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Microfungi isolated from *Sphagnum fuscum* from a Southern Boreal Bog in Alberta, Canada

MARKUS N. THORMANN, RANDOLPH S. CURRAH, AND SUZANNE E. BAYLEY
Department of Biological Sciences, University of Alberta, Edmonton, Alberta, T6G 2E9, Canada

Abstract. *Microfungi were isolated from living and decomposing* Sphagnum fuscum *from a southern boreal bog in Alberta, Canada. Fifty-five fungi (three ascomycetes, three basidiomycetes, 11 zygomycetes, 28 Fungi Imperfecti, 10 unnamed* mycelia sterilia*) are described in this study. Of the Fungi Imperfecti, 21 species have known sexual states (teleomorph) in the Ascomycota, while the remaining seven species are known only from their asexual state (anamorph) and could not be assigned to specific teleomorphic families. Thirty-six species represent new records from* Sphagnum *and 45 species are new records for* S. fuscum*. Nearly 52% of the 45 identified fungi originated from three families, Mortierellaceae (10 taxa, Zygomycota), Trichocomaceae (8 taxa, Ascomycota), and Hypocreaceae (5 taxa, Ascomycota), with the remaining fungi representing 12 additional families. The 55 fungi have the ability to utilize a variety of carbon sources, such as cellulose, tannic acid, and pectin, and thus are important organisms involved the mineralization of carbon in peatlands.*

Bogs and fens are the dominant peatland types in western Canada (Vitt et al. 2000). As a landform, peatlands cover approximately 14% of Canada's (National Wetlands Working Group 1988) and approximately 16% of Alberta's land surface (Vitt et al. 1996). Many of these peatlands are dominated by species of *Sphagnum,* which have the ability to acidify their surroundings and hold large quantities of water (Vitt & Andrus 1977). Both of these factors contribute, in part, to decreased decomposition rates and consequently the build-up of peat. Of the 21 known *Sphagnum* species in Alberta, *Sphagnum fuscum* (Schimp.) Klinggr. is one of the most common species and the dominant hummock-forming bryophyte species in continental bogs (Vitt & Andrus 1977).

The majority of peat that accumulates in continental western Canadian bogs consists of *Sphagnum*-peat. Because of the importance of peatlands to the global carbon cycle (Gorham 1991), it is important to understand the microbial communities (fungi and bacteria) involved in the decay of peat. Several studies have shown that fungal biomass and production exceeds that of bacteria in acidic ecosystems (Latter et al. 1967; Williams & Crawford 1983), suggesting that fungi may be the dominant decomposer organisms in peatlands. Furthermore, fungi synthesize a suite of enzymes that enable them to utilize a variety of carbon sources (Domsch et al. 1980). Thus, investigations into the fungal assemblages of *Sphagnum* species may provide a better understanding of the dynamics of carbon in peatlands.

Many fungi are cosmopolitan, but they may be either host-specific or quantitatively more common on living or decaying vegetation (Felix 1988). Habitat selectivity apparently is attributed to changes in litter quality throughout the process of decomposition, because desirable nutrients, such as nitrogen, phosphorus, or simple sugars, become scarce, while more complex structural polymers, such as lignin and lignocellulose, become comparably more dominant in the litter (Deacon 1984). This leads to a succession of fungi in the plant litter. For example, basidiomycetes may dominate ascomycetes during the latter stages of decomposition, because they may be able to synthesize the enzymes required for the degradation of complex carbohydrates (Deacon 1984).

Reports of microfungi associated with *Sphagnum* are scarce. Previous host indices list primarily macrofungi (Oudemans 1919; Saccardo 1898; Seymour 1929). Felix (1988) provided the first host index that includes microfungi and names only one species recorded specifically from *S. fuscum* (*Epibryon* sp., an ascomycete) as well as several others from other species of *Sphagnum.* In light of the dominance and importance of *S. fuscum* in bogs (Thormann & Bayley 1997), it is surprising that little is known about the fungi associated with this species. Therefore, we isolated in pure culture a series of fungi from living and decomposing *S. fuscum* from a southern boreal bog in Alberta, Canada. An annotated account of microfungi isolated from *S. fuscum* is provided.

METHODS

The Perryvale bog (58°28′ N, 113°16′ W) lies within the Subhumid Low Boreal ecoclimate region of Canada

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(Ecoregions Working Group 1989) and is dominated by *Picea mariana* (Mill.) BSP., *Vaccinium vitis-idaea* L., *Rhododendron groenlandicum* (Oeder) Kron & Judd, and *S. fuscum*. A more detailed site description with respect to vegetation composition and surface water chemistry is elsewhere (Thormann et al. 1999*b*, 2001).

The top three cm of approximately 20 individual, healthy-looking, living *S. fuscum* plants were collected in early May, July, and September 1997. A two-year decomposition study using nylon mesh bags (3 × 6 cm, one mm gauge) was initiated in early September 1997. Between five and eight individual fresh *S. fuscum* plants (top 3 cm) were placed into each of the decomposition bags. These bags were returned to the bog and placed horizontally approximately two cm below the peat surface. Sets of triplicate decomposition bags with decomposing *S. fuscum* were retrieved after 20 and 50 d in 1997, after eight and 12 months in May and September 1998, and after 20 and 24 months in May and September 1999.

