Mycology in Greenland – an introduction

Henning Knudsen

Exploration – the first wave

Rostrup (1888) was the first to publish an overview of the fungi of Greenland. Apart from short notes from various expeditions and a few published notes, he contributed most of the species himself by conducting a thorough study of the vascular plant herbarium from Greenland at the Botanical Museum in Copenhagen. By scrutinizing the herbarium plants for "puncta nigra" and other signs of fungi, he was able to find and identify 290 species including those published by others. These included species from Flora Danica (Hornemann 1836), Brown (1868), Bonorden (1874), Fuckel (1874) and Berkeley (1880). Rostrup also received material for identification from various expeditions to Greenland. This was often of better quality, since it was collected as being infected with fungi, not merely as a plant for the vascular herbarium. He received this type of material from E. Warming from the Fylla expedition, from J.A.D. Jensen, S. Hansen, P. Eberlin, L. Kolderup Rosenvinge, C. Ryder and G. Holm. He was even able to identify two fungi growing on *Dryas* and *Diapensia* from the first "herbarium vivum" collected in Greenland by Poul Egede in 1739.

Rostrup was a plant pathologist and had as such a splendid knowledge of the vascular plants. His flora of Danish plants was in use from 1860 and more than a hundred years later (Rostrup 1860). He found that 210 plants out of the then known 395 species in Greenland hosted one or more species of fungi. Rostrup continued his interest in Greenland fungi and published two more papers (1891, 1894) based on material collected in West Greenland (L. Kolderup Rosenvinge, N. Hartz) and East Greenland (N. Hartz). In 1894 he summarized the lists from Greenland to include 629 species, adding a few more in his last paper on Greenland (Rostrup 1904). It should be emphasized that by far the largest part of these are microfungi, only 148 belonging to the basidiomycetes.

Apart from this admirable work by Rostrup, the first arctic puff-ball (*Calvatia arctica*) was published by Ferdinandsen (1917) and many more fungi were added by the Danish pharmacist Lind (1910, 1924, 1926, 1933), again mostly micromycetes. Although Rostrup was interested in the plant-pathogenic fungi in Greenland, he never practised there as a plant pathologist, since he never visited Greenland. Therefore the papers included here by **Hoshino, Tojo and Yumoto** and by **Hoshino, Saito, Yumoto and Tronsmo** are the first treating plant pathogenic problems in Greenland. The *Typhula*-species they describe constitute a wide-spread problem in northern regions killing large areas of grass-fields which are used for winter fodder.

The second wave

Being a plant pathologist Rostrup's interest in fleshy fungi like agarics and related groups was modest, as were his abilities to identify them. Thus much remained to be done in this field, and that was one of the goals for the next larger enterprise in Greenlandic mycology, the Botanical Expedition to West Greenland in 1946. Morten Lange participated as the mycologist along with the lichenologist Mogens Skytte Christiansen and the botanist Tyge W. Böcher. Lange revised the macromycetes in three papers (1948, 1955, 1957), i.e. the fleshy basidiomycetes excl. the rusts and smuts but incl. some of the larger ascomycetes describing c. 230 basidiomycetes and 17 ascomycetes. He also included a sociological study of the fungi in various Greenland plant communities such as dwarf-*Betula* heaths, *Salix glauca*-shrubs, grass steppe, fell-fields, snow beds and sand dunes. He was the first to emphasize the large difference in the funga between oceanic and continental localities, often only separated by a few kilometers. Lange continued to visit

Greenland later on in a number of collecting trips. He payed special interest to the puffballs and other gastromycetes but also studied other subjects such as the specialisation of species of *Galerina* on *Sphagnum*-mosses together with his wife Bodil (Lange & Lange 1982). Gastromycetes were treated from Northeast Greenland (Lange 1976) and specific genera were treated separately such as *Bovista* (Lange 1987) and *Calvatia* (Lange 1990). The last remaining larger genus of gastromycetes in Greenland, *Lycoperdon*, was revised in the present paper by **Jeppson** based largely on the material collected by Lange. His interest in the Greenland fungi continued throughout his life, and at the Fifth International Symposium on Arctic-Alpine Mycology in Labytnangi in Siberia 1996 the participants celebrated his 50 years as an active mycologist in arctic areas together with him.

Norway also sent expeditions to East Greenland and as Rostrup had done 50 years before, the Norwegian mycologist Hagen investigated the collections of plants from the expeditions and was able to find 20 species of rusts and 12 smuts from central East-Greenland (Hagen 1946, 1947).

