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History and the Current Status of Fungal Inventory and Databasing in Japan

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Abstract Due to the regional broadening in south and north, Japan embraces a wide range of diversified organisms, and Fungi are not the exception. In spite of relatively long historical background in inventory of Japan's mycobiota, first compiled in 1905, much information remains to be added. Currently, rearrangement and databasing of the specimens in the mycological herbarium in National Science Museum (TNS) have been carried out, and some of the data is publically available. To extend the collection, strategic collection building, based on analysis of the specimens at hand and collaboration with other parties, are required. GBIF, an international biological databasing project, provides a good opportunity to integrate information of specimens conserved in the major mycological herbaria in Japan.

Key words: database, GBIF, Mycological Herbarium, TNS.

Introduction

The biodiversity of the fungi is vast. Some of them form large fruiting bodies known as mushrooms, toadstools, and vegetable wasps, but many of them form smaller fruiting bodies invisible without a hand lens, and the molds are invisible even to the naked eye. All these organisms, however, are formed by filamentous stands of catenulate cylindrical cells, called "hyphae".

Various estimations have been proposed for the total numbers of fungi (e.g. Kirk *et al.*, 2001). Roughly, the number of species of fungi is estimated between 80 thousand to 1 million (Hawksworth, 1991). The estimated number of species of fungi is the second largest among organisms on earth, following the insects (Gibbs, 2001). Although most of the fungi are invisible to the naked eye, many of them are important in our daily life. Fungi are good natural resources not only as food, but as other useful products. On the other hand, fungi can be deliterious, acting as pathogens that infect both our bodies and vegetables grown for food.

Japan is located between 24–46° latitude north, surrounded by oceans with both warm and cold currents. Japan is also affected by various air masses and other climatic factors. Because of the geographic location, Japan includes diverse climatic zones, which affects the biodiversity of fungi. Because of the climatic diversity, vegetation varies greatly, which again affects the diversity of fungi. It is suggested that Japan embraces a great biodiversity of fungi, but large numbers of fungi are still unexplored. In the present paper, I describe the current status of fungal inventory and databasing in Japan.

Historical Survey and Current Status of Fungal Inventory in Japan

There are two trends in the fungal inventory in Japan. One is to generate a cumulative checklist, and the other is to provide descriptions. The first trend started as early as the beginning of last century, largely because of phytopathological interest. In 1905, The first compilation of Japanese fungi was published by Mitsutaro Shirai (Shirai, 1905), "A List of Japanese Fungi Hitherto Known", which included 1,200 taxa. The publication was revised in the 1917 by I. Miyake, and enlarged to include 3,500 taxa (Shirai and Miyake, 1917), followed by another revision (Shirai and Hara, 1927). The lists included the current name, literature to show the occurrence, host, substrate, and rough distribution both in Japan and the world. Hara (1954) revised and published the list with some 7,300 taxa, which is the last checklist of Japanese fungi to have been published.

The second trend is to provide descriptions, represented by the massive compilation known as the "Mycological Flora of Japan". The project was begun by Seiya Ito before World War II, and the first volume for Phycomycetes (mastigomycetes and zygomycetes) was published in 1936 (Ito, 1936a). The following volumes for smut fungi and rust fungi, both known as important plant pathogenic groups, were published in 1936 and 1938 respectively (Ito, 1936b, 1938). The order of publication seems to have been prioritized according to the plant pathological interest. The project was interrupted by the war, and the following volumes for rust fungi (Ito, 1950), heterobasidiomycetes and polyporous fungi (Ito,1955), and agarics and gasteromycetes (Ito, 1959) were published after the war. However, the volume for yeasts and taphrinomycetes (Ito, 1964) was not published until just before Ito passed away. Volumes for some ascomycete groups with large number of fungi were left.

