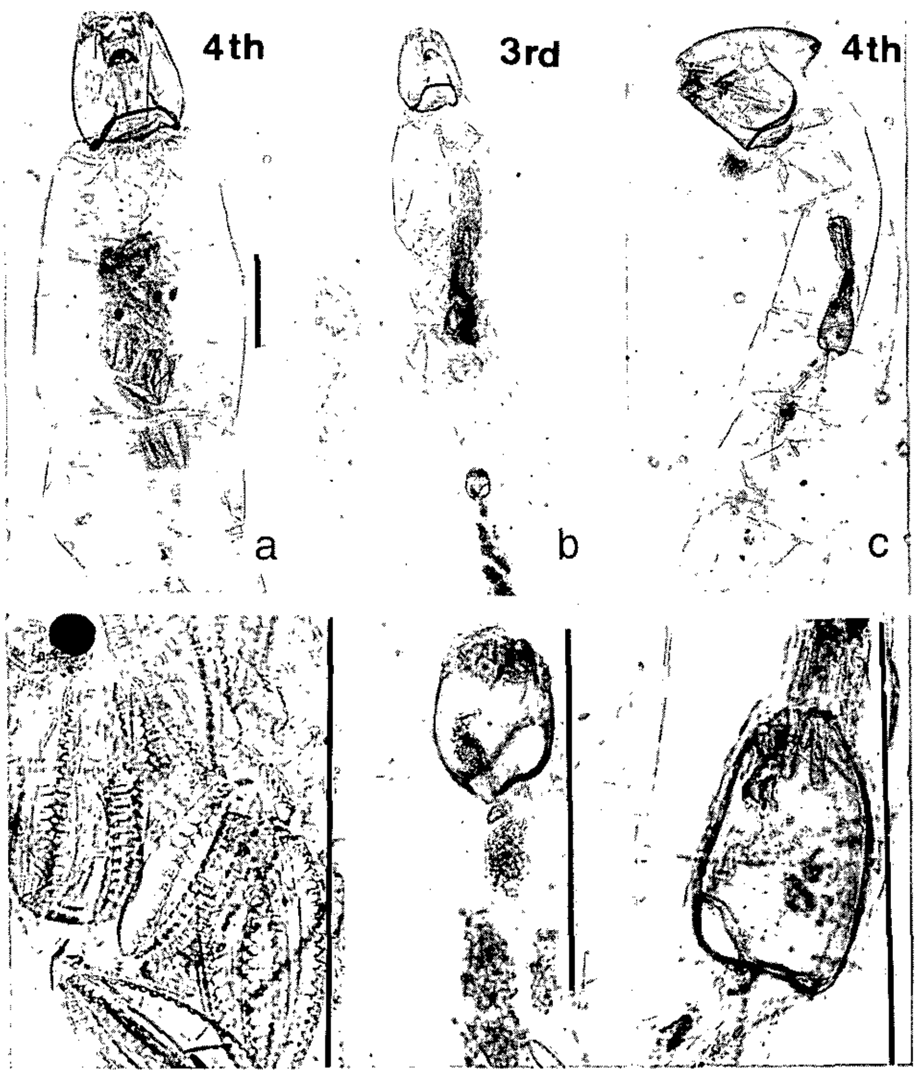

Fig. 7. Third- and 4th-instar larvae of *Procladius culiciformis* and their digestive tract contents.
a: Diatoms (*Suriella* sp.); b: A 2nd-instar larva of *Stictochironomus*; c: A 2nd-instar larva of *Procladius*.
Scale = 0.5 mm.

well as the 1st- and 2nd-instars of *P. culiciformis*. Large-sized diatoms and desmids such as *Frustria, Suriella, Closterium* and *Euastrum,* constituted most of the digestive tract contents of *P. culiciformis* larvae.

First- to 3rd-instar larvae of *S. akizukii* comprised only ca. 10% or 0.14 g m^{-2} of the annual mean biomass of all instars. Therefore the early instar larvae of *S. akizukii* found in the digestive tracts of *P. culiciformis* might have not been sufficient to maintain the latter species' high production. During the peak of *P. culiciformis* production in May-June 1991, no *S. akizukii* larvae were found in their digestive tracts. Instead, the high density and production of *P. culiciformis* must have been supported by the benthic algae.

The genus *Procladius* is the most commonly recorded chironomid from mire waters (Wrubleski, 1987). The larval density of this genus is between 15—1260 m^{-2} in oligotrophic pools of Ozegahara Mire (Kurasawa *et al.*, 1982). The highest larval density recorded so far for lakes is around 1000—1500 m^{-2} (Dusoge, 1980; Siegfried, 1984). The density of *Procladius* in pool 50 in Miyatoko Mire is far higher than those previously recorded for anywhere else.

The emergence peak of *P. culiciformis* was observed in August at the same time as the density peak of 2nd instar larvae of *S. akizukii* was observed. During the June—August period when the growth of the 4th-instar larvae of *P. culiciformis* was prominent, 1st-instar larvae of *S. akizukii* must have been abundant. Feeding on these small larvae might have stimulated the growth of *P. culiciformis* larvae before emergence.

The annual production (4.36 g m^{-2} $year^{-1}$) of *S. akizukii* larvae in pool 50 of Miyatoko Mire was equivalent to that reported for other large chironomids in eutrophic waters (Iwakuma, 1986). Among Tanypodinae larvae, the production value of *P. culiciformis,* 2.06 g m^{-2} $year^{-1}$, was second only to that of *Procladius choreus* (Meigen) in the eutrophic, shallow Eglwys Nunydd Reservoir (Tokeshi, 1995).

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10
Microbial Community and Cellulose Decomposition Activity in Peat Soils of Miyatoko Mire

Mikiya Hiroki and Makoto M. Watanabe

Microbial communities play important roles in mire ecosystems decomposing peat and other organic materials. The purpose of the present study was to identify the relationships among the topography, vegetation, microbial community and cellulose decomposition rates in a mire.

Our field survey was carried out in Miyatoko Mire from 28 April to 27 October, 1992. A total of 14 study sites were selected in the mire. According to the topography and vegetation, the study sites were classified into three types (Table 1): "hummocks" covered with *Sphagnum magellanicum* Brid. or *S. papillosum* Lindb. (type I); "hollows" covered with *S. cuspidatum* Hoffm. (type II); "hollow and streams" where *Sphagnum* seldom grew (type III).

Table 1. Topography and vegetation at each study site.

Type	Site no	Topography	Vegetation
I	2	hummock	*Sphagnum magellanicum*
	4	hummock	*S. papillosum, Rhynchospora alba, Osmundastrum cinnamomeum, Ilex crenata*
	6	hummock	*S. papillosum, S. magellanicum* (rare)
	7	hummock	*S. magellanicum*
	13	hummock	*S. magellanicum, S. papillosum, Phragmites australis*
II	3	hollow	*S. cuspidatum*
	8	hollow	*S. cuspidatum*
	10	hollow	*S. cuspidatum, Moliniopsis japonica*
	12	hollow	*S. cuspidatum*
III	1	along stream	*Drosera* sp.
	5	in stream	*P. australis*
	9	hollow	*S. cuspidatum* (rare), *M. japonica*
	11	along stream	*P. australis, M. japonica*
	14	in stream	*P. australis, S. cuspidatum* (rare)

The water contents of the soils fluctuated seasonally (Fig. 1). At sites 2, 3 and 7, where *Sphagnum* formed thick layers, these fluctuations were large, with the soil water content increasing from late April to late June and decreasing from late June to late August. Apart from site 1, the water contents of type III soil sites did not fluctuate appreciably.

The numbers of fungi (2—1000 × 10^4 CFU g^{-1}) and bacteria (8.5—9000 × 10^5 CFU g^{-1}) varied with the sites and sampling dates. Similar to the soil water contents, viable counts of fungi at type I sites (2, 7, 13), where *Sphagnum* formed thick layers, increased from 28 April to 22 June, decreased markedly from 22 June to 24 August and increased from 24 August to 27 October (Fig. 2).

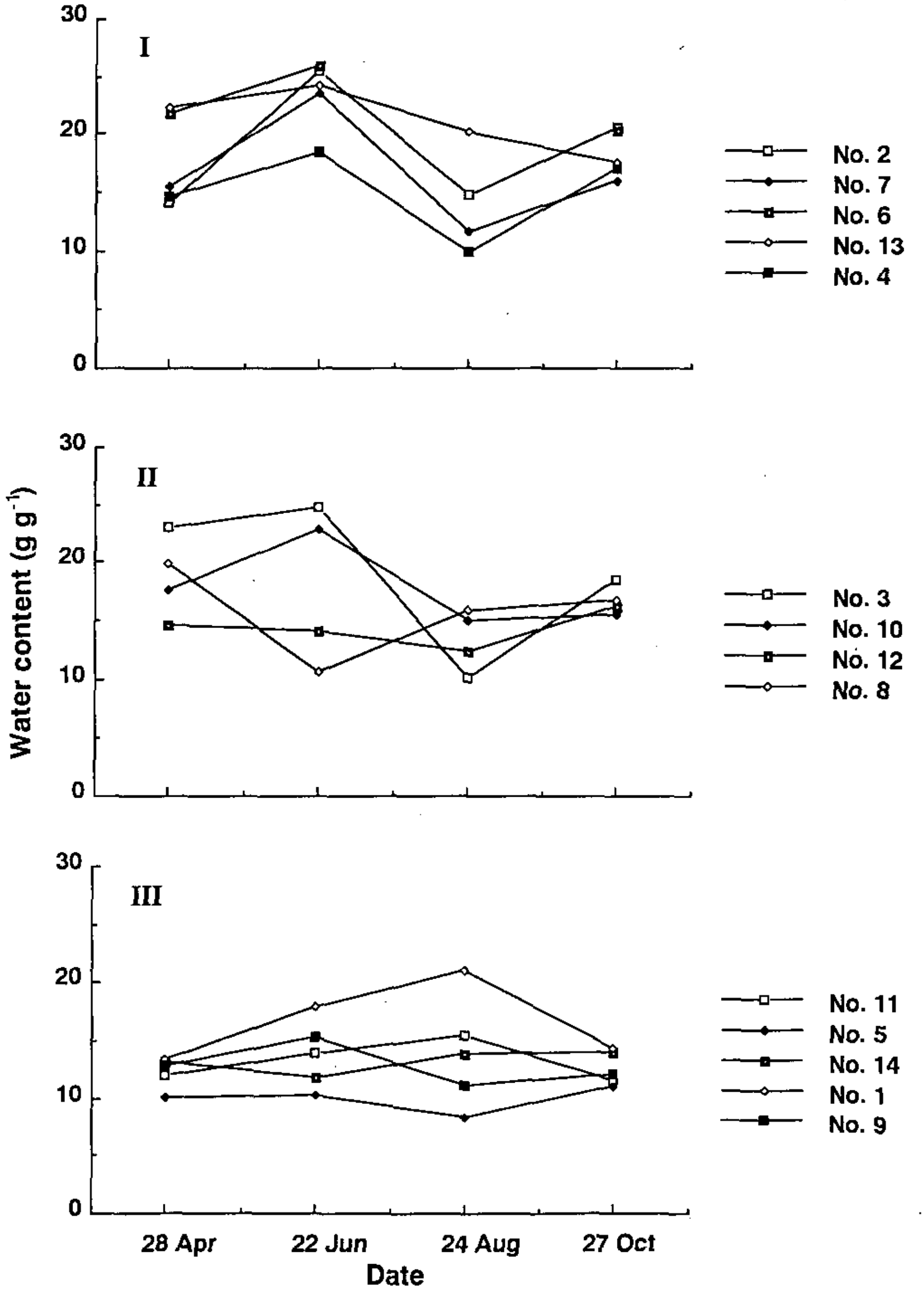

Fig. 1. Fluctuations of soil water content, expressed on a dry matter basis, in peat soils at each study site.

Similar to the pattern for the fungi, the fluctuations of the bacterial counts were large at type I sites, increasing from 28 April to 22 June and decreasing from 22 June to 24 August (Fig. 3).

The numbers of cellulolytic fungi (4.7—300 × 10^4 CFU g^{-1}) and cellulolytic bacteria (1.5—9.2 × 10^5 CFU g^{-1}) determined on 22 June also differed between sites (Fig. 4). Cellulolytic fungi were predominant in the *Sphagnum* peat of type I soils, while cellulolytic bacteria were predominant in the type III peat soils.

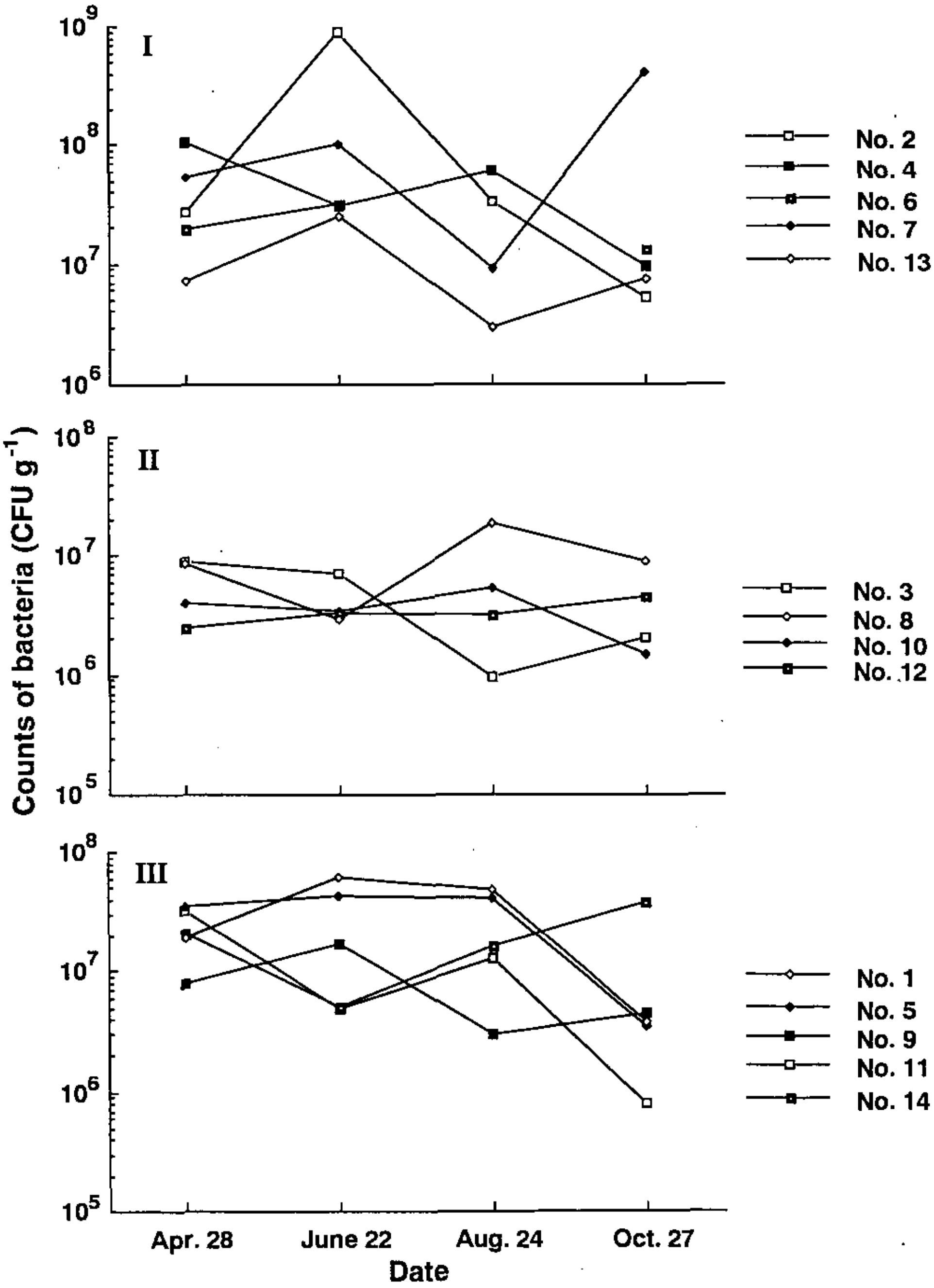

Fig. 2. Fluctuations of fungal viable counts, expressed on a dry matter basis, in peat soils at each study site.

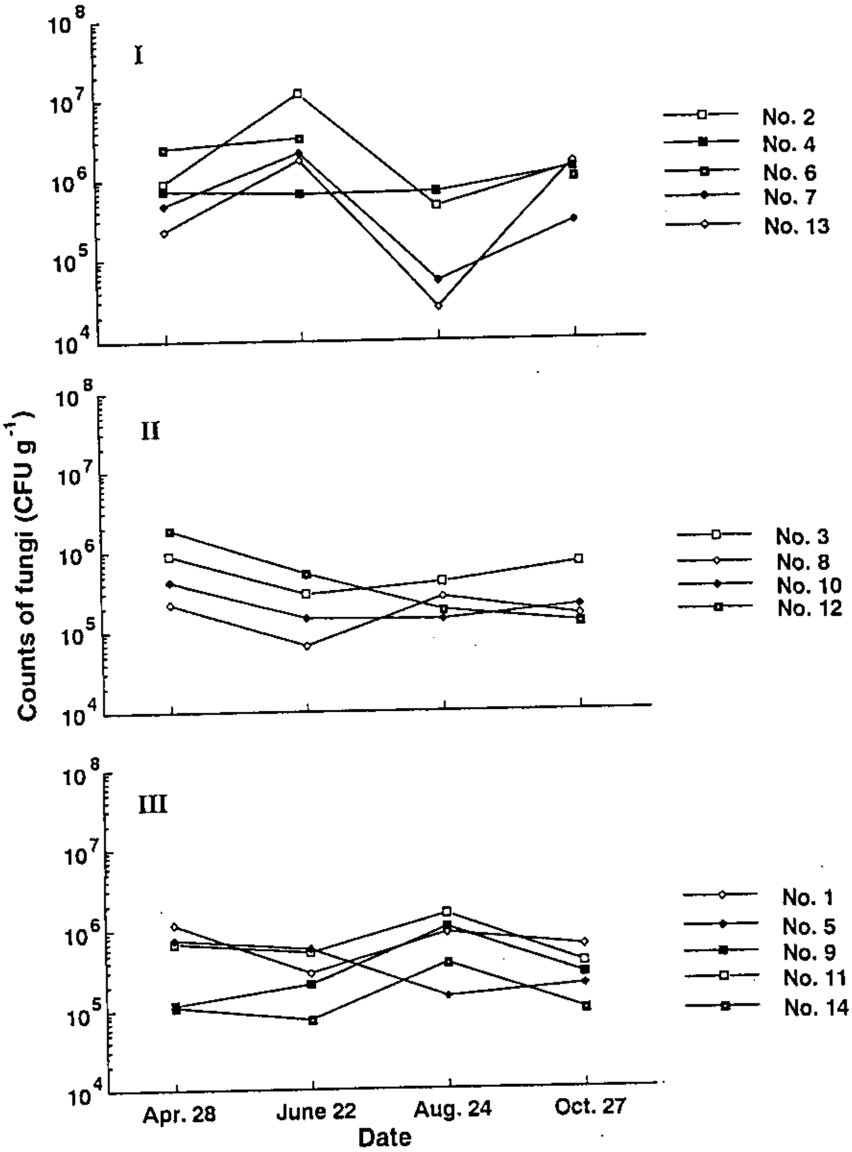

Fig. 3. Fluctuation of bacterial viable counts, expressed on a dry matter basis, in peat soils at each study site.

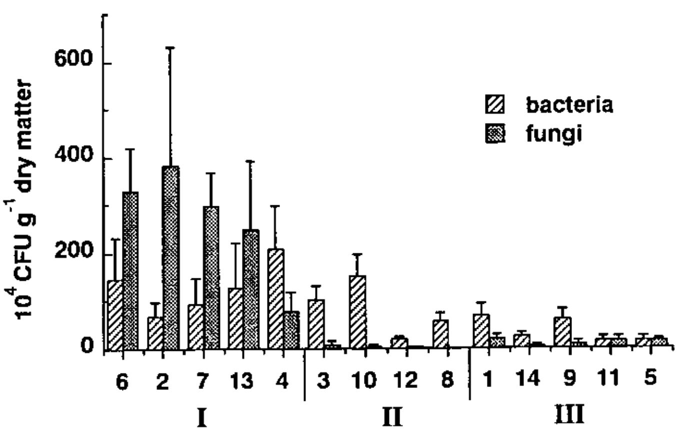

Fig. 4. Counts of cellulolytic microorganisms in peat soils. Bars show the standard deviations of counts of 4 replicate plates.

Decomposition rate of cellulose filter paper during a 6-month period ranged from 0.0002 to 0.0041 g g^{-1} day^{-1}, and tended to be higher in the peat of type II soils than in type I soils (Fig. 5).

No significant relationships between the decomposition rate of the cellulose paper tips and the numbers of viable cellulolytic fungi and bacteria in the peat were found (Fig. 6).

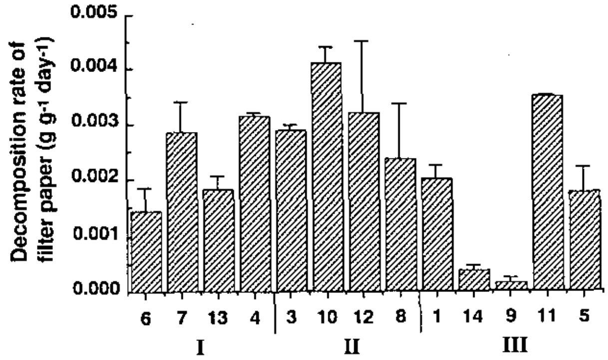

Fig. 5. Decomposition rate of cellulose filter paper buried at each study site. Bars show the differences between the duplicate filter papers buried at each site.