In 1971 a Japanese group of mycologists with a broad range of expertise undertook an investigation of the fungi in the Ammassalik-area in Southeast Greenland (Kobayasi *et al.* 1971). They recorded a broad variety of 160 species, contributing to the knowledge of this little known area of Greenland and adding groups of fungi hitherto unknown from Greenland.

The myco-ecologist Peter Milan Petersen had the opportunity to perform practically daily studies of the fungi in different habitats during his three year stay as the head of Arctic Station at Qeqertarsuaq/Godhavn on Disko Island. In a study of the fireplace fungi from central West Greenland (Petersen 1975) he found that the 16 obligate fire-place fungi in Greenland all are widespread on the Northern Hemisphere and none of them specific to arctic areas. This lack of a specific arctic element in this ecological group of fungi can be explained by the general lack of fire as an ecological factor in arctic areas, whereas it has a large impact on the vegetation in temperate and warmer areas. Petersen continued Lange's interest in the relation between fungi and plants and published articles on the ecology and phenology of the macromycetes in the Arctic (Petersen 1977). He discovered that the season for fructification in arctic areas is shorter than in temperate areas. In arctic areas the period from the soil temperature is high enough for growth of the mycelia and the production of fruitbodies and until the soil is frozen is always short, and in some years with bad weather (too dry, too cloudy and overcast with no sun or too cold) it may be too short. Another important factor for the formation of fruitbodies in the Arctic is the open land in combination with the strong, dry winds and the often shallow soil layer leading to soil desiccation. Moreover, the amount of litter in the Arctic is generally much lower than that of a temperate forest, thus also explaining the reduction of both numbers of species and of fruitbodies of litter saprotrophs.

Petersen together with Lamoure and Lange later published a checklist of the agarics from the Qeqertarsuaq/Godhavn-area (Lamoure *et al.* 1982). Likewise, Petersen and Korf (1982) published a list of inoperculate discomycetes from the same area. They included a number of vernal species of Sclerotiniaceae, mainly due to the fact that Petersen was present at this arctic site all year round.

The third wave

In 1978 T. Borgen started as a school-teacher in Paamiut, where he worked until 2000. He continued the exploration by Lange and Petersen and renewed the interest in Greenland mycology. Due to his long period as a resident in Greenland he was able to follow in detail the annual life of the fungi in their specific habitats and able to visit the same places over and over again thus having unique possibilities for studying the ecology and sociology of the fungi. Just as Lange and Petersen, **Borgen** was fascinated by the extreme differences within a few km between the coastal and the continental funga, describing them in the paper below.

Borgen's long stay in Greenland, along with the generally rising interest in arctic and alpine mycology initiated by the first the international symposium in 1980, have together had the strongest influence on the study of the Greenland fungi since then. Just like Petersen, Borgen was able to study the taxonomy, frequency, ecology and phenology of the ephemeral fungi throughout the entire seasons in contrast to the more common short-time studies by the expeditions. Borgen and Knudsen decided after two very fruitful expeditions in 1983 and 1984 to parts of Greenland virtually unexploited for fungi to make a new version of Langes "Macromycetes". Since then a number of papers have appeared as a preparation for this, treating various families or genera (Borgen 1983, 1998a, 1998b, Borgen and Arnolds 2004, Borgen and Høiland 1988, Knudsen and Borgen 1982, 1987, 1992, 1994, Knudsen and Lamoure 1990, Knudsen, Hallenberg and Mukhin 1993, Noordeloos 1984, Senn-Irlet 1992, Watling 1977a, 1977b).

In 1988, Steen A. Elborne started a Ph.D.-study of the Tricholomataceae in Greenland, but received a regular job before he could finish the study. However, his results have been widely used in the checklist of Greenland basidiomycetes included here by **Borgen, Elborne and Knudsen**. He also co-authored a paper on larger fungi associated with *Betula pubescens* in Greenland (Elborne and Knudsen 1990).

Another important factor for the progress in the study of arctic and alpine fungi is the publishing of a number of books illustrated with colour-pictures. Favre (1955, 1960) was the first to illustrate many arctic-alpine fungi in beautiful aquarelles. Later, Gulden *et al.* started a series of books on arctic and alpine fungi (1985, 1988, 1990) bringing fine photographs of many species never depicted before. To promote the fungi as a natural resource in Greenland, Borgen prepared a small guide including both the best edible species and a number of "first-time-photographed" arctic species along with a general description of the Greenland funga (Borgen 1993a, 1993b, in Danish and Greenlandic). It is interesting and a paradox that although the inuits traditionally use a broad variety of natural resources for food, fungi are not among them (Borgen 1993a). They were considered and spoken of in negative terms as in many other countries.