Following the bequest of Ito, Yoshio Otani, his son in law, started to work on the remaining volumes after he retired from the National Science Museum in 1983. Otani published the volumes for some groups of ascomycetes (Otani, 1988, 1995) in which all the taxa were described in Japanese, with previous literature citations, and sometimes with additional photos and line drawings. Because Otani passed away in 1997, groups with large numbers of species, such as discomycetes and loculoascomycetes remained unpublished. Unfortunately, the project took place over too long a period and was never completed. It is also noted that the project depended on very limited personnel, although with collaboration of many other colleagues.

In accordance with the ratification and in effect of Convention of Biological Diversity (CBD), the government formulated the National Biodiversity Strategy of Japan in 1992. The goal of this Biodiversity Strategy was "to prevent species extinction, to promote conservation and restoration of nature throughout Japan, including mountains, cities and ocean areas, and thus to devote 50 or 100 years to building up a verdant national land area in which all citizens can enjoy daily interaction with a wide variety of thriving life forms". With the increasing interest in the potential biological diversity and endangered species in Japan, the listing of all naturally occurring species was attempted. In 1995, the initial list for this purpose was prepared by the committee organized under the authorization of the Environment Agency, currently the Ministry of the Environment. For fungi, the list of 16,500 taxa largely relied on the work by Yoshimichi Doi, the former curator of mycological herbarium in TNS. Unfortunately, this list contained synonyms, which caused duplicated counts for the same taxa, and names for anamorphs of certain teleo-

Table 1. Currently estimated fungal taxa in Japan.

Fungal Group	Taxa in Japan (a)	Taxa in the World (b)	a/b %
Ascomycota	7,419	32,739	22.7
Basidiomycota	4,160	29,914	7.2
Chytridiomycota	140	914	15.3
Zygomycota	264	1,090	24.2
Anamorphic fungi	941	13,554	6.9

(a) Anonymous (2002)
(b) Kirk *et al.* (2001)

morphs were counted independently, which again gave duplicated counts.[1]

In 2004, in response to a request by The Union of Japanese Societies for Systematic Biology, the Mycological Society of Japan provided a revised count in the project "Japanese Biota Species Number Survey". The previous list was revised and inappropriate names were discarded as much as possible. The result largely depended on the work by Dr. Yousuke Degawa, Kanagawa Prefectural Museum of Natural History and Dr. Ken Katumoto, Prof. Emeritus, Yamaguchi University, and is currently being edited by Dr. Katumoto for publication.

Table 1 shows the number of currently estimated fungal taxa in Japan, classified in 5 major groups (phyla). The total number of fungi in Japan is now 12,924. The majority belong to the Ascomycota and Basidiomycota. However, the figures are considered to be still an underestimate. An example is taken from my research for the family Hyaloscyphaceae, discomycetes, a group of fungi that produce tiny, disk-like fruiting bodies or apothecia (Fig 1). Otani (1989) published a list of Japanese discomycetes which included 41 taxa of Hyaloscyphaceae to prepare a future volume of discomycetes in "Fungal flora of Japan". Since then, based on collections throughout Japan (Fig. 2), 29 taxa including 10 newly described species have been added to the list (Hosoya, 2002, 2004; Hosoya & Harada, 1999; Hosoya & Huhtinen, 2002; Hosoya & Otani, 1997a, 1997b; Ono and Hosoya, 2001; Tanaka and Hosoya, 2001). As has been stated by Korf (1958), "for the discosystematist, Japan is a relatively unexplored paradise".

Accumulation of data from the published literature is one of the major trends in Japan and indispensable for inventory. However, accumulation of previously collected data is not enough for inventory, because of potentially undocumented/undescribed taxa. Collecting specimens from the field is greatly encouraged. At the same time, data from the literature or from the field should be critically assessed for taxonomic validity and reliability. Ideally, the data should be based on voucher specimens. Functional collaboration on these three aspects is the key to completing Japan's fungal inventory.