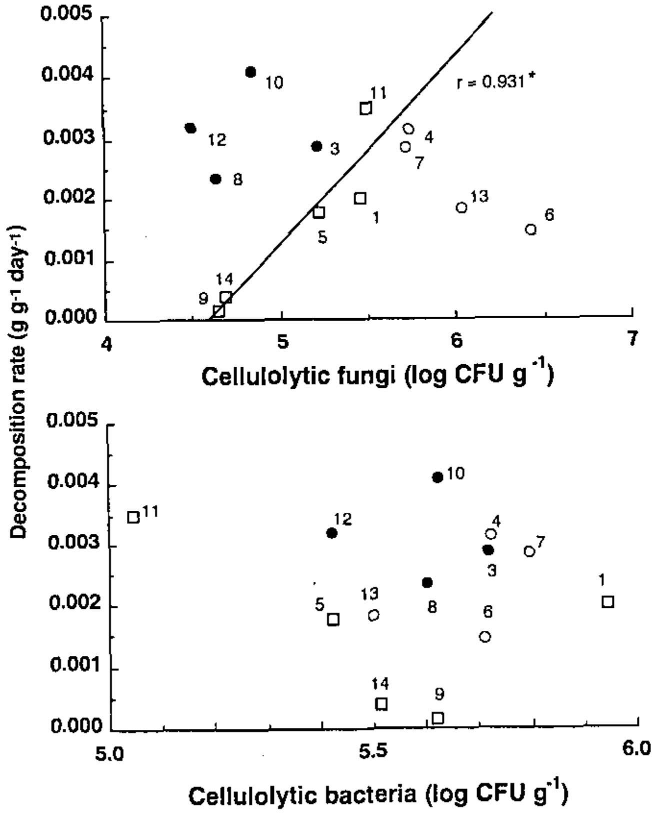

Fig. 6. Relationship between the viable counts of cellulolytic microorganisms, expressed on a dry matter basis, and the decomposition rate of cellulose filter paper in peat soils. I) hummocks; II) hollows; III) hollows and streams without *Sphagnum*. The decomposition rate was the mean value of those of the 2 types of filter paper. The regression line and coefficient in the upper figure were calculated for the hollows and streams without *Sphagnum* sites (5 squares).

There were, however, differences in the numbers of viable cellulolytic fungi and decomposition rates among the types of sites: at type I sites, decomposition was not rapid, while the counts of viable cellulolytic fungi were high; at type II sites, the ratio of decomposition rate to the number of viable cellulolytic fungi was highest; at type III sites, there was a positive correlation between viable counts of cellulolytic fungi and filter paper decomposition, and the ratio of the decomposition activity to viable counts of cellulolytic fungi was intermediate among the 3 types of sites.

These results suggest that topography and vegetation affect both microbial communities and the organic material decomposition activity in this mire (Table 2) and that both the fungal flora and its cellulolytic activity differ between the various mire soil types.

Table 2. Topography, vegetation, microbial communities and decomposition rate in peat soils at each type of site in Miyatoko mire.

Type of the sites	I	II	III
Topography	Hummock	Hollow	Hollow, stream
Predominant *Sphagnum*	*S. papillosum* *S. magellanicum*	*S. cuspidatum*	Rare
Degree of peat decomposition	Low	Medium	High
Moisture conditions	Fluctuate seasonally	Fluctuate seasonally	Steady
Microbial numbers	Fluctuate seasonally	Steady	Steady
Cellulolytic microorganisms	Fungi	Bacteria	Bacteria
Cellulose decomposition activity	Medium	Rapid	Variable

PART II. AKAIYACHI MIRE

11
Environment of Akaiyachi Mire

Toshio Iwakuma

Location and Geological features of Akaiyachi Mire

Akaiyachi Mire (37°30'36"N 140°0'30"E, altitude 525 m) extends north and west of the Akai River near its outlet into the northeast end of Lake Inawashiro. The mire is

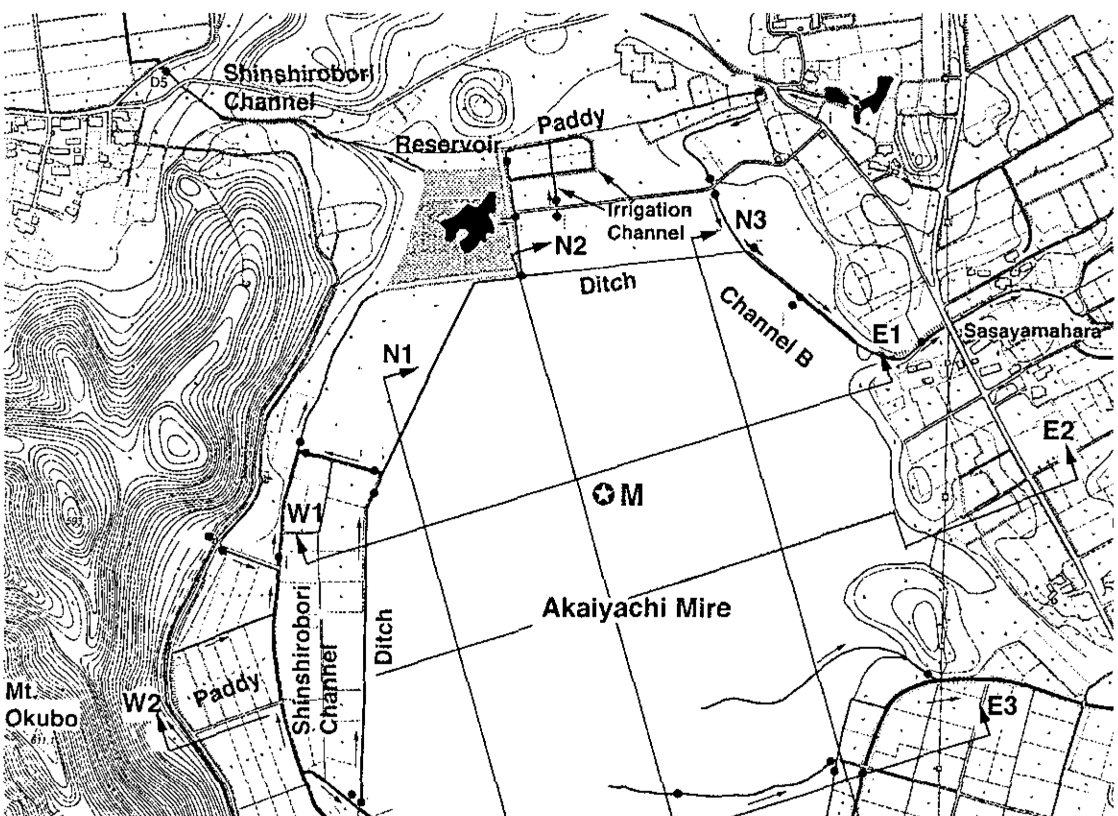

Fig. 1. Map of Akaiyachi Mire showing major waterways (based on the urban planning map of the city of Aizuwakamatsu 1/2500, Aizuwakamatsu, 1991). M: meteorological monitoring tower.

octagonal in shape, measuring ca. 900 m from north to south and ca. 700 m from east to west covering an area of 43.56 ha (Fig. 1).

The mire is surrounded mainly by rice paddies and partly by buckwheat or vegetable fields. Ditches and irrigation channels run along the mire's periphery.

The mire was surveyed with a laser theodolite (a surveying tool; Nikon DTM-A20CLG, Japan) in May 1994 (Iwakuma and Yamagata, 1996). The northern three quarters of the mire has a convex profile (Fig 2 a, b, f). The highest site (525.6 m above mean sea level (a.s.l.)) was located near the northeast tip of the mire; 150 m south of the northern rim and 150 m east of the western rim. The southern rim of the mire was lowest in altitude (523.0 m)

Peat profiles at 3 sites across the northern part of the mire were studied by Yoshioka (1961). *Sphagnum-Rhynchospora* peat, *Sphagnum-Moliniopsis* peat and *Sphagnum-Vaccinium oxycoccus* (*Sphagnum-Oxycoccus* in Yoshioka, 1961) peat accumulate to depths of 150 cm. Below this depth was found a 20 cm layer of

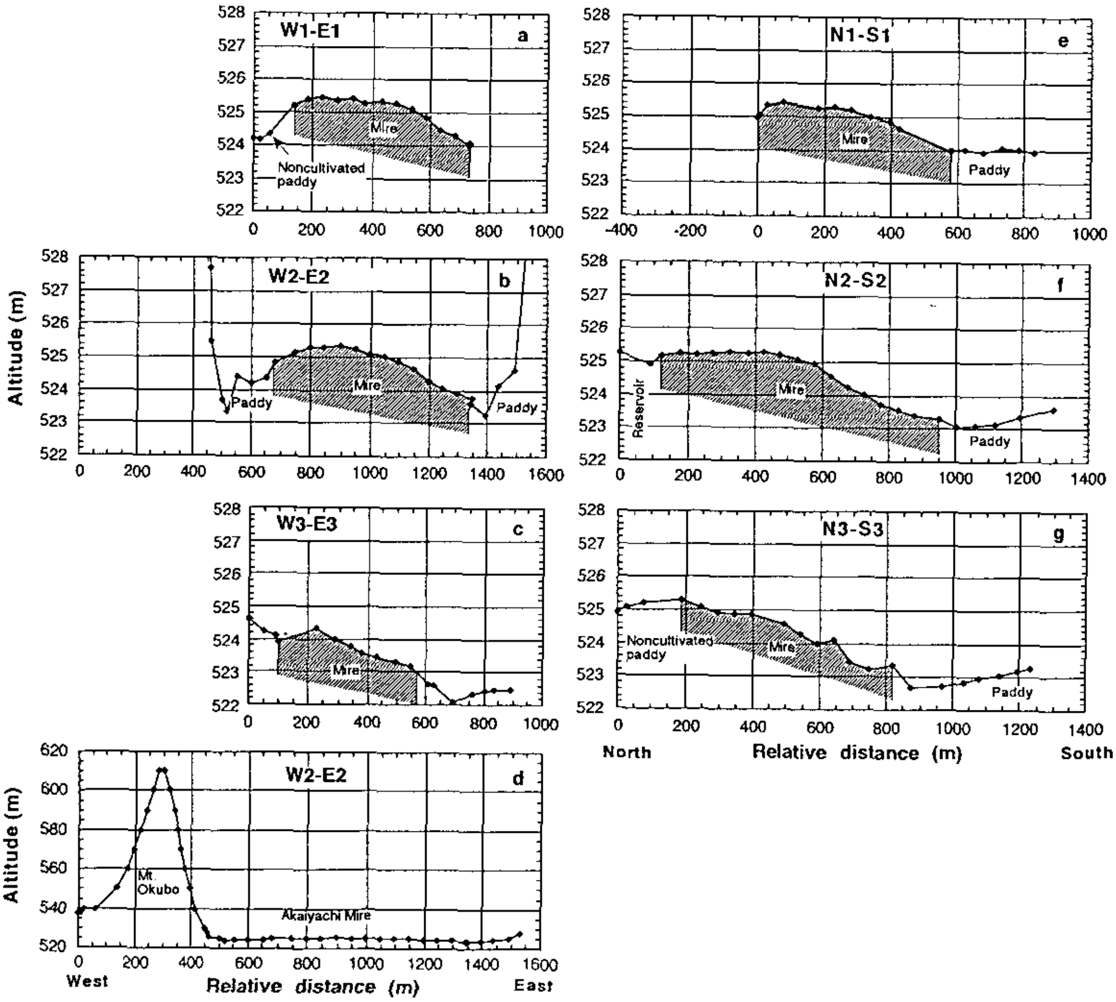

Fig. 2. Cross-sectional view of Akaiyachi Mire (redrawn from Iwakuma and Yamagata, 1996). The locations of transect lines are printed in Fig. 1.

Moliniopsis peat below which was a layer of *Phragmites* peat from 175 to 210 cm depth separated by a 60 cm layer of volcanic ash and sand with some remains of *Phragmites* and wood from a layer of wood remains from 270 to 325 cm, (Yoshioka, 1961). This stratigraphy, constituting evidence of a successional process from water-logged land to fen and finally into a bog, a rare example for Japanese mires, has been discussed by Yoshioka (1961) and Kashimura (1996).

The top layer of the bedrock, of the Akai Formation, consists of clay on top of a tephra layer dated 23,000 BP (Suzuki et al, 1982). The ^{14}C age determined for logs found at ca. 1.6 m depth in the peat layer of the southern rim of the mire was 6130 BP (Omoto, 1982; Suzuki et al., 1982). The age of the tephra found from 210 to 270 cm depths in the mire is ca. 5000 BP.

Meteorology

A meteorological monitoring tower was set up near the center of the mire in October 1991 (site M in Fig. 1). Air temperature, soil temperature at 10 cm depth, solar radiation, wind speed, and precipitation were recorded every 10 min from November 1991 until October 1992 and every 20 min thereafter (Iwakuma and Nohara, 1996).

Daily mean air temperature ranged from ca. -6 to ca. 29°C and the minimum and maximum air temperatures were -14 and 34°C, respectively, during the period from November 1991 to December 1994 (Fig. 3a). Snowfall events were observed during December to March period and duration of complete snow cover of the mire surface between December and March in 1991—1992, 1992—1993, and 1993—1994 was 91, 103, and 101 days (Iwakuma and Nohara, 1996). Soil temperature at 10 cm depth under the snow was essentially constant at 0.1—0.3°C (Fig. 3b). Daily maximum soil temperature increased rapidly just after the thaw of snow: from 1.9 to 3.3°C during 25 to 26 April 1992, from 1.3 to 4.1°C during 24 to 27 March 1993 and by 1.1 to 4.2°C during 31 March—5 April 1994 (Fig. 3b). No signs of freezing in the peat soils were observed. Solar radiation was highest either in May (1992) or in August (1993, 1994) (Fig 3c). Daily mean wind speed fluctuated in the range between 0.5 and 9.4 m s^{-1} throughout the year and the maximum wind speed reached 17.5 m s^{-1} (Fig. 3e, f).

Annual mean air temperatures at Inawashiro Meteorological Observatory (37°33'54" N 140°6'42"E, altitude 521 m), 8 km northeast of the mire, were (minimum and maximum values in parentheses): 9.6 (-14.6—31.0), 9.3 (-14,6—31.0), 8.9 (-11.9—29.1) and 10.1 (-11.7—34.2°C) for 1991, 1992, 1993 and 1994, respectively (Fukushima Local Meteorological Observatory, 1991, 1992, 1993, 1994) (Table 1). The total duration of sunshine was 1402, 1465, 1266 and 1667 h in 1991, 1992, 1993 and 1994, respectively. Annual precipitation in 1991, 1992, 1993 and 1994 was 1615, 1130, 1499 and 956 mm, respectively.

Annual mean air temperatures at Akaiyachi Mire, 8.5, 8.1, and 9.2°C in 1992, 1993, and 1994, respectively, were lower than those at the Inawashiro Observatory (Table 1). The maximum snow depths on the mire, recorded by serial photography,

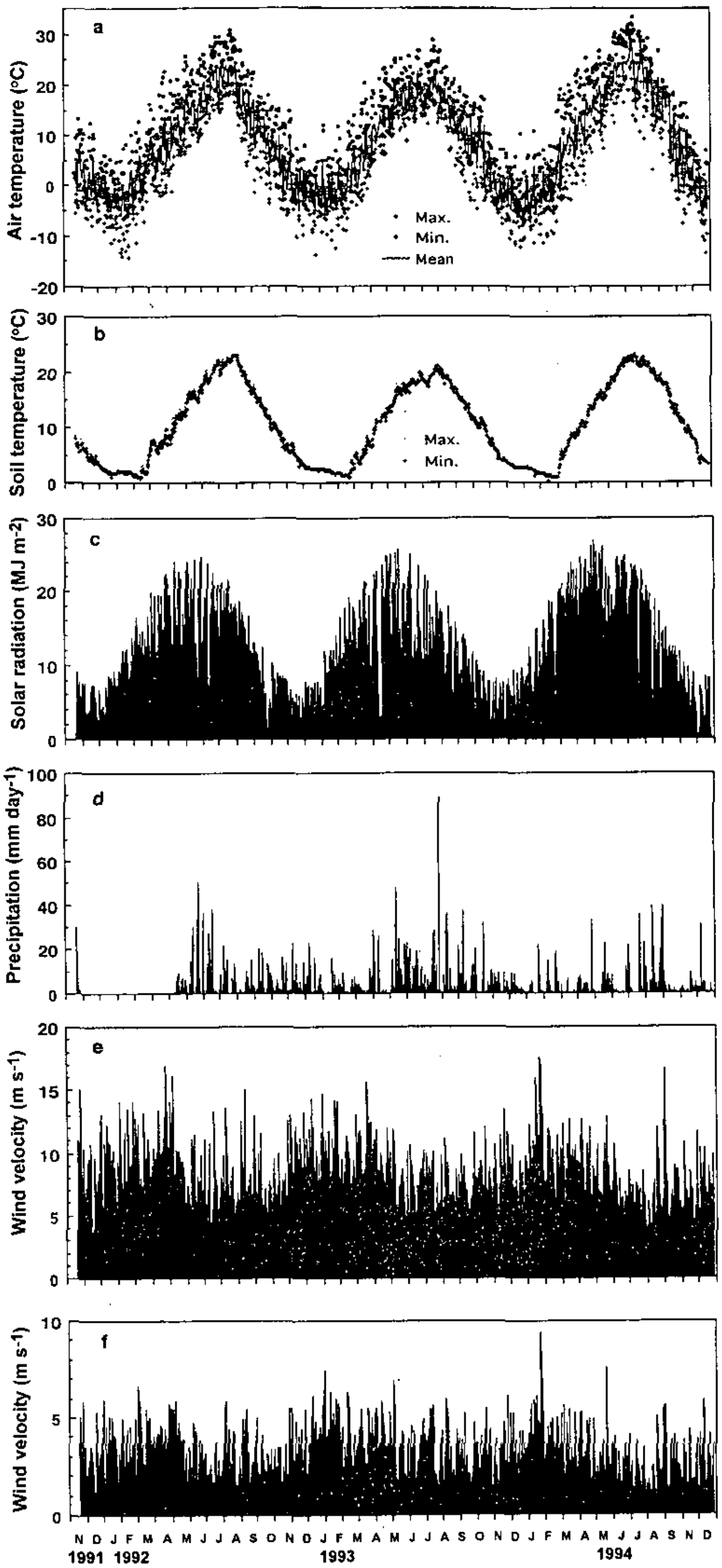

Fig. 3. Weather at the monitoring tower in Akaiyachi Mire. a: daily maximum, minimum and mean air temperatures; b: daily mean soil temperature; c: daily solar radiation; d: daily precipitation; e and f: daily maximum and mean wind velocity, respectively.

Table 1. Monthly meteorological data at Akaiyachi Mire (Iwakuma and Nohara, 1996) and at Inawashiro Meteorological Observatory from 1991 to 1994.