The *S. fuscum* was cleaned by removing roots and other plant tissues using fine forceps and a dissecting microscope. Each of ten randomly selected and cleaned segments of *S. fuscum* was cut with a flame-sterilized scalpel into approximately 10 smaller segments (approximately 0.5 × 0.5 cm in size). These were surface-sterilized for five minutes in 10% hydrogen peroxide and washed with distilled water (d-H_2O) prior to placing them on Potato Dextrose Agar (PDA, 39.0 g Difco potato dextrose agar, 1.0 liter d-H_2O), PDA with rose bengal (0.03%, a general fungal growth inhibitor), PDA with benomyl (0.0002%, selective for basidiomycetes), and Mycobiotic agar® (MYC, containing cycloheximide, 35.6 g Difco mycobiotic agar, 1.0 liter d-H_2O, selective for uncommon groups of ascomycetes e.g., fungi belonging to the Onygenales and Microascales). All media were amended with oxytetracycline (0.01%) to suppress bacterial growth. Plates were incubated at room temperature in the dark. Primary isolation plates were examined daily for the first two weeks, weekly for the following six months, and monthly for the following two years. Fungi were sub-cultured onto Malt Extract Agar (MEA, 15.0 g Difco malt extract agar, 20.0 g Difco agar, 1.0 liter d-H_2O) as soon as they grew from the plant material. For examination of microscopic morphology, slide cultures on mixed cereal agar (Pablum®, H. J. Heinz Company of Canada Ltd., 100.0 g mixed cereal, 15.0 g Difco agar, 1.0 liter d-H_2O) were prepared and mounted in polyvinyl alcohol and lactofuchsin (Sigler 1993).

Morphological dimensions are given as means with ranges as ''(smallest dimension)-mean dimension-(largest dimension)''. Means are based on ≥ 10 measurements in all cases. This notation style provides an indication of the minimum, mean, and maximum sizes of relevant morphological characters. Only distinguishing morphological and/or cultural characteristics for each taxon are provided in the annotations. This permits the separation of each taxon from closely related taxa within the same genus isolated in this study. Information on the distribution, sources of isolates, and enzymatic capabilities of fungal taxa is provided where such data could be found. Enzymatic tests for cellulase, polyphenol oxidases, amylase, and gelatinase were performed for some taxa according to Hutchison (1990). The test for laccase followed Stalpers (1978).

Isolates were scored as individual records if they originated from different *S. fuscum* segments on the same primary isolation plate or from different primary isolation plates. Multiple isolates originating from the same plant segment on the same primary isolation plate were scored as a single record. Identified species are treated alphabetically by genus and species. *Mycelia sterilia* are listed following the identified taxa. Representative living cultures and/or permanent microscope slides have been deposited at the University of Alberta Microfungus Collection and Herbarium (UAMH), the University of Alberta Cryptogamic Herbarium (ALTA), and the Centraalbureau voor Schimmelcultures (CBS).

Results and Discussion

Two hundred sixty-two records of fungi were obtained from living (88 records) and decomposing (174 records) *S. fuscum* from May 1997 to September 1999. We identified 45 species, including three ascomycetes, two basidiomycetes, 28 mitosporic fungi (fungi that reproduce asexually via the formation of spores, or conidia), and 11 zygomycetes (Table 1). Forty-one of the 45 species represent new records for *Sphagnum*. These 45 species represent 250 of the 262 records obtained from *S. fuscum* in this study. The remaining 12 records (< 5%) were sterile and could not be named; however, they were described based on morphological, physiological, and cultural characters. Molecular techniques may elucidate their identities or relationships to other fungal taxa.

Most of these species are common soil fungi, such as *Penicillium thomii*, *Trichoderma viride*, *Trichoderma harzianum*, *Mortierella ramanniana*, and *Mucor hiemalis* (Table 1), and are related to microfungi that have been isolated from peat in previous studies (Christensen & Whittingham 1965; Dal Vesco 1974–75; Dooley & Dickinson 1971; McLennan & Ducker 1954; Nilsson et al. 1992; Thrower 1954). Furthermore, *T. viride* and *Verticillium bulbillosum* have been isolated previously from another *Sphagnum* species, *Sphagnum magellanicum* Brid. (Dickinson & Maggs 1974), and *T. harzianum* has been shown to cause mass losses in the same *Sphagnum* species (Czastukhin 1967).

Three basidiomycetes were isolated from living *S. fuscum* (one from a May sample, *Bjerkandera adusta*; two from July samples, basidiomycete spp. 1 and 2). Only one of the two unidentified basidiomycete isolates produced clamp connections, a characteristic unique to basidiomycetes; however, colony characteristics, such as cottony-wooly aerial mycelium, bleached growth medium on the colony reverse, and sweet odor, are sufficient to suggest their placement in the Basidiomycota. Additionally, all three taxa produced arthroconidia, a common vegetative propagule of saprophytic basidiomycetes (Hutchison 1989). Their role in living tissues of *S. fuscum* is unexplained. Although the focus of this investigation was microfungi, we also collected conspicuous, epigeous fruiting bodies of basidiomycetes. Most of these were fruiting bodies of known ectomycorrhizal fungi of *Picea*, such as spe-

TABLE 1. Fungi from living and decomposing *Sphagnum fuscum*. Fungal classification is in accordance with Hawksworth et al. (1995). Numbers indicate the number of records obtained from living (L), decomposing (D), or living and decomposing *S. fuscum*.

Fungal classification					
Division	Order	Family	Fungi	Substrate	Accession number*
Zygomycota	Mucorales	Mortierellaceae	*Mortierella alpina*	D 3	ALTA 10686
			M. elongata	L 6, D 12	ALTA 10687
			M. horticola	L 1, D 3	ALTA 10691
			M. humilis	L 1	ALTA 10692
			M. isabellina	L 1, D 7	ALTA 10689
			M. minutissima	L 7, D 10	ALTA 10690
			M. ramanniana var. *angulispora*	L 5, D 9	ALTA 10693
			M. ramanniana var. *ramanniana*	L 2, D 6	ALTA 10694
			M. renispora	L 2, D 4	ALTA 10695
			M. verticillata	L 1, D 1	ALTA 10696
		Mucoraceae	*Mucor hiemalis*	L 10, D 26	ALTA 10697
Ascomycota	Dothideales	Sporormiaceae	*Sporormiella intermedia*	L 1	ALTA 10706
	Microascales	Microascaceae	*Kernia retardata*	L 2, D 1	UAMH 9613
	Sordariales	Sordariaceae	*Sordaria fimicola*	L 4	ALTA 10705, UAMH 9475
Basidiomycota	Poriales	Coriolaceae	*Bjerkandera adusta*	L 1	
	Unknown	anamorphic fungi	Basidiomycete sp. 1	L 3	ALTA 10853
			Basidiomycete sp. 2	L 1	ALTA 10854
Fungi Imperfecti**	Dothideales	Mycosphaerellaceae	*Cladosporium herbarum*	L 1	ALTA 10678
	Eurotiales	Trichocomaceae	*Aspergillus niger*	L 2, D 1	ALTA 10673
			A. versicolor	D 1	ALTA 10674
			Paecilomyces marquandii	L 1	ALTA 10855
			Penicillium funiculosum	L 9, D 4	ALTA 10856
			P. lividum	D 4	ALTA 10857
			P. montanense	D 2	ALTA 10858
			P. purpurogenum	L 5	ALTA 10859
			P. thomii	L 4, D 9	ALTA 10860
	Hypocreales	Hypocreaceae	*Fusarium aquaeductuum* var. *medium*	L 1	ALTA 10680
			Trichoderma aureoviride	D 2	ALTA 10707
			T. harzianum	L 1, D 2	ALTA 10708
			T. polysporum	D 2	ALTA 10712
			T. viride	L 4, D 12	ALTA 10713
	Leotiales	Sclerotiniaceae	*Botrytis cinerea*	D 1	ALTA 10676
	Onygenales	Myxotrichaceae	*Oidiodendron maius*	D 1	ALTA 10700, UAMH 9749

