

Regular Paper

Biodiversity and species-area relationship of basidiomycetous macrofungi on seven islands along the southwestern coast of the Kii-Peninsula

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Abstract

The biodiversity and species-area relationship of basidiomycetous macrofungi recorded on seven islands along the southwestern coast of the Kii-Peninsula were investigated from the viewpoint of the island biogeography. Some fungi such as *Marasmiellus candidus*, *Crepidotus mollis*, *Russula castanopsidis*, *Microporus flabelliformis*, *Polyporus arcularius*, *Phellinus gilvus*, and *Auricularia polytricha* were observed on four or more islands have in common. It should be noted that most of them are wood inhabiting saprophytes, except *R. castanopsidis*, which is an ectomycorrhiza former. The number of observed species on a given island was closely fitted to the natural vegetation area of the island by a conventional power function $S = cA^z$, where S is the number of species, A is the area, and c and z are constants. A deduced z value of 0.350 was relatively small in comparing with that of vascular plants but larger than that of animals that were assessed on other islands having similar geographical conditions with this study. There was no negative correlation between distance from the land community and the number of species. High similarities of the species composition between islands represented by Ochiai's index were exhibited between islands with similar sizes of area, islands locate close to the same land community, or islands distribute in clump.

Introduction

Fungal biodiversity, due to their functions as a decomposer of organic materials and as mycorrhiza forming partners associating plants in terrestrial environments, is one of the most important factors in evaluating and preserving ecosystems¹⁻³⁾. There have been many reports on the structure of fungal biodiversity in several land communities⁴⁻⁷⁾. The land community, however, is usually engaged in close interactions with the adjacent community. In contrast, an island is visibly discrete object and its resident populations can be easily identified thereby⁸⁾.

On the other hand, about species richness, it is well known that the species-area curves, number

of species on a given area, become asymptotic for large area⁹⁻¹¹⁾. To express this curve, Arrhenius¹⁰⁾ proposed a power function model with the formula $S = cA^z$, or linearized one $\log S = \log c + z \log A$ in logarithmic transformation, where S is the number of observed species, A is the area of the island, z and c are constant. Preston^{12,13)} considered biological meaning and the z value of this formula and theoretically deduced that the $\log \text{species} / \log \text{area}$ curves have a slope z of 0.27 with the range from 0.17 to 0.33 by errors in sampling and other factors. The constant c varies widely among taxa and according to the unit of area measurement. MacArthur and Wilson^{8,14)} focused on Preston's insight and expounded this formula by their equilibrium model in the theory of island biogeography. They assumed that a large island would provide

higher immigration rates due to its large target size and lower extinction rates due to large amount of resources and large niche divergence when compared with a small island. The equilibrium model determining biodiversity, species richness, combines the parameters of falling immigration rate curves and rising extinction rate curves with an increase in the number of resident species. After the proposal of MacArthur and Wilson's equilibrium model, there have been many theoretical approaches to test this model¹⁵⁻¹⁷⁾ and experimental approaches by monitoring the recolonization of arthropod fauna on small mangrove islands^{18,19)}. On the other hand, Connor and McCoy²⁰⁾ reassessed the appropriateness of the power function on the species-area relationship comparing with alternative function models in one hundred cases of many organisms on geographically different several archipelagos and reconfirm the appropriateness of the power function.

The monitoring fungal species turnover, immigration and extinction was also carried out under a laboratory insular habitat by using cellophane squares of various sizes²¹⁾ or an apple leaf²²⁾. These excellent experimental approaches by using insular habitat, on small-scale laboratory conditions allow easy monitoring of species turnover for testing the equilibrium model as reviewed by Wild-

man²³⁾. These conditions, however, cannot provide the actual island environment, which is much larger and usually has a large niche diversity variable among islands. As previously pointed out by Simberloff²⁴⁾, more field studies are necessary to appreciate the nature and structure of biodiversity from the viewpoint of island biogeography. In the present study, the species diversity of basidiomycetous macrofungi recorded on seven islands along the southwest coast of the Kii-Peninsula was investigated by using the power function with comparison of alternative model functions from the viewpoint of island biogeography.

