GROWTH AND PRODUCTION OF *SPHAGNUM* MOSSES FROM TAKADAYACHI MOOR IN HAKKODA MOUNTAINS, NORTHEAST JAPAN 2. GROWTH IN LENGTH MEASURED WITH A POINT LEVEL METHOD*

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INTRODUCTION

Sphagnum mosses are dominant species in many raised bogs in cool temperate zones in Japan. About 40 species of *Sphagnum* are mainly distributed from the central parts to the northern parts of Honshu and Hokkaido (Iwatsuki & Mizutani, 1972). Many people visited some raised bogs for their recreation and the *Sphagnum* carpets were crushed under their feet. The regeneration of *Sphagnum* mosses damaged by men has been tried in some bogs but the works resulted badly. For the regeneration and conservation of the mosses, it is very important to understand the growth. The growth of *Sphagnum* mosses in raised bog has been measured with some methods by many investigators in Scandinavia, Europe and North America (Boatman, 1977; Clymo & Reddaway, 1974; Ferguson & Lee, 1983; Forest & Smith, 1975; Hayward & Clymo, 1983; Lindholm, 1990; Moore, 1989; Pakarinen, 1978; Vasander, 1982; Wallen *et al.*, 1988; Wieder & Lang, 1983, etc.). In these measurements, sampling method or some indirect methods with cranked wires, nylon strips, innate markers or nets were used. The methods of measurement were reported in detail by Russell (1988) and Russell and Botha (1988).

In Japan, there were some studies about the growth of *Sphagnum* in Ozegahara Moor (Kashimura *et al.*, 1979; Kashimura, 1991), in Akaiyachi Moor (Kashimura & Kantani, 1987) and in Furen Mire (Tachibana *et al.*, 1987).

We tried to study about the growth of *Sphagnum* on Takadayachi Moor in

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northeast Japan since 1988. Ino and Takamine (1994) measured photosynthesis of some *Sphagnum* mosses with two IRGAs at the Mt. Hakkoda Botanical Laboratory in 1988. Fukushima *et al.* (1995) measured the seasonal changes of photosynthesis of three species of *Sphagnum* in this moor with a gas exchange method and calculated the primary production. In the research reported here, we measured the shoot elongation of three species of *Sphagnum* with a point level method which was developed by us and calculated the annual growth rates in dry weight with the shoot elongation rates and the volumetric concentration of the shoots. We will also discuss the growth based on the carbohydrate contents in the shoots in the next paper.

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MATERIALS AND METHODS

1. Site

The measurement of growth in length was carried out in Takadayachi Moor (40°37′N, 140°53′E, ca. 1,000 m a.s.l. and ca. 5.9 ha) which was situated on the southeast slope of Mt. Hakkoda-Ohdake (1,585 m a.s.l.) in Aomori Prefecture. Dominant *Sphagnum* species in this moor were *S. papillosum* and *S. nemoreum* on hummocks and *S. tenellum* in hollows. In Japan, *S. papillosum* is the typical hummock species (Kashimura, 1991) and one of the largest size species. *S. tenellum* is small mosses which is distributed in mountain raised bogs (Suzuki, 1972). The vegetation of Takadayachi Moor was described by Yoshioka (1963) and Fukushima *et al.* (1995). In this moor, *Phragmites australis*, *Parnassia palustris* var. *multiseta*, *Heloniopsis orientalis* and *Narthecium asiaticum* were main species on hummocks. *Rhynchospora yasudana* and *Juncus kamtschatcensis* were main vascular plants in hollows. General species were *Eriophorum vaginatum* and *Schizocodon soldanelloides* var. *soldanelloides*.

2. Measurement of the change of surface level of moss population (point level method)

We measured the distance from a plate set on top of rods to the surface of moss population. It was assumed that the shortening of the distance was caused by the elongation of shoots.

We thought that this method would not give large artificial effect to mosses, because the contact to shoots with sticks occurred only once in each measuremest. The mean growth rate in an area was taken with this method.