TABLE 1. Continued.

Fungal classification					
Division	Order	Family	Fungi	Substrate	Accession number*
			O. scytaloides	L 2, D 1	UAMH 9750, 9751
	Ophiostomatales	Ophiostomataceae	*Sporothrix* state of *Ophiostoma stenoceras*	D 3	UAMH 9753
			Sporothrix sp.	D 4	UAMH 9752
	Trichosphaeriales	Trichosphaeraceae	*Monocillium constrictum*	L 1	ALTA 10685
	Xylariales	anamorphic fungus	*Nodulisporium* sp.	L 1, D 1	ALTA 10698
Mitosporic fungi***			*Acremonium chrysogenum*	D 1	ALTA 10669
			A. cf. curvulum	D 3	CBS 102853, UAMH 9938
			A. strictum	D 1	ALTA 10670
			Verticillium bulbillosum	L 2, D 7	ALTA 10715
			V. cephalosporium	D 1	ALTA 10716
			V. lecanii	D 1	ALTA 10717
			V. psalliotae	L 2, D 10	ALTA 10718
Mycelia sterilia			*Mycelium sterilium* 1	L 1	
			Mycelium sterilium 2	L 1	
			Mycelium sterilium 3	L 1	
			Mycelium sterilium 4	D 1	
			Mycelium sterilium 5	D 1	
			Mycelium sterilium 6	D 2	
			Mycelium sterilium 7	L 1	
			Mycelium sterilium 8	D 1	
			Mycelium sterilium 9	D 1	
			Mycelium sterilium 10	D 2	

* ALTA = University of Alberta Cryptogamic Herbarium, CBS = Centraalbureau voor Schimmelcultures, UAMH = University of Alberta Microfungus Herbarium and Collection; ** Asexual states of fungi with known ascomycete sexual states; *** Unknown taxonomic position.

cies of *Cortinarius* and *Lactarius* (Kernaghan & Currah 1998), growing among the bog bryophyte species. Hutchison (1990) produced enzymatic profiles of 95 ectomycorrhizal fungi and found few of them to be able to utilize plant structural polymers, such as lignin, cellulose, or pectin. Based on the limited enzymatic abilities of the two unidentified basidiomycetes in this study (Table 2), they may be ectomycorrhizal fungi as well; however, this is speculative and molecular studies are necessary to elucidate their identities. Nonetheless, ectomycorrhizal fungi are prevalent in peatlands (Thormann et al. 1999*b*) and also may contribute to the mineralization of peat.

We identified only one dematiaceous (darkly-colored) fungus, *Cladosporium herbarum,* in this study (Table 1). However, other dematiaceous species, such as species of *Alternaria* Nees: Fr., *Cladosporium* Link: Fr., and *Phialophora* Medlar among others, have been isolated from peat in the past (Christensen & Whittingham 1965; Dal Vesco 1974–75; Dooley & Dickinson 1971; McLennan & Ducker 1954; Nilsson et al. 1992; Thrower 1954). Two additional records were dematiaceous, *Mycelia sterilia* 3 and 8; however, these could not be named.

In a related study, *Alternaria alternata* (Fr.) Keissler, *Arthrinium* state of *Apiospora montagnei* Sacc., *Geotrichum* sp. Link: Fr., a newly described species — *Scleroconidioma sphagnicola* Tsuneda, Currah & Thormann (Tsuneda et al. 2000), and an unidentified dematiaceous fungus were isolated from a necrotic patch of *S. fuscum* from the same bog (A. Tsuneda pers. comm.). It is expected that *S. fuscum* from these necrotic patches harbor different suites of fungi than those of healthy-looking *S. fuscum,* but our data are insufficient to address this hypothesis.

So far, only a small geographical area has been surveyed and generally only aboveground bryophyte tissues have been examined for fungal epi- and endophytes (Felix 1988), resulting in an incomplete picture of the richness of fungi on bryophytes. Furthermore, previous reports often provide only basic descriptive information about fungi associated with bryophytes (e.g., agarics or boletes). Alternatively, the ''peat'' mycota was investigated in Australian (McLennan & Ducker 1954; Thrower 1954), North American (Christensen & Whittingham 1965; Dooley & Dickinson 1971), and European (Dal Vesco 1974–75; Nilsson & Rülcker 1992, Nilsson et al. 1992) peatlands. However, peat consists of a heterogeneous assemblage of partially decomposed organic matter, including roots of different vascular plants, different mosses, and other microbes, and the specific origin of individual fungal taxa remains uncertain in those studies. Thus, neither type of study, descriptive or soil mycota studies, provides information specific enough for bryologists and mycologists concerned with the occurrences of specific fungi on/in specific bryophyte species.