Materials and Methods

Study area

This study was performed on seven islands along the southwest coast of the Kii-Peninsula, Japan, four islands of which are distributed in the Tanabe Bay area, and three islands in the Shionomizaki area (Fig. 1). Area and some characteristics of each island are summarized in Table 1. Komarujima is the smallest having an total area of 548 m² followed in rising order by Maruyama, Hatakejima, Motoshima, Myogajima, Tsuyajima, and Kii-Oshima having 9.92 km², respectively.

Table 1. Area and some characteristics of observed seven islands along the southwestern coast of the Kii-Peninsula.

Island	Total Area (m ²)	Contribution (%) in total area				Distance (m) from the land community	Distance (m) from the nearest larger island	Covering of tree plants
		Rocks & sand shores	Natural vegetation	Agricultural & forestry field	Residence, buildings, & others			
Komarujima	548	79	21	0	0	1500	150	poor
Maruyama	2030	75	23	0	2	150	L ^{a)}	medium
Hatakejima	26000	40	59	0	1	1500	L	medium
Motoshima	35900	40	52	0	8	500	L	partly dense
Myogajima	46600	33	55	0	12	750	250	dense
Tsuyajima	273000	32	49	19	0	2000	250	dense
Kii-Oshima	9920000	5	49	32	14	1200	L	dense

a): Distance from the land community is smaller than the distance from any larger island.

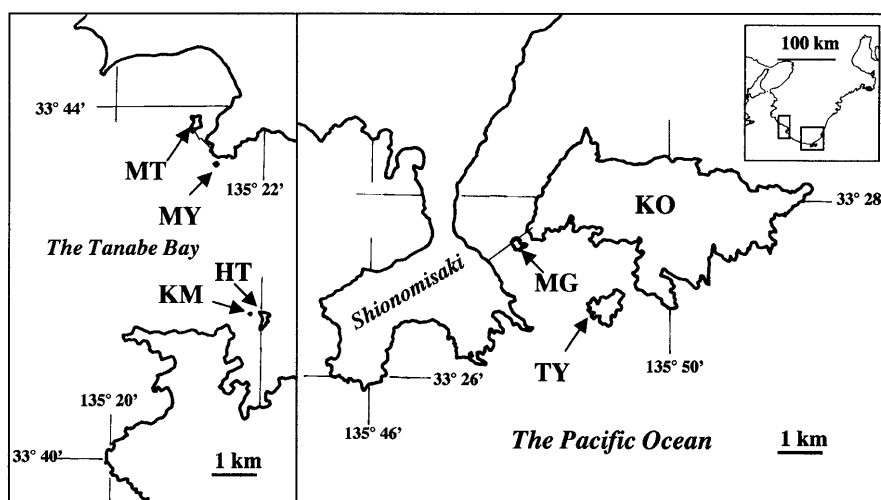


Fig. 1. Map showing the location of the observed islands, in the Tanabe Bay area (left) and the Shionomisaki area (right), along the southwestern coast of the Kii-Peninsula. Inset on the upper right of the figure represents the Kii-Peninsula.

Abbreviations of islands: KM, Komarujima; MY, Maruyama; HT, Hatakejima; MT, Motoshima; MG, Myogajima; TY, Tsuyajima; KO, Kii-Oshima.

