Investigations of fungal diversity in wooden structures and soils at historic sites on the Antarctic Peninsula[1]

Brett E. Arenz and Robert A. Blanchette

Abstract: Investigations of microbial diversity in Antarctic are important to begin to understand ecosystem functioning and decomposition processes. This study documents fungi at 9 historic sites on the Antarctic Peninsula collected from wooden structures, other organic materials, and soils during a joint National Science Foundation and British Antarctic Survey expedition in 2007. Many of these sites had wooden structures built by the British during the World War II Operation Tabarin, but others visited included the American "East Base" on Stonington Island and the Swedish hut on Snow Hill Island. Fungi were cultured on several different media and pure cultures were obtained and identified by DNA sequencing of the internal transcribed spacer region. *Cadophora* species previously found to attack historic wooden structures on Ross Island, Antarctica, were found at all but 1 location sampled in the Peninsula region. Fungi causing decay in the historic wooden structures and artifacts and those causing mold problems inside the structures are of great concern, and conservation efforts are urgently needed to help preserve these important polar heritage structures. The results presented also expand our knowledge on the identity of fungi present throughout the Antarctic Peninsula region and provide insights into the organisms responsible for decomposition and nutrient recycling.

Key words: Antarctica, fungi, wood decay, biodeterioration, historic conservation.

Résumé : Les recherches portant sur la diversité microbienne de l'Antarctique sont importantes afin de commencer à comprendre le fonctionnement de l'écosystème et les processus de décomposition. Cette étude documente les populations de champignons de 9 sites historiques de la péninsule Antarctique recueillis sur des structures de bois, sur d'autres matériaux organiques et dans le sol, au cours d'une expédition de la « National Science Foundation » et du « British Antarctic Survey en 2007 ». Des structures de bois construites par les Britanniques lors de l'Opération Tabarin pendant la deuxième guerre mondiale étaient présentes sur plusieurs sites, les autres sites visités comprenant la base américaine « East Base » de l'Île de Stonington et les cabanes construites pas les Suédois sur l'Île Snow Hill. Les champignons ont été cultivés sur différents milieux, des cultures purifiées ont été obtenues et identifiées par séquençage d'ADN de la région de l'espaceur interne transcrit (ITS). Des espèces appartenant à *Cadophora*, tenues précédemment responsables de la détérioration des structures de bois de l'Île Ross en Antarctique, ont été trouvées dans tous les sites échantillonnés de la péninsule sauf un. Les champignons causant la pourriture des structures de bois historiques et des artéfacts et ceux qui causent des problèmes de moisissure à l'intérieur de ces structures sont préoccupants et des efforts sont instamment requis pour aider à préserver cet héritage polaire d'importance. Les résultats présentés élargissent aussi nos connaissances sur l'identité des champignons présents à travers la région de la péninsule Antarctique et donnent un aperçu des organismes responsables de la décomposition et du recyclage des nutriments.

Mots-clés : Antarctique, pourriture du bois, détérioration biologique, conservation historique.

[Traduit par la Rédaction]

Introduction

The Antarctic Peninsula has been the target of significant exploration over the past decades and many nations constructed huts or relatively large bases there in the early and middle part of the last century. The British in particular established a large presence in this region for not only scientific and geographic exploration, but also to reinforce their claims of territorial sovereignty. The buildings and materials left behind from these expeditions still exist and many have been classified as historic monuments by the Antarctic treaty system, but unfortunately deterioration and decay are causing significant problems for their long term preservation.

Past research on historic wooden structures in other regions of Antarctica has found that they are affected by both abiotic and biotic forms of degradation. Abiotic forms include wind erosion, oxidation of metals (Otineo-Alego et al. 2000), and salt defibration of wood fibers (Blanchette et al. 2002). Biotic deterioration is largely due to fungi that can cause both disfiguring mold growth on the surface of artifacts and a soft-rot type of wood decay (Blanchette et al.

Received 30 September 2008. Accepted 1 October 2008. Published on the NRC Research Press Web site at cjm.nrc.ca on 30 January 2009.

B.E. Arenz[2] and R.A. Blanchette.[3] Department of Plant Pathology, University of Minnesota, 495 Borlaug Hall, 1991 Upper Buford Circle, St. Paul, Minnesota 55108, USA.

[1]This article is one of a selection of papers in the Special Issue on Polar and Alpine Microbiology.

[2]Corresponding author (e-mail: aren0058@umn.edu).
[3]Corresponding author (e-mail: robertb@umn.edu).

2004*a*). The fungi found to be responsible for decaying wood were several species of *Cadophora* including *Cadophora malorum*, *Cadophora luteo-olivaceae*, and *Cadophora fastigiata*, as well as several previously undescribed *Cadophora* species. Although this past research took place in the Ross Sea region of Antarctica where it is relatively very cold and dry, environmental monitoring inside the huts has revealed that during the Austral summers conditions that are conducive to fungal growth (temperatures above 0 °C and relative humidity above 80%) occur frequently (Held et al. 2005). A survey of fungal diversity at these Ross Sea historic sites has found that the most abundantly isolated species affecting the historic wood and artifacts were also isolated from soils around the structures and from more distant and remote areas (Arenz et al. 2006). A number of cosmopolitan species were also identified that had not been previously reported from Antarctica although these species were found in relatively low frequency.

Historic sites on the Antarctic Peninsula have not been the subject of mycological investigations and little is known about the microorganisms present in these areas. If these polar heritage sites are to be adequately preserved, it is important for conservators to know what factors are contributing to the deterioration and decay of the wood and artifacts. Since the Antarctic Peninsula has a relatively warmer and more humid climate than the Ross Sea region of Antarctica, degradation processes likely take place faster and a greater abundance of diverse fungi could be expected. This study was done to determine fungal diversity present at 9 historic sites on the Antarctica Peninsula in woods, organic materials, and soils, to make comparisons with other previous studies completed on the opposite side of Antarctica in the Ross Sea region and to learn more about these organisms and their role in polar ecosystems.