Carbon constitutes approximately 48% of *Sphagnum*-derived peat (Thormann et al. 1999*a*). This carbon is hypothesized to be mineralized at greater than current rates under a global warming scenario, releasing CO_2 into the atmosphere (Yavitt et al. 1993), suggesting that peatlands with their significant carbon deposits may provide a positive feedback to global warming. The fungi isolated in this study have the ability to degrade a variety of carbon sources (Table 2). For example, cellulose and lignin-like compounds constitute 38 and 30% of the structural polymers of *Sphagnum* or *Sphagnum*-derived peat, respectively (Turetsky et al. 2000; Yavitt et al. 1997). Thirty-two of 55 of our fungal taxa (58%) have the ability to utilize cellulose as a carbon source, while polyphenol oxidases, the enzymes required for the degradation of lignin and lignin-like substances, were detected in 13 of our taxa (24%) (Table 2). For example, *T. viride, P. thomii, Verticillium psalliotae, V. bulbillosum, Sordaria fimicola,* and *M. hiemalis* have broad enzymatic profiles (Table 2), were isolated predominantly from decomposing *S. fuscum* (Table 1), and likely contribute significantly to the mineralization of peat. Tsuneda et al. (2001) showed that *Oidiodendron maius* and *Acremonium cf. curvulum* are efficient decomposers of *S. fuscum* cell walls. Their modes of degradation differ in that *O. maius* decomposes all cell wall components simultaneously. In contrast, *A. cf. curvulum* shows a preferential decay mode, attacking first surficial cell wall components and then decaying underlying microfibrillar elements. Therefore, fungi have evolved specialized modes of decomposition of organic matter, making them important organisms in the decomposition of peat in peatlands.

Caution has to be taken when interpreting the enzymatic data compiled in Table 2. For example, different isolates of the same fungal species may exhibit different enzymatic profiles. Furthermore, the enzymatic ability of a fungus in vitro may differ from its ability in situ. In vitro data only indicate the enzymatic potential of the fungus under investigation.

Twenty-one of the 55 species (38%) in this study were isolated from decomposing *S. fuscum* exclusively, while 15 of the 55 fungal species (27%) were isolated from living *S. fuscum,* and the remaining 19 species (35%) were isolated from both living and decomposing *S. fuscum.* An annotated list of these fungi follows.

TABLE 2. Enzymatic abilities, where known, of fungi isolated from living and decomposing *Sphagnum fuscum* from a bog in southern boreal Alberta, Canada. Other CHOs include xylans, sugars (sucrose, galactose, mannose, fructose, maltose), and paraffin, while phenolics include lignin and tannins. Enzymatic profiles are summarized from the literature and our studies (see text for references).

Fungi	Cellulose	Phenolics	Starch	Pectin	Gelatin	Other CHOs	Chitin	Fats
Acremonium chrysogenum	+	+				+		+
A. cf. curvulum	+		+					
A. strictum	+				+	+		
Aspergillus niger		+	+			+	+	+
A. versicolor	+		+	+		+		+
Basidiomycete sp. 1	+	+						
Basidiomycete sp. 2		+						
Bjerkandera adusta		+						
Botrytis cinerea	+	+		+		+		
Cladosporium herbarum	+	+	+	+				
Fusarium aquaeductuum var. *medium*	+	+						
Kernia retardata	+		+		+			
Monocillium constrictum	+	+	+		+			
Mortierella alpina						+	+	
M. elongata				+		+	+	
M. horticola							+	
M. humilis						+	+	
M. isabellina						+		
M. minutissima						+	+	
M. ramanniana var. *angulispora*			+	+				
M. ramanniana var. *ramanniana*	+		+	+		+		
M. renispora								
M. verticillata							+	
Mucor hiemalis	+		+	+			+	
Nodulisporium sp.	+		+					
Oidiodendron maius	+	+	+	+	+			
O. scytaloides		+	+	+				
Paecilomyces marquandii			+		+		+	
Penicillium funiculosum	+		+			+		
P. lividum	+		+	+				
P. montanense								
P. purpurogenum	+		+	+				
P. thomii	+		+	+				
Sordaria fimicola	+		+					
Sporormiella intermedia			+					
Sporothrix state of *Ophiostoma stenoceras*		+	+	+				
Sporothrix sp.					+			
Trichoderma aureoviride	+		+		+			
T. harzianum	+		+			+		
T. polysporum	+				+	+	+	
T. viride	+		+	+	+		+	+
Verticillium bulbillosum	+		+		+			
V. cephalosporium	+		+		+			
V. lecanii	+		+	+			+	
V. psalliotae	+		+		+			
Mycelium sterilium 1	+				+			
Mycelium sterilium 2			+		+			
Mycelium sterilium 3								
Mycelium sterilium 4		+	+		+			
Mycelium sterilium 5					+			
Mycelium sterilium 6	+		+		+			
Mycelium sterilium 7								
Mycelium sterilium 8		+		+		+		
Mycelium sterilium 9		+		+		+		
Mycelium sterilium 10		+		+		+		

Annotated list of fungi from living and decomposing Sphagnum fuscum *plants*

Acremonium chrysogenum (Thisum. & Sukop.) W. Gams

Conidia ellipsoidal (2.8)–3.5–(4.1) μm × (1.0)–1.5–(1.9) μm; widespread; reported from soil, decaying vegetation, marine water (Gams 1971), first report from *S. fuscum*; cellulolytic, lignolytic, utilizes fats and other carbohydrates (Gams 1971).

Acremonium cf. *curvulum* W. Gams

Colony 13–21 mm in diam. after ten days on MEA; mycelium mostly submerged and appressed, few white tufts, reverse faint creamy-yellow to faint yellow-orange; phialides simple, smooth, no collarette, tapering towards apex, (20)–44–(80) μm; conidia lightly to acutely curved, weakly apiculate at base, rounded at tip, sparsely produced, (5.0)–6.3–(8.1) μm × (1.3)–1.9–(2.2) μm; uncommon; reported from soil, water, vegetation (Gams 1971), first report from *S. fuscum*; cellulolytic, utilizes starch (this study).