Month	Akaiyachi Mire: Air temperature			Wind speed		Solar radiation	Precipitation	Soil temperature			Inawashiro Observatory: Air temperature			Wind speed		Duration of sunshine	Precipitation
	Mea	Max.	Min.	Mean	Max.			Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.		
	°C	°C	°C	$m\ s^{-1}$	$m\ s^{-1}$	$MJ\ m^{-2}$	mm	°C	°C	°C	°C	°C	°C	$m\ s^{-1}$	$m\ s^{-1}$	h	mm
1991																	
Jan											-2.7	4.9	-11.8	2.4	6	87.6	68
Feb											-2.8	8.3	-14.6	2.6	10	85.2	120
Mar											1.2	12.0	-10.1	2.3	7	147.8	74
Apr											9.1	21.9	-5.0	2.4	8	191.3	37
May											13.4	29.4	-1.1	2.1	6	184.8	49
Jun											19.0	30.4	10.9	1.8	5	89.2	210
Jul											20.9	31.0	13.0	1.7	6	87.2	316
Aug											20.9	30.8	10.0	1.6	5	135.0	217
Sep											18.1	29.9	0.0	1.5	10	113.5	137
Oct											12.1	22.6	0.0	2.1	9	77.1	242
Nov	3.1	13.2	-5.4	2.7	15	54.1	32.0	6.9	8.7	5.6	5.0	16.4	-2.7	1.8	6	115.2	102
Dec	0.7	12.4	-7.9	2.4	13.1	143.2		5.0	7.4	3.2	1.4	13.3	-6.2	2.0	7	87.7	43
Annual											9.6	31.0	-14.6	2.0	10.0	1402	1615
1992																	
Jan	-1.7	6.1	-11.4	2.5	12.2	151.5	2.0	2.2	3.3	1.0	-1.1	6.0	-11.9	1.9	7	90.1	63
Feb	-3.2	10	-14.4	2.8	14.1	231.3		1.9	2.2	1.5	-2.5	9.6	-12.5	2.2	6	116.0	68
Mar	1.3	12.6	-11.5	3.4	13.2	311.2		2.1	6.0	0.8	2.1	12.8	-8.6	2.4	10	111.8	56
Apr	6.7	22.7	-2.0	3.5	16.9	360.9		7.3	10.1	5.3	7.6	23.6	-1.2	2.3	10	154.6	107
May	10.1	21.1	-1.2	3.1	16.1	397.6	59.5	10.9	13.2	7.0	11.2	21.6	-0.8	2.1	7	105.6	96
Jun	15.1	25.6	6.4	2.6	11.5	466.1	163.0	15.6	17.7	12.0	16.3	26.9	8.5	1.9	8	126.9	155
Jul	19.6	29.5	10.2	2	13.3	440.4	164.5	19.6	22.2	16.2	20.6	31.5	12.0	1.5	6	110.3	161
Aug	21.5	30.6	14.4	2.7	13.6	465.6	97.5	22.0	23.4	19.4	22.3	31.1	14.9	1.6	6	180.1	71
Sep	16.1	28.9	4.0	2.8	15	365.4	48.0	19.9	23.3	16.1	16.8	30.0	5.3	1.8	6	151.8	41
Oct	10.9	22.4	-1.4	2.3	11.6	188.4	95.0	14.6	17.6	11.8	11.5	23.8	1.5	1.7	8	128.5	126
Nov	5.4	15.3	-4.9	2.4	12.5	165.4	66.0	9.2	12.1	5.9	6.1	17.3	-3.9	1.8	8	126.1	63
Dec	0.6	14.5	-10.4	2.8	13.2	110.3		5.2	7.3	3.0	1.3	13.5	-11.4	2.1	7	62.9	123
Annual	8.5	30.6	-14.4	2.7	16.9	3654	696	10.9	23.4	0.8	9.3	31.5	-12.5	1.9	10.0	1465	1130
1993																	
Jan	-1.6	7.9	-13.8	3.2	14.6	149.7		2.6	3.3	2.3	-1.1	7.6	-11.9	2.2	8	68.8	87
Feb	-1.8	11.8	-12.5	3.9	14.2	206.1		2.1	2.6	1.5	-1.0	13.5	-11.3	2.6	7	93.5	107
Mar	0.2	12.4	-8.9	2.9	13	359.1		1.8	4.1	1.1	0.7	12.6	-7.9	2.0	6	125.9	72
Apr	4.7	20.2	-3.9	3.4	15.6	340.9		5.5	8.5	3.4	5.8	20.9	-2.5	2.3	7	128.7	76
May	11.5	23.3	1.8	3.4	11.9	402.8	2.5	10.7	13.6	6.5	12.3	24.3	0.8	2.2	7	181.7	156
Jun	15.6	25.1	9.4	2.6	11.9	385.7	203.5	15.8	17.9	12.7	16.7	26.2	9.2	1.7	6	87.3	188
Jul	17.6	26.8	8.7	3	10.6	376.6	161.5	18.3	20.1	16.2	18.7	28.4	10.2	1.7	7	72.3	160
Aug	18.7	28.7	12.1	2.9	10.1	375.0	229.0	19.4	21.1	17.2	19.9	29.1	12.1	1.8	9	106.5	211
Sep	16.3	26.8	6.7	2.6	11.1	285.7	123.0	18.7	20.8	16.2	17.2	27.0	9.0	1.7	9	83.0	113
Oct	9.7	19.5	-3.2	2.5	11.6	258.7	110.5	14.3	17.3	11.3	10.4	20.6	-1.7	1.8	6	137.5	126
Nov	6.3	17.6	-4.6	2.7	12	162.5	99.5	10.3	12.1	7.1	6.9	18.7	-2.4	1.8	6	102.5	116
Dec	-0.2	10	-7.6	2.9	13.4	117.5	39.0	5.3	8.0	3.5	0.5	11.0	-7.2	2.1	6	78.0	87
Annual	8.1	28.7	-13.8	3.0	15.6	3420	969	10.4	21.1	1.1	8.9	29.1	-11.9	2.0	9.0	1266	1499
1994																	
Jan	-3.2	10.2	-12.2	2.4	10.6	175.4		2.9	3.6	2.6	-2.7	5.0	-11.5	1.9	6	83.1	67
Feb	-2.6	10.8	-11.4	4.2	17.5	211.7		2.3	2.7	1.3	-1.9	7.9	-10.6	2.6	6	78.0	93
Mar	-1.1	7.8	-11.4	3.3	11.9	377.3		1.3	1.8	0.3	-0.4	8.1	-8.5	2.4	7	158.9	78
Apr	7.2	20.1	-4.2	2.8	12.7	510.6	14.5	6.1	9.0	1.0	8.2	20.8	-4.0	2.1	7	205.7	19
May	12.1	25.4	0.3	3	12.6	499.7	79.0	10.8	13.9	8.1	13.6	25.9	1.2	2.0	7	158.3	58
Jun	16.5	26.7	6.5	2.6	12.9	544.3	60.5	15.4	17.4	13.3	17.9	26.8	8.1	1.9	7	150.7	43
Jul	22.4	30.6	12.4	2.3	10.7	556.8	57.0	20.0	22.6	17.0	23.5	31.3	13.7	1.7	5	202.9	115
Aug	24.1	33.5	10.6	1.9	8.5	572.0	79.5	22.5	23.3	21.0	24.3	34.2	16.2	1.7	7	207.7	39
Sep	18.9	29.1	-12.7	2.1	16.6	339.9	228.5	20.4	22.8	18.3	19:5	28.9	10.0	1.8	7	89.6	206
Oct	12.6	20.8	0.8	2.1	9	268.0	40.0	16.3	19.6	12.2	13.3	22.4	0.0	1.6	7	122.0	86
Nov	4.2	16.2	-7.7	1.9	11.7	170.7	32.0	10.3	13.7	7.8	6.1	17.7	-3.8	1.8	6	125.0	28
Dec	-1	8.1	-13.6	2.2	10.4	93.9	2.5	4.8	7.9	3.1	-0.1	13.1	-11.7	1.6	5	85.2	124
Annual	9.2	33.5	-13.6	2.6	17.5	4320	594	11.1	23.3	0.3	10:1	34.2	-11.7	1.9	7.0	1667	956

were 59 and 80 cm for the winters of 1992 and 1994, respectively (Iwakuma and Nohara, 1996).

Surface water flow

Surface water flow around the mire is complex (Fig. 1). Three major outflows from the mire have been observed: 1) water seeping from the northern part of the mire and flowing via irrigation channels into the northwestern reservoir, 2) water seeping out from the western rim of the mire, collecting in the ditch and flowing into the Shinshirobori Channel, and 3) surface water flowing out from the eastern rim of the mire and into the Akai River (Iwakuma et al., 1996). The chemical composition of the mire water clearly differed from the waters of the surrounding areas (Iwakuma et al., 1996). The elevation of most parts of the mire are higher than those of the surrounding waterways and water generally flows from the mire outwards. In this sense, Akaiyachi Mire is a bog (Gore, 1983).

At southeastern part of the mire, however, the elevation of adjacent land is higher than that of the mire (Fig. 2c). Agricultural runoff flows through a channel just inside the northeastern rim of the mire (Fig. 1, stream B). The impact of agricultural activities at these sites have not been well studied.

Change in vegetation

The landscape and vegetation in the western and southwestern zones of the mire have changed extensively during the past 35 years. In 1961 the northern half of the mire was covered with *Sphagnum* mosses and the western to southwestern zone with *Osmunda japonica* (Yoshioka, 1961). The present vegetation in the western to southwestern zone is a *Pinus densiflora-Sasa palmata* community (Takehara, 1996). This vegetation change must have been accelerated by the construction of the ditch along the western rim of the mire (Kashimura, 1991).

Takehara (1996) studied the vegetation at 157 sites selected from 50 × 50 m grids and found 66 plant species. *Phragmites australis* (Cav.) Trin. et Steud. appeared most frequently (94.3%) and the 3 *Sphagnum* species, *S. papillosum* Lindb., *S. magellanicum* Brid. and *S. palustre* L., appeared at more than half the sites (Fig. 4).

Protection of the threatened mire

The mire was designated as a natural monument by the Japanese Government in 1928. The protected area was 53.97 ha at that time but the surrounding area remained unprotected and allowing agricultural activities there to continue. Due to a pressing need for rice production, rice paddy construction during the late 1940s to early 1950s in the marginal zones of the mire was allowed. Therefore the present protected area has been reduced to 43.56 ha. There is no boardwalk in this mire.

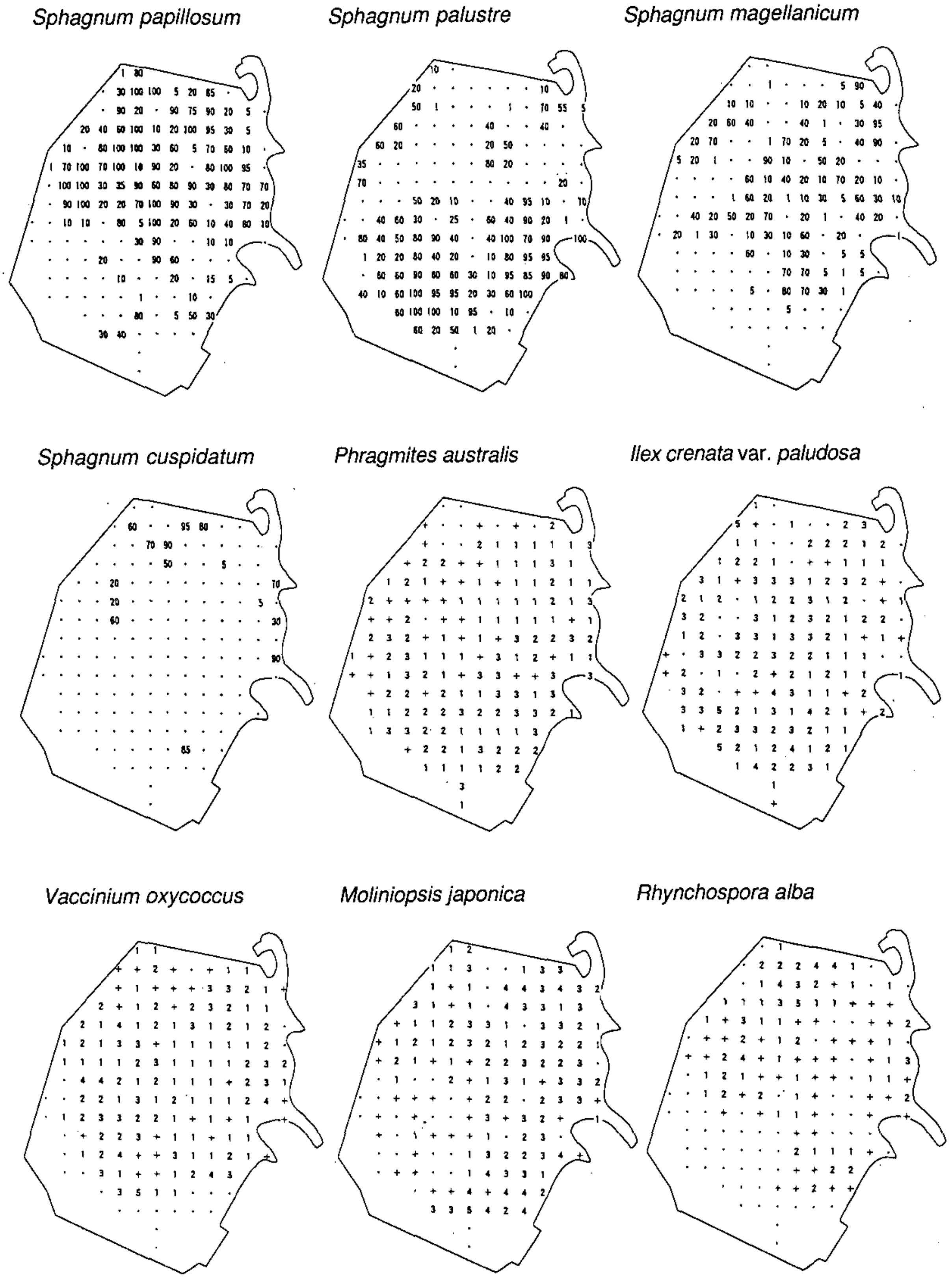

Fig. 4. Distributions of the main plant species in Akaiyachi Mire (Takehara, 1996).
Numerals indicate the percentage cover for *Sphagnum* species or Braun-Blanquet's dominance for others.

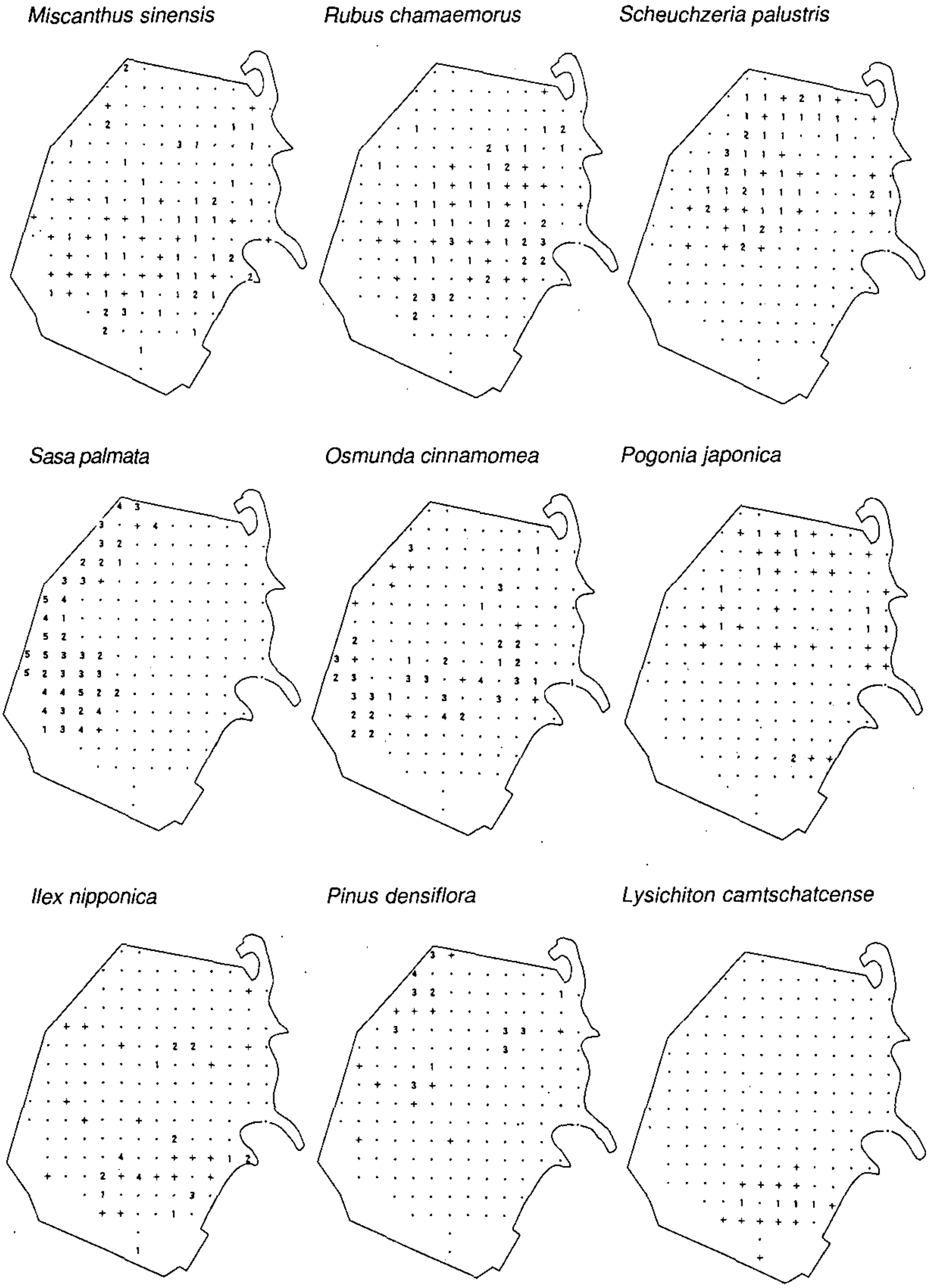

Fig. 4. continued.

The peat layer extends beyond the mire's edge: 2.75 m deep just outside the southern rim (Suzuki and Manabe, 1981), 75 cm deep at the foot of Mt. Okubo, ca. 150 m outward of the western rim of the mire, and 60 cm deep at the eastern rim of the mire (Yoshioka, 1961). These observations indicate that the original mire area was much larger than the mire's area at present. The area between Mt. Okubo and the present mire is much lower in altitude than the western rim of the mire (Fig. 2a, b). Construction of an irrigation channel, the Shinshirobori Channel was completed around 1929 to carry water from the Akai Riverto the northeastern Aizu Plain. The level of the water surface in this channel is 1.2—1.7 m lower than that along the western rim of the present mire (Iwakuma and Yamagata, 1996). The mire surface declines steeply towards the western rim (Fig. 2a, b) where a ditch was constructed in 1971.

The impact of land use on the mire ecosystem is presented in Chapters 12 and 13, which follow.

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12
Monitoring Akaiyachi Mire with Overlaid CASI Images and a Detailed Digital Elevation Model

Yoshiki Yamagata and Toshio Iwakuma

The vegetation of Akaiyachi Mire was classified with Compact Airborne Spectral Imager (CASI) data. A detailed Digital Elevation Model (DEM), based on the data obtained with a laser theodlite (a surveying tool), was overlain with CASI images to analyze the relationship between the vegetation distribution and the slight elevation differences within the mire. This relationship exists because the water content distribution in the mire is affected by elevation differences.

Methods

The analytical procedures were as follows:

1) An airborne spectral image (CASI) with 1.9 × 2.2 m ground resolution was acquired over the Akaiyachi Mire on 2 June 1994 (Table 1). The mire plants were in their initial growth stages when the image was acquired. Radiance data from 3 channels (green, red and near infrared wavelength bands) known to be effective for detecting differences in mire vegetation were used for the analysis (Table 2).

2) Land locations and elevations were measured on 50 m square grid points both inside and outside the mire with a laser theodlite (Iwakuma and Yamagata, 1996). The data were interpolated and transformed into a 2m DEM, to which the CASI image was geometrically corrected. A 3D view image of the CASI data was produced using this DEM. By comparing these images, relationships between wetland vegetation conditions and elevation differences were revealed.

Table 1. The conditions of CASI image acquisition. CASI can acquire images with any band configuration from 400 to 950 nm. The image we acquired had a ground resolution of ca. 2 m. The flight was conducted at 11 a.m. on a very clear day when the mire plants were in early states of their growth

Sensor	CCD (CASI)
Altitude	7,000 ft (1,600 m above ground)
IFOV	0.0690° (along track) 35.40° (swath)
Ground resolution	1.9 × 2.2 m
Image size	512 × 512 pixel
Dynamic range	12 bit
Acquisition date	2 June 1994
Acquisition time	11:00 a.m.

Table 2. Spectral channels of CASI. We selected 10 channels with 10 nm bandwidths. Channel 1 corresponded to blue, channels 2 and 3 to green, channels 4, 5 and 6 to red, and the other channels to near infrared bands. We used data from channels 3, 7 and 10 to classify the mire vegetation.

Channel	Spectral bands (nm)
1	460—470
2	550—560
3	595—605
4	635—645
5	655—665
6	675—685
7	695—705
8	715—725
9	745—755
10	825—835

3) The k-means clustering (unsupervised learning) method was used to classify the CASI image. Twenty cluster classes were first calculated and merged into 8 vegetation community classes identified from the results of a ground based vegetation investigation (Takehara, 1996). We have succeeded in classifying the *Sphagnum* moss types.

4) A comparison of a detailed topographic map and a plot of mire vegetation revealed correspondence between elevation differences and vegetation types such as *Sphagnum* moss types, grasses invading *Sphagnum* moss areas and pine trees at the periphery of the mire.

Classification of mire vegetation

The spectral radiance of each vegetation class (Fig. 1) was measured using the spectral scan mode of the CASI sensor. The vegetation classes corresponding to the vegetation

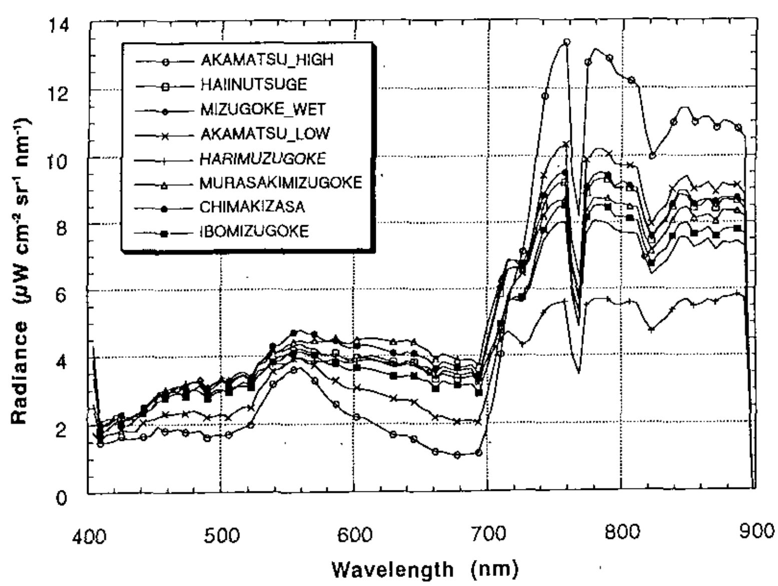

Fig. 1. Spectral radiance of each vegetation class.

types were as follows: Akamatsu_high (high red pine trees), Haiinutsuge (*Ilex crenata* var. *paludosa*), Mizugoke_wet (wet *Sphagnum palustre*), Akamatsu_low (low red pine trees), Harimizugoke (*Sphagnum cuspidatum*), Chimakizasa (*Sasa palmata*) and Ibomizugoke (*Sphagnum papillosum*).