Taking Hyaloscyphaceae as an example, Otani (1989) counted 41 taxa in Japan based on the previous literature data. However, critical examination of the literature data revealed 2 invalid combinations and 3 doubtful taxa. In the TNS mycological herbarium there are 70 specimens distributed among 17 taxa. These specimens do not always give direct proof of each record, but can

[1] Many fungi reproduce both sexually and asexually. The asexual state is sometimes recognized as an independent taxon from the sexual state, because they are not always accompanied with sexual states, and the sexual state of the given asexual state is not always clearly connected. Therefore, the term anamorph is applied to the asexual state and often given a name seperate from their teleomorph, the term for the sexual state. This treatment is somewhat peculiar from other organisms, but current International Code of Botanical Nomenclature guarantees the name of the anamorph in article 59. Anamorphic fungi have in the past been classified to Deuteromycota (or Deuteromycotina), but currently they are grouped as "anamorphic fungi". In the present paper, term "anamorphic fungi" is applied.

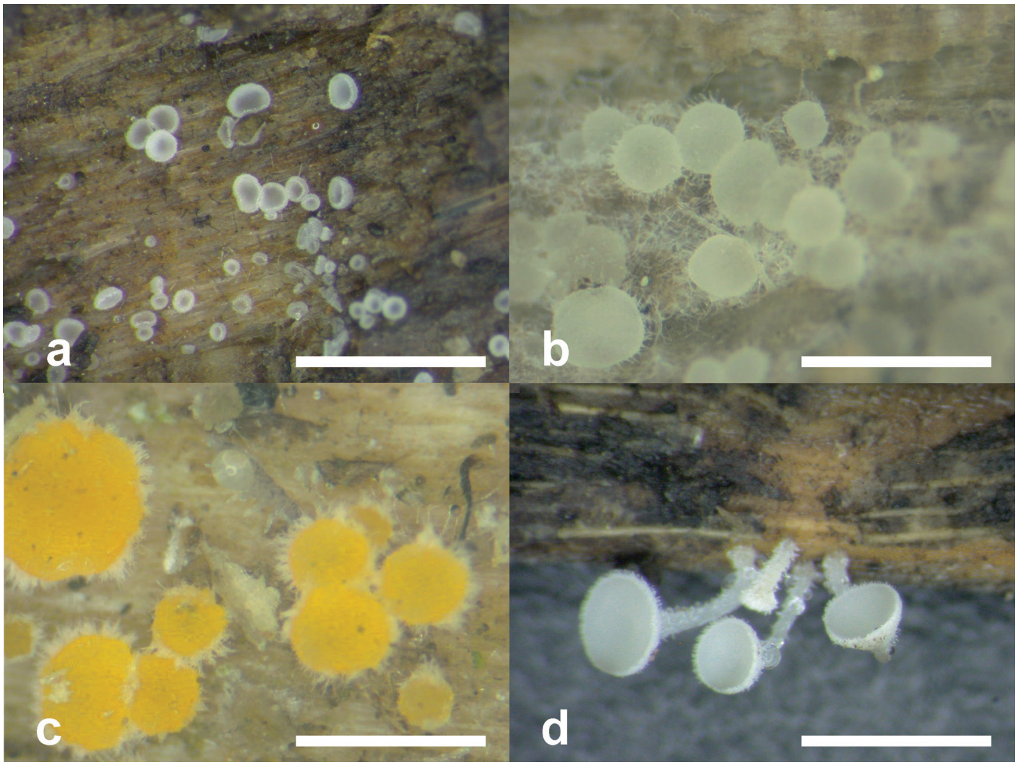

Fig. 1. Examples of Hyaloscyphaceae, discomycetes. a. *Hyaloscypha* sp., b. *Arachnopeziza cornuta*, c. *Arachnopeziza aurata*, d. *Lachnum* sp. Scales: 1 mm.