It is a pleasure to present in these proceedings the latest contributions to the study of macrofungi in Greenland: the papers on the genera *Galerina* and *Phaeogalera* by **Gulden** as well as the above-mentioned treatment of *Lycoperdon* by **Jeppson.** In the paper on *Collybia s. str.* by **Hughes and Petersen** they introduce molecular methods on Greenland fungi. Here they show that the three widespread species are genetically more or less similar throughout their distribution in the Northern Hemisphere, but the Greenlandic populations have one or more special features possibly because they are small and isolated.

Recently Chlebicki and Knudsen (2001), Chlebicki and Raitviir (2003) and Raitviir (2003) have contributed a number of pyrenomycetes and discomycetes new to Greenland and some new to science.

Apart from the publications many mycologists contributed to the knowledge of Greenland fungi through their collections during the past 25 years. Most of their material is deposited at the Botanical Museum, University of Copenhagen (C) and most of the collections are entered in a database as a preparation for the forthcoming funga of basidiomycetes. A preliminary list of basidiomycetes is included here by **Borgen, Elborne and Knudsen**.

Adaptations by arctic-alpine fungi

The life conditions in the Arctic are extreme and like other organisms the fungi need to adapt to these conditions. The short growth period has favoured short life cycles and this subject has been repeatedly noted by different authors. Lind (1934) noted that comparatively many rusts, smuts and species of Dothideales have a perennial mycelium in the host, enabling them to grow as soon as the season starts. Many rusts have a simplified life cycle, only producing one kind of spores ("micropuccinia") instead of a life cycle with three spore forms ("eupuccinia") more commonly seen in warmer areas. Favre (1955) pointed to the "nanisme" of some of the macrofungi found in alpine areas, expressed in a reduced number of gills and size of the carpophores. He also measured the spores of 64 species found both in alpine areas as well as in lower altitudes. Of these, 47 had the same spore-size in both areas, whereas 16 had larger spores in the alpine areas and one had smaller spores. Unfortunately he did not mention which species he used, and since the taxonomy within alpine and arctic fungi have changed much since Favre, it is possible that some of his larger-spored forms and varieties have now been recognized as new taxa. Also, it would have been interesting to know if these large-spored taxa had two- or four-spored basidia. Savile (1972, 1982) pointed to other adaptations among arctic and alpine fungi: suppression of conidial states or the opposite, suppression of the ascomatal state, both leading to a simplified and shorter life-cycle or alternatively but leading to the same result, a simultaneous occurrence of the anamorph and the teleomorph: a prolongation of the life cycle to be able to mature over more than one season: a simplification of the breeding system so that time is not wasted waiting for a hybridisation from another mycelium by being self-fertile, etc. As mentioned below lichenisation is relatively more common in arctic areas than in warmer areas. This type of double-organisms are especially adapted to a life where they may be dormant for a long period due to the cold and often dry weather found in Arctic areas and they thus prevail here. Among the basidiomycetes in Arctic areas there seems to be relatively more 2-spored species than in warmer areas, but this is so far only a theory (Knudsen and Borgen, unpublished).

It is not known whether these 2-spored taxa are anamorphs of normal 4-spored forms of the same taxon, or whether they are specimens created after a normal sexual cycle with merging of two different mycelia. In the first case time and energy is saved by not having to find a partner, in the second case some energy is saved by making only two spores in each basidium instead of the normal four. The relative occurrence of species with small fruitbodies is larger than in warmer areas. This may reflect two different adaptations: the relative scarcity of vegetable material for degradation or that small fruitbodies may need a shorter time to evolve. One of the exceptions is the delicious *Lepista multiforme,* which may form quite large rings or tufts of fruitbodies especially around or at the margin of pingos, small hills with disturbed soil created by the permafrost.

