Analysis of Forest Ecosystems: Vertical structure of Woody Plants and Mushrooms in Evergreen Broad-leaved Forests

Osamu YAMAGUCHI and Yoko TSUCHIDA*

(Received September 20, 1994)

ABSTRACT

A total of twenty-one mature evergreen broad-leaved forests were examined for woody plants and mushrooms therein in refernce to analysis of vertical structure. A total of 167 woody plants and a total of 128 mushroom species were analyzed for their fruit types and colors. Canopy trees have dry and brownish fruits. The trees of the undertree layer have juicy and purple fruits. The trees of the shrub and grass layers have juicy and red fruits. The vertical separation of niches in woody plants is reflected also into that of fungi. Mushroom color is arranged to three color types of brownish, purple, and red patterns in this order of vertical distribution.

INTRODUCTION

Ecosystem is composed of three functional groups of organisms as well as inorganic matters, namely, green plants as producers, animals including insects as consumers, and fungi and bacteria as reducers or decomposers. One of the typical terrestrial ecosystems is a forest. Huge woody plants and well developed forest crown is also a symbol of the abundance and diversity of lives of consumers and decomposers. The crown reaches forty meters in height in the central part of our country. That enables the mass of lives to separate their niches one another. At present, there are mainly six types of forest ecosystems in our country; subtropical rain forest, evergreen broad-leaved forest, substitutional forest dominated by pines and deciduous oaks, summer green forest, coniferous forest, and windswept grassland. Especially in equilibrium and climax forests, the woody plants are divided into some layers according to its distinct crown heights. They make so-called stratification in cosequence of competition and habitat segregation (Whittaker, 1975). Usually there are four or five layers of branch territory (Nakanishi et al., 1983). These vertical layers provide specific and corresponding niches to the aminals, fungi and bacteria therein. Habitat segregation especially in vetrtical distribution is expected. Here in this article, some characteristics of vertical structure of woody plants and mushrooms are described in equilibrium evergreen broad-leaved forests.

MATERIALS AND METHODS

Study sites: Evergreen broad-leaved forests are preserved in primeval state in some restricted areas of our country. Most of them are assigned as natural monuments although they are not in extensive area. Most of them are histrorically attached forests to shines or to temples. A total of twenty-one such forests are chosen in the western part of Honshu. They are listed in Table 1. Thirteen of them are of natural monuments (Numata, 1984). Two are of Hyogo prefectural monuments. The remainig six are not assigned yet to monument, however the vegetation is quite similar to the former and is in equilibrium state (Iwabuchi et al., 1994). The examinaton of vegetation and the mushroom survey was done from October of 1989 to April of 1994. A quadrat measuring 20 x 20 meters was built at each forest. All the forest trees with height of more than 0.3 meters were scored after identification. In some forests, the vegetation was refered from Numata(1984) and Miyawaki (1981). They are further divided into four layers; tree layer (B1), undertree layer (B2), shrub layer (S), and grass layer (K) accoring to Nakanishi et al. (1983). Fruits and seeds were also

Department of Biology, Hyogo University of Teacher Education, Yashiro, Hyogo 673-14, Japan.
*Present address: Takahira Elementary School, Shimozato, Sanda, Hyogo 669-14

Table 1. Summary of main vegetation in twenty-one climax evergreen broad-leaved forests examined.