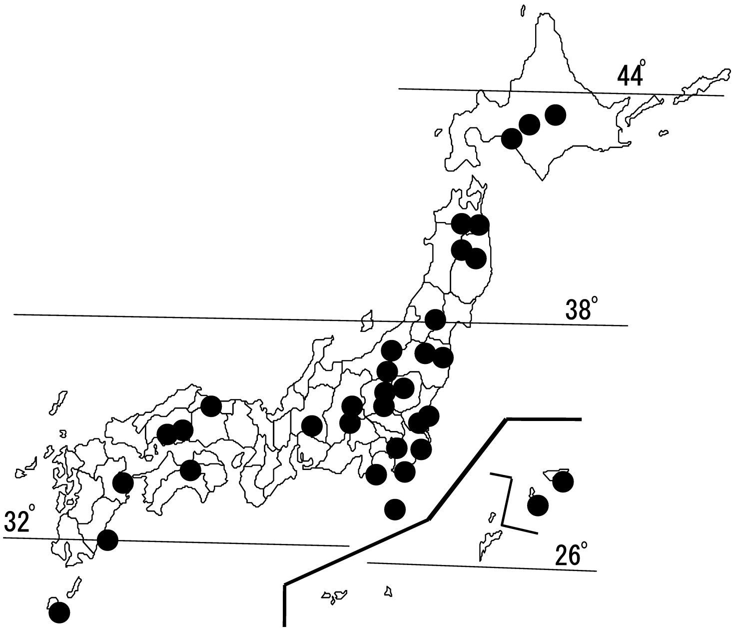

Fig. 2. Collection sites for discomycetes in Japan.

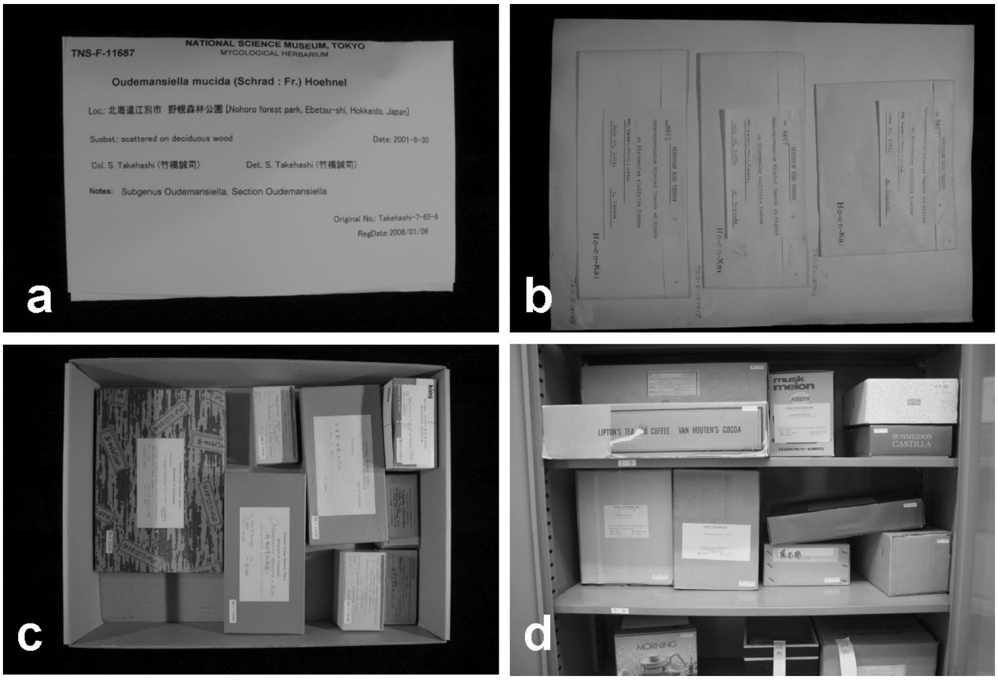

Fig. 3. Conservation format in TNS mycological herbarium. a. Paper pockets; b. Paper pockets fixed to a larger sheet; c. Boxes of standardized sizes. d. Larger containers of various sizes.

be taken as partial support for fungal inventory in Japan. Databasing these specimens will contribute greatly to generating a more complete and reliable inventory.