Lichenizations occur in all climates but are especially dominant in areas where conditions are harsh and other organisms therefore are missing. The typical lichenization between an ascomycete and an alga can illustrate this. In Greenland the number of lichens (1050 species) is of roughly the same multitude as the number of basidiomycetes (850 species), whereas in temperate areas like UK the number of basidiomycetes (incl. subspecific taxa) is 3670 (Legon and Henrici 2005), more than twice the number of lichens (1600) (Purvis *et al.* 1993). Among the basidiomycetes the numbers for comparison are small, but two species of *Multiclavula* and four species of *Lichenomphalia* are found in Greenland, and only two of these are found in temperate lowland in Europe and with a lower abundance. Similarly *Omphalina griseopallida* occurring only in the Arctic has been shown to have some kind of symbiosis with both a liverwort and a blue-green alga enabling the consortium to metabolise even when the temperature is below zero.

Wood-decaying fungi in the Arctic

In arctic areas the amount of wood is small. Only low scrubs mostly of dwarf *Salix* and *Betula* occur and in sheltered places also of *Alnus* and *Sorbus*. The amount of wood produced by these scrubs is generally too small to serve as substrate for wood-decaying basidiomycetes. The apparent lack of such fungi led Vassilkov (1967) to conclude that there was an absolute absence of wood-decaying macromycetes in the tundra. This is however not correct, but the subject has been very little studied. As it could be expected the northernmost limit of wood-decaying fungi is not an "all or nothing" situation but a gradual diminishing of the number of species along with the decrease in the size of the available "trunks". It is important to underline that as long as wood is present, saprotrophs are also present. In their paper from 1993, Knudsen, Hallenberg and Mukhin investigated three valleys in Greenland for wood-decaying fungi and compared the general composition of the funga. A number of common corticioid fungi occurred on the finger-thick branches and "trunks". In the present paper by **Mukhin**, the differentiation of the corticioid fungi occurring on *Salix glauca* and *Betula glandulosa* is studied near Sisimiut, close to the northern limit of these two important Greenland scrubs. He found 40 species, covering many taxonomic groups of wood-decaying fungi, but only one species from the important group the polypores. They seem to be unable to live so far north in Greenland, where the "trunks" only have diameters of 1-4 cm. In East Greenland, at 70° N, a number of crepidotoid fungi occur on woody substrates even in strongly wind-exposed fell-field areas with creeping dead "trunks" of *Salix* spp. surviving for many years. Here it was possible to find *e.g. Crepidotus* spp. and *Pellidiscus pallidus* on the wind-protected underside of the trunks (Senn-Irlet 1992). The number of polypores found on drift-wood at the mouth of river Lena at 71° N by Kotiranta and Mukhin (2000) indicates that the lack of polypores in the Arctic in general is not caused by climatic factors but by the lack of sufficiently large woody substrates.

Truffles in Greenland

Truffles are usually thought of as something exotic not only in price but also in occurrence, the Mediterranean area being the well known "homeland" for these delicacies. Truffles are also present in cold temperate areas *e.g.* 40-50 species are known from Denmark (Lange 1956) and the UK (Pegler, Spooner and Young 1993). From arctic and alpine sites truffles are less known and less common. Kers (1982) reported *Hymenogaster tener* and *H. vulgaris* in low mountains from Swedish Lapmark at 68° N, and during ISAM III on Svalbard in 1988 I found a *Hymenogaster* associated with *Salix herbacea* at 78° N, c. 1000 km from the North Pole (unpubl., herb. C). In Greenland three species of truffles have been found: 1) *Elaphomyces* sp. by Milan Petersen (herb. C); 2) *Alpova diplophloeus*, associated with the arctic *Alnus crispa*; 3) a *Hymenogaster* sp. was found under *Salix glauca* in East Greenland during an expedition in 1987. However, their presence and importance in Greenland is minimal compared to the subalpine belt in Australia, where **Trappe and Claridge** in the paper below have revealed 18 species, yet still a fragment of the existing. There is probably no perspective in utilizing arctic and alpine truffles for food, but it is interesting that also this type of mycorrhizal fungi exists all the way to the extreme North.

Special features of the Arctic funga

The Greenlandic funga generally is similar in composition to the European, but the number of species is less. The checklist by **Borgen, Elborne and Knudsen** shows that all of the recently established major clades of the hymenomycetes have representatives in Greenland. A number of genera also have one or more species which are obligate or predominantly arctic-alpine in their distribution. Some of these are listed in the enumeration below. Many litter- or wood-decaying genera do not have specific arctic-alpine species, but are present with some widespread representative(s) (not listed).