Materials and methods

Nine sites on the Antarctic Peninsula were visited in January 2007 from the British Antarctic Survey (BAS) ship HMS *Endurance* (Table 1). The sites consisted of 7 historic British bases: Base A (Port Lockroy Station), Base D on Hope Bay, Base E on Stonington Island, Base F (Wordie House), Base V (View Point Station), and Base W on Detaille Island; and Base Y on Horseshoe Island (Fig. 1). In addition, Otto Nordenskjöld's Swedish expedition hut on Snow Hill Island was visited as well as the oldest standing American base in Antarctica, East Base, on Stonington Island (Fig. 2). Small samples (<100 g) of wood, soil, and other organic artifacts, such as textiles, rope, and foodstuffs, were collected, placed in sterile bags, and kept at 4 °C onboard the HMS *Endurance* until they were brought to the laboratory at the University of Minnesota, St. Paul, Minnesota, for processing at the conclusion of the 4 week trip.

Fungi were isolated from the samples by culturing on several types of media including malt extract agar (1.5% Difco malt extract), a semiselective medium to culture basidiomycetes (Worrall 1991) (1.5% Difco malt extract, 0.2% yeast extract, 0.006% benlate, with 0.2% lactic acid and 0.001% streptomycin sulfate added after autoclaving), Difco potato dextrose agar, and Sabauroud dextrose agar (4% dextrose, 1.5% agar, 1% polypeptone peptone, with 0.001% cyclohexamide and 0.005% chloramphenicol added after autoclaving). Isolates were cultured at 8 and 20 °C. Pure cultures were obtained after subsampling.

DNA was extracted by a phenol–chloroform procedure. This procedure was modified from Zhong and Steffenson (2001) in that the mycelium and the spores were collected by scraping the surface of the agar plate containing the pure isolate, rather than filtering a liquid culture. Also, 700 μL of the lysis buffer was used instead of 7 mL. Ribosomal DNA was amplified via PCR with the primers ITS1 and ITS4 (Gardes and Bruns 1993). PCR amplification was performed using an Amplitaq Gold PCR Master-mix and a 1 μL template DNA and following the manufacturer's instructions (Applied Biosystems, Foster City, California). A MJ Research PTC Minicycler (Watertown, Maryland) was used with the following profile: 94 °C for 5 min, 35 cycles of 94 °C for 1 min, 50 °C for 1 min, and 72 °C for 1 min, followed by a final extension step of 72 °C for 5 min. PCR products of appropriate size (500–600 bp) were verified by electrophoresis of the amplicons on a 1% agarose gel with a SYBR green 1 (Molecular Probes, Eugene, Oregon) prestain and transilluminating with a Dark Reader DR45 (Clare Chemical Research, Denver, Colorado). Sequencing was performed for both primers using the ABI PRISM Dye Terminator Cycle Sequencing Ready reaction kit (Applied Biosystems) and an ABI Prism 377 automated DNA sequencer. DNA sequence data were analyzed by Chromas software (Technelysium Ltd., Helensvale, Australia) and assembled into a consensus sequence. The sequences were compared with others in GenBank using BLASTn (Altschul et al. 1990) to find the best match.

Selected wood samples were cut with a cryostat freezing microtome and observed with a Hitachi S3500 scanning electron microscope (SEM).

Results and discussion

A total of 186 samples were analyzed from all locations (Table 1), a large portion of which came from East Base because this was a very large historic site and the main focus of the deterioration assessments during the event. From these samples, 81 taxa were identified from 295 fungal isolations (Table 2). Ascomycetes (58) were dominant among the isolates with a smaller component of basidiomycetes (17) and zygomycetes (6). The most predominant genus isolated was *Cadophora*, which represented 18% of all isolates, and *Cadophora* spp. were found at all sites except Nordenskjold's hut on Snow Hill Island. Other frequently isolated genera were *Penicillium* (14%) *Geomyces* (11%), *Nectria* (5%), *Rhodotorula* (5%), *Cryptococcus* (4%), *Phoma* (3%), and *Hormonema* (3%). Of the 295 total isolations, 54 were obtained from soil samples. The most frequently isolated genera from these soil samples were *Geomyces* (24%), *Cryptococcus* (19%), *Rhodotorula* (13%), *Pseudeurotium* (7%) and *Nectria* (6%).