Current Status of Databasing in TNS Mycological Herbarium

A total rearrangement of the specimens and revision of the database has been carried out in TNS mycological herbarium for the past 1.5 years. Currently some 90,000 specimens have been recorded. The specimens are conserved in various containers. Reflecting the biodiversity of fungi, the shape and size of the containers varies. Most of the specimens are dried, while some are conserved in formarine in various glass containers. Most of the dried specimens are conserved in a paper pocket of 10×15 cm. Specimens that cannot be contained in paper pockets are conserved in cardboard boxes of various sizes (Fig. 3). Most of the specimens are stored in cardboard drawers on steel shelves. Previously, the specimens were arranged on the basis of an obsolete taxonomic system by the orders. However, the taxonomy of fungi is being drastically revised, hence taxonomy even at the order level is still not stable (Kirk *et al.*, 2001). The new alphabetical arrangement within broad taxonomic groups enables specimens to be more easily found and managed with the help of the computer database. For particular specimens that cannot be accommodated to the paper pockets, the locality in the herbarium is indicated in the database. The higher taxonomic rank for specimen arrangement is similar to that in PDD, the mycological herbarium in Landcare Research (Table 2).

The database is constructed by Microsoft Access. At present about 30% of the registered specimens have been incorporated to the database. Of these, 6,512 records (3,000 species in 816 genera) of various fungi and 9,869 records (2,566 species in 96 genera) of rust fungi have been

Table 2. Comparisons of conventional higher taxonomy and taxonomy for storage in PDD and TNS.

<table>
<tr><th>Conventional taxonomy</th><th>PDD</th><th>TNS</th></tr>
<tr><td>Mastigomycotina</td><td rowspan="2">Phycomycetes</td><td>Mastigomycetes</td></tr>
<tr><td>Zygomycotina</td><td>Zygomycotes</td></tr>
<tr><td>Ascomycotina</td><td>Ascomycetes</td><td>Ascomycetes</td></tr>
<tr><td rowspan="6">Basidiomycotina</td><td>Aphyllophorales</td><td>Aphyllophorales</td></tr>
<tr><td rowspan="2">Agarics/Gasteromycetes</td><td>Agarics</td></tr>
<tr><td>Gasteromycetes</td></tr>
<tr><td rowspan="2">Rusts/Smuts</td><td>Rusts</td></tr>
<tr><td>Smuts</td></tr>
<tr><td colspan="2">Heterobasidiomycetes</td></tr>
<tr><td>Deuteromycotina</td><td colspan="2">anamorphic fungi</td></tr>
</table>

Conventional taxonomy based on Ainsworth (1973).

made publilcally available. The former dataset has been provided to GBIF (Global Biodiversity Information Facility) project (described below) and disclosed in the database package "Database of Fungal Specimens Maintained at the Selected Japanese Herbaria under the GBIF Japan Project" whereas the latter in "A list of the specimens of the Uredinales kept in TNS". Both databases are available on the web (http://research.kahaku.go.jp/db/english/). Database structure is continuously being revised and improved based on my experiences and advises from colleagues including those at Landcare Research.

With the rearrangement of the database, statistical analysis of the specimens becomes possible. Analyzing the 6,512 records of fungi available, most of them originate from Japan, followed by New Zealand, Finland, USA, and other countries (Fig. 4). Most of the Japanese collections are composed of Basidiomycota, followed by Ascomycota, anamorphic fungi and a few other fungi (Fig. 5).

Strategic Collection Building

How can we increase biodiversity of the collection to support inventory? One answer is to carry out collecting more strategically. Analyzing the data of the specimens at hand, localities rarely visited and taxonomic groups poorly represented will become clear. Analysis of the collecting sites of the specimens provided to GBIF revealed that the south-west part of Japan is less often visited, with most specimens from areas close to Tokyo, influenced by the location of TNS (Fig. 6). Some prefectures have larger numbers of specimens due to the presence of particular collections contributed to TNS.