Mycorrhizal species:
Amanita (arctica, nivalis, groenlandica, mortenii), Cortinarius (polaris, alpinus, parvannulatus, pauperculus, phaeopygmaeus, subtorvus), Hebeloma (alpinum, kuehneri, polare), Inocybe (borealis, egenula, giacomi, longispora, mundula, ursinella), Laccaria (pumila), Lactarius (alpinus, brunneoviolaceus, griseus, lanceolatus, pseudouvidus, salicis-reticulatae, salicis-herbaceae, nanus, dryadophilus, torminosulus), Leccinum (rotundifoliae), Naucoria (tantilla), Russula (nana, pascua, dryadicola, dryadophila, heterochroa, groenlandica, violaceoincarnata, norvegica, citrinochlora, saliceticola).

Saprotrophic species:
Agaricus (aristocratus, salicophilus), Agrocybe (permagna), Arrhenia (auriscalpium, salina), Calvatia (cretacea, arctica, turneri, bellii), Clitocybe (festiva, lateritia, dryadicola, paxillus), Conocybe (ammophila), Cystoderma (arctica), Entoloma (alpicola, bicorne, bipellis, borgenii, langei, olidum, subarcticum, subsepiaceum), Fayodia (arctica), Galerina (arctica), Gymnopus (alpinus, alkalivirens, benoistii, loiseleurietorum), Hygrocybe (citrinopallida, cinerella, biminiata, rubrolamellata, salicis-herbaceae), Hypholoma (lapponicum), Lepiota (favrei), Lepista (multiformis, pseudoectypa), Lichenomphalia (alpina, hudsoniana, velutina), Lycoperdon (frigidum, lambinonii, niveum, norvegicum), Marasmius (epidryas, kallioneus), Melanoleuca (subalpina), Multiclavula (corynoides, vernalis), Mycena (badiceps, alexandri, citrinomarginata), Omphaliaster (borealis), Omphalina (arctica, chionophila, rivulicola), Ramariopsis (subarctica), Stropharia (alpina), Typhula (borealis).

Even though all major clades are represented in Greenland, it is also obvious that a number of larger genera are particularly scarce in arctic areas e.g. *Tricholoma, Hygrophorus, Lyophyllum, Lepiota* and *Boletus*, and many small genera are totally lacking. In *Amanita* the ringed group is practically absent, whereas the *Amanitopsis*-group is well represented with species occurring in temperate areas, but also with a specific arctic element.

Genera with small fruitbodies are well represented like *Omphalina s.l.* and *Mycena*. Likewise the often moss-related genus *Galerina* is well represented with 24 species as shown by **Gulden** in the paper below.

It is "a striking fact, that we do not have any genus of fungi especially indigenous to the northern polar regions" (Lind 1934: 139), a fact which was later corroborated by Savile (1982). "This warrants the conclusion that the arctic floras has not developed in the arctic habitats but is an intense mixture of species of highly different age and different origin." (Lind 1934: 139).

Distribution of arctic-alpine fungi

The geographical distribution of arctic fungi was first described by Lind (1927b), when he published a study on 422 arctic circumpolar micromycetes.

Due to insufficient sampling the distribution of the Greenlandic fungi is only very superficially known compared e.g. to the plants, but a few distributional types can be sketched. Species following *Betula pubescens* as their mycorrhizal host and species demanding large trunks for substrate are only found in the subarctic part of South Greenland and in the southern part of Southwest Greenland. They include a number of well known species from temperate areas, e.g. *Hydnum repandum, Postia tephroleuca, Phellinus lundellii, Chondrostereum purpureum, Pluteus cervinus, Tubaria confragosa, Cortinarius alboviolaceus, Russula emetica* and *Lactarius trivialis* (Elborne and Knudsen 1990, Borgen 1993a).

Fungi forming mycorrhiza exclusively with *Alnus crispa* have in a similar way restricted their distribution to the limited range of this scrub in Southwest Greenland: *Alpova diplophloeus, Paxillus filamentosus* and *Amanita friabilis*. It is also in this region that a number of mycorrhizal species occur with smaller *Betulas*, either scrubs of *B. pubescens* or *B. nana* and *B. glandulosa*. They include *e.g. Rozites caperatus, Paxillus involutus* and *Boletus subtomentosus*.