False color was applied to the 3-D view of the CASI image using the DEM (Fig. 2). At the southern part of the mire, where it is surrounded by rice paddies, soil water content was low and consequently, red pine trees were distributed widely. The overall shape of the mire was dome-like.

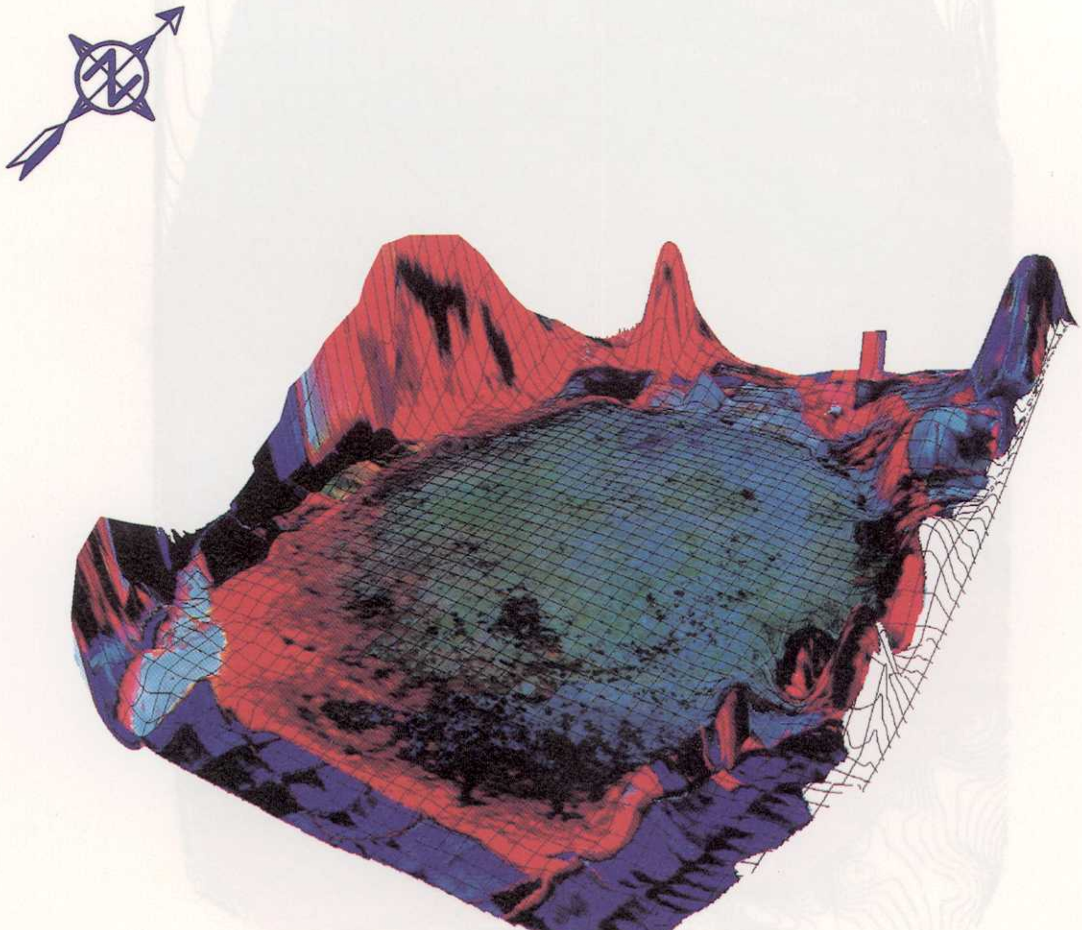

Fig. 2. 3-D view of the CASI false color image using the Digital Elevation Model. Elevation is exaggerated 5-fold. Red corresponds to vegetation cover and blue corresponds to water inundated areas.

The false color CASI image of Akaiyachi Mire was also overlain on a 2D detailed DEM (Fig. 3). The mire elevation was highest in the northwest region and declined gradually towards the southeast. The maximum difference in land elevation was about 2.5 m. Vegetation classes were classified with a clustering algorithm (ISODATA) and the results displayed with the DEM contour lines (Fig. 4).

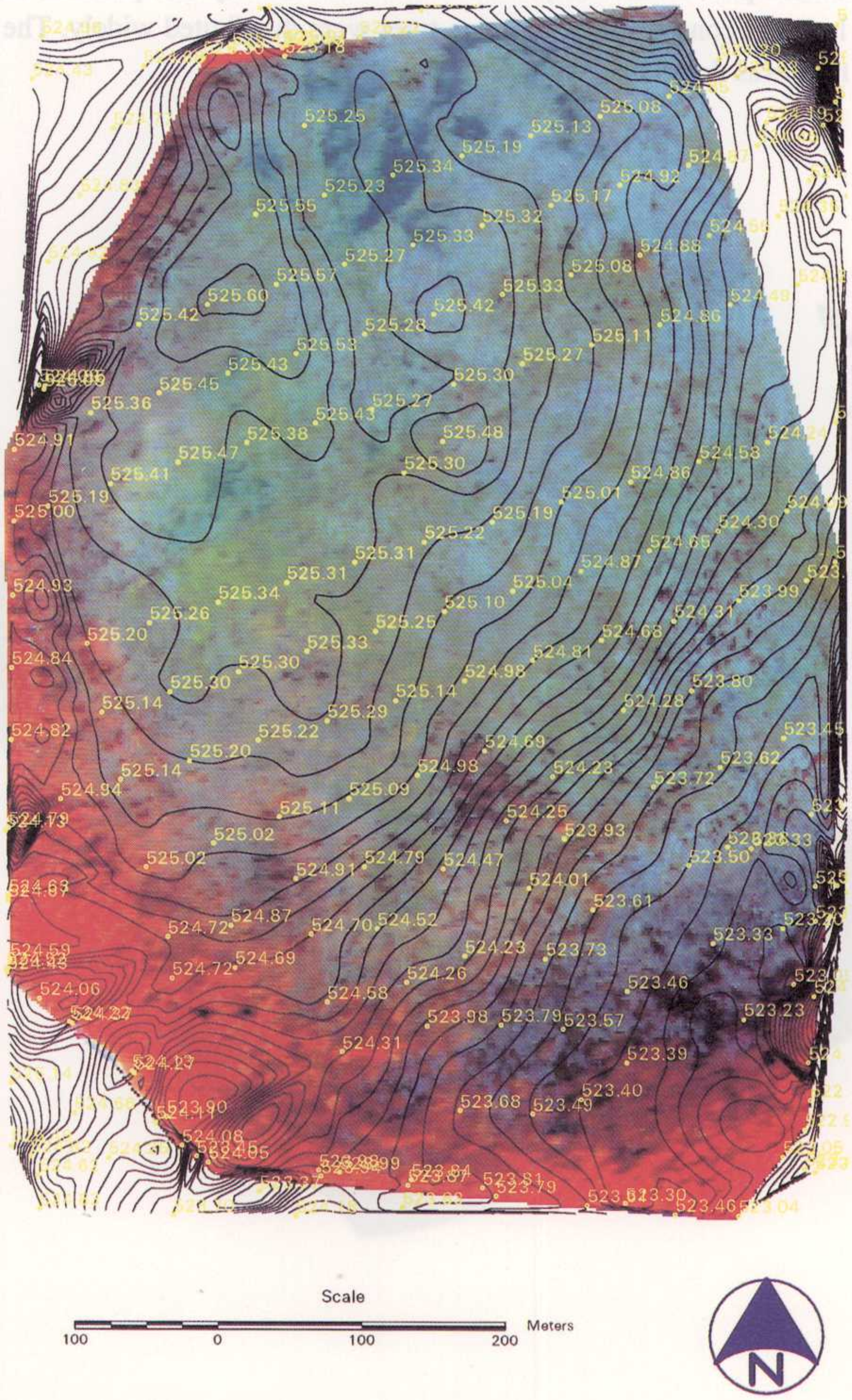

Fig. 3. False color CASI image of Akaiyachi Mire overlain on a detailed 2D DEM. Contour lines show actually measured elevations (m).

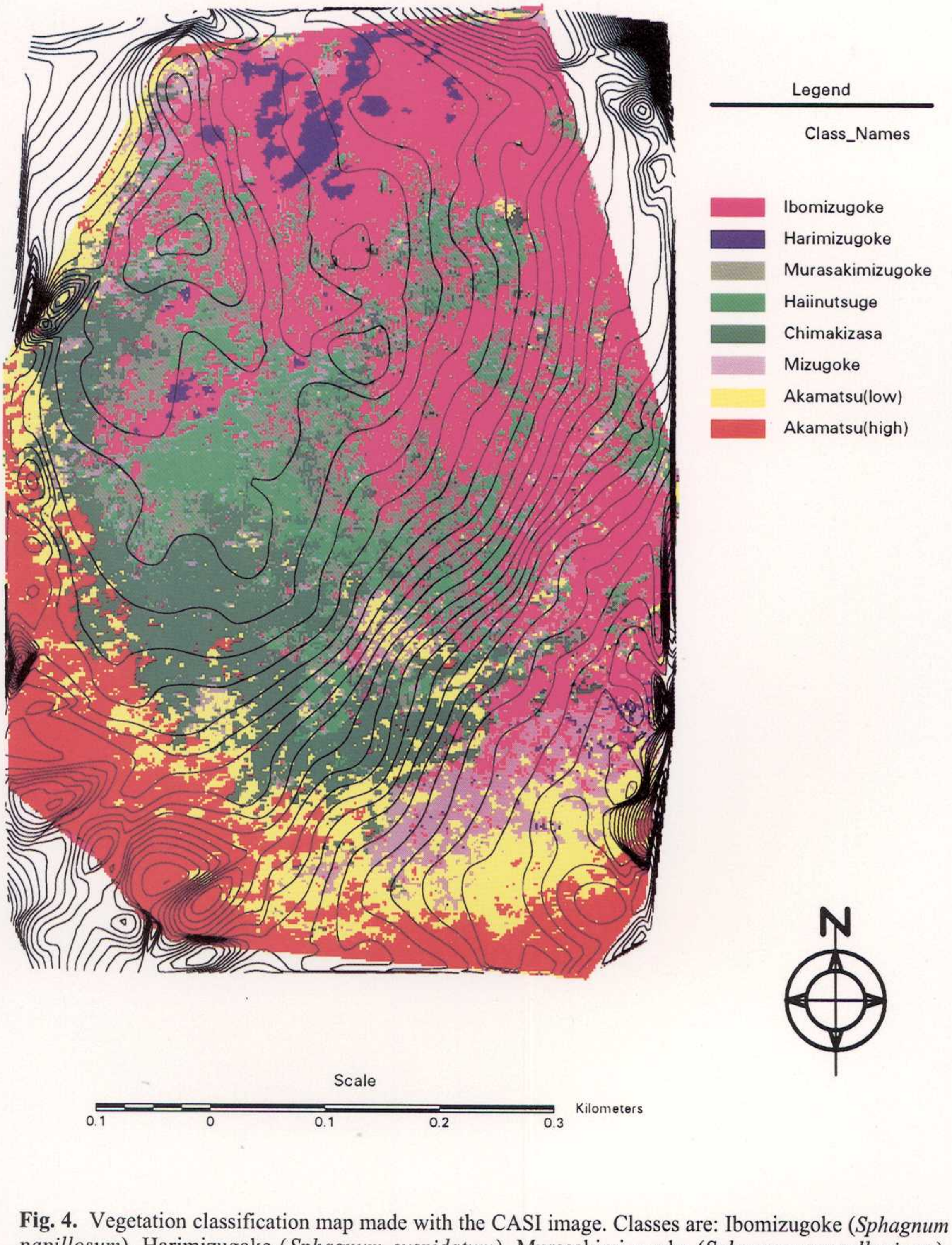

Fig. 4. Vegetation classification map made with the CASI image. Classes are: Ibomizugoke (*Sphagnum papillosum*), Harimizugoke (*Sphagnum cuspidatum*), Murasakimizugoke (*Sphagnum magellanicum*), Haiinutsuge (*Ilex crenata var. paludosa*), Chimakizasa (*Sasa palmata*), Mizugoke_wet (wet *Sphagnum palustre*), Akamatsu_high (high red pine trees), Akamatsu_low (low red pine trees).

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13
Effects of Land Use in the Surrounding Area on Bamboo Grass Invasion into Akaiyachi Mire

Seiichi Nohara and Mikiya Hiroki

Akaiyachi Mire (43.56 ha, altitude 525 m) is a small mire in northern Japan. The mire was designated as a natural monument by the Japanese government in 1928. Land use types in the areas adjacent to the mire were paddy and buckwheat agriculture (Fig. 1).

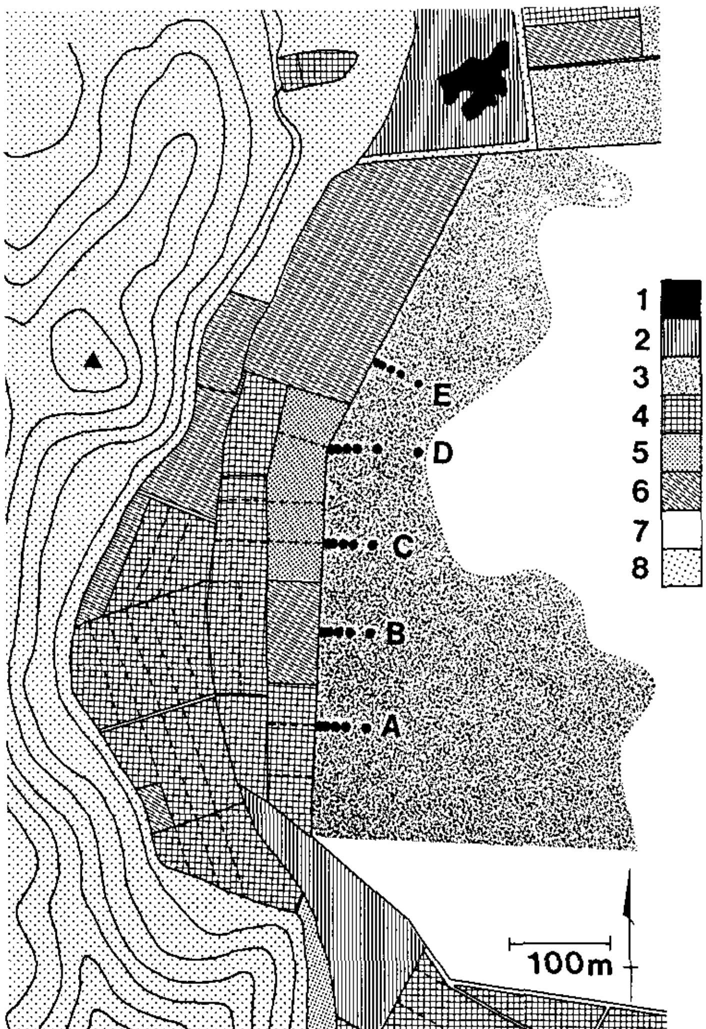

Fig. 1. Map of the Akaiyachi Mire study site. 1: open water, 2: *Phragmites australis*, 3: bamboo grass (*Sasa palmata*), 4: paddy field, 5: buckwheat field, 6: non cultivated paddy field with brush, 7: special reserve area of Akaiyachi Mire, 8: mountains.

Deep trenches have been constructed along the mire periphery, which are thought to be contributing to desiccation of the mire. Bamboo grass (*Sasa palmata*) and red pine (*Pinus densiflora*) have been invading the southeast marginal area of the mire.

The height of the groundwater table is an important factor affecting the growth of higher plants in a mire ecosystem (Hogetsu and Oshima, 1982). Here, we report on the effects of land use in the areas surrounding Akaiyachi Mire on this ecosystem's waters and the enhancement of bamboo grass growth. The study, conducted in 1995, focused on land use and its effect on mire desiccation.

Edge effects

Groundwater tables were monitored along five 90-m transect lines (21 wells, pit holes of 0.5 m depth) from the mire periphery inward (Fig. 1). Groundwater tables were highest in June (at transects C, D and E, they seemed to be higher in late June!) and had decreased by September due to low precipitation during the summer (Fig.2). Along transect A, the groundwater table descended from the mire periphery, adjacent to a rice paddy, inward, suggesting that groundwater and nutrients were seeping from the

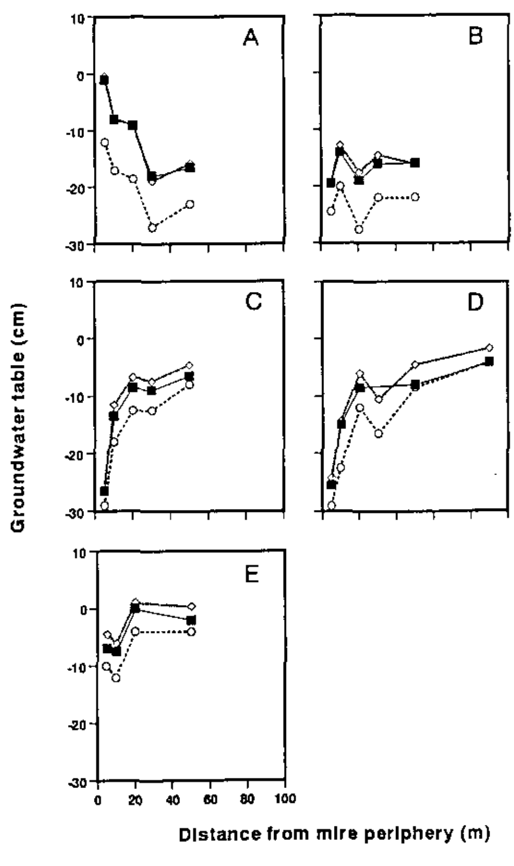

Fig. 2. Changes in groundwater table elevation with distance from the mire edge toward the center measured on 9 June (squares), 30 June (diamonds) and 10 September (circles). Values represent depth of the water table below the ground surface.

paddies into the mire. The construction of channels for buckwheat agriculture caused the decline in the groundwater table 20 m in from the edge of the mire. The deep trenches in the buckwheat fields seemed to desiccate the mire.

Sasa palmata shoot heights were higher at peripheral sites than at those closer to the center of the mire (Fig.3). Photosynthetic and transpiration rates of *S. palmata* were also higher at peripheral sites (Fig.4). The descent of the groundwater table due to trench construction and the seepage of fertilizer from paddy fields into the mire seemed to facilitate the spread of *S. palmata* and *Pinus densiflora* into Akaiyachi Mire. These plants were not reported to be present in the mire 30 years ago. We conclude that the marginal area or ecotone played a very important role by protecting the mire.

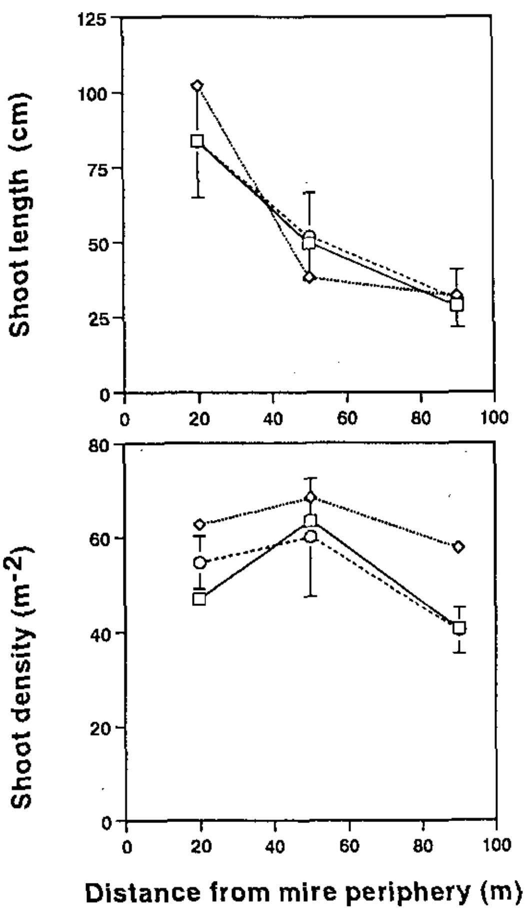

Fig. 3. Mean *Sasa palmata* shoot height (upper panel) and density (lower panel) 20, 50 and 90 m into Akaiyachi Mire from the mire periphery. Open squares: 20 April, open diamonds: 6 June, open circles: 10 September. Bars indicate sample standard deviation (n=3).

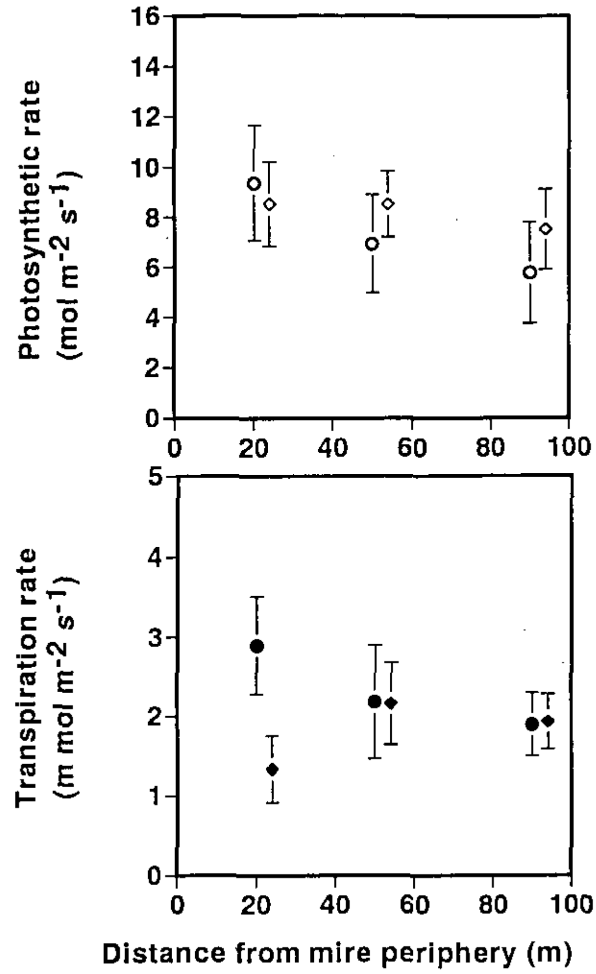

Fig. 4. Changes in the rates of Bamboo grass (*Sasa palmata*) photosynthesis (upper panel) on 30 June (open diamonds) and 10 September (open circles) and transpiration (lower panel) on 30 June (solid diamonds) and 10 September (solid circles) in Akaiyachi Mire. Bars indicate sample standard deviations (n=20).