The experimental sites, 15 cm × 30 cm areas, were prepared at each population and 30 cm aluminum rods were inserted to 15 cm in depth at the four corners of each site. A transparent plastic rectangular plate was set horizontally on the upper portion of the rods. A hundred holes, 2 mm in diameter, were made in

Table 1. Mean elongation rate of shoot measured with sticks with disk and without disk from July to October 1991 (mean ± 95% confidence limit; n = 100)

	S. papillosum (mm season^{-1})		S. nemoreum (mm season^{-1})	
	disk	no disk	disk	no disk
Mean	11.09	10.26	6.86	6.75
Maximum	18.81	29.15	15.71	19.67
Minimum	2.68	−3.08	0.95	−4.54
95% c.l.	0.06	0.10	0.04	0.09

central 9 cm × 9 cm area of the plate. Another plate with 100 holes in central 9 cm × 9 cm area was set 12 mm below from the above plate. The distance from the upper plate to the surface of the moss population was measured at 100 points with 100 slender sticks. A stick was dropped through a hole of the upper plate and the hole directly below and was marked at the position of the upper plate. The distance was measured in the laboratory in a few days with a slide calipers. In 1990's measurement, slender sticks often dropped to interstice among shoots. In 1991's measurement, a small disk, 5 mm in diameter, was attached to the end of each stick. Comparisons between the elongation rates taken by sticks with a disk and without a disk were done at the same sites in 1991. The elongation rates and the standard errors from July to October are shown in Table 1. When the sticks with a disk were used, the range of the data was smaller. After the measurement, the plates were removed but four rods were left.

For the monthly measurement, two experimental sites were prepared in each species population in 1990 and the measurement in 1991 was carried out at three sites for *S. tenellum* and *S. nemoreum* populations and four sites for *S. papillosum*.

Near the experimental sites of *S. papillosum* and *S. nemoreum*, cranked wires were set to measure the elongation, in May 1990. Ten wires were set per a plot and three plots were prepared in each species population. A light plate, 3 cm × 3 cm in size, was put on the surface near the wire in May. After the level of the plate was recorded on the wire, the plate was removed. In October, the plate was put again on the moss surface and the level was recorded on the wire. The distance between the marks corresponds to the elongation growth.

3. Measurement of volumetric concentration

From four to ten cores were sampled with cylinders at each population. Two types of cylinders were used and each size was 82 mm or 50 mm in diameter and 50 mm in length. Samples were taken in October 1991 and 1992. October was the end of the growing season. The length of the produced stems in the season is equal to the elongation of the shoots, because new stems are formed under capitulum and thickening growth does not occur. The top parts (0 to 10 mm), which include capitulum, were cut off in all the samples and the dry weight of 10 to 40 mm parts (volumetric concentration) was measured in *S. nemoreum* and *S. papillosum*. It was assumed that the weight of that parts corresponded to the mean weight of the produced shoots in the season. In *S. tenellum*, the volumetric concentration of 10 to 30 mm parts was measured, because the parts of under 40 mm were decomposed. Net production can be calculated with the elongation rate and the volumetric concentration.

RESULTS AND DISCUSSION

The distance between the upper plate and the moss surface at 100 points was measured every month from May to October. The measurement in *S. papillosum* and *S. nemoreum* populations was carried out at two sites in 1990 and three or four sites in 1991. The surface structure of a 9 cm $\times$ 9 cm site in *S. papillosum* population in May 1991 is shown in Fig. 1. The surface was not flat and the difference between the peak and the bottom was smaller than 20 mm.

The decrease of the distance during the six months from May to October showed the elongation growth in the period. The patterns of elongation growth from May to October in 1990 and 1991 are shown in Figs. 2, 3 and 4.

The mean elongation growth of *S. papillosum* in June and July was larger than in other months (Fig. 2) and the amount corresponded to 50 to 70% of yearly growth. The growth from late September to the middle of October was not observed except for two sites. The mean elongation rate was 5.7 mm y^{-1} in 1990 and 14.3 mm y^{-1} in 1991 (Table 2). The rate in 1991 was over twice of that in 1990. Hayward and Clymo (1983) reported that the growth in this species was affected by the light intensity and water table. There was not a clear difference between light intensities in 1990 and 1991 (Fukushima et al., 1995) but the effect to the growth was not clear. Although we did not measure directly the change of water table, it was estimated that the effects were large (Fukushima et al., 1995).