To support and to reinforce collecting activity, help of amateurs will be indispensable. Some of the amateur societies in Japan are very enthusiastic and their knowledge and experience are

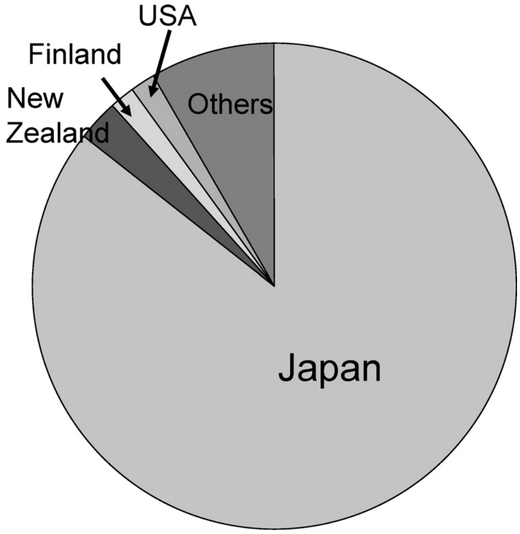

Fig. 4. Origin of the disclosed specimens for GBIF project in TNS mycological herbarium.

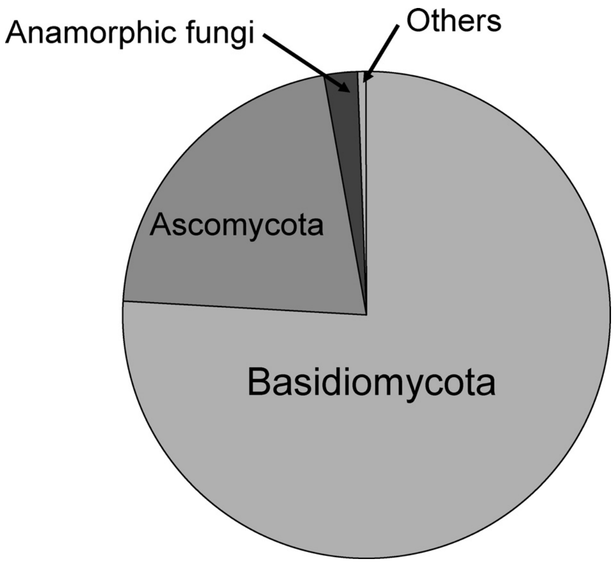

Fig. 5. Higher taxonomy of the Japanese specimens disclosed for GBIF project in TNS mycological herbarium.

quite significant. Also, collaboration with other mycoloigcal herbaria in Japan in exchanging specimens and participation in joint collecting would be of great value toward increasing the number of specimens. If specimen data from several mycological herbaria are combined, an increasd understanding of the fungal biodiversity in Japan will occur. Such collaboration is being carried out under the GBIF project as mentioned below.

GBIF is an international organization to make the world's biodiversity data electronically accessible. Countries participating in GIBF donate and get an allocation for pursuing the project. Currently, seven Japanese mycological herbaria and a culture collection (Table 3) are involved in the project, receiving the allocation from the financial year 2002 to 2005. Herbaria with historical