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PART III. KUSHIRO MIRE

14
Environment of Kushiro Mire

Toshio Iwakuma

Hokkaido comprises 22% of Japan's total land area. The extent of peatlands on Hokkaido in the past, is estimated to have been 200,642 ha based on drilling to a depth of 3 m at sites on a 550 by 270 m grid performed by the Hokkaido National Agricultural Experiment Station. Extant mires cover 76,000 ha, about 38% of the original peatland area (Sakaguchi, 1979). Large mires of several thousands to tens of thousands of hectares in extent are distributed in the lowlands: Sarobetsu, Kushiro, Kiritappu, Bekanbeushi, Shibetsu Mires and others. Kushiro Mire (lat 43°05'—43°17'N long 144°22'—144°37'E, altitude 1.5—20 m, area 18,290 ha) is the largest mire in Japan and is one of the 9 registered Ramsar Convention sites in this country. The Ramsar Convention is the abbreviated name for the 'Convention on Wetland of International Importance, especially as Waterfowl Habitats'.

Geological features of Kushiro Mire

Kushiro Mire, located north of Kushiro City, has developed on an alluvial plain of the Kushiro River and its tributaries which flow south towards the Pacific Ocean. The mire is palmate, measuring ca. 13 km from west to east and ca. 18 km from south to north (Fig. 1) and topographically flat with a gentle slope towards the south in the northern half and towards the southeast to east in the southern half.

The formation of the mire has been documented by Okazaki and Suzuki (1977) as follows. During the last glacial period about 18,000 years ago, when sea level was more than 80 m lower than at present, the area was a vast alluvial plain with peatlands on it and terraces to the east and west. Tributary rivers of the ancient Kushiro River eroded the terraces into deep valleys. These valleys were eroded further by the sea when the area became a large bay with rising sea level during a warm period some 6000—10,000 years ago. A sand bar developed blocking the mouth of the bay. With the decrease in sea level about 3000—4000 years ago, the alluvial plain and sand bar emerged again from within the bay and the present Kushiro Mire began to develop from the western side eastward. The eastern 3 inlets remained as lake basins, namely Lakes Shirarutoro, Toro and Takobu.

Peat depths vary spatially ranging from 1 to 5 m, but mostly falling within the 2—3 m range. Most of the sites where peat depths exceed 2 m contain a tephra layer dating from 2300 BP. Fen peat, consisting of reed and sedge remains, covers most of the mire area (Okazaki and Suzuki, 1977).

Hydrology

The Kushiro River (stream length 121 km, catchment area 251,000 ha), originating from Lake Kussharo, is the major river flowing through Kushiro Mire to the Pacific Ocean. There are 12 tributaries on the western side of the river and 4 tributaries on the east, including the 3 maritime coastal lakes, Lakes Shirarutoro (340 ha), Toro (620 ha) and Takobu (140 ha) (Okazaki and Ito, 1977). The mire is mostly a fen fed by these waters. Bog ecosystems are found in the central west Onnenai area between the Onnenai and Oshima Rivers (see Fig. 1).

Meteorology

Weather records from Kushiro Meteorological Observatory (lat 42°58'30"N long 144°23'30"E, altitude 32 m), located 1 km inland from the Pacific coast, were averaged for the 30 years from 1961 to 1990 (National Astronomical Observatory, 1996); annual mean air temperature was 5.7°C, monthly mean air temperature in January and August were -6.1 and 17.8°C, respectively and annual precipitation was 1043 mm (Fig. 2). The striking climatic features of Kushiro are the high frequency of fog, 116 days per year and 68 days for the 4 months from June through September (30 year average for 1931—1960, see Fig. 2) and the low amount of snowfall. The numbers of days with snow depth between 0—10 cm and ≥ 10 cm were 48 and 46 days, respectively, values much

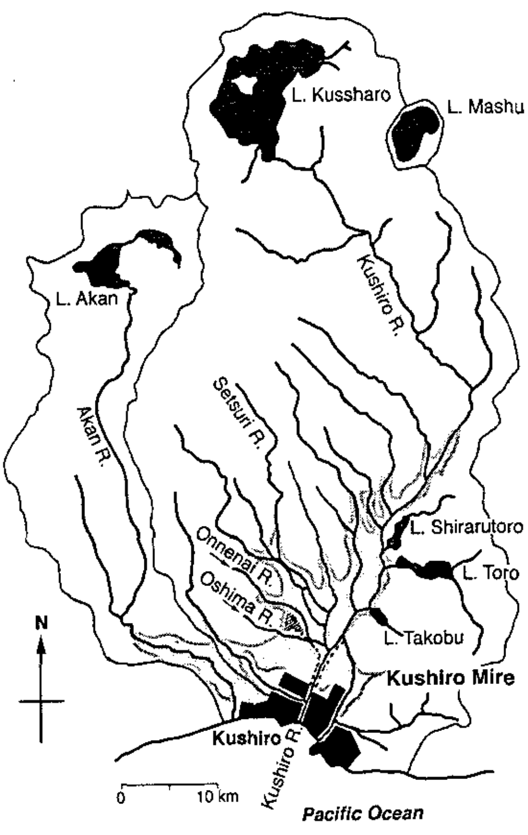

Fig. 1. Kushiro Mire and its watershed. Shading between the Onnenai and Oshima Rivers indicates the bog system in the mire.

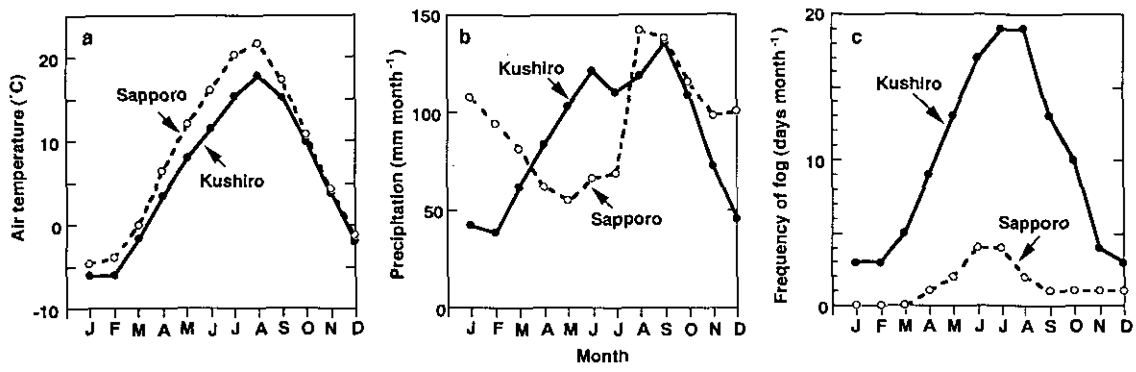

Fig. 2. Monthly mean values of air temperature (a) and precipitation (b) averaged for 30 years from 1961 to 1990 and frequency of fog (c) averaged for 30 years from 1931 to 1960 (National Astronomical Observatory, 1996).

lower than those for western Hokkaido, e.g., 23 and 108 days, respectively, in Sapporo (30 year average for 1961—1990). The low snowfall results in the freezing of the peat-soil during winter: freezing of the top 30 cm of soil was observed in alder and reed vegetated areas and in the top 30—50 cm of soil in *Sphagnum* bogs (Umeda et al., 1991). Such freezing is unlikely in the snow covered mires of Honshu, e.g., Akaiyachi and Miyatoko Mires.

Vegetation

Tanaka (1977) listed about 550 taxa of plants from Kushiro Mire and its surrounding areas. Tsujii et al. (1991) have added another 100 taxa to Tanaka's list. Tsujii et al. (1991) classified the vegetation of Kushiro Mire into 4 categories, *Sphagnum*, sedge, reed (*Phragmites australis*) and alder (*Alnus japonica*) based on real-color aerial photographs taken from a radio-controlled helicopter.

Protection of the mire

The land of Kushiro Mire, particularly that from the southern rim inward, has been changed by conversion to urban or agricultural uses since 1884. The rivers flowing through the mire have been altered by waterworks accordingly. The winding water course of the old Kushiro River was straightened into the present Kushiro River. Nevertheless the northern central area of the mire, which included bog systems, has remained undeveloped.

The Japanese Government designated a part of the mire (5011 ha) as a natural monument in 1952 and as a national wildlife protection area in 1969. The mire was first recognized as vital habitat for a threatened crane species (*Grus japonensis*) of national symbolic importance. The mire was designated in 1987 as a national park covering 26,861 ha, with 24% of the area as a special protection zone, the highest rank among 5 protective categories (Koumaru, 1993). However the mire's vast watershed area remains unprotected and feeds agricultural runoff into the rivers which flow through and feed the mire.

Several remote sensing approaches were employed to identify land use and vegetation in the mire. These results are described in Chapters 15 through 18, which follow.

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15
Land Cover Monitoring with a Vegetation-Soil-Water Index

Yoshiki Yamagata and Mikio Sugita

Vegetation monitoring has been one of the main focal points of remote sensing study since remote sensing research began. Many vegetation indices, using red and infrared reflectance, have been devised. The Perpendicular Vegetation Index (PVI), Ratio Index and Normalized Vegetation Index are among the well known indices of this type. The Perpendicular Vegetation Index, proposed by Richardson and Wiegand (1977), was defined as the distance from the soil line on a scatter plot of near infrared (NIR) versus red reflectance (Fig. 1). The pixel vectors of bare land in such plots vary with soil moisture content. The PVI was developed as a vegetation index to effectively monitor the vegetation biomass without being affected by differences in soil background.

In the present study, we propose a new index called a Vegetation-Soil-Water (VSW) index to monitor land cover conditions (Yamagata et al., in press). The VSW index is defined as a natural extension of PVI for monitoring not only vegetation conditions but also soil and water conditions as well. The definition of VSW index is shown in Fig. 2 which shows the relationship between VSW indices and the end member triangle on a NIR-Red scatter plot. The PVI measures only vegetation parameters, whereas the VSW index monitors vegetation, soil and water parameters simultaneously by measuring the distances PV, PS and PW for vegetation, water and soil, respectively.

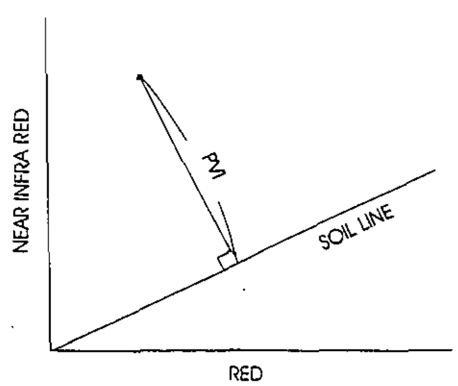

Fig. 1. Relationship between the PVI and the soil line in a NIR-Red scatter plot. Soil spectral points with different soil moistures comprise the soil line. Vegetation spectral points scatter above the soil line

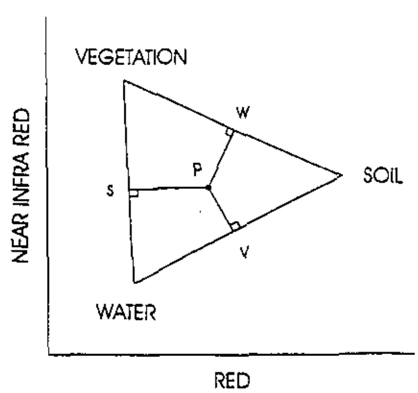

Fig. 2. Relationship between VSW indices and the end member triangle of a NIR-Red scatter plot.

Landsat Thematic Mapper (TM) scenes were used for the analyses (Fig. 3). Wetland plants in Kushiro Mire were in the beginning of their growing season in June, and in their maximum growth stage in August. All the vegetation was dead in October. These scenes show how the vegetation changes seasonally and year by year for 5 years.

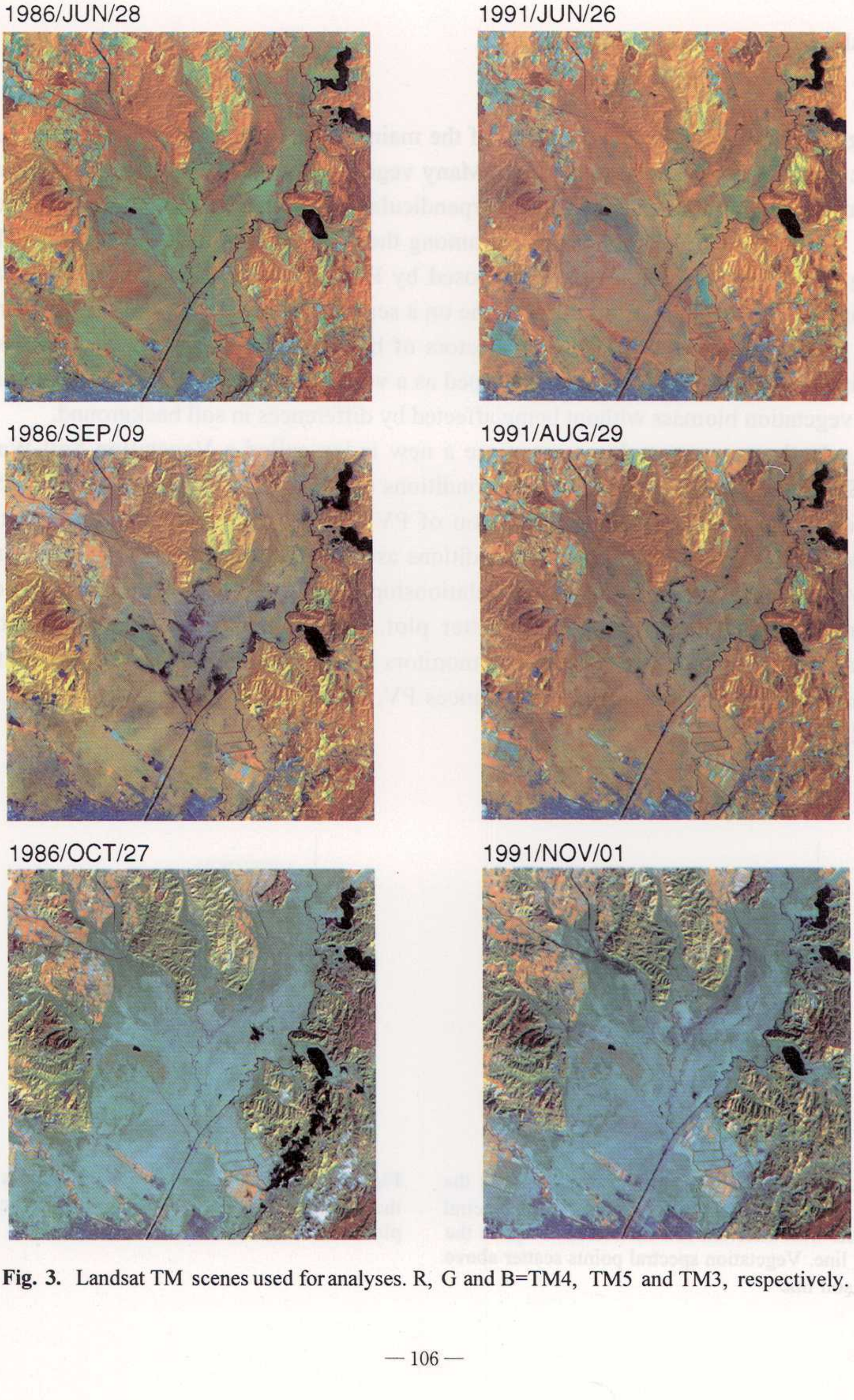

Fig. 3. Landsat TM scenes used for analyses. R, G and B=TM4, TM5 and TM3, respectively.

We determined the end member spectral points for vegetation, soil and water (VSW) with an algorithm to fit a triangle to the spectral distribution. This automatic end member determination also standardizes the spectral responses of scenes. Scatter plots of the TM scenes on NIR-red axes were overlain with the determined VSW end member points (Fig. 4).

Finally, the VSW index was used to monitor land cover change in the Kushiro Mire with Landsat TM images to evaluate the effectiveness of our approach for wetland monitoring (Fig. 5). Changes in the vegetative components of the Kushiro Mire, both seasonally and over the full 5 year period we examined, could be easily resolved from these color composite images.

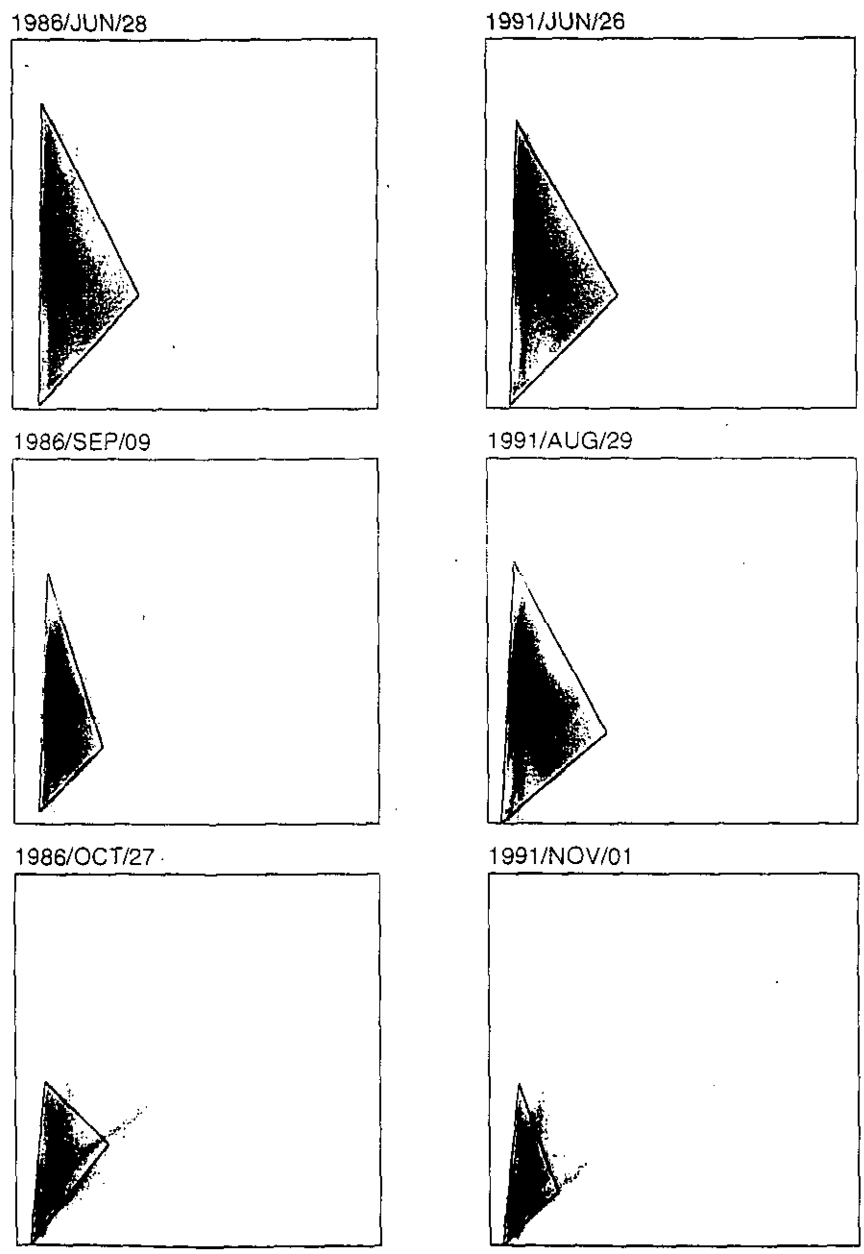

Fig. 4. Scatter plots of TM scenes on NIR-Red axes overlain with the determined VSW end member points.