One of the most obvious geographical gradients in Greenland occurs from the oceanic coast to the continental inland. Two good examples of oceanic species are *Hygrocybe lilacina* and *Arrhenia salina*. Two examples of the opposite, species preferring the inner continental parts with dry and relatively warm summers at the origin of the long fjords in central West Greenland are the single record of *Geastrum minimum* (Lange 1948) and *Russula groenlandica* (Knudsen and Borgen 1992). More examples on the difference between the fungi in the outermost, oceanic areas and the inner, more continental parts can be found in **Borgen** below.

Some species are distributed more or less throughout Greenland. In this group some of the small saprotrophic fungi belong, *e.g. Arrhenia lobata, A. auriscalpium, Marasmius epidryas* and *Lichenomphalia hudsoniana*, but also some mycorrhiza-forming species like *Russula delica, R. nana, Lactarius dryadophilus, Laccaria pumila* and *Cortinarius alpinus*.

Knudsen and Mukhin (1998) listed 28 species of arctic or arctic-alpine agarics recorded both from North America and Eurasia and thus having a more or less circumpolar distribution, which admittedly for many of the species still is fragmentary known. In the paper below by **Cripps and Horak** the distribution of *Arrhenia auriscalpium* is shown and its world-wide distribution – limited to the northern hemisphere – is discussed. The closely related species *A. salina* seems to have a similar distribution though only along the coasts, but both in Arctic and Antarctic areas (Knudsen and Mukhin 1998, as *A. littoralis*). *A. auriscalpium* is not connected to a specific plant, but an example of this was given by Knudsen and Lamoure (1990), who showed that the world distribution of *Lactarius dryadophilus* falls inside the distribution of its mycorrhizal partner (*Dryas* spp.).

The harsh conditions in the Arctic limit the number of species, but these conditions may also indirectly favour some groups of fungi. At least it is obvious that pioneer fungi, occurring on disturbed soil, on naked soil along riverbeds, in gravelly soil along paths *etc.* such as *Laccaria, Hebeloma* and many members of Pezizales flourish in arctic areas, where the competition could be reduced due to a restricted number of species. *Agrocybe* is a typical open-land genus and in concordance with this a new species collected several times was found to be restricted to the treeless alpine zone in the Rocky Mountains. It is described below in the paper by **Moser and Horak**.

Biodiversity of arctic-alpine fungi

Hawksworth (1991) pointed out that in any large but restricted area e.g. of the size of a country, the number of fungal species is 6-8 times larger than the number of vascular plant species in the same area. The number of vascular plants in Greenland is 515 (Bay 1993). Therefore, the number of fungi should according to Hawksworth be 3,000-4,000 species incl. lichenized fungi (= lichens). The two major taxonomic groups of fungi in

Table 1. Biodiversity of Greenland Fungi.

Basidiomycetes	837	(Borgen, Elborne and Knudsen)(alien species excluded)
Ascomycetes		
Lichenized	1050	(Hansen 2001 and later updates)
Non-lichenized		
Taphrinales	4	(Rostrup 1894)
Discomycetes		
Pezizales	100	(Dissing 1982 and later updates)
Helotiales	200	(Raitviir and Knudsen in prep.)
Pyrenomycetes	180	(Rostrup 1894)
Anamorphic fungi	200	(Rostrup 1894, Lind 1910-1933, Alstrup and Hawksworth 1990)
Zygomycetes	3	(Rostrup 1894)
Chytridiomycetes	15	(Kobayasi et al. 1971)
Fungi in Greenland ca.	2600	

Greenland are the basidiomycetes and the ascomycetes. A checklist of the basidiomycetes is included here (**Borgen, Elborne and Knudsen**) enumerating 856 species. This includes a number of alien species, partly introduced on timber from the USA. Another group of mycorrhizal species has been introduced on the roots of conifer seedlings planted in the last three decades in South Greenland, partly from USA and partly from Denmark. If these 19 alien species are excluded from the list 837 remain. The number of lichenized fungi was given as 950 by Hansen (2001), but has recently been updated to include ca. 1050 species (E.S. Hansen, pers. comm.). The remaining part of the Greenland fungi is constituted by the non-lichenized ascomycetes, which worldwide is the largest of these three groups. Broadly speaking this group includes two major groups, the discomycetes and the pyrenomycetes. The operculate discomycetes (Pezizales, cup fungi) were investigated by Dissing (1982), who made a checklist including 78 species, and later additions by several persons has enlarged the number to ca. 100 species. The inoperculate discomycetes (Helotiales, disc fungi) is generally a larger group, but has not been thoroughly investigated in Greenland. However, 200 species have so far been recorded including several recently described species (Chlebicki and Knudsen 2001, Raitviir 2003a, 2003b, Raitviir and Chlebicki 2003, Raitviir and Knudsen in prep.). The small group of ascomycetes called witches brooms, Taphrinales, is represented by four species (Rostrup 1894).