Our isolates differ from *A. curvulum* because they are slower to sporulate, have scant aerial mycelium, and less intense coloration of the medium. Conidial and phialidic dimensions and growth rates are similar to *A. curvulum.* Our isolates were used in a study examining cell wall degradation of *S. fuscum* (Tsuneda et al. 2001).

Acremonium strictum W. Gams

Conidia cylindric, (4.0)–4.4–(5.7) μm × (0.9)–1.5–(2.0) μm; cosmopolitan; reported from soil, vegetation, wood, fungi, dung, jet fuel, aquatic habitats, human tissues, and air (Domsch et al. 1980), first report from *S. fuscum*; utilizes a variety of carbohydrates (Domsch & Gams 1969), cellulolytic, gelatinolytic (this study).

Aspergillus niger van Tieghem

Conidia globose, verrucose, (3.5)–4.8–(5.4) μm; cosmopolitan; reported from soil, animals, human tissues, foods, decaying vegetation, and air (Domsch et al. 1980; Klich & Pitt 1994), first report from *S. fuscum*; chitinolytic (Kawasaki & Ito 1964), utilizes starch (Barton et al. 1972), fats, tannins, and other carbohydrates (Domsch et al. 1980).

Aspergillus versicolor (Vuill.) Tiraboschi

Conidia globose, echinulate, (2.2)–2.7–(3.0) μm; cosmopolitan; reported from soil, vegetation, animals, water, and foods (Domsch et al. 1980), first report from *S. fuscum*; weakly cellulolytic (Reese & Downing 1951), pectinolytic (Domsch et al. 1980), utilizes starch (Franz 1975) and a variety of carbohydrates (Trique 1968).

Basidiomycete sp. 1

Colonies 83 and 74 mm in diam. after seven days on MEA and PDA, respectively, reverse bleached; aerial mycelium white, patchy, floccose; hyphae smooth, hyaline, 2.0–4.0 μm in diam.; clamp connections abundant; conidiophores absent or micronematous; arthroconidia hyaline, abundant, dry, aseptate, smooth, various shapes (rectangular, barrel-shaped, curved, edges rounded when mature), (4.0)–6.0–(16.0) μm × (2.0)–3.0–(4.0) μm; odor sweet; exudate clear to golden-yellow, abundant, among aerial hyphae; isolated on PDA and PDA with benomyl; polyphenol oxidase negative, laccase positive, cellulolytic (this study).

Basidiomycete sp. 2

Colonies 85 and 80 mm in diam. after seven days on MEA and PDA, respectively, reverse not bleached; aerial mycelium white, patchy; hyphae hyaline, smooth, 2.5–4.0 μm in diam.; clamp connections absent; conidiophores absent or micronematous; arthroconidia hyaline, abundant, dry, aseptate, smooth, various shapes (rectangular, barrel-shaped, curved, branched, edges rounded when mature), abundant, dry, (3.0)–4.5–(6.0) μm × (2.0)–2.5–(3.0) μm; chlamydospores absent; odor absent; exudate absent; isolated on PDA with rose bengal; polyphenol oxidase negative, laccase positive (this study).

Bjerkandera adusta (Willd.: Fr.) Karst.

Mycelium white, cottony-wooly, colony reverse bleached; clamp connections absent; arthroconidia hyaline, rectangular, abundant, dry, (5)–9–(13) μm × (2.5)–3.0–(3.5) μm; odor strong, sweet; cosmopolitan; from wood (Stalpers 1978), first report from *S. fuscum*; polyphenol oxidase positive, laccase positive (Stalpers 1978).

The presence of simple septa, the bleached colony reverse, strong odor, and a positive reactions for laccase separates this basidiomycete from other arthroconidial basidiomycetes (Stalpers 1978) and the mycoparasite *Geotrichopsis mycoparasitica* Tzean & Estey (Tzean & Estey 1991). Additionally, exudate absence, bleached colony reverse, sweet odor, clamp connection presence, and polyphenol oxidase synthesis separates *B. adusta* from basidiomycetes 1 and 2.

Botrytis cinerea Pers.: Pers.

Macroconidia pale brown, obovoid, smooth-walled, often with protuberant hilum, (10)–11–(13) μm × (5)–6–(7) μm; microconidia globose, (2.4)–2.8–(3.2) μm; cosmopolitan; reported from vegetation, animal tissues, air, and soil (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic (Basu & Ghose 1960), pectinolytic (Domsch & Gams 1969), utilizes tannin (Flanagan & Scarborough 1974) and other carbohydrates (Domsch et al. 1980).

Cladosporium herbarum (Pers.) Link: S. F. Gray

Conidia ellipsoidal to cylindric, ends rounded, verruculose, scars prominent, (2)–8–(16) μm × (2)–3–(4) μm; cosmopolitan; reported from vegetation, soil, aquatic habitats, dung, animal tissues, air, and food (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic (Marsh et al. 1949), pectinolytic (Domsch & Gams 1969), utilizes lignin and starch (Domsch 1960).

Fusarium aquaeductuum var. *medium* Wollenw.

Phialides simple or branched near the base, septate, (58)–80–(119) μm; macroconidia curved to (sometimes) straight, (usually) tri-septate, (38)–44–(52) μm × (3.8)–4.3–(5.0) μm; microconidia ellipsoidal to slightly curved, (sometimes) septate, (6)–7–(10) μm × (1.5)–1.8–(2.0) μm; cosmopolitan; reported from water, sewage, fungal sporocarps, peat (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic (Gersonde & Kerner-Gang 1968), utilizes polyphenolics (Barz et al. 1976).

Kernia retardata Udagawa & Muroi

Ascomata black, globose to pyriform, non-ostiolate, (140)–185–(250) μm; ascospores reddish-brown, single-celled, reniform, smooth, (5.0)–5.4–(6.0) μm × (3.0)–4.3–(5.0) μm; uncommon; reported from decaying vegetation, foods, soil, dung, wood (Lumley et al. 2000), first report from *S. fuscum*; cellulolytic, gelatinolytic, utilizes starch (this study). Anamorph a *Scopulariopsis*; conidia (4.0)–5.9–(7.0) μm × (2.0)–2.3–(2.5) μm (ALTA 10703).