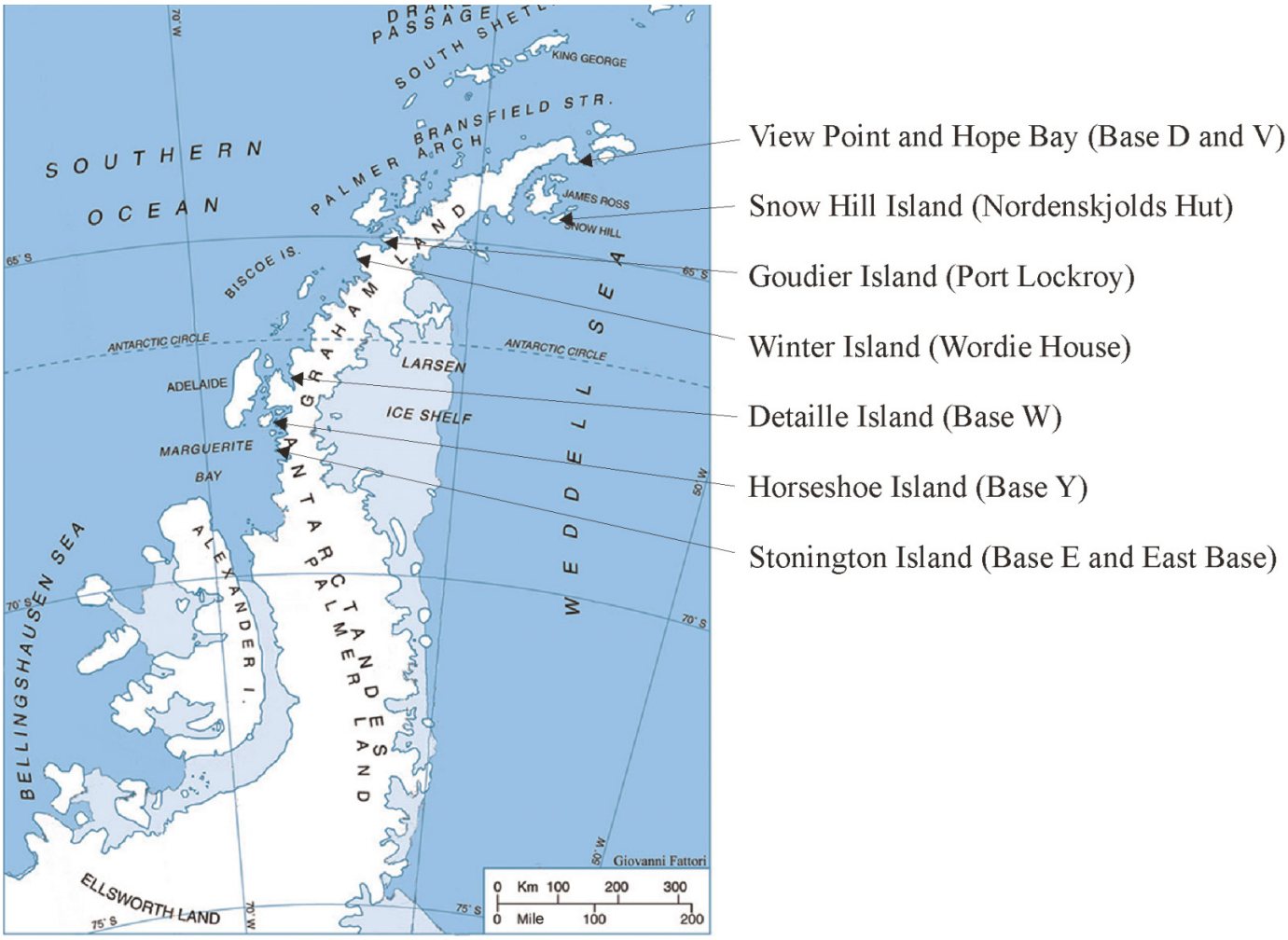
At the phylum level, 82% of the isolates were ascomycetes, 15% of the isolates were basidiomycetes, and 3% of the isolates were zygomycetes. When comparing this with previous work at Antarctic historic sites located in the Ross Sea region (Arenz et al. 2006), a similar result was found with 75% ascomycetes, 21% basidiomycetes, and 1% zy-

Table 1. Sampling locations with the original national affiliation of the site, the year of construction, and the number of samples analyzed for fungi.

Site	Location	National affiliation	Year of construction	Coordinates	No. of samples
Base D	Hope Bay	British	1945	63°24′S, 56°59′W	12
Base V (View Point)	Duse Bay	British	1953	63°32′S, 57°23′W	10
Nordenskjöld's Hut*	Snow Hill Island	Swedish	1902	64°27′S, 57°12′W	19
Base A (Port Lockroy)*	Goudier Island	British	1944	64°49′S, 63°30′W	16
Base F (Wordie House)*	Winter Island	British	1947	65°15′S, 64°16′W	15
Base W	Detaille Island	British	1956	66°52′S, 66°48′W	18
Base Y*	Horseshoe Island	British	1955	67°49′S, 67°18′W	20
East Base*	Stonington Island	American	1940	68°11′S, 67°00′W	59
Base E*	Stonington Island	British	1961	68°11′S, 67°00′W	17

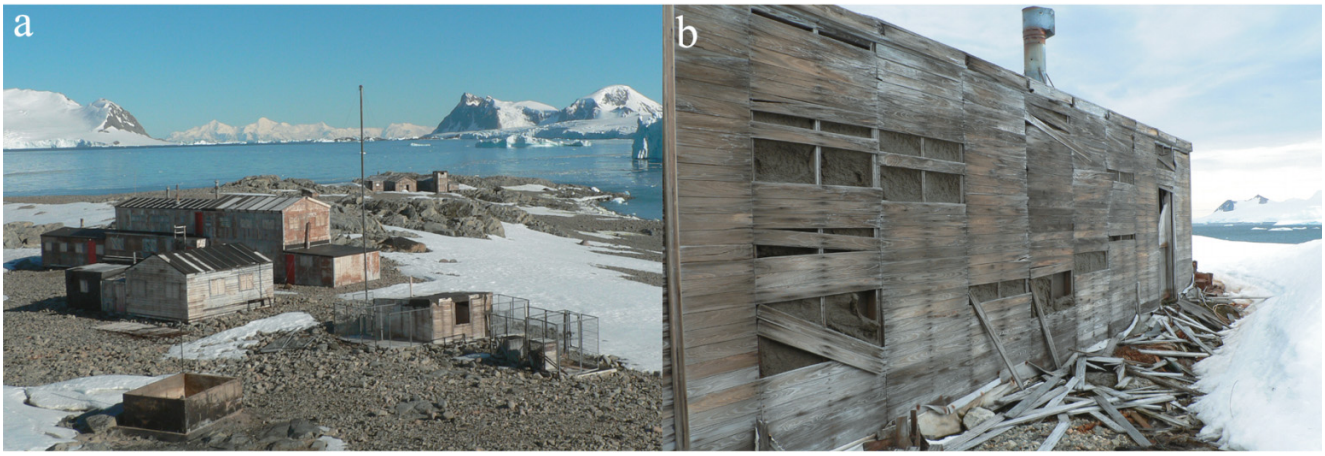
*Designated as a historic monument by the Antarctic Treaty.