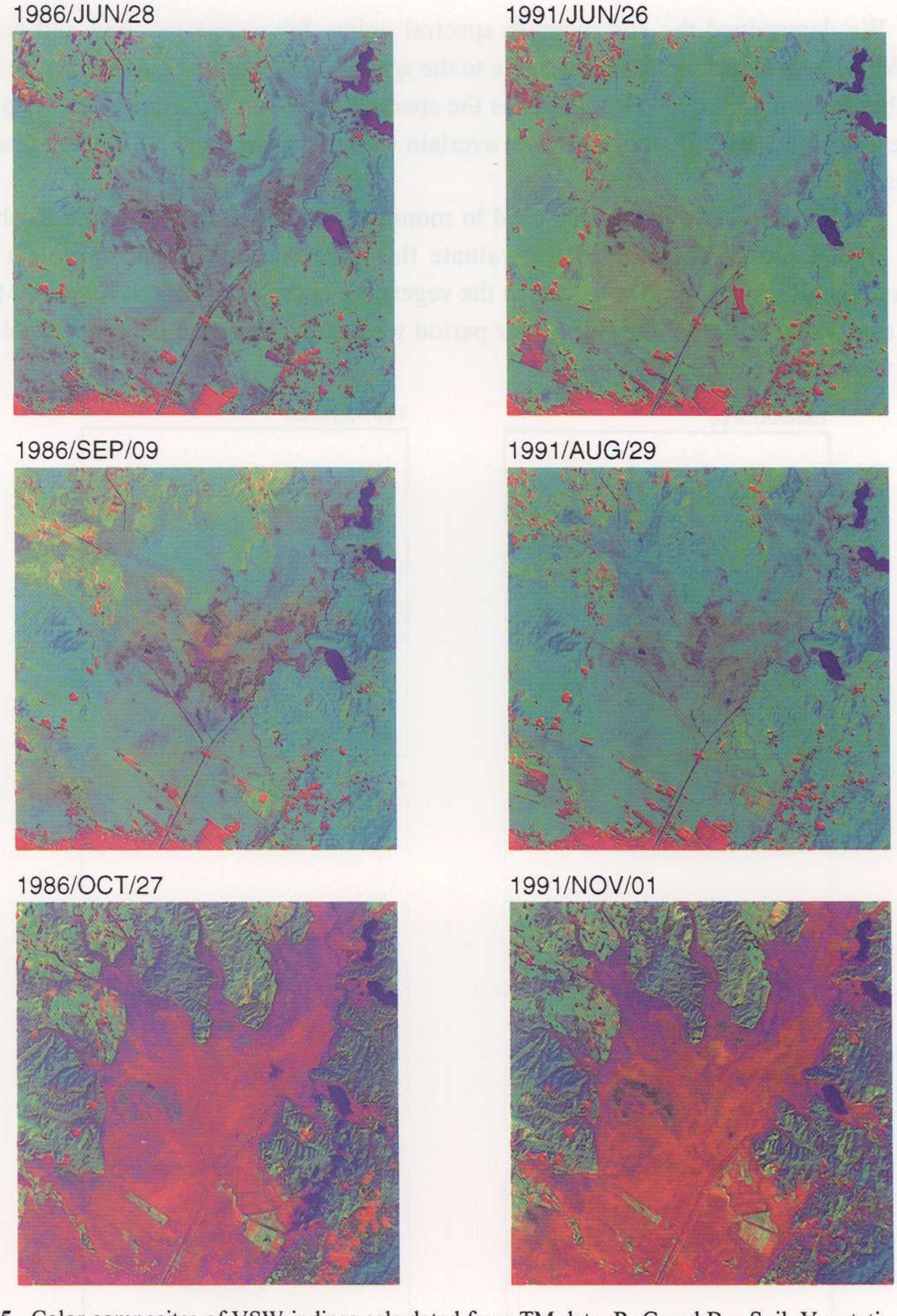

Fig. 5. Color composites of VSW indices calculated from TM data. R, G and B = Soil, Vegetation and Water, respectively.

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16
Wetland Vegetation Classification with Multi-temporal Landsat TM Data

Yoshiki Yamagata, Hiroyuki Oguma and Hiroko Fujita

Wetland monitoring, particularly wetland vegetation classification, is crucial for preserving valuable wetland ecosystems. The development of remote sensing techniques for wetland monitoring is urgent. To improve the accuracy of vegetation classification, we have investigated wetland vegetation classification with multi-temporal Landsat TM images. Landsat satellites have 7 bands. The first 3 channels are visible bands. Channel 4 (near infrared) is the most effective band for monitoring vegetation differences. The signals from channels 5 and 7 (mid infrared) are related to soil moisture content of the surface. Channel 6 (thermal) has lower resolution (120m). We used channels 3, 4 and 5 for the vegetation classification analyses presented here (Table 1).

Table.1. Characteristics of Landsat TM sensor.

Channel	Wavelength (μm)	Band	Resolution (m)
1	0.45—0.52	Blue	30 × 30
2	0.52—0.60	Green	30 × 30
3	0.63—0.69	Red	30 × 30
4	0.76—0.90	Near IR	30 × 30
5	1.55—1.75	Mid IR	30 × 30
6	2.08—2.35	Mid IR	30 × 30
7	10.4—12.5	Thermal	120 × 120

Because the growth pattern of wetland vegetation varies with vegetation type, we can use such changes in temporal growth patterns, which appear in the multi-temporal images, to classify vegetation types. We have studied the biomass growth patterns of various vegetation types during their growing season to clarify their temporal growth patterns. For example, the above ground biomasses of reed and sedge test sites change at different rates throughout the growing season (Fig.1). Sedges begin to grow more than one month earlier than reeds. Such differences can be used to discriminate between the two types of sites using data from multi-temporal TM scenes.

Spectral reflectances were also measured to examine the differences between vegetation types (Fig. 2). Spectral reflectance signatures differ among vegetation types, and also change from season to season (Fig. 3). Based on these differences, it is possible to classify the vegetation types using data from multi-temporal TM scenes.

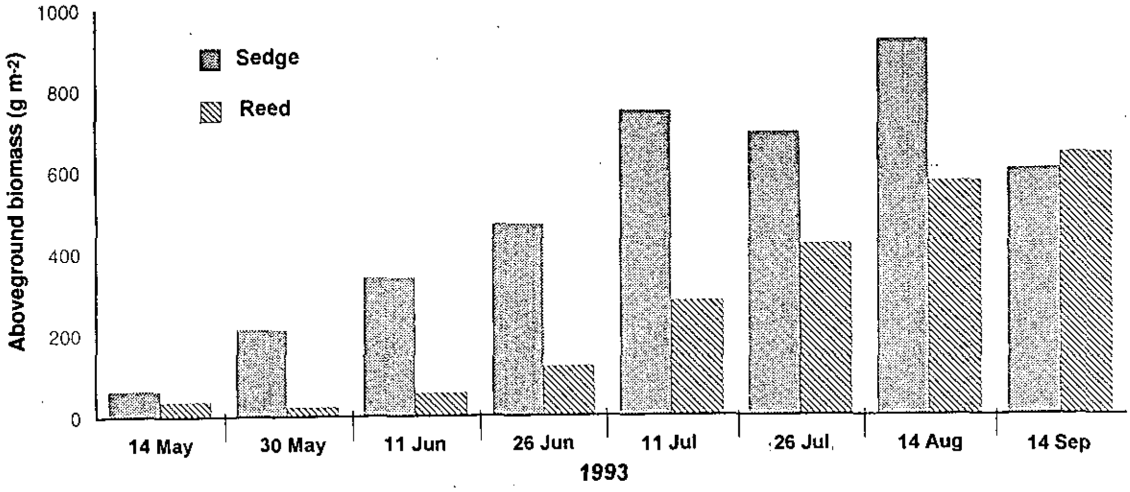

Fig. 1. Seasonal changes in above ground biomass of reed and sedge test sites.

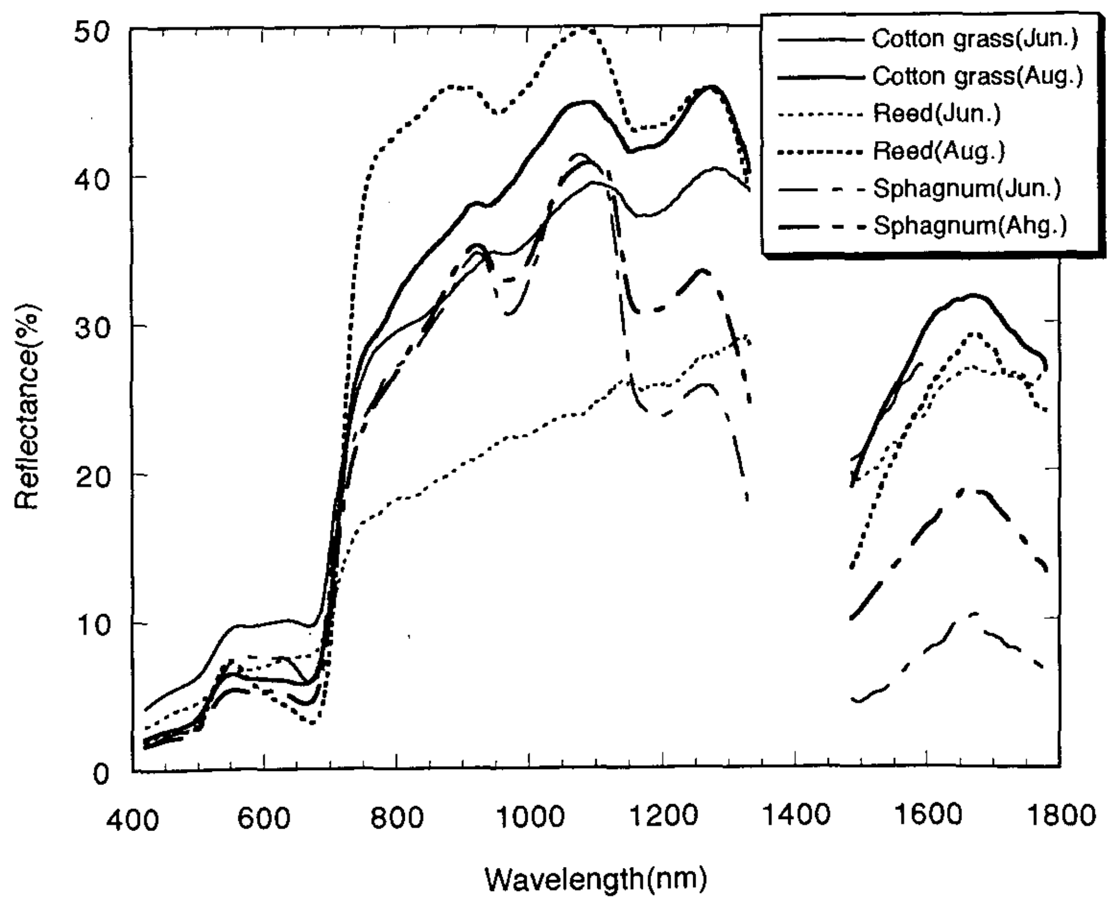

Fig. 2. Spectral reflectance characteristics of 3 wetland vegetation types in June and August.

We used multi-temporal multi-spectral signatures from Landsat TM scenes taken in June, August and November (Fig. 3) to classify wetland vegetation types. The June scene shows the early stage of wetland vegetation growth. The August scene shows the maximum extent of vegetation growth, while the November scene shows senescent vegetation.

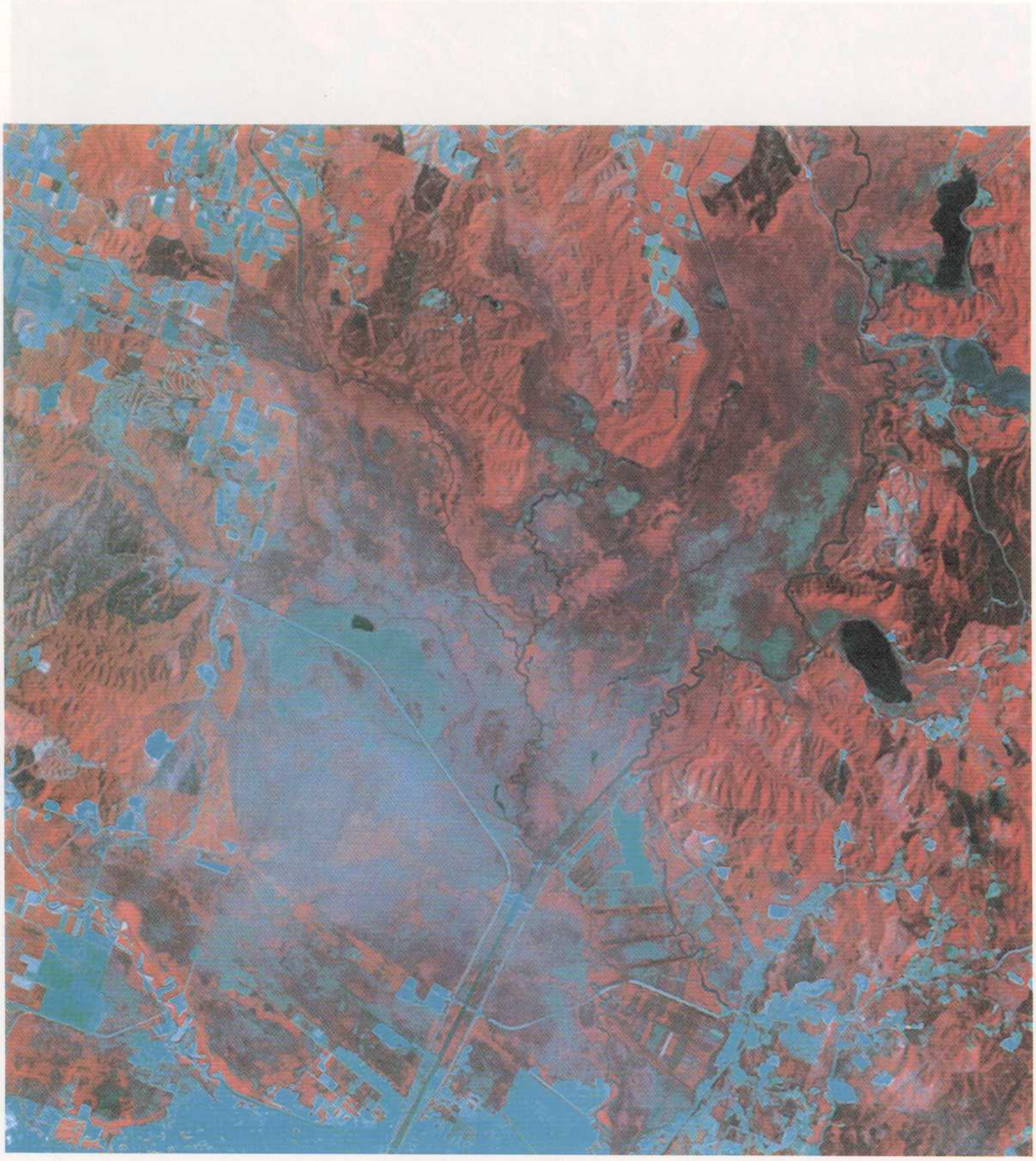

Fig.3 (a) Landsat TM scene in June. R, G and B=TM4, 5 and 3, respectively.

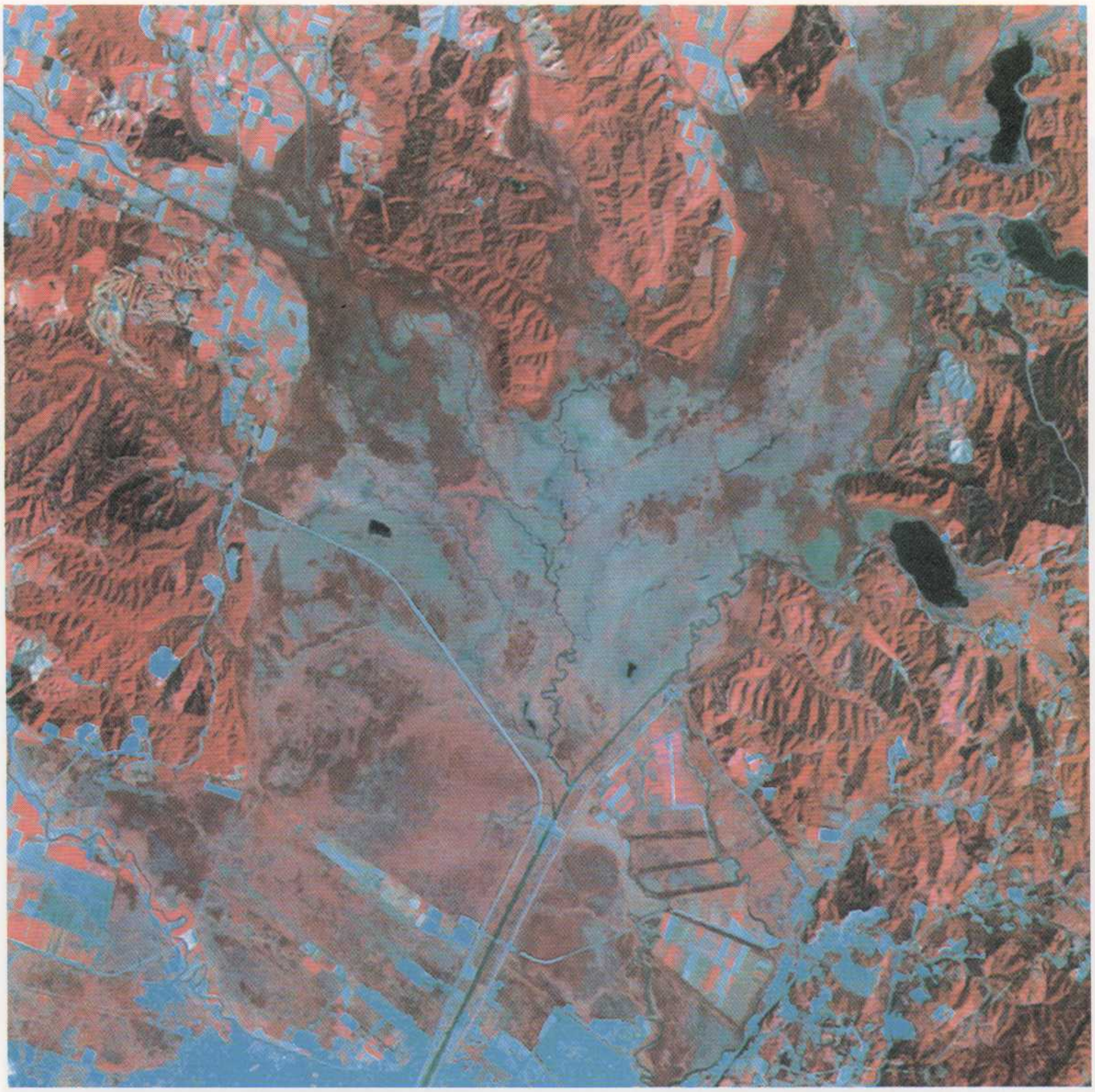

Fig.3 (b) Landsat TM scene in August. R, G and B=TM4, 5 and 3, respectively.

We succeeded in producing an accurate wetland vegetation classification map with the results of supervised classifications from the multi-temporal Landsat TM images (Fig. 4). Classified vegetation classes are *Sphagnum* moss covered bog, sedge dominated marsh, reed dominated marsh and *Alder* forest. It had been difficult to discriminate between sedges and reeds in the conventional vegetation classification of Kushiro Mire

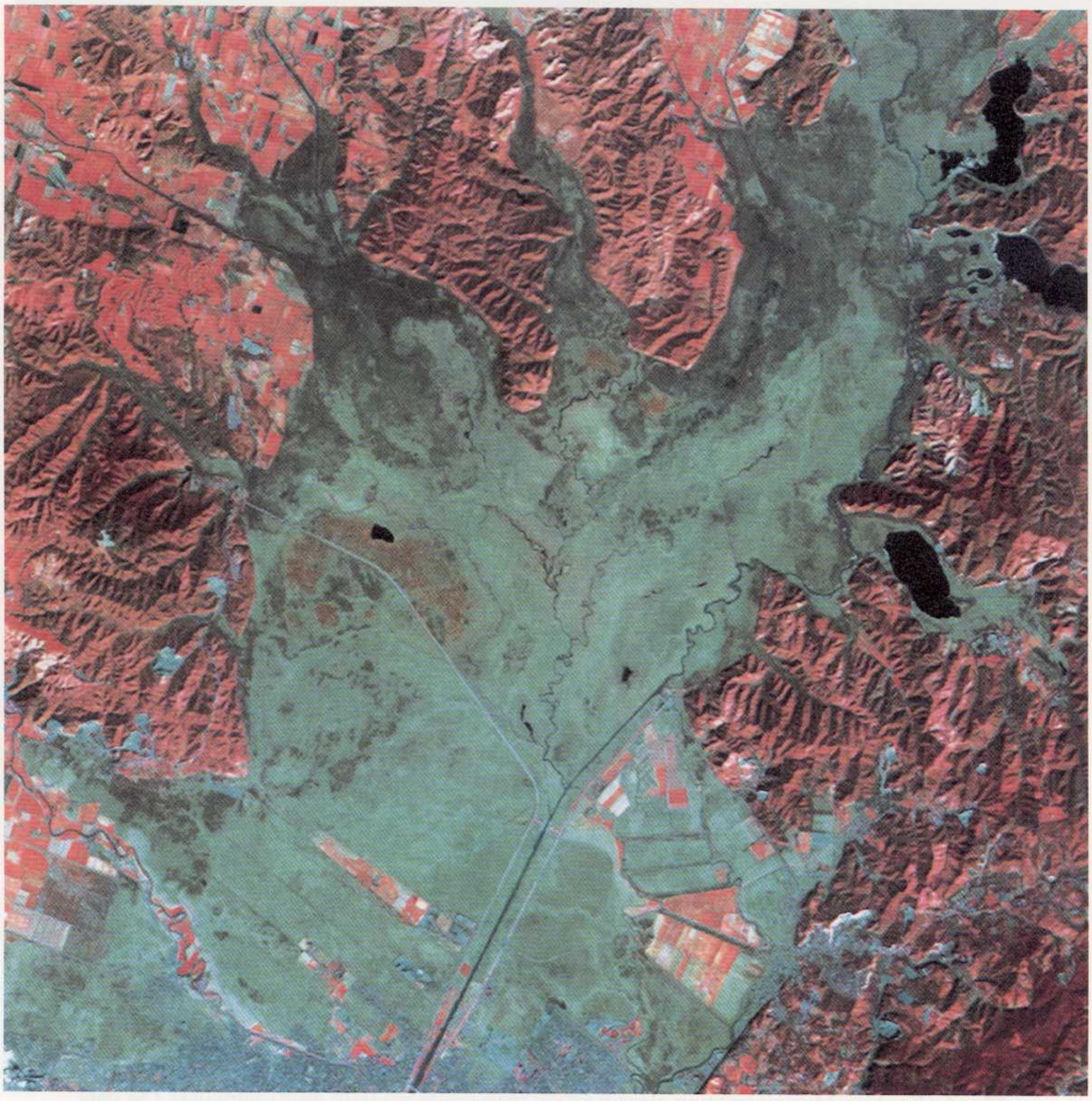

Fig.3 (c) Landsat TM scenes in November. R, G and B=TM4, 5 and 3, respectively.

using mosaics of aerial photographs. The accurate classification of sedges and reeds has been achieved for the first time in this analysis using multi-temporal TM data.