The elongation rates of *S. nemoreum* differed from sites to site in the population. The growth in July was the largest in the growing season in most sites and it corresponded to about 30% of yearly growth (Fig. 3). The elongation in many sites stopped in October, but in two sites, the elongation was observed. The mean elongation rate was 20.0 mm y^{-1} in 1990 and 11.9 mm y^{-1} in 1991 (Table 2). The rate in 1990 was higher than that in 1991 and this tendency differed from that of *S. papillosum*. The report of the elongation rate of *S. nemoreum* was meager.

The elongation rate of *S. tenellum* was lower than those of other two *Sphagnum* species and the standard error of mean was larger (Fig. 4). The mean elongation rate was 6.8 mm y^{-1} in 1990 and 4.6 mm y^{-1} in 1991 (Table 2), and the difference between these two rates was smaller than the difference in other species.

The change of surface level was measured with the cranked wire method in *S. papillosum* and *S. nemoreum* populations. The mean rate (mm y^{-1}) at each

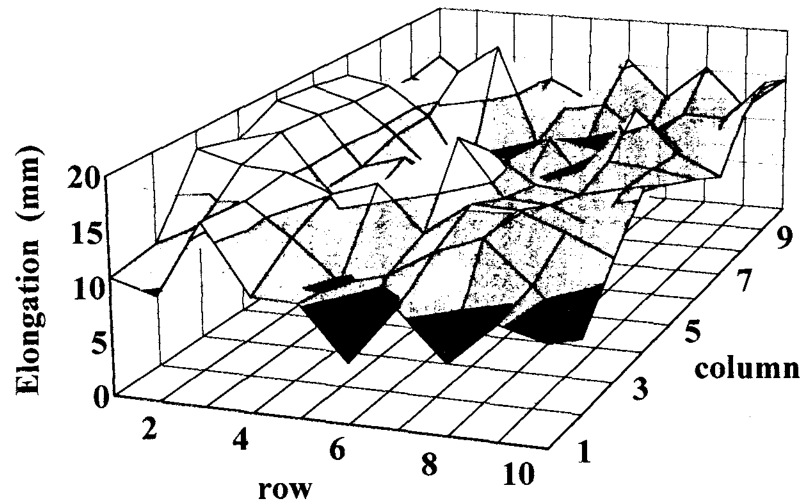

Fig. 1. Surface structure of a site (9 cm×9 cm) of *Sphagnum papillosum* population in May 1990

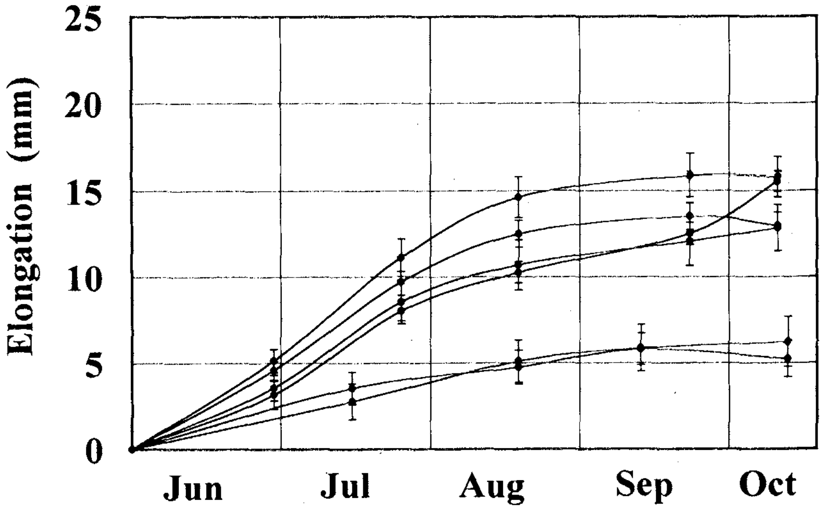

Fig. 2. Seasonal shoot elongation of *Sphagnum papillosum* population
Each point is the mean of 100 points at a site and each line shows the mean elongation at a site. Vertical line is the 95% confidence limit of the mean.