Fig. 1. Map of the sampling locations on the Antarctic Peninsula.



gomycetes representing the total isolates. This agrees with a recent review (Ludley and Robinson 2008) concerning "decomposer" basidiomycota in the polar regions that found few studies reporting filamentous basidiomycetes from Antarctic regions south of the sub-Antarctic. Most of the basidiomycetes found in maritime and continental Antarctica are yeasts, and in the present study, basidiomycetous yeasts predominated. Arenz et al. (2006) recently found only yeasts and no filamentous basidiomycetes in an extensive study in the Ross Sea region. Although more research needs to be done, it is likely that ascomycetes function as the primary filamentous decomposers in the more southerly Antarctic soil ecosystems. It should be noted that, in general, filamentous fungi are less commonly isolated in the Dry Valleys and basidiomycete yeasts dominate those soil fungal communities (Atlas et al. 1978, Connell et al. 2008, Vishniac

Fig. 2. (*a*) Stonington Island, Base E (British) is in the foreground and East Base (American) is in the background. (*b*) Exterior wall of the former bunkhouse at East Base, with an abundance of dislodged and deteriorated wooden boards.



1996). Dry Valley soils are characterized by very arid conditions and low nutrient availability, even by Antarctic standards, and these conditions may be responsible for excluding filamentous ascomycetes at these sites.

Additional comparisons of this study with the Ross Sea region study (Arenz et al. 2006), show a large amount of similarity in specific fungal taxa. As a percentage of all 82 taxa identified, 62% were from identical genera, 34% were also similar species, and 21% also matched the same GenBank accessions. As a percentage of the total number of isolates this increased to 77%, 64%, and 46% for similar genera, species, and GenBank accessions, respectively. Even though the Ross Sea region study area (Arenz et al. 2006) was 10° further south and roughly 3500 km away from the historic sites in this study, the overall profile of fungal taxa appeared to be very similar.

The most noticeable difference found was the large presence of *Penicillium* spp. in this study (14%) compared with the 2% observed in the Ross Sea area investigation (Arenz et al. 2006). Many of these species are part of a larger group of *Penicillium* spp. (subgenus *Penicillium*), which have commonly been associated with spoiling of refrigerated foods and as a dominant fungal component of subglacial Arctic ice (Sonjak et al. 2006). These species are relatively rare in soils in temperate areas (Frisvad and Samson 2004) and were not found in soils analyzed from the Peninsula region in the study reported here; however, they have been reported from soils in other previous studies carried out from the Antarctic Peninsula (Hughes et al. 2007) as well as the Ross Sea region (Göttlich et al. 2003, Sun et al. 1978) and even Dry Valley soils (Connell et al. 2006).

The large presence of *Geomyces* spp. (11%) is similar to what was previously observed in the Ross Island region (14%) (Arenz et al. 2006). *Geomyces* spp. have been observed frequently in Antarctic soils (Baublis et al. 1991, Tosi et al. 2005, Connell et al. 2006), and their dominance in soil samples in this study (24%) is not surprising. Marshall (1998) speculated that they may have a keratoniphilic role in ornithogenic soils. All sites in the present study were in coastal areas with some amount of bird life, and Port Lockroy on Goudier Island is in the middle of a thriving Gentoo penguin rookery.

The most significant finding of this study is the high prevalence of *Cadophora* spp. among the historic sites visited (18% of all isolates). At least 1 isolate was found from samples at all 9 sites except Nordenskjöld's hut on Snow Hill Island. Not only has this genus emerged as the primary group of decay fungi attacking wood and complicating conservation efforts at historic sites in the Ross Sea region (Blanchette et al. 2004*a*), but it has also been isolated from historic wood from the Canadian High Arctic (Blanchette et al. 2008). Its high relative abundance on wood and artifacts in historic sites studied in this research is a cause for concern for conservators working to preserve these structures and artifacts in this environment. Results from SEM confirm that wood from where *Cadophora* species were isolated had an extensive soft-rot type of decay (Fig. 3), and in laboratory studies this genus has been found to cause the same type of decay (Held et al. 2006). Soft rot causing fungi have been found to be the dominant type of wood decay in extreme environments where conditions do not support white and brown rot fungi (Blanchette et al. 2004*b*).

Although collection time at each location did not allow for an inspection of all woods, sufficient sampling was done to provide a preliminary account of the fungi present and the condition of the historic structures. The overall condition of the sites and artifacts ranged widely from those in very good condition, such as Base Y on Horseshoe Island and Nordenskjöld's hut on Snow hill Island, to those in much more deteriorated condition, such as Station W on Detaille Island, Base D in Hope Bay, and East Base on Stonington Island (Fig. 2). The condition of the buildings was usually affected by the state of the roofs, which were largely intact at Base Y and Nordenskjöld's hut, leading to relatively dry conditions inside the structures that would restrict fungal growth. However, the roofs at Station W and Base D had lost much of their water protection properties, and, consequently, a significant amount of moisture entered the huts and large fungal blooms were observed causing significant damage to the artifacts inside. A detailed assessment of deterioration and decay at East Base has been published separately (Arenz and Blanchette 2008).