Contribution of rocks and sand shores, natural vegetation, and artificially disturbed area in total area were variable among islands. In Tanabe Bay, Maruyama is connected by a land bridge made of rocks at low tide but is 150 m apart from the land community. Motoshima is connected by breakwater but is 500 m apart from the land community. In the Shionomisaki area, Myogajima and Kii-Oshima have been bridged with Shionomisaki since 1999. Tsuyajima is 2000 m apart from Shionomisaki community but close to Kii-Oshima, at a distance of 250 m. These seven islands are 'land bridge islands', which were connected to the land community of the Japanese archipelago and continental Asia until the end of the glacial epoch. A mean annual temperature is about 17°C in the both areas and a mean annual precipitation is about 1700 mm in the Tanabe Bay area and 2600 mm in the Shionomisaki area, respectively. The warm temperate evergreen broad-leaved forest dominates in these areas. *Castanopsis cuspidata* Schottky var. *sieboldii* Nakai, *Quercus philly-*

raeoides A. Gray, *Myrica rubra* Sieb. & Zucc., and *Daphniphyllum macropodum* Miq. are dominant trees on most island. Tree plant covering was somewhat depend on the sizes of island as shown in Table 1. The mature vegetation such as dense *Castanopsis* stands are developed on any islands in the Shionomisaki area, while they are relatively poor on smaller islands in the Tanabe Bay area. There have been documented on seed plants, 771 species belonging to 114 families on Kii-Oshima²⁵⁾ and 107 species belonging to 53 families on Motoshima²⁶⁾. Kii-Oshima has a population of over 1600, and several cultivated plants have been historically introduced. Tsuyajima was used for intensive planting of some kinds of Parmaceae plants during 1950s, but has been follow since 1960s. Hatakejima was used for cultivation of *Morus alba* L. until the 1950s. Recently, nearly ten percent of the natural vegetation on Myogajima has cut out to build a bridge, and ruderal plants grew below the bridge at present. While on the other islands, human activities have been very low.

Survey and data analysis

Observations of basidiomycetous macrofungi were intensively carried out from April to November of 1998-2002 on Kii-Oshima^{27,28)}, and 2001-2003 on the other six islands²⁹⁾. Field observation was mostly performed in the natural vegetation area on any islands, but also in the plantation of the hinoki cypress, *Chamaecyparis obtusa* (Sieb. et Zucc.) Endl., on Kii-Oshima. Identification of fungal species was made by referring to color illustrations^{30,31)}. Some of the Polyporaceae species were identified by Dr. T. Hattori, Forestry Products Research Institute, Tsukuba, and some of the other taxa by Dr. T. Fukiharu, Natural History Museum and Institute, Chiba. Most of the collected specimens are available at the herbarium of Kii-Oshima Experimental Station, Field Research and Education Center of Kyoto University.

To assess the appropriateness of the conventional power function model for explaining species-area relationship, 'fitting to the regression line' were compared among the following function models: untransformed ($S = zA + c$), logarithmic ($S = z \log A + c$), exponential ($\log S = zA + \log c$), and power function ($\log S = z \log A + \log c$), according to Connor and McCoy²⁰⁾. For calculation, area of the natural vegetation was used as an area of each island instead of its total area, because most fungi were recorded in the natural vegetation and the contributions of natural vegetation area to total area was varied among islands as shown in **Table 1**. 'Fitting to the regression line' was evaluated by correlation coefficient (r) and ratio of mean square (F) of the explained variation which due to linear regression to that of the unexplained variation which is error around regression line according to Sokal and Rohlf³²⁾.

The similarity of species composition between any two island communities was represented by Ochiai's index (OI)³³⁾ according to the following formula: $OI = C / \sqrt{a} \sqrt{b}$, where a and b are the numbers of observed species on the two islands, respec-

tively, C is the number of species they have in common. This index gives values between 0, meaning no similarity, and 1, meaning complete similarity, as the same those by Sørensen³⁴⁾ or Jaccard³⁵⁾. While this index is effective to compensate the evaluations in comparison with other indices, especially when the difference in the number of species between islands is relatively large³⁶⁾. To compare the indices nonparametric analysis, Mann-Whitney U-test, was performed according to Sokal and Rohlf³²⁾.