plot was 28.8±4.6 (95% confidence limit), 30.5±4.0 and 31.6±4.7 in *S. papillosum* and 21.3±5.8, 11.8±2.3 and 20.5±3.0 in *S. nemoreum* population, respectively. The rate of *S. tenellum*, hummock species, was not measured because this species was too small to be measured with this method. These rates were higher than the rates taken with the point level method shown in Table 2. One of the reasons was estimated that the elongation of well-grown shoots in a small area was

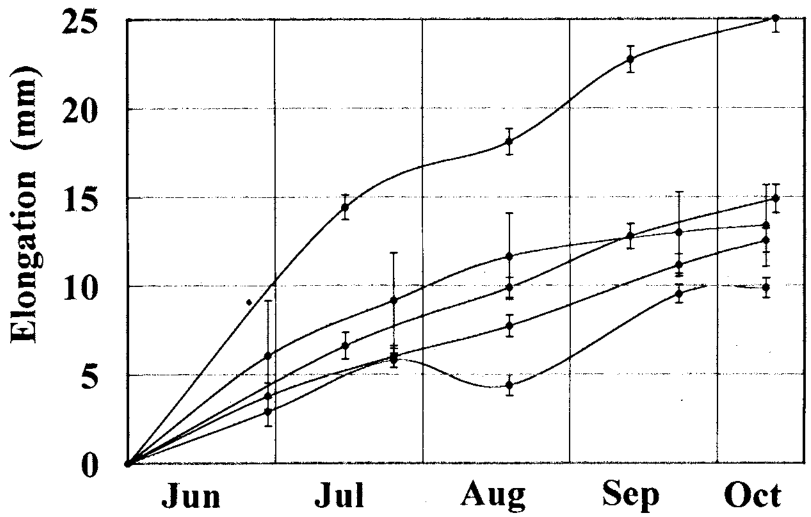

Fig. 3. Seasonal shoot elongation of *S. nemoreum*. Refer to Fig. 2 for lines and points.

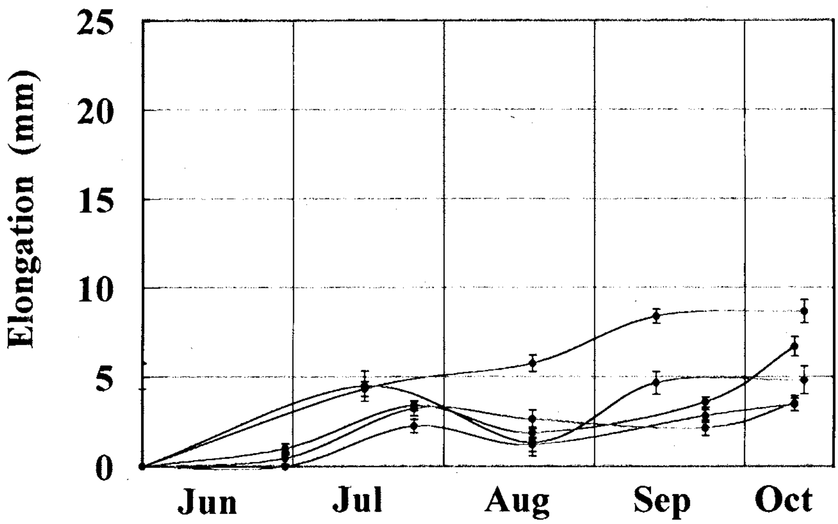

Fig. 4. Seasonal shoot elongation of *S. tenellum* Refer to Fig. 2 for lines and points.

measured with the cranked wire method.

The mean shoot biomass in the layer from 1 cm to 4 cm (volumetric concentration of shoots) of *S. papillosum* and *S. nemoreum* and the biomass from 1 cm to 3 cm of *S. tenellum* are shown in Table 3. The volumetric concentration of *S. tenellum* sampled in 1991 was very large and the volumetric concentration in 1990 was about 66% of that in 1991. The deviation of the mean rates among the sites of *S. papillosum* was the smallest and the concentration was the lowest. The

Table 2. Shoot elongation rates in a growing season (mean ± 95% confidence limit. n = 100)