Forest	Kuki Shrine	Kasuga Shrine	Kasuga taisha Shrine	Hase-dera Temple	Oonamo-chi Shrine	Nyuuga-wakami Shrine	Kinumaki Shrine	Yagumo Shrine	Tairyu-ji Temple	Taisanji Temple	Sumi-yoshi1 Shrine	Ootoshi Shrine	Sumi-yoshi2 Shrine	Sumi-yoshi3 Shrine	Oohi Shrine	Kurata-hachiman Shrine	Oonomi-nosukune Shrine	Matsu-gami Shrine	Hakuto Shrine	Shizuki Hill	Hotsu-misaki Temple
Prefecture	Mie	Waka-yama	Nara	Nara	Nara	Nara	Hyogo	Hyogo	Hyogo	Hyogo	Hyogo	Hyogo	Hyogo	Hyogo	Hyogo	Tottori	Tottori	Tottori	Tottori	Yamagu-chi	Kochi
Tree layer																					
Podocarpus macrophyllus		○												○	○	○		○		○	
Podocarpus nagi			○																		○
Marchis thunbergii	○	○					○								○	○	○	○	○	○	○
Cinnamomum comphora	○	○					○		○		○	○		○	○					○	
Litsea coreana					○				○						○			○		○	○
Castanopsis sieboldii	○	○					○		○						○	○	○	○	○	○	○
Castanopsis cuspidata			○	○	○			○		○	○	○		○	○						
Quercus salicina			○	○		○		○		○						○		○	○		
Quercus glauca	○		○	○	○		○	○	○	○	○	○	○	○	○						
Quercus acuta									○												
Quercus sessilifolia			○		○	○							○					○	○		
Daphniphyllum teijsmannii		○					○			○					○	○				○	○
Elaeocarpus sylvestris		○																		○	○
Undertree layer																					
Camellia japonica	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Cleyera japonica	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
Eurya japonica	○	○	○	○		○		○	○	○	○	○	○	○		○	○	○	○	○	
Cinnamomum japonicum		○					○	○	○		○		○	○	○	○	○		○	○	○
Neolitsea sericea		○			○											○		○	○	○	○
Stauntonia hexaphylla		○							○	○					○		○		○		
Shrub layer																					
Illicium anisatum	○		○			○							○								
Aucuba japonica			○	○	○			○	○	○	○	○			○		○	○	○	○	○
Ardisia crenata	○	○						○				○	○	○	○	○					○
Chloranthus glaber	○	○			○										○						○
Maesa japonica	○		○												○						○
Grass layer																					
Ardisia japonica	○		○									○	○	○	○			○	○	○	
Ardisia crispa								○							○	○					
Trachelospermum asiaticum			○		○	○		○	○	○	○	○	○	○	○		○	○	○	○	
Damnacanthus indicus	○	○			○	○									○					○	○

Table 2. Similarity indeces (SI) in woody plant vegetation between fifteen climax evergreen broad-leaved forests. Forests in Box A are classified as inland-typed, and those in Box C are classified as seashore-typed. Box B is overlapped.

	Oonamochi Shrine	Sumiyoshi2 Shrine	Sumiyoshi3 Shrine	Yagumo Shrine	Taisanji Temple	Matsugami Shrine	Oonominosukune Shrine	Tairyuji Temple	Kuratahachiman Shrine	Hakuto Shrine	Shizuki Hill	Oohi Shrine	Kuki Shrine	Kasuga Shrine	Hotsumisaki Temple
Oonamochi	-	0.31	0.32	0.38	0.31	0.28	0.21	0.39	0.20	0.24	0.26	0.35	0.23	0.20	0.25
Sumiyoshi2		-	0.65	0.52	0.40	0.36	0.26	0.39	0.32	0.28	0.21	0.29	0.26	0.21	0.14
Sumiyoshi3			-	0.50	0.44	0.32	0.23	0.33	0.29	0.23	0.25	0.39	0.32	0.26	0.14
Yagumo				-	0.53	0.20	0.38	0.39	0.35	0.30	0.26	0.38	0.31	0.20	0.23
Taisanji	A				-	0.24	0.33	0.41	0.29	0.35	0.19	0.32	0.39	0.31	0.24
Matsugami						-	0.33	0.31	0.34	0.50	0.35	0.27	0.25	0.22	0.29
Oonominosukune							-	0.43	0.47	0.37	0.32	0.41	0.30	0.35	0.29
Tairyuji								-	0.28	0.38	0.30	0.32	0.26	0.32	0.26
Kuratahachiman						B			-	0.38	0.43	0.45	0.38	0.48	0.33
Hakuto											0.39	0.40	0.28	0.32	0.38
Shizuki											-	0.47	0.48	0.47	0.48
Oohi												-	0.50	0.53	0.42
Kuki													-	0.51	0.52
Kasuga														-	0.61
Hotsumisaki									C						-

examined in that period.