This study demonstrates that a diverse range of fungi are present at these historic sites, many of which have a circum-

Table 2. List of taxa isolated in this study including best blast match with percent identity and overall nucleotide overlap of the internal transcribed spacer (ITS) region. The number of isolations by location and total isolations are also included as well as sample type (wood (w), other (o), or soil (s)).

			Location											
Best blast match	Percent identity	Overlap	Hope Bay	View Point	Snow Hill	Port Lockroy	Wordie House	Detaille Island	Horseshoe Island	East Base	Base E	**Total no. of isolates**	Sample type	Genbank Accession No.
Ascomycetes														
Alternaria tenuissima strain bxq41209 (EF556213)	100	547/547			2							2	w	FJ235934
Ascomycete sp. 6/97-36 (AJ279469)	99.6	544/546		1								1	w	FJ235935
Ascomycete sp. BC12 (DQ317343)	99.6	529/531				3						3	w	FJ235936
Ascomycete sp. BC15 (DQ317348)	100	520/520	1	1					2	2	1	7	w, s, o	FJ235937
Ascomycete sp. WRCF-A1(AY618686)	99.8	458/459							1			1	w	FJ235938
Aureobasidium pullulans (AF121283)	99.2	523/527								1		1	w	FJ235939
Cadophora fastigiata (DQ317326)	100	546/546								7		7	w	FJ235940
Cadophora luteo-olivacea strain 18 (DQ404348)	99.8	594/595				1		2		5		8	w, o	FJ235941
Cadophora malorum (DQ317328)	100	559/559		5		9	2	3	1	10	6	36	w, o	FJ235942
Cadophora melinii strain 435 (DQ404351)	97.9	521/532	1									1	s	FJ235943
Candida novakii strain NRRL Y-27346 (DQ911449)	97.8	260/292							2			2	w	FJ235944
Candida zeylanoides (AB278160)	100	622/622								1		1	w	FJ235945
Cladosporium cf. subtilissimum CBS 172.52 (EF679390)	99.8	511/512			2							2	w, o	FJ235946
Cladosporium cladosporioides isolate 2728 (EU272532)	100	528/528			1				2	1		4	w	FJ235947
Coniochaeta ligniaria (AY198390)	99.8	550/551					2		2	2		6	w, o	FJ235948
Dactylaria sp. olrim414 (AY781221)	99.8	457/458					1					1	w	FJ235949
Dactylella tenuifusaria strain CBS617.95 (DQ494371)	92.5	136/147					1					1	w	FJ235950

Table 2 (*continued*).

Best blast match	Percent identity	Overlap	Location									**Total no. of isolates**	Sample type	Genbank Accession No.
			Hope Bay	View Point	Snow Hill	Port Lockroy	Wordie House	Detaille Island	Horseshoe Island	East Base	Base E			
Davidiella macrospora strain CBS 138.40 (EU167591)	100	538/538			2							2	w, o	FJ235951
Debaryomyces hansenii voucher MCCC2E00222 (EF194843)	100	613/613			2	1	1					4	w, s	FJ235952
Dothioraceae sp. BC10 (DQ317340)	100	562/562		1					1			2	w	FJ235953
Exophiala sp. BC36 (DQ317336)	100	565/565		2				3	1			6	w, o	FJ235954
Foliar endophyte of *Picea glauca* sp. Q1 (AY561213)	99.4	517/520					3			2	1	6	w, o	FJ235955
Fungal endophyte isolate 5 (EU747834)	99.6	511/513			1							1	o	FJ235956
Geomyces pannorum strain VKM FW-969 (DQ189225)	100	528/528	1						4	3		8	w, s	FJ235957
Geomyces sp. BC7 (DQ317337)	100	556/556			1	4			3	5	2	15	w, o, s	FJ235958
Geomyces sp. BC9 (DQ317339)	100	552/552				1		1		4		6	w, o, s	FJ235959
Geomyces sp. FMCC-3 (DQ499473)	99.5	547/550								1		1	w	FJ235960
Geomyces sp. T489/9b (AY345348)	99.6	516/518								1		1	s	FJ235961
Helotiales sp. MK9 (EU700254)	96.4	459/476			1							1	s	FJ235962
Hirsutella sp. ICMP14250 (EF029185)	97.4	526/540					1					1	w	FJ235963
Hormonema dematioides E99156 (AY253451)	100	574/574		2					1	6	1	10	w, o	FJ235964
Iceman fungal clone T2709 (X88771)	97.4	484/497	1							3		4	w, s	FJ235965
Nectria sp. olrim170 (QY805576)	99.6	472/474					1					1	w	FJ235966
Nectriaceae sp. BC4 (DQ317333)	98.2	514/517	1	1	1	2	1	2	1	4		13	w, o, s	FJ235967
Oidiodendron griseum strain UAMH 8528 (AF062796)	97.5	512/525								1		1	w	FJ235968
Penicillium camemberti isolate 944 (DQ681327)	99.8	530/531		1								1	w	FJ235969

Table 2 (*continued*).