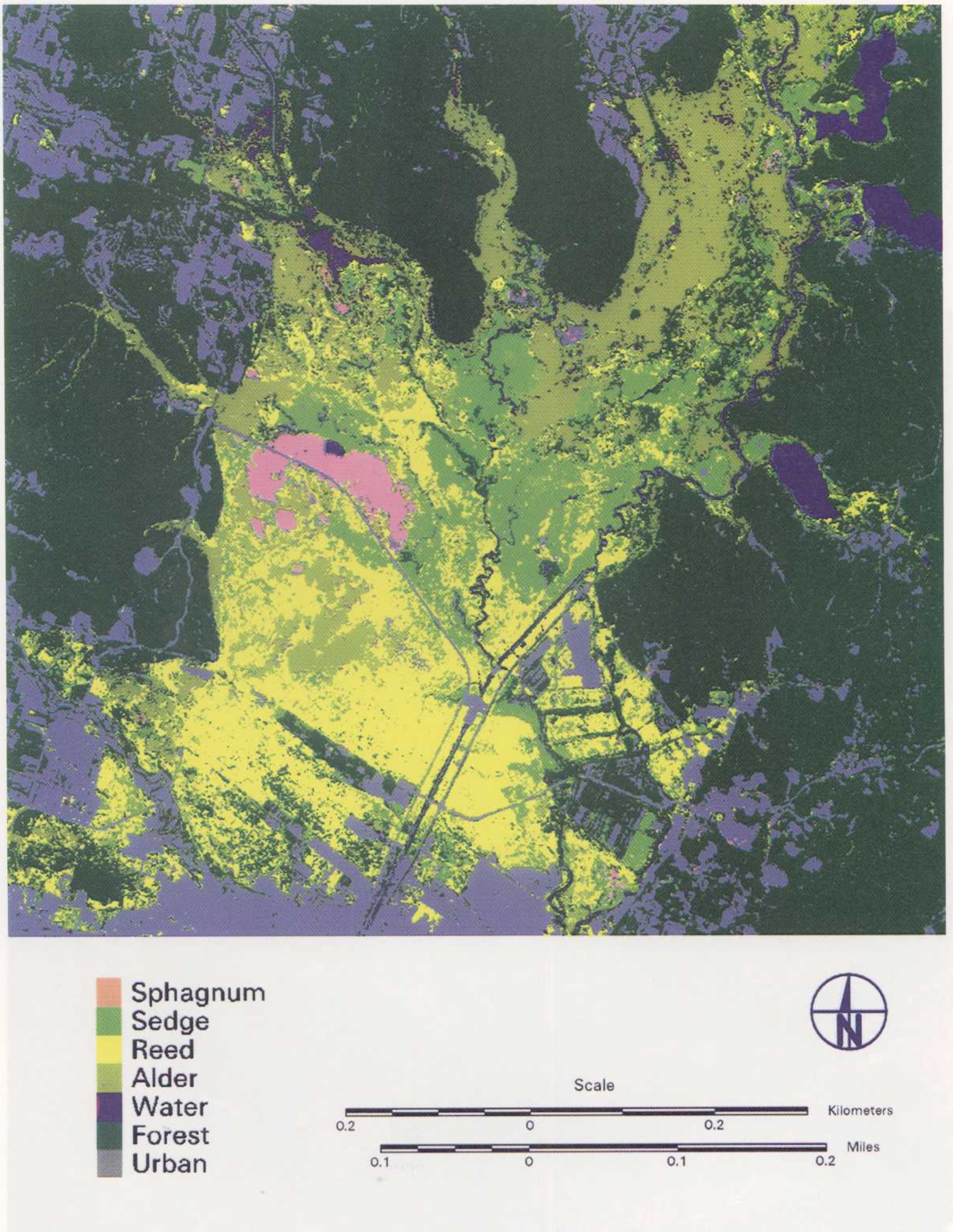

Fig. 4. Kushiro Mire vegetation classification map produced with multi-temporal TM data

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Selection of Effective Spectral Bands from Airborne MSS Data to Classify Wetland Vegetation

Yoshiki Yamagata and Hiroyuki Oguma

Effective spectral bands for the production of a wetland vegetation classification map of Kushiro Mire were selected from airborne multispectral scanner (MSS) data (Tables 1 and 2, Figs. 1 and 2).

Table 1. Spectral bands of airborne MSS used for band selection. Channels 1 and 2 are blue bands, channel 3 is a green band, channels 4 and 5 are red bands, channels 6, 7 and 8 are near infrared bands and channels 9 and 10 are mid infrared bands.

Channel	Wavelength (nm)
1	425—439
2	499—519
3	570—592
4	654—669
5	688—708
6	723—740
7	762—782
8	820—900
9	1520—1720
10	2060—2450

In the process of band selection, we determined the optimal band combinations using maximum Jeffries-Matsushita (JM) distance between the classes and maximum classification accuracy of the test data as standards. Then, in order to check how the classification method affected the results of band selection, we tried band selection also with the minimum distance method as the classifier (Table 3). Band selections were performed using 20 different sets of training and test data to decrease the dependence of the selection results on the training data. The resulting band selections were evaluated to rank the effectiveness of each band. The spectral signatures of the various vegetation types, Isotutuji (*Ledum palustre*), Suge (*Carex lyngbyei*), Yoshi (*Phragmites australis*), Mizugoke (Sphagnaceae), Hannoki (*Alnus japonica*), Titou (Sphagnaceae with small ponds), differed (Fig. 3).

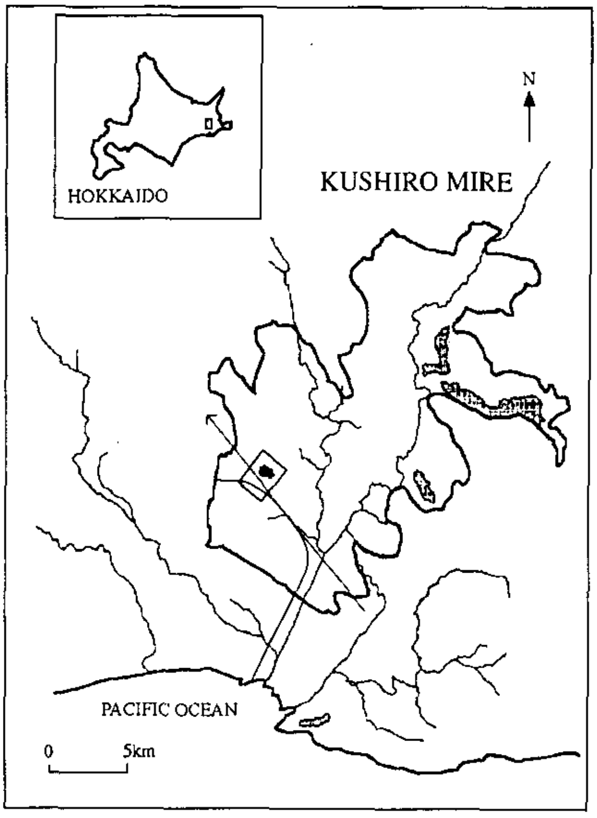

Fig. 1. Kushiro Mire and the study area. Kushiro Mire is in the eastern part of Hokkaido, Japan. Total area is 18,000 ha.

Table 2. Data acquisition conditions of airborne MSS.

Sensor	J-SCAN-AT-18M
Altitude	2500 m
IFOV	6.25 m
Number of pixels	512 × 512
Dynamic range	8 bit
Date	23 June 1992
Time	17:00—17:06

The first 3 selected bands were common for both JM distance and classification accuracy of test data as standards (Table 3a). These 3 bands are, 1: a near infrared band (Channel 8: 0.82—0.90 mm) which is sensitive to plant biomass, 2: a mid infrared band (Channel 9: 1.52—1.72 mm) which is sensitive to the water content of the surface and 3: a green band (Channel 3: 0.57—0.59 mm). This order of the first 3 selected bands was same for both the maximum likelihood and minimum distance methods. However, both the selection standards and classification methods changed the bands selected after the band selected 4th. Some vegetation classes, such as Hannoki, Suge and Yoshi, are distinct in spectral feature spaces, but other classes, such as Mizugoke, Isotutuji and Titou (pool), are difficult to discriminate amongst using only 2 channels, channels 8 and 9 (Fig. 4).

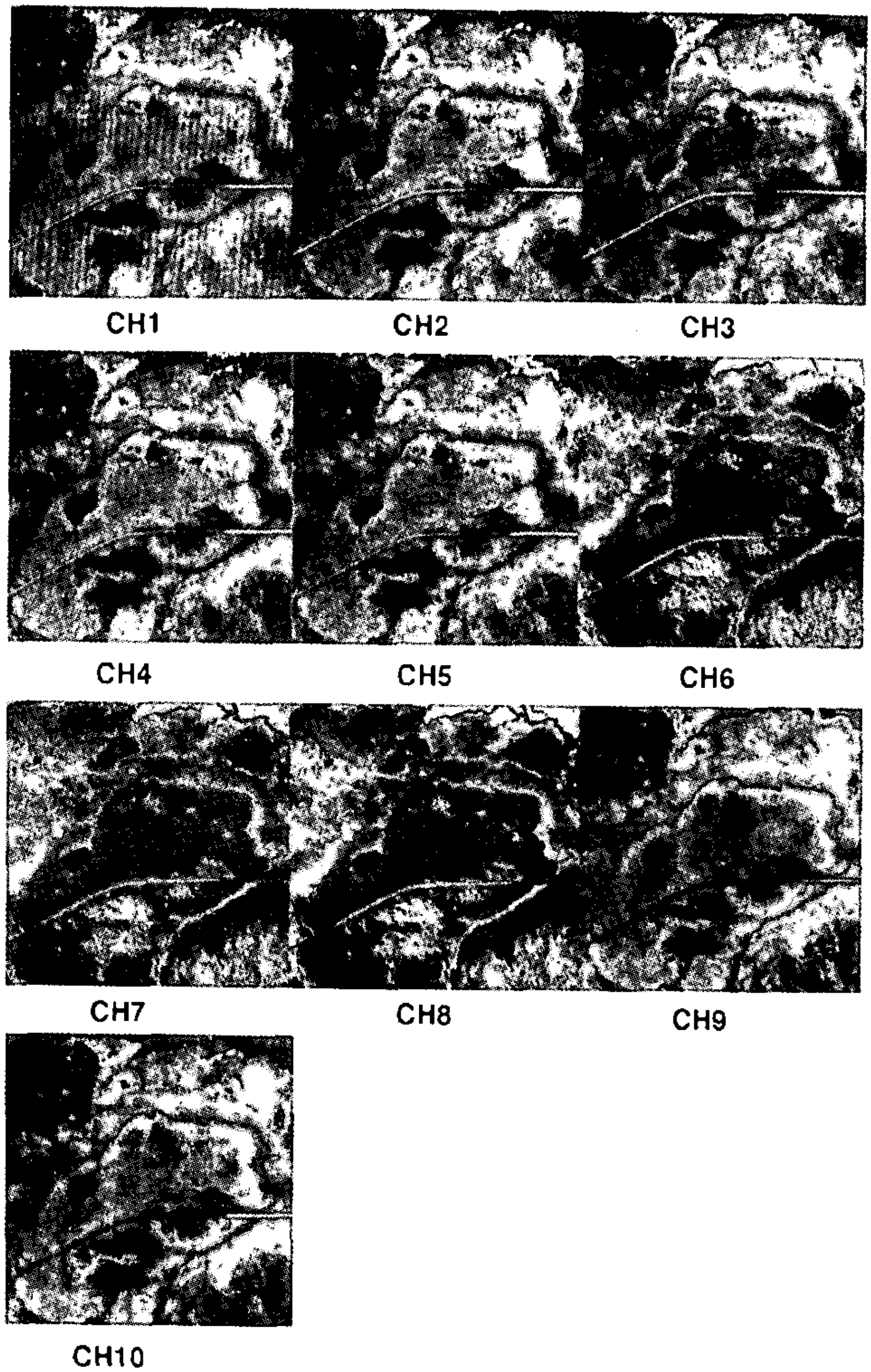

Fig. 2. Unaltered images from the data of each airborne MSS channel. A sphagnum moss covered bog area with a small lake is located at the center of the scene. An artificial dike and a road, which are changing the vegetation conditions in the wetland, run from east to west.

Table 3 a). Bands were selected by maximizing the mean JM distance between classes. Selected channels are listed in the order of selection from the left. Depending on the training data set, selected bands differ in the second and later selected channels. A minus sign before a channel number indicates that the channel was not selected, despite having been selected in the preceding step.

Training Data			Selected Channel (from left)
1	2	3	8 9 3 -3 5 10 1 3 6 4 2 7
4	5	6	8 3 9 2 10 6 1 5 4 7
2	4	6	8 3 9 2 10 1 -2 5 2 6 4 7
1	3	5	8 9 5 2 10 4 1 6 3 7
1	2	4	8 3 9 10 1 5 -10 10 6 4 2 7
3	5	6	8 9 3 10 2 6 5 4 1 7
1	2	5	8 10 3 9 -10 10 6 1 5 4 2 7
3	4	6	8 3 9 5 6 2 -5 10 5 1 4 7
1	2	6	8 3 9 5 10 1 6 4 7 2
3	4	5	8 3 9 2 10 6 1 4 5 7
1	3	4	8 3 9 4 2 -4 6 10 1 4 5 7
2	5	6	8 10 3 9 -10 10 2 5 6 1 4 7
1	3	6	8 3 9 5 6 1 10 2 4 7
2	4	5	8 10 3 9 -10 2 10 6 1 5 4 7
1	4	5	8 10 3 9 -10 2 -3 10 3 6 5 1 4 7
2	3	6	8 9 3 5 10 1 6 2 4 7
1	4	6	8 3 9 5 6 2 10 1 7 4
2	3	5	8 9 3 10 1 6 5 4 2 7
1	5	6	8 4 3 -4 9 4 10 2 5 6 7 1
2	3	4	8 3 9 2 6 1 10 4 5 7

Table 3 b). Bands were selected by maximizing classification accuracy of test data. Selected channels are listed in the order of selection from the left. Depending on the training data set, selected bands differ in the second and later selected channels. Selected channels often changed as the number of bands to select increased. A minus sign before a channel number indicates that the channel was not selected, despite having been selected in the preceding step.

Training Data			Selected Channel (from left)
1	2	3	4 -4 5 6 4 -5 10 2 -4 5 -6 8 -2 4 6 3 2 7 9 1
4	5	6	8 5 3 -5 9 5 6 -8 10 8 7 4 1 2 -7 7
2	4	6	8 5 3 -5 9 6 7 5 1 10 -1 2 4 1
1	3	5	10 3 8 -10 9 6 7 10 4 5 2 1
1	2	4	8 3 5 -5 9 10 7 4 1 2 -3 -4 5 6 -7 3 4 7
3	5	6	6 3 -6 8 9 7 2 -3 5 6 -7 1 -2 10 -1 2 4 1 7 -10 10 3
1	2	5	10 3 8 9 1 6 -8 -1 4 7 5 -6 8 1 2 6
3	4	6	10 5 8 -10 9 3 4 10 1 -3 6 7 2 3 -4 4
1	2	6	8 3 9 5 2 6 4 -6 10 1 7 6
3	4	5	8 9 3 -3 5 6 2 1 -2 3 10 2 4 -10 10 7
1	3	4	6 5 3 -5 9 5 10 4 -6 8 2 6 -10 10 7 1
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2	4	5	8 9 3 -3 4 6 5 1 3 -6 10 7 2 6 -10 10
1	4	5	8 3 6 -8 -6 8 9 6 10 7 4 5 2 1
2	3	6	10 3 8 -10 9 4 6 5 10 7 2 1
1	4	6	8 9 3 -9 10 6 9 -10 7 10 2 1 -4 5 -7 4 7
2	3	5	6 4 3 -4 -6 8 9 4 2 -4 7 -2 5 10 4 6 -7 1 2 -4 4 7
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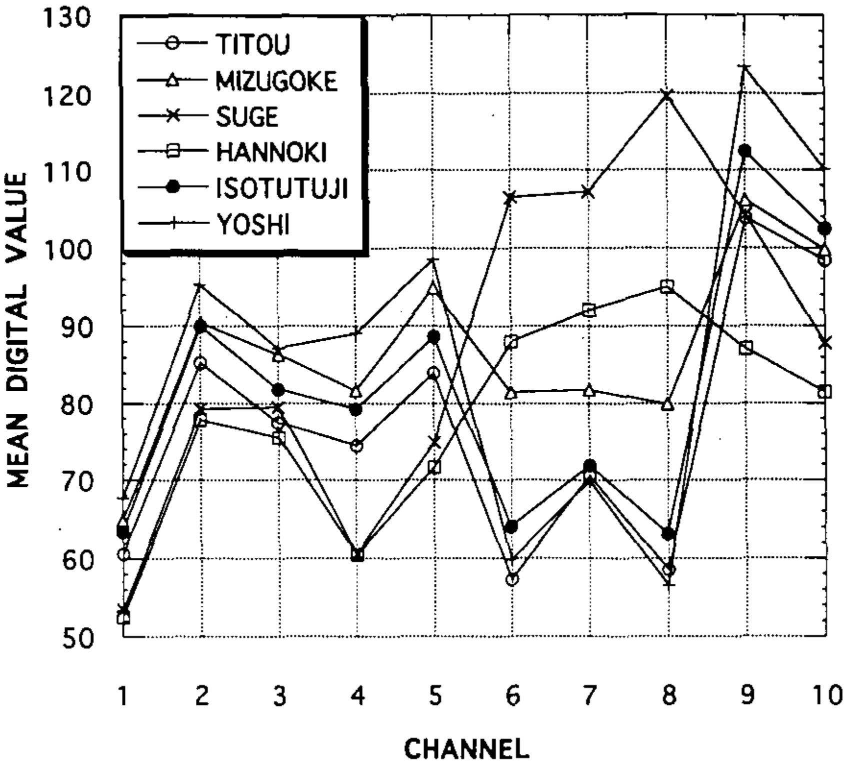

Fig. 3. Spectral characteristics of vegetation classes.

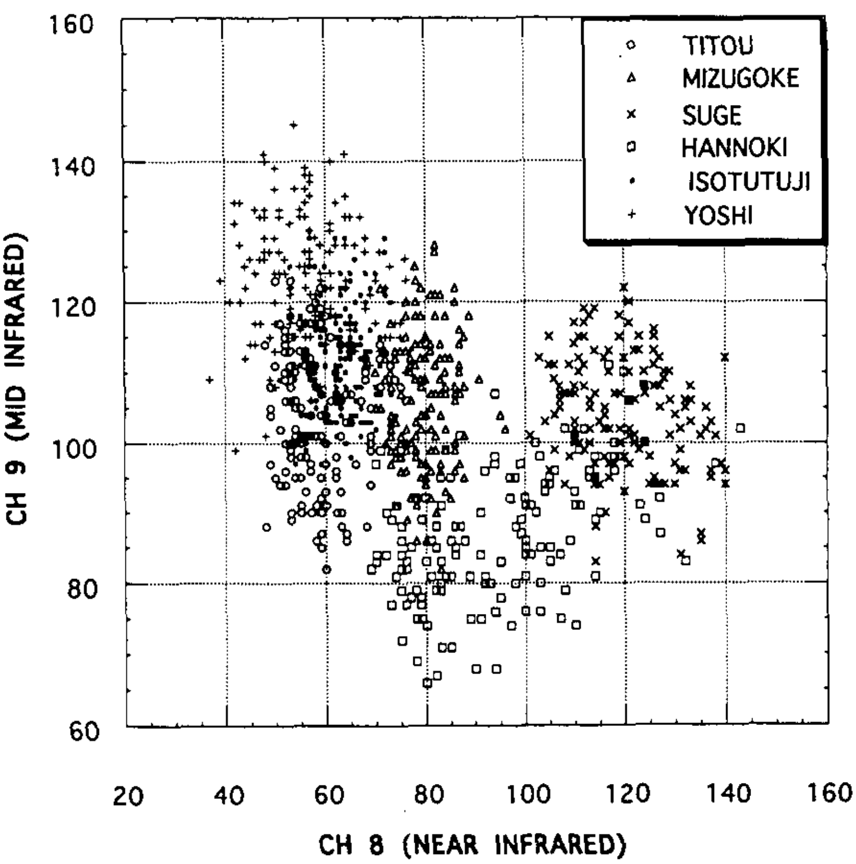

Fig. 4. Scatter diagram of vegetation classes for channel 9 (near infrared band) versus channel 8 (red band).