Analysis: Diversity and identity in woody plants between the forests was expressed by a quanty known as the similarity index, SI. The SI was defined as follows: SI = 2C/(A+B), where A and B are the numbers of species observed at forests A and B, respectively. C is the number of species observed in common (Odum, 1971).

RESULTS

Characteristics of stratification of vegetation in evergreen broad-leaved forests: Lucidophyllous forest is characterized by some common trees. Either *Castanopsis sieboldii* or *C. cuspidata* is the most popular canopy tree. They are observed in nineteen forests out of twenty-one as shown in Table 1. Otherwise, other orks such as *Quercus myrsinaefolia* or *Q. gilva* replaced them presumably due to a stochastic process. *Camellia japonica* and *Cleyera japonica* are more characteristic and representative to the forests especially in undertree layer. The former was observed in all the forests examined, and the latter was observed in the nineteen forests. *Eurya japonica* and *Cinnamomum japonica* are also quite popular in the undertree layers. *Aucuba japonica* is the most common tree in the shrub layers, and was observed in the fourteen forests. *Trachelospermum asiaticum* was the most popular creeper vine in the grass layers, and was observed in the sixteen forests. The representative woody plants to specific layers are summerized in Table 1.

Diversity in vegetion is seen rather in minor groups of trees. A total of 167 woody plant species were observed in a mass of 21 forests. On the average, 35.5 ± 2.48 species were in a single forest. The similarity in vegetation is expressed as the similarity index, SI. The distribution of SI values between the forests is shown in Table 2. The maximum value was 0.65, and the minimum was 0.14, respectively. The average was 0.34 ± 0.01. The forests which have high SI values are grouped and boxed in Table 2. There exist three types of vegetation; seashore-type, inland-type, and mixed type. The seashore-type is characterized by accompaniment of *Custanopsis sieboldii, Machilus thunbergii, Podocarpus macrophyllus, Ficus erecta,* and *Litsea japonica.* While the inland-type is characterized by *Custanopsis cuspidata, Quercus salicina, Photinia glabra,* and *Osmanthus heterophyllus.* In any forests, the verticul structure was easily recognized, and it was made of four layers.

Stratification in flower color and fruit color: Blooming of evergreen oaks makes the forests golden yellow in the end of spring. Therefore, the forests are easily recognisable by the color as well as by the high crowns. However, the trees in the undertree or shrub or grass layers do not always bloom in spring, and their flower colors are also variable. Distribution of blooming seasons and flower colors was examined in each layer of the above evergreen broad-leaved forests by using the criteria of Hayashi (1985) and Satake et al. (1989). Flower color was described by atmosphere of each flower as a whole. This was not always the same to the color of petals. The results are shown in Table 3. The majority of canopy trees bloom in spring, and its mode of flower color is yellow. The trees in undertree, shrub and grass layers bloom also in spring, but its flowing period is in more wide range including winter. The mode of flower color is not yellowish but white.

Fruiting season, fruit color, and truit type was also examind in the same manner. The fruit type is defined whether it is an acorn coverd with dry hard skin or a soft fruit with juicy pulp. The fruiting season is concentrated in autumn for the canopy trees and the trees in the other layers. However, the latter has a more wide rage in fruiting period. There were three major types of fruits in any layers; brownish dry fruit, purple juicy fruit, and red juicy fruit. The majority of canopy trees has the former type. Twenty-four woody plant species out of sixty-two have the type of dry brown fruits. Twenty-two out of fourty-five woody plant species in the undertree layer have the type of purple juicy fruits. While the majority of trees in the shrub and grass layers have red juicy fruits. A total of twenty-nine species out of sixty have that type.