Monocillium constrictum W. Gams

Colony faint orange to ochre; phialides simple, densely arranged along hyphae, (8)–11–(19) μm; conidia slightly curved, apex rounded, base apiculate, (4)–5–(6) μm × (1.0)–1.4–(1.7) μm; cosmopolitan; reported from plants, air, fungal sporocarps (Gams 1971), first report from *S. fuscum*; cellulolytic, gelatinolytic, utilizes tannic acid and starch (this study).

Mortierella alpina Peyronel

Sporangiophores simple, swollen at the base; sporangiospores ellipsoidal to cylindric, (3.5)–4.1–(5.0) μm × (1.5)–2.2–(2.5) μm; cosmopolitan; reported from soil (Domsch et al. 1980), first report from *S. fuscum*; chitinolytic (Domsch 1960), utilizes other carbohydrates (Mil'ko & Gabryushina 1968).

Mortierella elongata Linnem.

Sporangiophores simple or branched near the base; sporangiospores ellipsoidal to short-cylindric, (6.0)–8.2–(10.0) μm × (3.0)–4.5–(6.0) μm; cosmopolitan; reported from soil, rhizosphere of plants (Domsch et al. 1980), first report from *S. fuscum*; weakly pectinolytic (Domsch & Gams 1969), chitinolytic (Jackson 1965), utilizes other carbohydrates (Mil'ko & Gabryushina 1968).

Mortierella horticola Linnem.

Sporangiophores simple or with one side-branch; sporangiola spheric to globose, spinulose, (8)–11–(15) μm; cosmopolitan; reported from soil, roots of herbaceous plants (Domsch et al. 1980), first report from *S. fuscum*; chitinolytic (Jackson 1965).

Mortierella humilis Linnem.

Sporangiophores branched near the base; sporangiola spheric to globose, finely verrucose, (7)–11–(15) μm; cosmopolitan; reported from a variety of soils and compost (Domsch et al. 1980), first report from *S. fuscum*; chitinolytic (Gray & Baxby 1968), utilizes other carbohydrates (Mil'ko & Gabryushina 1968).

Mortierella isabellina Oudem. & Koning

Sporangiophores simple or branched; sporangiospores globose to slightly angular, (2.2)–2.6–(3.1) μm; cosmopolitan; reported from soil and vegetation (Domsch et al. 1980), first report from *S. fuscum*; utilizes a variety of carbohydrates (Mil'ko & Gabryushina 1968).

Mortierella minutissima van Tieghem

Sporangiophores simple or branched near base; sporangiospores globose, (3.5)–4.0–(5.0) μm; cosmopolitan; reported from soil and wood (Domsch et al. 1980), first report from *S. fuscum*; chitinolytic (Gray & Baxby 1968), utilizes other carbohydrates (Mil'ko & Gabryushina 1968).

Mortierella ramanniana Möller

Sporangiophores simple or branched; sporangiospores angular, smooth, (2.4)–3.0–(3.6) μm (var. *angulispora* (Möller) Linnem.) or oval to ellipsoid, smooth, (2.8)–3.3–(3.8) μm (var. *ramanniana* (Naumov) Linnem.); cosmopolitan; reported from soil, decaying vegetation, dung, and animal tissues (Domsch et al. 1980), first report from *S. fuscum*; pectinolytic, cellulolytic, utilizes starch (Flanagan & Scarborough 1974).

Mortierella renispora Dixon-Stewart

Sporangiophores simple, with a broad foot cell; sporangiospores globose to reniform, (1.5)–2.1–(2.5) μm × (4.0)–4.1–(4.5) μm; cosmopolitan; reported from soil (Dixon-Stewart 1932; Mehrotra & Mehrotra 1964), first report from *S. fuscum.*

Mortierella verticillata Linnem.

Sporangiophores verticillately branched; sporangiola spheric to globose, (7)–10–(13) μm; cosmopolitan; reported from soil and roots of plants (Domsch et al. 1980), first report from *S. fuscum*; chitinolytic (Gray & Baxby 1968).

Mucor hiemalis Wehmer

Sporangiophores simple or slightly sympodially branched, up to 1.8 cm long; sporangiospores ellipsoidal, (4.8)–5.6–(7.0) μm × (2.5)–3.1–(4.8) μm; cosmopolitan; reported from soil, vegetation, dung, and foods (Domsch et al. 1980), first report from *S. fuscum*; hemicellulolytic (Loub 1960), chitinolytic (Domsch 1960), pectinolytic (Domsch & Gams 1969), utilizes starch (Franz 1975).

Nodulisporium sp.

Colony grayish-brown, velvety towards margin, 20 mm in diam. after seven days on MEA; conidiophores branched, (46)–118–(259) μm; conidiogenous cells (12)–18–(24) μm; conidia light brown, solitary, dry, truncate, ellipsoidal to obovoid, (3.2)–3.8–(4.1) μm × (1.3)–1.7–(2.1) μm; the genus is cosmopolitan; species are reported from herbaceous plants, wood, decomposing plant materials (Deighton 1985; Ellis 1971); cellulolytic, utilizes starch (this study).

Oidiodendron maius Barron

Conidiophores (150)–260–(350) μm × (1.8)–2.8–(3.8) μm; arthroconidia hyaline, (3.0)–3.6–(4.0) μm × (1.9)–2.1–(2.2) μm; cosmopolitan; reported from soil and roots of Ericaceae (Hambleton & Currah 1997), first report from *S. fuscum*; pectinolytic, cellulolytic, utilizes starch, gelatin, and tannic acid (this study). This isolate was used in a study examining the degradation of *S. fuscum* cell walls (Tsuneda et al. 2001).

Oidiodendron scytaloides Gams & Söderström

Conidiophores (35)–75–(225) μm; arthroconidia hyaline, (2.0)–3.1–(4.0) μm × (1.3)–1.6–(1.7) μm; chlamydospores dark, ellipsoidal, finely verrucose, in terminal

and intercalary series, (3.2)–4.1–(6.0) μm × (2.0)–2.9–(4.8) μm; cosmopolitan; reported from conifer forest soil (Gams & Söderström 1983), first report from *S. fuscum*; pectinolytic, utilizes starch, tannic acid (this study).