Results

Consequently, in total, 194 species of basidiomycetous macrofungi belonging to 35 families have been recorded on the seven islands. Most fungi were recorded in the natural vegetation excepting a few species, e.g., *Marasmiellus chamaecyparidus* (Hongo) Hongo and *Antrodiella gypsea* (Yasuda) Hattori & Ryv. those were observed in the plantation of hinoki cypress on Kii-Oshima. **Table 2** shows the number of species observed on the seven islands, not counted the two species mentioned above, with major species recorded on four or more islands in common. *Marasmiellus candidus*, *Crepidotus mollis*, *Microporus flabelliformis*, *Polyporus arcularius*, and *Phellinus gilvus* were commonly observed on six or all of the islands. Additionally, *Russula castanopsidis* and *Auricularia polytricha* were observed on five islands. These fungi, excepting the ectomycorrhiza forming *R. castanopsidis*, are wood inhabiting saprophytes.

The number of observed species on a given island was closely fitted to the natural vegetation area of an island by a conventional power function, $S = cA^z$, with fitted constants c and z of 0.926 and 0.350, respectively (**Fig. 2**, left). Any models, excepting exponential function ($r = 0.593$, $F = 2.72$, $P > 0.25$), provided significant positive correlation and F value ($P < 0.01$), i. e., untransformed ($r = 0.935$,

Table 2. Basidiomycetous macrofungi observed on four or more islands among seven islands have in common and total number of species on each island along the southwestern coast of the Kii-Peninsula.

Taxon and Species	Island ^{a)}						
	KM	MY	HT	MT	MG	TY	KO
TRICHOLOMATACEAE							
<i>Marasmiellus candidus</i> (Bolt.) Sing.		+	+	+	+	+	+
AGARICACEAE							
<i>Agaricus praeclaresquamosus</i> Freeman			+	+		+	+
<i>Leucocoprinus fragilissimus</i> (Rav.) Pat.			+	+	+		+
CREPIDOTACEAE							
<i>Crepidotus mollis</i> (Schaeff.: Fr.) Kummer	+	+	+	+	+	+	+
RUSSULACEAE							
<i>Russula castanopsidis</i> Hongo			+	+	+	+	+
STEREACEAE							
<i>Xyloborus spectabilis</i> (Klotz.) Boidin.				+	+	+	+
POLYPORACEAE							
<i>Microporus flabelliformis</i> (Fr.) Kuntze		+	+	+	+	+	+
<i>Perenniporia tephropora</i> (Mont.) Ryv.				+	+	+	+
<i>Polyporus arcularius</i> Batsch.: Fr.	+	+	+	+	+	+	+
<i>Pycnoporus coccineus</i> (Fr.) Bond. & Sing.		+		+	+		+
HYMENOCHAETACEAE							
<i>Phellinus gilvus</i> (Schw.: Fr.) Pat.		+	+	+	+	+	+
TREMELLACEAE							
<i>Tremella mesenterica</i> Retz.: Fr.				+	+	+	+
AURICULARIACEAE							
<i>Auricularia polytricha</i> (Mont.) Sacc.			+	+	+	+	+
Number of other species	1	3	32	23	27	40	134
Total number of species	3	9	41	36	39	51	147
Total number of families	3	5	14	15	16	21	33

a): Abbreviations of islands are the same as those described in Fig. 1. Islands from left to right are arranged in rising order of sizes of area.

+, observed; no + sign, not observed.

F=34.9) and logarithmic ($r=0.936$, $F=35.1$). The power function provided the highest values ($r=0.969$, $P<0.01$; $F=77.0$, $P<0.001$) among the four functions. In the power function, using the size of the natural vegetation area gave slightly better fitting and smaller z value than those calculated by using the total area of each island ($r=0.954$, $F=50.1$, $z=0.391$). On the other hand, there was no negative correlation between the distance from the land community and the number of species (Fig. 2, right; $r=0.263$, $P>0.05$).