		1990	1991
	plot	mm season^{-1}	mm season^{-1}
S. papillosum	E	6.22 ± 1.46	15.75 ± 1.14
	F	5.22 ± 1.06	15.49 ± 0.56
	R	--	12.83 ± 1.34
	T	—	12.95 ± 0.78
S. nemoreum	C	25.04 ± 0.79	12.56 ± 0.67
	D	14.90 ± 0.09	9.88 ± 0.55
	L	—	13.39 ± 2.29
S. tenellum	A	4.83 ± 0.78	3.47 ± 0.35
	B	8.68 ± 0.65	6.71 ± 0.54
	M	--	3.53 ± 0.42

Table 3. Volumetric concentration of shoots (mean ± 95% confidence limit)

	1990		1991	
	g cm^{-1} m^{-2}	n	g cm^{-1} m^{-2}	n
S. papillosum	84.0 ± 16.8	4	66.2 ± 5.2	4
S. nemoreum	99.5 ± 16.9	10	71.2 ± 15.6	4
S. tenellum	292.4 ± 47.2	10	442.9 ± 77.2	4

volumetric concentration of *S. tenellum* was much larger than that of other species.

Yearly matter production was calculated with the elongation rate and the volumetric concentration of shoots in each species, and the results are shown in Table 4 with other data. These rates were 44-194 g m^{-2} in *S. papillosum*, 79-249 g m^{-2} in *S. nemoreum* and 141-297 g m^{-2} in *S. tenellum* population. As to *S. papillosum* and *S. nemoreum*, there were large differences between the rates in the two years. The differences between the growth rates in the two species were not caused by the radiation and temperature, because there were no clear differences in daily mean PFD and daily mean moss temperature between the two years (Fukushima *et al.*, 1995). Clymo and Hayward (1982) estimated that the productivity of fairly continuous carpets of *Sphagnum* seemed generally to be in the range 100-600 g m^{-2}y^{-1}. Against our expectation, the smallest species, *S. tenellum*, had the highest production. It seemed that the high production was caused by the high density of the shoots. Gerdol (1995) measured the linear growth rates of hollow species and hummock species and reported that hollow species were usually more productive than hummock species in wet periods. We reported that

Table 4. Elongation rates and production rates of some *Sphagnum* mosses

Species	Elongation ($mm\ yr^{-1}$)	Production rate ($g\ m^{-2}\ yr^{-1}$)	Sites	References
Hummocks				
S. fuscum	6-18	270-320	Finland	Lindholm & Vasander 1990
	4-21	70-330	Finland	Pakarinen 1978
	7-31	69-303	Ontario, Canada	Rochefort *et al.* 1990
	6- 7	75- 84	Quebec, Canada	Moore 1989
S. fuscum/S. rubellum	7-23	25- 75	Sweden	Wallen *et al.* 1988
S. magellanicum	—	500	Virginia, USA	Wieder & Lang 1983
	39	320	Minnesota, USA	Grigal 1985
	47	262	Akaiyachi moor, Japan	Kashimura & Kantani 1987
	8-20	210-230	Finland	Lindholm & Vasander 1990
	16-22	50- 70	Sweden	Wallen *et al.* 1988
	10	95	Sweden	Aerts *et al.* 1992
	34-41	143-167	Southern Alps, Italy	Gerdol 1995
S. magellanicum/S. fuscum	36	300	Minnesota, USA	Grigal 1985
S. magellanicum/S. nemoreum	—	134	Quebec, Canada	Moore 1989
S. nemoreum	10-25	70-249	Takadayachi moor, Japan	in this study
	—	230-430	England	Clymo 1970
	—	75-135	England	Clymo & Reddaway 1974
	20-23	360-454	Southern Alps, Italy	Gerdol 1995
	8- 9	70- 79	Quebec, Canada	Moore 1989
S. papillosum	67	489	Akaiyachi moor, Japan	Kashimura & Kantani 1987
	14-33	114-281	Furen mire, Japan	Tachibana *et al.* 1987
	24-41	210-610	England	Clymo 1970
	25-32	260-380	Finland	Lindholm & Vasander 1990
	6-38	66-386	Ozegahara moor, Japan	Kashimura 1982
	33	—	Yugoslavia	Gaberscik & Martincic 1987
	—	210	Quebec, Canada	Moore 1989
	5-16	44-104	Takadayachi moor, Japan	in this study
S. russowii	10	62	Quebec, Canada	Bartsch & Moore 1985
Hollows				
S. angustifolium	131	520	Minnesota, USA	Grigal 1985
	20-60	160-400	Finland	Lindholm & Vasander 1990
	20-39	97-198	Ontario, Canada	Rochefort *et al.* 1990
	4-17	29-127	Quebec, Canada	Moore 1989
	4- 9	19- 58	Quebec, Canada	Bartsch & Moore 1985
S. angustifolium/S. recurvum	91	370	Minnesota, USA	Grigal 1985
S. angustifolium/S. warnstorfii	11	73	Quebec, Canada	Bartsch & Moore 1985
S. fimbriatum	79	158	Hosyojiri moor, Japan	Kashimura 1982
S. balticum	11	109	Sweden	Aerts *et al.* 1992
S. balticum/S. majus	19-51	210-410	Finland	Pakarinen 1978
S. majus	26-29	240-320	Finland	Lindholm & Vasander 1990
S. recurvum	—	980	The Netherlands	Brock & Bregman 1989