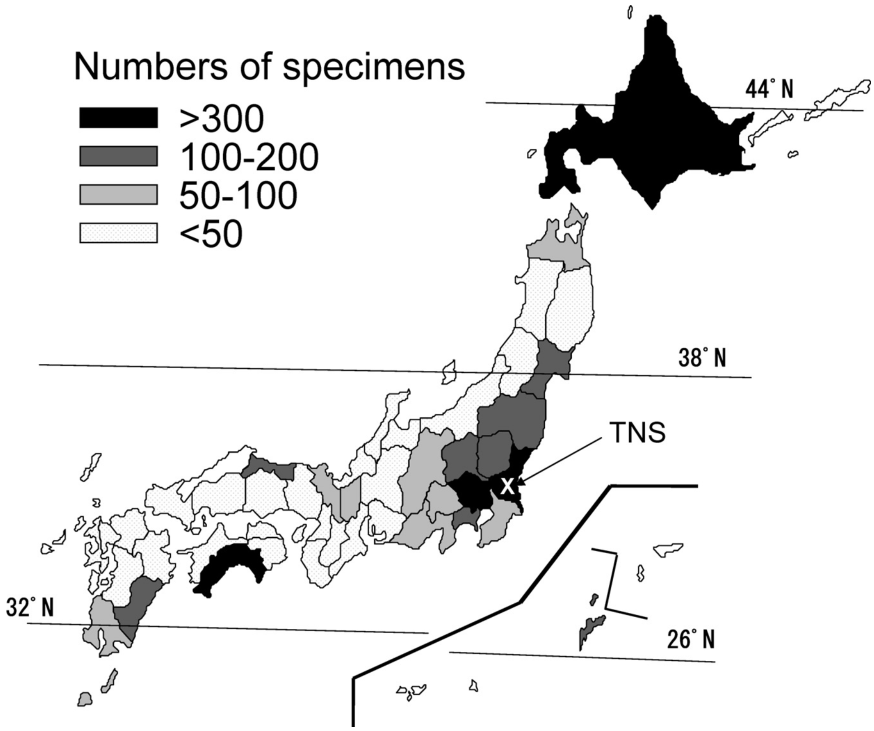

Fig. 6. Numbers of specimens by prefectures.

Table 3. Mycological herbaria in Japan participating in GBIF project.

Acronym	Herbaria/Culture collection	Featuring elements
JCM	Japan Collection of Microorganisms	Fungal isolates
KPM	Kanagawa Prefectural Museum	Fungi of Kanagawa Pref., Zygomycetes
KYO	Kyoto Univ.	Henmi Coll. & Tsuda Coll.
TFM	Inst. Forestry & Forest Products	Wood-rot fungi & parasitic fungi of trees
TMI	Tottori Mycological Institute	Agaricales, Aphyllophorales, & parasitic fungi on mushrooms
TNS	National Science Museum	Collection in wide areas in Japan
TSH	Univ. of Tsukuba	Ustomycetes
YAM	Yamaguchi Univ.	Hino-Katumoto Coll. (on bamboos)

specimens in the Northern part of Japan have not yet been incorporated, and further collaboration is desired. In the project, each herbarium provides information for the database in the particular format. The collected data are united as a single file and delivered over the internet. Some 22,000 records have so far been accumulated.

Currently, the majority of the specimens are basidiomycetes, followed by ascomycetes and some anamorphic fungi (Fig. 7a). The top 10 genera in the number of the specimens are: P*uccinia*, *Coleosporium*, *Uromyces*, *Coriolus* (*Trametes*), *Melampsora*, *Amanita*, *Russula*, *Lactarius*, *Trametes*, and *Tricholoma*. Most of them are rust fungi, and some agarics are also included. However, this composition does not reflect Japan's naturally occurring biodiversity.

Analyzing taxa diversity on a phylum basis, the proportion of Basidiomycota decreases because they have many duplication for the same taxon. However, basidiomycota still are the ma-

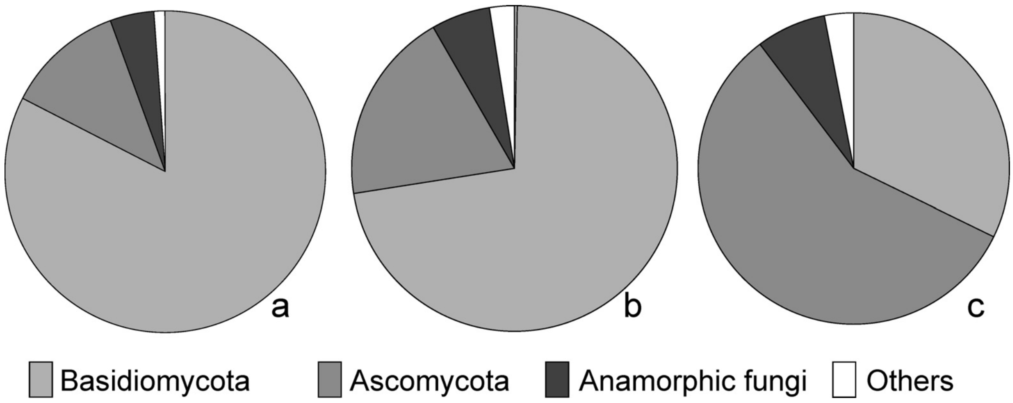

Fig. 7. Higher taxonomy of the Japanese specimens disclosed for GBIF project in TNS mycological herbarium a. Nos. of specimens by phyla. b. Nos. of taxa c. Nos. of taxa based on the literature data in Table 1.