We evaluated the value of each band for discriminating amongst wetland vegetation types by calculating the mean JM distance between the classes (JM) and also by checking the classification accuracy attained with the maximum likelihood (ML) and minimum distance (MD) methods (Fig. 5). Band 8 (near infrared) and band 9 (mid infrared) were the most valuable for classification, and band 3 (Green) follows in every case.

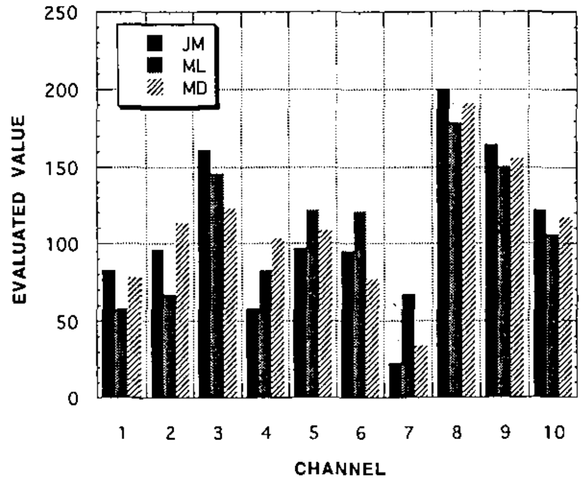

Fig. 5. Evaluated value of each band for discriminating wetland vegetation types.

Classification accuracy, as evaluated by JM distance of training classes, increases as the number of channels used increases (Fig. 6). On the other hand, if evaluated by the classification accuracy of test data classification, there exists a maximum accuracy at a certain number of channels less than 10. This corresponds to the optimal band selection for production of an accurate vegetation classification map.

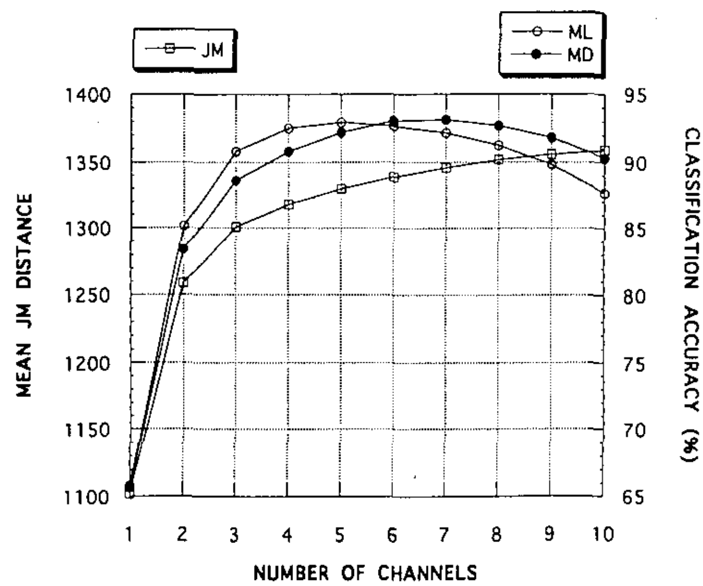

Fig. 6. Relationship between the number of bands used for classification and classification accuracy.

Classification accuracy using test data saturates at a certain number of bands. In the case of the maximum classification method, the classification accuracy decreased after the 5th band. Our wetland vegetation map was produced using the band combination of MSS data which resulted in maximum classification accuracy with test data (Fig. 7). While conventional aerial photography-based wetland vegetation maps could not classify the vegetation types in bog areas, we have succeeded in classifying bog vegetation into community types dominated by Isotutuji (*Ledum palustre*), Suge (*Carex lyngbyei*), Yoshi (*Phragmites australis*), Mizugoke (Sphagnaceae) and Hannoki (*Alnus japonica*). This is the first vegetation classification map of the bog area in Kushiro Mire.

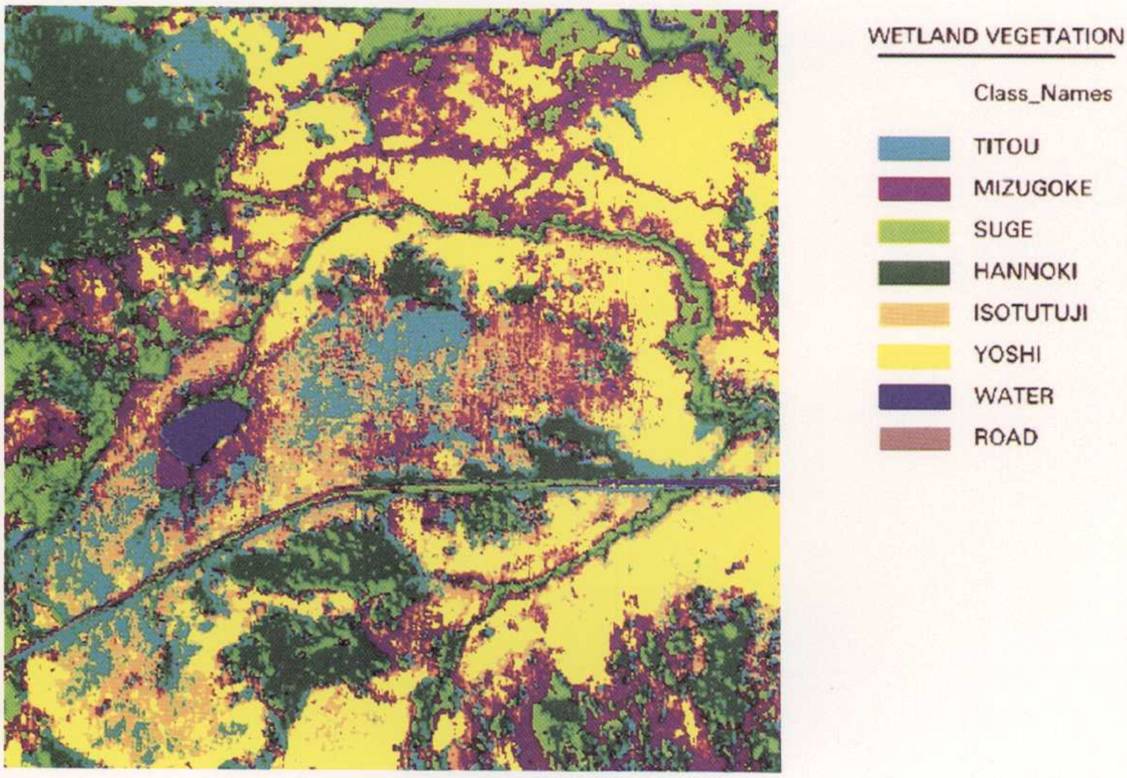

Fig. 7 Wetland vegetation classification map produced from airborne MSS data. Classified vegetation types are Isotutuji (*Ledum palustre*), Suge (*Carex lyngbyei*), Yoshi (*Phragmites australis*), Mizugoke (Sphagnaceae), Hannoki (*Alnus japonica*), Titou (Sphagnaceae with small ponds). It had been difficult to classify the detailed vegetation differences in bog areas because conventional vegetation maps were produced from aerial photographs.

18
Unmixing Wetland Vegetation Types with a Subspace Method Using Hyperspectral CASI Imagery

Yoshiki Yamagata

A new approach to unmix vegetation types with a subspace method is proposed and an experiment to test these methods with hyperspectral images was conducted. Unmixing with a subspace method entails calculating the projection of each unknown pixel vector on the subspace of each class. This method is more robust to noisy data than are conventional methods and it works simultaneously as an effective feature extraction and data reduction procedure. The performance of this method was tested in an unmixing experiment using a hyperspectral airborne Compact Airborne Spectral Imager (CASI) image acquired over the Kushiro mire (eastern Hokkaido, Japan). Unmixing of the 7 wetland vegetation classes was calculated by this new method and the results were compared with those obtained from unmixing via a least squares method, quadratic programming and an orthogonal subspace projection method. These unmixing methods were evaluated as tools for wetland vegetation monitoring.

The basic idea behind the subspace method is that the class spectral vector lies mainly in a small class-specific subspace instead of within the entire dimension of the spectral space. If the class subspace is determined from the training sample of each class, class membership values can be calculated by the projection of the mixel observation spectral vector from the corresponding subspaces from which the training samples were drawn. There are 3 ways of calculating the subspace in the subspace method; these are the algebraic, statistical and learning subspace methods. In this paper, a statistical subspace method called the CLAss-Featuring Information Compression (CLAFIC) algorithm is used. This method is known to be fast and effective in cases where the volume of training data is moderate. The CLAFIC algorithm determines the class subspace in order to maximize the projection of the class vector on the corresponding class subspace. However, by maximizing the projections for all classes at the same time, the separation between the similar classes decreases.

In order to avoid this drawback, we have employed the Enhanced CLAFIC algorithm which maximizes the projection on the class subspace to which the training vector belongs and also simultaneously minimizes the projection on other subspaces.

We conducted an unmixing experiment using a 288 channel CASI and compared the results with those of conventional statistical unmixing methods to check whether unmixing by the subspace method works effectively for hyperspectral images. We used a CASI image acquired over the Kushiro Mire on the eastern part of the island of

Hokkaido (Fig.1) for our analysis. The CASI spectral sensor can measure a spectrum from 470 to 920 nm with a 1.8 nm band width. The specifications and data acquisition conditions for the CASI sensor are shown in Table 1. The image was acquired at an altitude of 3,000 m from a Cesna 404 aircraft. The ground resolution is longer (12.6 m) along the aircraft flight direction than the swath (3.7 m). Each pixel in the image (Fig. 2) represents the mean spectral radiance of the ground target.

There are various wetland plants in this study area. Reed, sedge and *Ledum*, in particular, overlap and are continuously distributed over the sphagnum moss.

Before the analysis, the CASI image was corrected for the geometric distortion caused by the rolling of the airplane and the digital numbers were converted to radiance values. The spectral characteristics of the 7 land cover classes used for unmixing varied (Fig. 3). All of these classes are wetland vegetation communities except for the road and water classes. The spectral differences between these vegetation classes are difficult to discern using a common remotely sensed image with a small number of bands.

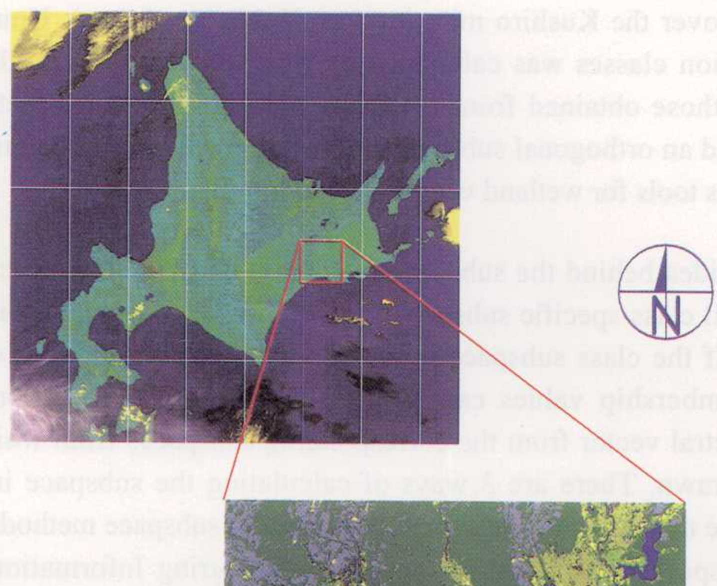

Fig. 1. Kushiro Mire.

Table 1. Specifications of CASI image acquisition

Specifications of CASI sensor	
Band width	1.8 nm
number of bands	288 channels
Band range	410.3—923.7 nm
Image size	39 pixels, 489 lines
Dynamic range	12 bit
Image acquisition conditions	
Altitude	3000 m
Velocity	200 km h^{-1}
Ground resolution	3.7 m (along swath) 12.6 m (along flight)
Date	31 Aug 1993
Time	11:25—11:30
Weather	Clear

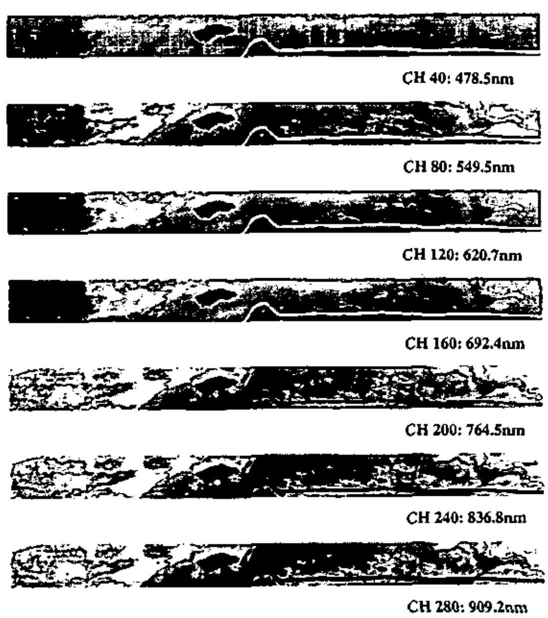

Fig. 2. Seven sample channels from the CASI image for Kushiro Mire. The first 4 channels are in the visible wavelength range and the others are in the near infrared. Lake Akanuma and the artificial dike across the area are clearly visible in the center.

The lack of established methods to resolve mutually overlapping and continuously changing vegetation distributions has, until now, hindered research on wetland vegetation classification. However wetland ecosystem conservation planning and global warming modeling urgently require more wetland vegetation classification research.

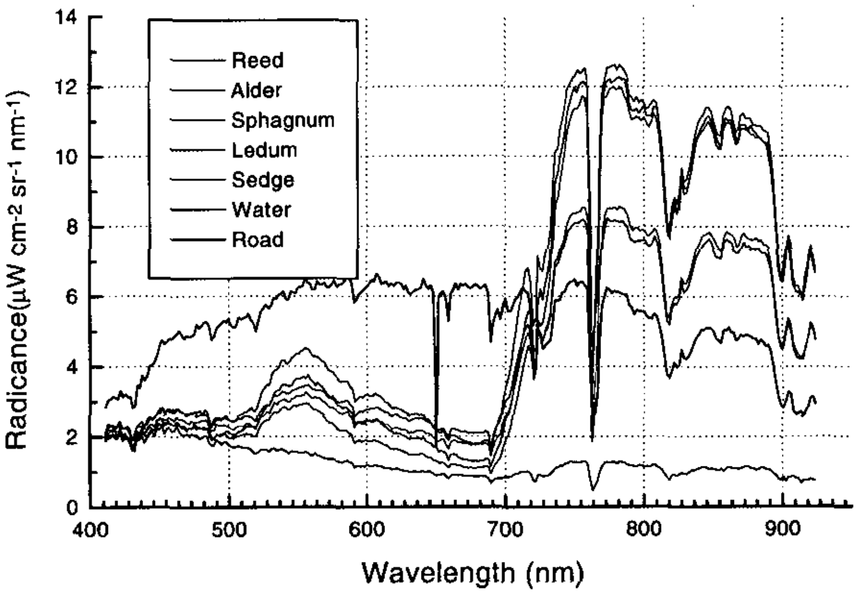

Fig. 3. Spectral signatures of wetland vegetation communities.

The following 3 conventional unmixing methods were compared with unmixing by the subspace method applied to the CASI image of Kushiro mire (Fig. 4):

1) Least squares method: Assuming a linear mixing model, area fractions of each class are determined by a least squares model using the training data (Fig. 5).

2) Quadratic programming: A constraint requiring that the area fractions add up to 1 is added to the linear mixing model, and a least squares solution is obtained by the quadratic programming method (Fig. 6).

3) Orthogonal subspace projection method: First, the projection of the mixel vector onto the orthogonal complement space spanned by the class vectors of the other classes is computed. Then the inner product of this projected vector and the class vector is calculated (Fig. 7).

Here the unmixed vegetation classes are reed (*Phragmites*), alder (*Alnus*), moss (*Sphagnum*), *Ledum* and sedge (*Carex*). Comparison of the results of the various unmixing methods reveals the following:

1) Spectrally distinct classes such as road, water and sedge (see Fig. 3) are well unmixed by the subspace method (see Fig. 4).

2) Spectrally similar classes such as Ledum and Moss (see Fig. 3) are unmixed sufficiently only by quadratic programming (see Fig. 6).

3) The results achieved by the orthogonal subspace projection method (see Fig. 7) are identical to those of the least squares method (see Fig. 4).

4) Quadratic programming (see Fig. 6) produces the most accurate pattern of unmixing across all classes, however it is the most time consuming to implement. The subspace method is a very fast algorithm owing to many fast and stable eigenvalue problem algorithms. Unmixing, by this approach, is performed by a simple inner product calculation which is suitable for parallel processing.

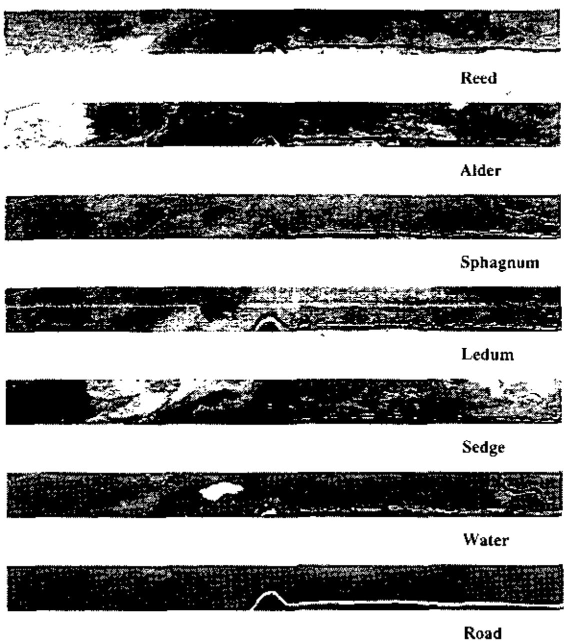

Fig. 4. Class unmixing derived from the subspace method, Kushiro.

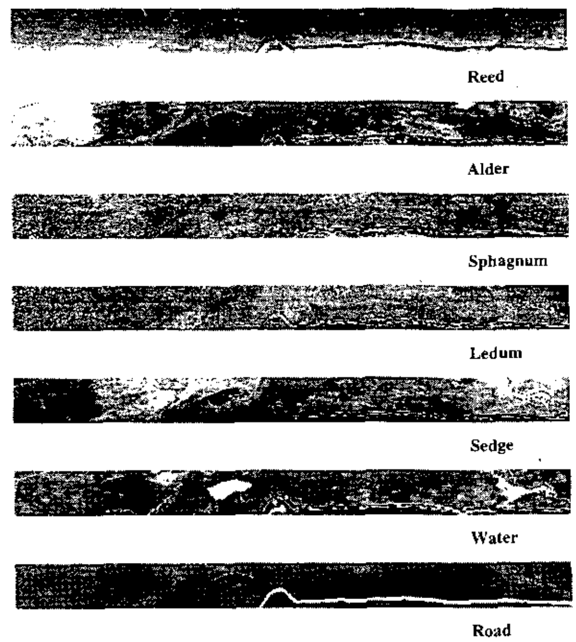

Fig. 5. Class unmixing derived from a least squares model, Kushiro.

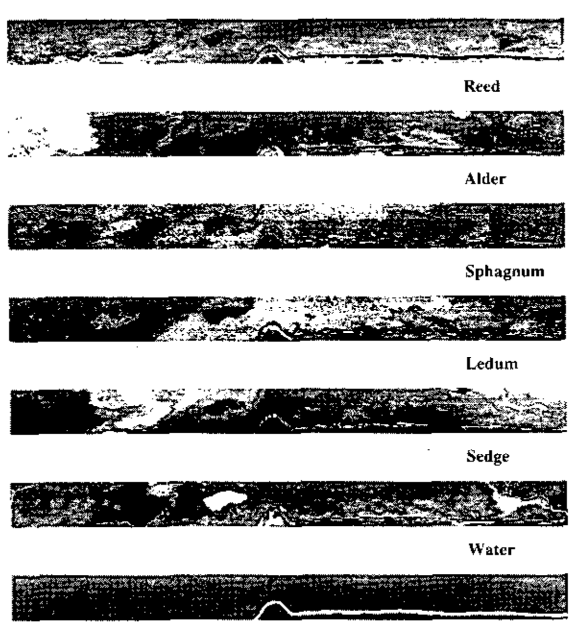

Fig. 6. Class unmixing derived from a quadratic programming method, Kushiro.

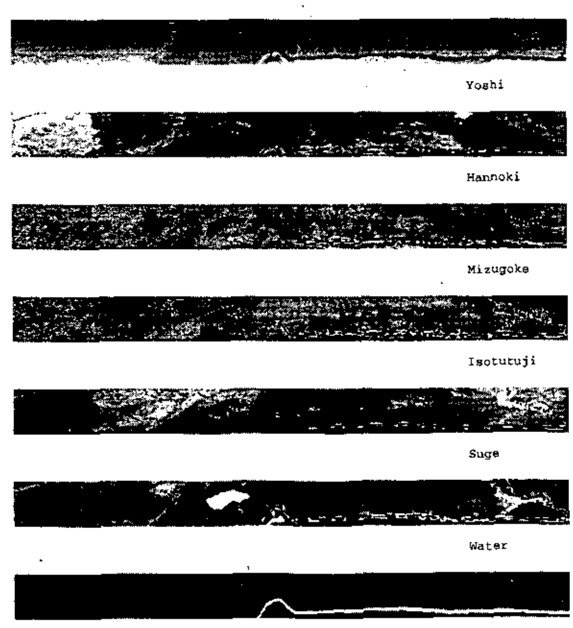

Fig. 7. Class unmixing derived from the orthogonal subspace projection method, Kushiro