Stratification in mushroom distribution: Mushroom survey was done simultaneously or independently with the examination of vegetation. A total of 128 mushroom species was identified.

Table 3. Distribution of flowering seasons, flower color types, fruiting seasons, fruit color types, and fruit types in the vertical structure of equilibrium evergreen broad-leaved forests. Figures are number of woody plant species.

Stratification	Flowering season	Flower color type	No. of species	Fruiting season	No. of species	Fruit color type	Fruit type	No. of species
Tree layer								
	spring	white	9	spring	1	brown	dry	24
	spring	yellow	24	summer	7	red	dry	2
	spring	green	9	autumn	47	red	juicy	11
	spring	red	3	winter	7	purple	dry	2
	spring	purple	3			purple	juicy	23
	summer	white	4					
	summer	yellow	4					
	summer	green	2					
	summer	purple	1					
	autumn	white	1					
	autumn	yellow	2					
(Total)			(62)		(62)			(62)
Undertree layer								
	spring	white	6	spring	2	brown	dry	12
	spring	yellow	7	summer	2	brown	juicy	2
	spring	green	1	autumn	35	red	dry	1
	spring	red	2	winter	6	red	juicy	8
	spring	purple	3			purple	juicy	22
	summer	white	12					
	summer	yellow	4					
	summer	green	3					
	autumn	white	3					
	autumn	yellow	3					
	winter	red	1					
(Total)			(45)		(45)			(45)
Shrub layer								
	spring	white	11	spring	3	brown	dry	11
	spring	yellow	7	summer	5	red	juicy	19
	spring	green	2	autumn	31	purple	juicy	16
	spring	red	1	winter	7			
	spring	purple	5					
	summer	white	6					
	summer	yellow	3					
	summer	green	4					
	summer	purple	2					
	autumn	white	3					
	winter	white	1					
	winter	yellow	1					
(Total)			(46)		(46)			(46)
Grass layer								
	spring	white	6	spring	1	white	juicy	1
	spring	yellow	1	summer	1	yellow	juicy	1
	summer	white	4	autumn	5	brown	dry	2
	summer	yellow	1	winter	7	red	juicy	10
	autumn	white	1					
	winter	yellow	1					
(Total)			(14)		(14)			(14)
Pooled								
	spring		100	spring	7	white		1
	summer		50	summer	15	yellow		1
	autumn		13	autumn	118	brown		51
	winter		4	winter	27	red		51
						purple		63
(Total)			(167)		(167)			(167)
		white	67				dry	54
		yellow	58				juicy	113
		green	21					
		red	7					
		purple	14					
(Total)			(167)					(167)

Table 4. Vertical distribution of mushrooms and its systematic grouping in evergreen broad-leaved forests.

Stratification	Systematic groupe	No. of species	Mushroom species
Tree layer	- (not found)	-	-
Undertree layer	Agaricales	2	*Pleurotus ostreatus, Lentinus edodes*
	Aphyllophorales	4	*Laetiporus versisporus, Coriolus brevis, Phellinus robustus, Elfvingia applanata*
	Heterobasidiomycetes	3	*Auricularia polytricha, Auricularia auricula, Exidia uvapassa*
Shrub layer	Agaricales	9	*Marasmius leveilleanus, Crinipellis stipitaria, Mycena crocata, Mycena galericulata, Oudemansiella mucida, Micromphale* sp., *Pluteus atricapillus, Gymnopilus liquiritiae, Crepidotus badiofloccosus*
	Aphyllophorales	20	*Xylobolus annosus, Coriolus versicolor, Coriolus hirsutus, Trichaptum fuscoviolaceum, Trichaptum biforme, Microporus vernicipes, Microporus flabelliformis, Daedaleopsis purpurea, Cyclomyces fuscus,* and others
	Heterobasidiomycetes	1	*Exidia glandulosa*
	Ascomycotina	2	*Trichocoma paradoxa, Bisporella citrina*
Grass layer	Agaricales	73	*Amanita virgineoides, Amanita porphyria, Amanita pseudoporphyria, Amanita fuliginea, Cortinarius subalboviolaceus, Russula cyanoxantha, Russula castanopsidis, Russula omiensis, Lactarius gracilis,* and others
	Aphyllophorales	7	*Clavulinopsis miyabeana, Clavulinopsis fusiformis, Sparassis crispa, Fistulina hepatica, Thelephora palmata, Sarcodon scabrosus, Coltricia cinnamomea*
	Gasteromycetidae	4	*Astraeus hygrometricus, Gaestrum saccatum, Lycoperdon perlatum, Ileodictyon gracile*
	Ascomycotina	3	*Cordyceps ophioglossoides, Xylaria polymorpha, Elaphomyces granulatus*
(Total)		(128)	