S. recurvum	--	135	England	Forrest & Smith 1975
	--	610	Virginia, USA	Wieder & Lang 1983
	8-43	230-600	England	Clymo 1970
	79-99	348-442	Southern Alps, Italy	Gerdol 1995
S. cuspidatum	126	841	Akaiyachi moor, Japan	Kashimura & Kantani 1987
	--	180-790	England	Clymo 1970
	18-51	88-203	Ozegahara moor, Japan	Kashimura 1982
S. tenellum	4- 9	141-297	Takadayachi moor, Japan	in this study
Lawn and others				
S. compactum	6-20	65-154	Ozegahara moor, Japan	Kashimura 1982
S. flexuosum	20-40	150-340	Finland	Lindholm & Vasander 1990
S. riparium	34-54	310-490	Finland	Lindholm & Vasander 1990
	2	9	Quebec, Canada	Bartsch & Moore 1985
S. riparium/S. lindbergii	3	14	Quebec, Canada	Bartsch & Moore 1985
S. warnstorfii	25-41	260-350	Finland	Lindholm & Vasander 1990
	18-24	108-142	Quebec, Canada	Moore 1989
S. warnstorfii/S. angustifolium	4-11	36- 90	Quebec, Canada	Moore 1989

the primary production rates calculated by photosynthetic rates and respiration rates were 32 and 107 g m^{-2} (1991 and 1993) in *S. papillosum*, 219, 207 and 187 g m^{-2} (1990, 1991 and 1993) in *S. nemoreum* and 141, 141 and 206 g m^{-2} (1990, 1991 and 1993) in *S. tenellum*, respectively (Fukushima *et al.*, 1995). These rates were similar to the rates in each species calculated with the elongation rates.

To compare our data with others, elongation rates and net production rates of some species of *Sphagnum* are shown in Table 4. Our elongation rates and net production rates of *S. papillosum* were smaller than those in other studies. The reason was not clear. If the effect of the changes of water table or nutrient flush supply to the moss growth are studied, the reason may become clear.

SUMMARY

1) The elongation rate of the shoots of *Sphagnum papillosum, S. nemoreum* and *S. tenellum* was measured in 1990 and 1991 on Takadayachi raised bog in northeast Japan.

2) The elongation rate was measured with a point level method. We thought this method would cause very small damage by touching the shoots. The mean rate at 100 points in 9 cm × 9 cm area was measured.

3) The elongation rate in 1991 was 13-16 mm per a season in *Sphagnum papillosum*, 10-13 mm in *S. nemoreum* and 3-7 mm in *S. tenellum*. The elongation rate in 1990 and 1991 differed among three species. The rate of *S. papillosum* in 1990 was higher than that in 1991 but it was contrary in *S. nemoreum*.

4) Shoot density was measured with cylinders, 50 mm in height and 50 or 82

mm in diameter.

5) Growth rate of shoots in dry matter was calculated 44-104 g $m^{-2}y^{-1}$ in *S. papillosum*, 70-249 g $m^{-2}y^{-1}$ in *S. nemoreum* and 141-297 g $m^{-2}y^{-1}$ in *S. tenellum* populations.

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