Best blast match	Percent identity	Overlap	Location									**Total no. of isolates**	Sample type	Genbank Accession No.
			Hope Bay	View Point	Snow Hill	Port Lockroy	Wordie House	Detaille Island	Horseshoe Island	East Base	Base E			
Penicillium chrysogenum isolate NRRL 35688 (EF200101)	100	573/573			1							1	o	FJ235970
Penicillium commune isolate NRRL 35686 (EF200099)	100	562/562		1	1							2	w	FJ235971
Penicillium corylophilum strain FRR 802 (AY373906)	100	559/559									1	1	o	FJ235972
Penicillium mali (AF527056)	100	547/551			1		1	1		3		6	w, o	FJ235973
Penicillium roquefortii strain FRR 849 (AY373929)	100	570/570							1	1		2	w	FJ235974
Penicillium sp. BC37 (DQ317344)	100	571/572	4		3		1	3		11	3	25	w, o	FJ235975
Penicillium sp. Psf-2 (EF660439)	100	561/562			1							1	o	FJ235976
Penicillium verrucosum strain ATCC 44407 (AY373937)	100	562/562								1	2	3	w, o	FJ235977
Phialocephala dimorphospora isolate olrim310 (AY606304)	99.4	473/476					1					1	w	FJ235978
Phoma herbarum strain ATCC 26648 (AY293800)	98.5	525/533		1	3					2		6	w, o	FJ235979
Protoventuria alpina strain CBS 140.83 (EU035444)	99.6	552/559		2					1			3	w, o	FJ235980
Pseudeurotium bakeri strain MCJAxII (DQ529304)	99.2	514/517				2		1				3	s	FJ235981
Pseudeurotium desertorum CBS 986.72 (AY129288)	95.6	488/510		1								1	s	FJ235982
Rhinocladiella atrovirens strain WRCF-AB3 (AY618683)	99.2	508/512					2					2	w	FJ235983
Sydowia polyspora strain CUBC-F1 (DQ787428)	99.8	508/509									1	1	w	FJ235984
Thelebolaceae sp. BC17 (DQ317350)	100	524/524							1			1	s	FJ235985
Thelebolaceae sp. BC18 (DQ317351)	99.8	526/527				1					1	2	w	FJ235986

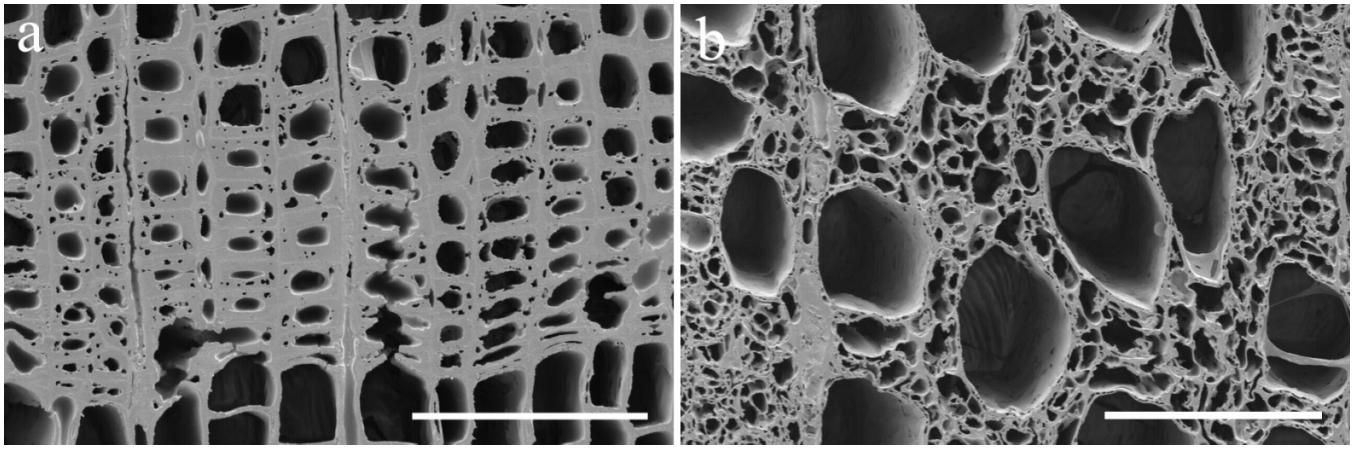
Table 2 (*continued*).

Best blast match	Percent identity	Overlap	Location									**Total no. of isolates**	Sample type	Genbank Accession No.
			Hope Bay	View Point	Snow Hill	Port Lockroy	Wordie House	Detaille Island	Horseshoe Island	East Base	Base E			
Ulocladium botrytis strain UAMH 7841 (AY625070)	99.8	576/577			2							2	w, o	FJ235987
Uncultured ascomycete (AM901709)	100	585/585									1	1	w	FJ235988
Uncultured ascomycete (AM901737)	99.7	572/574	2		2	2	1		1			8	w, s	FJ235989
Uncultured fungus isolate PS21 (EF159531)	99.6	501/503		1								1	w	FJ235990
Uncultured *Pyronemataceae* clone DGGE band BD6 (DQ317369)	99.7	338/339					1					1	w	FJ235991
Basidiomycetes														
Amyloathelia crassiuscula (DQ144610)	92.1	537/646					3					3	w	FJ235992
Antarctic yeast CBS 8913 (AY040666)	98.2	561/571									1	1	w	FJ235993
Cerinosterus luteoalbus strain WRCF-AW12 (AY618667)	95.4	413/433							1			1	w	FJ235994
Cryptococcus gastricus strain ATCC 32042 (EU266562)	99.8	607/608	2						1			3	s	FJ235995
Cryptococcus sp. BC25 (DQ317361)	99.8	491/492					1					1	o	FJ235996
Cryptococcus sp. NRRL Y-17490 (AF444449)	100	594/594								1		1	o	FJ235997
Cryptococcus sp. YSAR10 (AM922286)	99.8	587/588						1				1	s	FJ235998
Cryptococcus terricola ATCC:32040 (EU252550)	99	591/597		1								1	s	FJ235999
Cryptococcus victoriae strain CBS 8884 (AF444645)	100	512/512	1			1		1	3			6	s, w	FJ236000
Glacial ice basidiomycete GI254 (AF261656)	100	592/592			1						2	3	s, o	FJ236001
Rhodotorula laryngis strain CBS2221 (AF190014)	100	548/548	1						1			2	w, s	FJ236002
Rhodotorula minuta strain CBS 7296 (AF444620)	97.6	520/532								1		1	w	FJ236003
Rhodotorula sp. BC22 (DQ317357)	100	560/560				1		1			2	4	w, o, s	FJ236004

Table 2 (*concluded*).