Table 3 shows the similarity of species composition between islands by using Ochiai's index. Overall, relatively high similarities were exhibited

on the two islands having similar sizes of area, and a significant correlation was detected between ratios of log areas of smaller to larger and the similarities of species composition (the arcsine transformation, $\sin^{-1}\sqrt{\quad}$, was performed on both variables; $r=0.654$, $P<0.01$). While it is noted that even each size of area were largely different by more than ten folds, the similarities between MY and MT, MG and KO, and TY and KO, exhibited significantly higher than those in the other pairs ($U=51$, $P<0.05$).

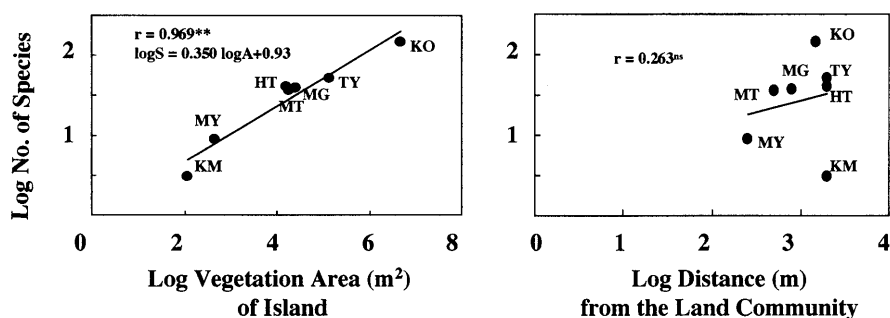


Fig. 2. The relationship of area of natural vegetation to species number (left) and distance to species number (right) of basidiomycetous macrofungi recorded on seven islands along the southwestern coast of the Kii Peninsula. Abbreviations of islands are the same as those described in Fig. 1.

Table 3. Similarity of the species composition between any two islands.

Island	Island ^{a)}						
	KM	MY	HT	MT	MG	TY	KO
KM		0.385 (2) ^{b)}	0.217 (3)	0.289 (3)	0.183 (2)	0.160 (2)	0.095 (2)
MY			0.214 (4)	0.389 (7)	0.316 (6)	0.231 (5)	0.220 (8)
HT				0.373 (14)	0.304 (12)	0.222 (10)	0.343 (26)
MT					0.395 (15)	0.300 (13)	0.302 (22)
MG						0.323 (17)	0.404 (31)
TY							0.423 (37)

Similarity of the species composition was represented by Ochiai's index, $OI = C / \sqrt{a} \sqrt{b}$, where a and b are the number of species on respective islands, and C is the number of species they were observed to have in common.

a): Abbreviations of islands are the same as those described in Fig. 1. Islands from left to right are arranged in rising order of sizes of area.

b): Numerals in parentheses the number of species on respective islands to have in common.

Discussion

A large island could develop mature vegetation which supply host plants for variable types of ectomycorrhizal fungi and substrates for saprophytic fungi, additionally, the dense tree stands protect wind blowing into the forest and keep soil water content. In contrast, small islands are often exposed to direct oceanic wind and high tide and these disturbances inhibit the establishment of mature tree stands and sufficient niche for fungi.

While the fungi listed in Table 2 are regarded as successful colonizers of the study area by their commonness even on small islands, most of them were wood-inhabiting saprophytes characterized by the formation of many small basidiocarps over the surface of the substrate, which was usually a dead log, branch, or twig, but not leaf-litter.