Paecilomyces marquandii (Massee) Hughes

Diffusible yellow pigment on MEA; phialides swollen at base with long, tapering neck, (9)–11–(12) μm; conidia fusiform, in chains, (3.0)–3.6–(4.3) μm × (1.8)–2.1–(2.5) μm; cosmopolitan; reported from soil (Domsch et al. 1980), first report from *S. fuscum*; gelatinolytic (Borut 1960), chitinolytic (Jackson 1965), utilizes starch (Franz 1975).

Penicillium funiculosum Thom

Conidiophores biverticillate, (59)–74–(140) μm; phialides acerose, (9)–11–(12) μm; conidia ellipsoidal to spheric, (2.5)–2.9–(3.4) μm; cosmopolitan; reported from soil (Pitt 1988), first report from *S. fuscum*; cellulolytic (Gochenaur 1975), utilizes various sugars (Dickinson & Boardman 1970) and starch (Dickinson & Boardman 1970).

Penicillium lividum Westling

Conidiophores monoverticillate, distinctly vesiculate, (150)–180–(240) μm; phialides ampulliform, (7)–9–(10) μm; conidia blue, broadly ellipsoidal, distinctly rough-walled, (3.3)–3.8–(4.1) μm; cosmopolitan; reported from peatlands, undisturbed forest soils (Christensen & Backus 1961; Pitt 1988), first report from *S. fuscum*; cellulolytic (Franz & Loub 1959), pectinolytic, utilizes starch (Flanagan & Scarborough 1974).

Penicillium montanense Christensen & Backus

Conidiophores monoverticillate, distinctly vesiculate, (150)–180–(240) μm; phialides ampulliform, (9)–11–(12) μm; conidia grayish turquoise, spheric, distinctly spinose, (3.2)–3.6–(4.1) μm; common; reported from bogs and conifer forests (Christensen & Backus 1962; Christensen & Whittingham 1965), first report from *S. fuscum.*

Penicillium pupurogenum Stoll

Diffusible red pigment on Czapek's Yeast Extract agar; conidiophores biverticillate, (95)–210–(295) μm; phialides ampulliform, (8)–10–(12) μm; conidia spheric to ellipsoidal, rough-walled, (2.9)–3.2–(3.5) μm; cosmopolitan; reported from soil (Pitt 1988), first report from *S. fuscum*; cellulolytic, pectinolytic, utilizes starch (Flanagan & Scarborough 1974).

Penicillium thomii Maire

Conidiophores monoverticillate, distinctly vesiculate, (280)–310–(370) μm; phialides ampulliform, (8)–10–(12) μm; conidia sub-spheric to ellipsoidal, rough-walled, (3.5)–4.0–(4.5) μm; cosmopolitan; reported from decaying vegetation, foods, fungi, soil (Pitt 1988); pectinolytic (Flanagan & Scarborough 1974), cellulolytic (Jefferys et al. 1953).

Sordaria fimicola (Rob.) Ces. & de Not.

Ascospores dark brown to black, single-celled, broadly fusiform to ovoid and/or subglobose, germ pore, gelatinous sheath, (20)–23–(26) μm × (10)–13–(15) μm; cosmopolitan; reported from a variety of substrates, principally the dung of herbivores and soil (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic, utilizes starch (this study).

Sporormiella intermedia (Auersw.) Ahmed & Cain

Ascospores dark brown to black, multiseptate (typically triseptate) with constrictions at septa, gelatinous sheath, oblique germ slits, (50)–58–(65) μm × (10)–12–(13) μm; widespread; reported from herbivore and carnivore dung (Ahmed & Cain 1972), first report from *S. fuscum*; utilizes starch (this study).

Sporothrix state of *Ophiostoma stenoceras* (Robak) Melin & Nannf.

Phialides simple, erect, (22)–30–(43) μm, with an inconspicuous conidiogenous denticle at apex; conidia hyaline, ovoid to fusiform, (3.2)–4.4–(5.2) μm × (1.1)–1.5–(1.9) μm; sexual state immature; cosmopolitan; reported from wood, herbaceous plants, human tissues, soil (de Hoog 1974), first report from *S. fuscum*; pectinolytic, utilizes starch, tannic acid (this study).

Sporothrix sp.

Mycelium hyaline when young, becoming purplish to black after 10 d on MEA, mycelium purple on cereal agar; phialides simple, erect, (3)–7–(15) μm, conidiogenous denticle at apex, 2–3 μm wide; phialidic conidia hyaline, ovoid to fusiform, single-celled, contain large oil body, (2.0)–2.8–(3.2) μm × (1.3)–1.8–(2.0) μm; lateral conidia pale brown, abundant, globose, (1.5)–2.5–(3.2) μm. The genus is reported from soil, plants, human tissues, decomposing vegetation (de Hoog 1974); gelatinolytic, unable to utilize tannic acid, starch, or pectin (this study).

Trichoderma aureoviride Rifai

Colony reverse golden to golden-yellow from needle-shaped crystals in medium; conidia obovoid, smooth, (2.2)–3.9–(4.4) μm × (1.9)–2.6–(3.1) μm; cosmopolitan; reported from soil, vegetation, cork (Rifai 1969), first report from *S. fuscum*; cellulolytic, gelatinolytic, utilizes starch (this study).

Trichoderma harzianum Rifai

Conidia subglobose to oval, smooth, (2.2)–2.5–(3.0) μm; cosmopolitan; reported from soil, vegetation, paper, textiles, and jet fuel (Domsch et al. 1980); cellulolytic (Park 1976), utilizes starch (Franz 1975) and other carbohydrates (Domsch et al. 1980).

Trichoderma polysporum (Link: Pers.) Rifai

Mycelium white, sterile hyphae extend beyond phialide apices; conidia ellipsoidal, smooth, (3.3)–3.6–(4.0) μm × (1.4)–1.8–(2.1) μm; cosmopolitan; reported from soil, plant litter, rhizosphere of plants (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic (Park 1976), weakly chitinolytic (Jackson 1965), utilizes a variety of sugars (Danielson & Davey 1973).