Best blast match	Percent identity	Overlap	Location									Total no. of isolates	Sample type	Genbank Accession No.
			Hope Bay	View Point	Snow Hill	Port Lockroy	Wordie House	Detaille Island	Horseshoe Island	East Base	Base E			
Rhodotorula sp. BC29 (DQ317365)	99.8	550/551	1	1				1	4			7	w, o, s	FJ236005
Sistotrema brinkmannii strain ATCC 26295 (DQ899094)	100	581/581	4				2	1				7	w, o	FJ236006
Sporidiobolus salmonicolor strain PYCC 5245 (EF592129)	99.8	572/573									1	1	w	FJ236007
Uncultured basidiomycete (AM901895)	99.8	584/585	1									1	s	FJ236008
Zygomycetes														
Helicostylum elegans (AB113014)	99.5	648/651								2		2	w, o	FJ236009
Mortierella sp. 04M 158 (AY842393)	100	627/627	1									1	s	FJ236010
Mortierella sp. Finse 23-07-02 (AJ541798)	97.7	618/631								3		3	w	FJ236011
Mortierella sp. WD35C (EU240119)	99.8	624/625							1			1	s	FJ236012
Mortierellaceae sp. BC21 (DQ317354)	99.8	614/615							1			1	s	FJ236013
Mucor hiemalis strain CBS 201.65 (DQ118992)	99.8	627/627	1									1	s	FJ236014
Total no. of taxa per location			23	22	28	28	26	21	37	84	26	295		

Fig. 3. (*a*) Scanning electron micrograph of soft rot in wood collected from Wordie House (Base F, Detaille Island, Antarctic Peninsula). Fungi have attacked the cells causing cavities throughout the secondary cell-wall layer. (*b*) Soft rot occurring in birch (*Betula sp*.) collected at East Base (Stonington Island, Antarctic Peninsula). Fungi have caused extensive erosion of secondary cell walls as well as cavity formation. The bar represents 100 μm.



polar distribution. Although a few filamentous basidiomycetes were found, which are rare in Antarctica, the predominant group of decay fungi appears to be ascomycetes in the *Cadophora* genus. This genus is present in abundance at all but one of the visited historic sites on the Antarctic Peninsula, and preservation efforts need to consider these destructive microbes when trying to conserve these structures and artifacts. The environmental conditions on the Antarctic Peninsula appear more conducive to wood decay than the colder and drier Ross Sea region, and decay rates are likely to be much greater. The widespread and relative abundance of *Cadophora* spp. suggests they are important organisms in soil ecosystem dynamics and nutrient recycling in these polar regions. This report also provides insight into the many other fungi that can be found in Antarctica, some of which undoubtedly play important roles for successful ecosystem functioning. Since little is known about these microorganisms, there is a need for continued study to better understand how they survive in these harsh environments and what nutrients they are utilizing in the absence of exotic substrates left behind by expeditions.

Acknowledgements

We thank the British Antarctic Survey (BAS) for providing the opportunity for a joint NSF/BAS event and specifically J. Shears, D. Burkitt, and M. Morrison for their cooperation, discussions, and assistance with sampling at the historic sites. We also thank the officers and crew of the HMS *Endurance* for accommodation and transportation to these remote locations. We thank J. Jurgens for assistance with sample preparations and SEM and B. Held for helpful discussions and assistance in the laboratory. This research serves as partial fulfillment of PhD requirements at the University of Minnesota. This work is supported by National Science Foundation Grant No. 0537143.

References

Altschul, S.F., Gish, W., Miller, W., Myers, E.W., and Lipman, D.J. 1990. Basic local alignment search tool. J. Mol. Biol. **215**: 403–410. PMID:2231712.

Arenz, B.E., and Blanchette, R.A. 2008. East Base, SOS: assessment of deterioration and recommendations for conserving this important Antarctic historic site. *In* Cultural heritage in the Arctic and Antarctic regions. *Edited by* S. Barr and P. Chaplin. Vol. XVII in the ICOMOS Monuments and Sites series. pp. 79–84.

Arenz, B.E., Held, B.W., Jurgens, J.A., Farrell, R.L., and Blanchette, R.A. 2006. Fungal diversity in soils and historic wood from the Ross Sea region of Antarctica. Soil Biol. Biochem. **38**: 3057–3064. doi:10.1016/j.soilbio.2006.01.016.

Atlas, R.M., Di Menna, M.E., and Cameron, R.E. 1978. Ecological investigations of yeasts in Antarctic soils. Antarct. Res. **30**: 27–34.

Baublis, J.A., Wharton, R.A., and Volz, P.A. 1991. Diversity of micro-fungi in an Antarctic dry valley. J. Basic Microbiol. **31**: 3–12. doi:10.1002/jobm.3620310102. PMID:11539818.

Blanchette, R.A., Held, B.W., and Farrell, R.L. 2002. Defibration of wood in the expedition huts of Antarctica: an unusual deterioration process occurring in the polar environment. Polar Rec. (Gr. Brit.), **38**: 313–322.