The total number of species recorded on each island shown in Table 2 seems to be a lower estimation than the actual number of species growing there especially on the large islands. However, it is obvious that islands with larger area are capable

of carrying larger numbers of species belonging to a wider variety of families. The highest correlation coefficient and F value obtained from the power function in this study suggest that the power function is better or the best model for explaining the species-area relationship as demonstrated by Connor and McCoy²⁰ from 100 cases of variable organisms on several archipelagos. Wildman²¹ also deduced that the power function was the best and only one appropriate model for fitting to species-area relationship of hypho-mycetous fungi on experimental insular habitat by using the cellophane squares cut into 4, 16, 64, 256, and 1024 mm², and obtained the fitted constant z of 0.363. The present study showed that the power function is effective to evaluate and predict the species diversity of basidiomycetous macrofungi on actual islands. However, insofar as we know, there is no comparable data on z value of basidiomycetous fungi on actual islands assessed in other regions. While it would be worth to compare the presented z value with those of other organisms observed on small islands including less than 10 km² and distributed near from land (continental) community as similar geographical conditions in the present study by using data sets reassessed by Connor and McCoy²⁰. The present z value was relatively smaller comparing with those of vascular plants on the Channel Is., California (0.416)³⁷ or (0.445)³⁸, and islands in Gulf of Finland (0.482)³⁹, while, it was larger comparing with those of animals such as birds on the Orkney Is. (0.311)⁴⁰ and the Channel Is. (0.209)³⁸, reptiles on New Guinea Cays (0.140)⁴¹, arboreal arthropods on mangrove islands (0.221)⁴², orthoptera (0.269) and ants (0.188) on the Tsucan archipelago⁴³.

Although the land fungal community of the southwestern Kii-Peninsula is not known in detail, the adjacent land community is a major source pool for immigration and establishment of the island community. So, it would be expected that the number of species on an island remote from the land community is smaller than that on an island

closer to the land community. While the present data provided no proof of a negative correlation between distance from the land community and the number of species, suggesting that distance effect on immigration rate would be small, and many fungi have enough ability of spore dispersal insofar within 2 km, as reviewed by Burnett⁴⁴. Islands having similar sizes carried similar species composition on both suggesting not only size dependent species counts as above but also size dependent species composition. In contrast, it is noted that high similarities of the species composition were exhibited between some pairs of islands, even of which area was largely different each other. The high similarity shown between Moto-shima and Maruyama seems due to their location of which close to the same land community. The high similarities shown between Myogajima and Kii-Oshima, and Tsuyajima and Kii-Oshima would be partly attributable to their clumped distribution. Although Myogajima and Tsuyajima are remote from the land community, especially Tsuyajima which is 2 km apart, they are close to the large island Kii-Oshima that has a large fungal diversity. Although many fungi would have a great ability of spore dispersal as mentioned, species turnover with continuous immigrations of some kinds of fungi from the close large community of Kii-Oshima seem to affect species composition among closely adjacent islands, an effect so called 'stepping stone'.

The present study suggests that assessing island communities from the viewpoints of island biogeography is effective to elucidate the structure of fungal species diversity in comparison with the other organisms. To appreciate the mode of colonization comparing among taxa of basidiomycetous fungi, further analysis of species composition will be needed.

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和文摘要

紀伊半島南西海岸域の7つの島々における大型担子菌類の多様性および種数-面積関係

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紀伊半島南西海岸域に分布する7つの島で記録した大型担子菌類の多様性と種数-面積関係について、島の生物地理学的観点から調べた。シロホウライタケ、チャヒラタケ、カレバハツ、ネンドタケ、ウチワタケ、アミスギタケ、アラゲキクラゲなどの種は4つ以上の島々で共通して観察された。外生菌根を形成するカレバハツを除いて、これらのほとんどの種が木材腐朽菌であったことは注目された。各島での記録種数は島の自然植生面積に対して、慣例的な累乗式、 $S = cA^z$ 、によく適合した。ここで、 S は種数、 A は面積、 c と z は定数である。得られた z 値、0.350は、本研究と類似の地理的条件をもつ他地域で調べられた維管束植物のそれと比較して小さく、動物のそれよりも大きかった。種数と陸群集からの距離との間に負の相関性はみられなかった。落合の指数で示した島間の種類類似度は、植生面積が似通った島間で高く、さらに共通の陸群集から近距離にある島間、あるいは近接して分布する島間で高かった。

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