Trichoderma viride Pers.: S. F. Gray

Conidia green, globose, roughened, (3.2)–3.7–(4.1) μm; cosmopolitan; reported from soil, aquatic ecosystems,

vegetation, dung, foods, and animal tissues (Domsch et al. 1980); cellulolytic (Reese & Levinson 1952), pectinolytic (Domsch & Gams 1969), chitinolytic (Domsch 1960), gelatinolytic and utilizes starch (this study).

Verticillium bulbillosum W. Gams & Malla

Conidia curved, in slimy heads, length variable, primary conidia often longer and more curved than secondary conidia, (2)–3–(6) μm × (1)–1–(2) μm; chlamydospores intercalary or terminal on lateral hyphae; uncommon; reported from soil, ectomycorrhizal fungi (Gams 1971); cellulolytic, gelatinolytic, utilizes starch (this study).

Verticillium cephalosporium W. Gams

Conidia globose to subglobose, (2.0)–3.3–(4.3) μm × (1.0)–1.4–(1.8) μm; uncommon; reported from soil (Gams 1971), first report from *S. fuscum*; cellulolytic, gelatinolytic, utilizes starch (this study).

Verticillium lecanii (Zimm.) Viégas

Conidia cylindric to ellipsoidal, in slimy heads, (3.1)–4.7–(6.5) μm × (1.6)–1.9–(2.2) μm; cosmopolitan; reported from soil, insects, plant litter (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic, chitinolytic (Domsch 1960), pectinolytic, utilizes starch (Flanagan & Scarborough 1974).

Verticillium psalliotae W. Gams

Conidia sickle-shaped with pointed ends, in slimy heads, (5.2)–6.7–(8.5) μm × (1.0)–1.2–(1.7) μm; widespread; reported from fungi, dung, soil, and insects (Domsch et al. 1980), first report from *S. fuscum*; cellulolytic, gelatinolytic, utilizes starch (this study).

Mycelia sterilia

Twelve records remained sterile in culture and could not be named. Morphological, physiological, and cultural characteristics were used to separate these into ten distinct taxa.

1.—Colonies 80 and 70 mm in diam. after seven days on MEA and PDA, respectively; mycelium white, patchy; hyphae hyaline, smooth, 2.5–4.0 μm in diam.; benomyl tolerant; isolated on PDA with benomyl; cellulolytic, gelatinolytic, unable to utilize cellulose, pectin, starch, or tannic acid (this study).

2.—Colonies 12 and 8 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium white, patchy; hyphae hyaline, septate, smooth, forming coils, 2.5–3.5 μm in diam.; isolated on PDA; gelatinolytic, utilizes starch, unable to utilize cellulose, pectin, or tannic acid (this study).

3.—Colonies 7 and 5 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium mouse grey, abundant; hyphae dematiaceous, septate, smooth, toruloid cells frequent, forming coils, 2.5–3.0 μm in diam.; isolated on MA; unable to utilize cellulose, gelatin, pectin, starch, or tannic acid (this study).

4.—Colonies 82 and 70 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium white, scant; hyphae hyaline, septate, smooth, 4.0–5.5 μm in diam.; chlamydospores abundant, smooth, 8–10 μm in diam.; isolated on PDA; utilizes gelatin, starch, and tannic acid, unable to utilize cellulose or pectin (this study).

5.—Colonies 43 and 44 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium white, patchy; hyphae hyaline, septate, smooth, swollen near septa, 4.0–5.5 μm in diam.; isolated on PDA; gelatinolytic, unable to utilize cellulose, pectin, starch, or tannic acid (this study).

6.—Colonies 83 and 78 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium white, patchy; hyphae hyaline, septate, smooth, 2.5–3.0 μm in diam.; isolated on PDA; cellulolytic, gelatinolytic, utilizes starch, unable to utilize pectin or tannic acid (this study).

7.—Colonies 65 and 80 mm in diam. after seven days on MEA and PDA, respectively; aerial mycelium white, patchy; hyphae hyaline, septate, smooth, thick-walled, swollen near septa, 2.5–4.0 μm in diam.; isolated on PDA with benomyl; unable to utilize tannic acid (this study).

8.—Colonies 85 mm in diam. after three days on MEA and PDA; aerial mycelium white, patchy; hyphae hyaline to tan, septate, smooth, 5.5–9.0 μm in diam.; isolated on PDA with rose bengal; cellulolytic, gelatinolytic, utilizes starch, unable to utilize pectin or tannic acid (this study).

9.—Colonies 85 mm in diam. after three days on MEA and PDA; aerial mycelium white, patchy; hyphae hyaline, septate, smooth, forming coils, 5.0–6.0 μm in diam.; hyphae hyaline, aggregates infrequent, 25–40 μm in diam.; isolated on PDA with rose bengal; cellulolytic, gelatinolytic, utilizes starch, unable to utilize pectin or tannic acid (this study).

10.—Colonies 85 mm in diam. after three days on MEA and PDA; aerial mycelium white, patchy; hyphae tan, septate, smooth, 4.5–5.5 μm in diam.; hyphal aggregates tan, abundant, 50–100 μm in diam.; isolated on PDA with rose bengal; cellulolytic, gelatinolytic, utilizes starch, unable to utilize pectin or tannic acid (this study).

Conclusions

Forty-five fungal species were identified in a systematic survey of microfungi associated with living and decomposing *S. fuscum.* Of these, 36 represent new records for fungi on *Sphagnum* and 45 species are new records for *S. fuscum.* These fungi showed varying abilities to utilize a variety of carbon sources and are important organisms in the mineralization of carbon in peatlands. Undoubtedly, there are many additional fungi that are associated with this bryophyte. Alternative culturing techniques, growth media, and growth conditions in future investigations will reveal additional fungal species and ultimately add to our understanding of the mycota associated with this dominant bog bryophyte species.

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