Two large groups have not been investigated since the days of Rostrup, the pyrenomycetes and the anamorphic fungi ("fungi imperfecti"). Of these, Rostrup recorded 180 and ca. 170 respectively. Since some of the "fungi imperfecti" are asexual states of some of the pyrenomycetes, this number will eventually be reduced. On the other hand it should be noted that Rostrup never set his foot in Greenland, and thus never collected any of these fungi himself. A more focused field-investigation will therefore no doubt lead to the recovery of many more species. A recent scrutiny of one genus of plants (*Dryas*) lead to the discovery of five new species for Greenland and one for science (Chlebicki and Knudsen 2001). Some other small groups are also present, but very little investigated. However, Kobayasi *et al.* (1971) included a few Zygomycetes and ca. 15 Chytridiomycetes. Finally, for complementation it should be mentioned that the Myxomycetes/Mycetozoa were investigated by Gøtzsche (1989), who recorded 54 species, but they are excluded from the fungi. This is also the case for the "oomycetes". Thus, these two groups are excluded from Table 1, but included by Hawksworth (1991) in his paper on the ratio between the number of plants and the number of fungi in an area.

Although no special search has been undertaken for Helotiales, pyrenomycetes and anamorphic fungi in Greenland, and the latter two groups have not been the object of any research in Greenland for the past 100 years, it is clear that the total number of fungi in Greenland (at least 3000 incl. the lichens) is close to the number predicted by Hawksworth (1991). This makes the fungi the largest group of terrestrial organisms in Greenland, and probably generally the largest group of organisms in Arctic terrestrial areas. This is in contrast to temperate areas, where animals constitutes the most species rich group and by far outnumber the fungi. The number of terrestrial animal species in Greenland is less than 1000 (Jensen 1999).

In Great Britain the number of non-lichenized species of ascomycetes is 3500 (5100 minus 1600 lichens, see Cannon *et al.* 1985), the number of basidiomycetes 3670 (incl. subspecific taxa, see Legon and Henrici 2005) and the number of lichens 1600 (incl. Ireland, see Purvis *et al.* 1993). Thus, if the relative number of ascomycetes compared to basidiomycetes in Greenland is the same as for Great Britain, at least 350 more ascomycetes should occur in Greenland than presently known. This figure is most probably too small, since the large number of basidiomycetes in Great Britain is favoured by the large variety of dead wood and woody shrubs acting as substrate for many saprotrophs, and also by the large number of living trees and shrubs acting as mycorrhizal symbionts. The ratio of ascomycetes to basidiomycetes in arctic areas is therefore probably larger than in temperate areas. Hawksworth (1991) concluded that "in boreal to arctic and antarctic habitats where vascular plant numbers are low, the ratio will also be much higher" (than 1: 6-8), and gave an example from Antarctica where the ratio was 1: 7.

In Russian arctic areas the number of fungi is 1750 (Karatygin *et al.* 1999) excl. the lichens. Of these, 650 are basidiomycetes, 470 pyrenomycetes, 100 Leotiales, 50 Pezizales and 300 anamorphic fungi. The differences between Greenland and arctic Russia probably reflect the degree of exploration by different specialists rather than a real difference, and if so, it should be possible to take the highest numbers from each of the two areas. This would give 850 basidiomycetes, ca. 800 ascomycetes and ca. 300 anamorphic fungi, i.e. roughly 2000 fungi plus the lichenized fungi, in all 3000 species in the Arctic.

From the figures given here it may therefore be safely concluded that fungi constitute the largest group of terrestrial organisms in Greenland, and that at least 3000 species occur, although we are still lacking a few hundred. The impact of this significant group of organisms upon the Greenlandic ecosystems is still largely unknown and needs to be surveyed.

Note

In the account given above, fungi are considered in the current sense excluding e.g. most of the phycomycetous groups and the myxomycetes. Also lichenized fungi (= lichens) and lichen-parasites have been excluded (except in the section on biodiversity) in spite of a comprehensive literature from Greenland. These fungi are traditionally treated by lichenologists in their own special fora and have not been included in the symposia on arctic and alpine mycology.

Authors of papers included in this volume are mentioned above in bold letters.

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