Blanchette, R.A., Held, B.W., Jurgens, J.A., McNew, D.L., Harrington, T.C., Duncan, S.M., and Farrell, R.L. 2004*a*. Wood-destroying soft rot fungi in the historic expedition huts of Antarctica. Appl. Environ. Microbiol. **70**: 1328–1335. doi:10.1128/AEM.70.3.1328-1335.2004. PMID:15006750.

Blanchette, R.A., Held, B.W., Jurgens, J.A., and Haight, J.E. 2004*b*. Wood deterioration in Chacoan great houses of the southwestern United States. Conserv. Manage. Archeol. Sites, **6**: 204–212.

Blanchette, R.A., Held, B.W., and Jurgens, J.A. 2008. Northumberland House, Fort Conger, and the Peary Huts in the Canadian High Arctic: current condition and assessment of wood deterioration taking place. *In* Cultural heritage in the Arctic and Antarctic regions. *Edited by* S. Barr and P. Chaplin. Vol. XVII in the ICOMOS Monuments and Sites Series.

Connell, L., Redman, R., Craig, S., and Rodriguez, R. 2006. Distribution and abundance of fungi in the soils of Taylor Valley, Antarctica. Soil Biol. Biochem. **38**: 3083–3094. doi:10.1016/j.soilbio.2006.02.016.

Connell, L., Redman, R., Craig, S., Scorzetti, G., Iszard, M., and Rodriguez, R. 2008. Diversity of soil yeasts isolated from South Victoria Land, Antarctica. Microb. Ecol. **56**: 448–459. doi:10.1007/s00248-008-9363-1. PMID:18253776.

Frisvad, J.C., and Samson, R.A. 2004. Polyphasic taxonomy of *Penicillium* subgenus *Penicillium*. A guide to identification of food

and air-borne terverticillate Penicillia and their mycotoxins. Stud. Mycol. **49**: 1–173.

Gardes, M., and Bruns, T.D. 1993. ITS primers with enhanced specificity for basidiomycetes—Application to the identification of mycorrhizae and rusts. Mol. Ecol. **2**: 113–118. doi:10.1111/j.1365-294X.1993.tb00005.x. PMID:8180733.

Göttlich, E., de Hoog, G.S., Genilloud, O., Jones, B.E., and Marinelli, F. 2003. MICROMAT: Culturable fungal diversity in microbial mats of Antarctic lakes. *In* Antarctic biology in a global context. *Edited by* A.H.L. Huiskes, W.W.C. Gieskes, J. Rozema, R.M.L. Schorno, S.M. van der Vies, and W.J. Wolff. Backhuys Publishers, Leiden, The Netherlands. pp. 251–254.

Held, B.W., Jurgens, J.A., Arenz, B.E., Duncan, S.M., Farrell, R.L., and Blanchette, R.A. 2005. Environmental factors influencing microbial growth inside the historic huts of Ross Island, Antarctica. Int. Biodeterior. Biodegrad. **55**: 45–53. doi:10.1016/j.ibiod.2004.06.011.

Held, B.W., Jurgens, J.A., Duncan, S.M., Farrell, R.L., and Blanchette, R.A. 2006. Assessment of fungal diversity and deterioration in a wooden structure at New Harbor, Antarctica. Polar Biol. **29**: 526–531. doi:10.1007/s00300-005-0084-3.

Hughes, K.A., Bridge, P., and Clark, M.S. 2007. Tolerance of Antarctic soil fungi to hydrocarbons. Sci. Total Environ. **372**: 539–548. doi:10.1016/j.scitotenv.2006.09.016. PMID:17157897.

Ludley, K.E., and Robinson, C.H. 2008. 'Decomposer' basidiomycota in arctic and antarctic ecosystems. Soil Biol. Biochem. **40**: 11–29. doi:10.1016/j.soilbio.2007.07.023.

Marshall, W.A. 1998. Aerial transport of keratinaceous substrate and distribution of the fungus *Geomyces pannorum* in Antarctic soils. Microb. Ecol. **36**: 212–219. doi:10.1007/s002489900108. PMID:9688783.

Otineo-Alego, V., King, G., Hughes, J., and Gillet, R. 2000. Rush from the Antarctic: a record of pollutants in wilderness environments. *In* Proceedings for Corrosion and Prevention 2000, Auckland, New Zealand, 19–22 November 2000. Australasian Corrosion Association, Auckland. pp. 34–41.

Sonjak, S., Frisvad, J.C., and Gunde-Cimerman, N. 2006. *Penicillium* mycobiota in Arctic subglacial ice. Microb. Ecol. **52**: 207–216. doi:10.1007/s00248-006-9086-0. PMID:16897300.

Sun, S.H., Huppert, M., and Cameron, R.E. 1978. Identification of some fungi from soil and air of Antarctica. Antarct. Res. **30**: 1–26.

Tosi, F., Onofri, S., Brusoni, M., Zucconi, L., and Vishniac, H. 2005. Response of Antarctic soil fungal assemblages to experimental warming and reduction of UV radiation. Polar Biol. **28**: 470–482. doi:10.1007/s00300-004-0698-x.

Vishniac, H.S. 1996. Biodiversity of yeasts and filamentous microfungi in terrestrial Antarctic ecosystems. Biodivers. Conserv. **5**: 1365–1378. doi:10.1007/BF00051983.

Worrall, J.J. 1991. Media for selective isolation of hymenomycetes. Mycologia, **83**: 296–302. doi:10.2307/3759989.

Zhong, S., and Steffenson, B. 2001. Virulence and molecular diversity in *Cochliobolus sativus*. Phytopathology, **91**: 469–476. doi:10.1094/PHYTO.2001.91.5.469. PMID:18943591.