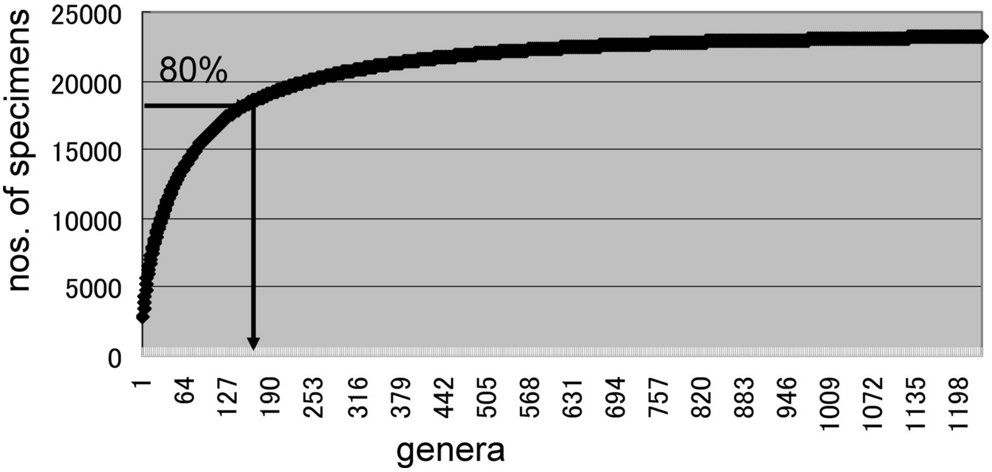

Fig. 8. Pareto analysis of the specimens by genera.

jority in the specimens (Fig. 7b). Nevertheless, based on literature data, the number of Ascomycota is about twice that of the Basidiomycota (Fig. 7c). Thus, there is a discrepancy between what we have (specimens in the herbarium) and what we know (literature data).

Pareto analysis of the specimens, where the genera are sorted in the order of number of specimens to obtain the cumulative count, reveals that 80% of the specimens are composed of 166 genera (less than 20% of genera), indicating that current collection is biased towards a limited number of common genera. Consequently, we should focus on collecting documented taxa for which we have no collections in the herbaria.

Toward The Understanding of The Fungal Biodiversity in Japan

As discussed above, both fungal inventory in Japan and the TNS mycological herbarium are at a turning point. Currently, the discrepancy between what we have and what we know is substantial. By collecting the specimens more strategically, the overlap between records and specimens will be increased. Only when the specimens conserved in the museums overwhelm the literature data, will the inventory be fully supported by specimens. To improve the situation and for continuous development, several issues are enumerated. 1) Continuous updating of the data is required. Reflecting enormous advances in fungal taxonomy, there have been drastic changes in fungal names, especially in the higher taxonomy. To manage the system in more convenient and well-organized manner, establishment of a common database for higher taxonomy is required. 2) Participation of more organizations to increase taxon and locality diversity is desired. Hopefully, the budget should be guaranteed and will be increased. Also, continuous improvement of the system for easier participation, maintenance, and to reduce confusion is required. 3) To match recent advances, development of the system that makes DNA level analysis possible is required. 4) To increase professional mycologists of next generation is greatly desired. Currently, there are no university courses for fundamental mycology. Although mycology has been taught in plant pathology laboratories, the majority of the plant pathology laboratories are directed towards virology, and mycology has been paid less attention. Nevertheless, fungi are one of the most popular and threatening organisms for vegetative products, and loss of education could become a huge problem in the future. As a national center of mycology, reinforcement of the function of the National Science Museum in mycological research is desired.

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