However, there was about a quarter of mushrooms which were not able to be classified. Most of them seem to be nondescribed species. Thus, they were tentatively excluded from the present analysis. They could be divided into the three classes for their vertical distribution; undertree layer, shrub layer, and grass layer. There was no mushroom in the tree layer. In the layers of undertree and shrub, there were twenty-four aphyllophorales species and four heterobasidiomycetes species as shown in Table 4. All of them are saprophytic in the gain of energy. On the contrary, seventy-three species were of agaricales in the grass layer, and it was 84 per cent. Fifty-five species out of them are ectomycorhyzal, and twenty-two are saprophytic. The majority of the former are symbiotic to the host trees of oaks dominated in the forests (Imazeki and Hongo, 1987 and 1989). No remarkable differences in mushroom distribution were observed between the present evergreen broad-leaved forests.

There was a conspicuous habitat segreagation between two fungal species of *Laetiporus versisporus* and *Fistulina hepatica*. Both of them are alive commonly on the woods of *Castanopsis sieboldii* and *C. cuspidata*. Their mushrooms have never been observed to appear on the same tree trunk. While the former appears on the higher parts of the trunks, the latter does on trunk quite near to the ground. A total of eleven and fifteen mushrooms were observed for *F. hepatica* and *L. versisporus*, respectively. Their fruiting sites are shown in Table 5. *L. versisporus* has a wider range of host specificity. This species also has a later fruiting time than *F. hepatica*.

Table 5. Vertical distribution of the mushrooms of *Fistulina hepatica* and *Laetiporus versisporus* in evergreen broad-leaved forests.

Species	Host wood	Fruiting site	Stratification	No. of mushrooms	Forest	Date of collection
Fistulina	*Castanopsis cuspidata*	trunk near ground	grass layer	2	Yagumo Shrine	Oct 18, 1991
hepatica	*C. sieboldii*	trunk near ground	grass layer	1	Tairyuji Temple	Oct 4, 1992
	C. sieboldii	trunk	shrub layer	1	Tairyuji Temple	Oct 4, 1992
	C. cuspidata	trunk near ground	grass layer	2	Yagumo Shrine	Oct 14, 1992
	C. sieboldii	trunk near ground	grass layer	5	Kinumake Shrine	Nov 10, 1992
(Total)				(11)		
Laetiporus	*C. cuspidata*	trunk	undertree layer	4	Sumiyoshi1 Shrine	Oct 18, 1991
versisporus	*Quercus crispula*	trunk	undertree layer	1	Furusatonomori*	Oct 30, 1992
	C. cuspidata	trunk near ground	grass lalyer	3	Sumiyoshi1 Shrine	Nov 13, 1992
	Q. myrsinaefolia	decayed trunk	undertree layer	4	Sumiyoshi2 Shrine	Nov 13, 1992
	C. sieboldii	trunk	undertree layer	1	Tairyuji Temple	Nov 21, 1992
	C. cuspidata	trunk	undertree layer	1	Yagumo Shrine	Dec 6, 1992
	Q. salicina	trunk	undertree layer	1	Yagumo Shrine	Dec 6, 1992
(Total)				(15)		

* Summer green forest dominated by *Fagus crenata* and *Quercus crispula* and located in Tottori prefecture.

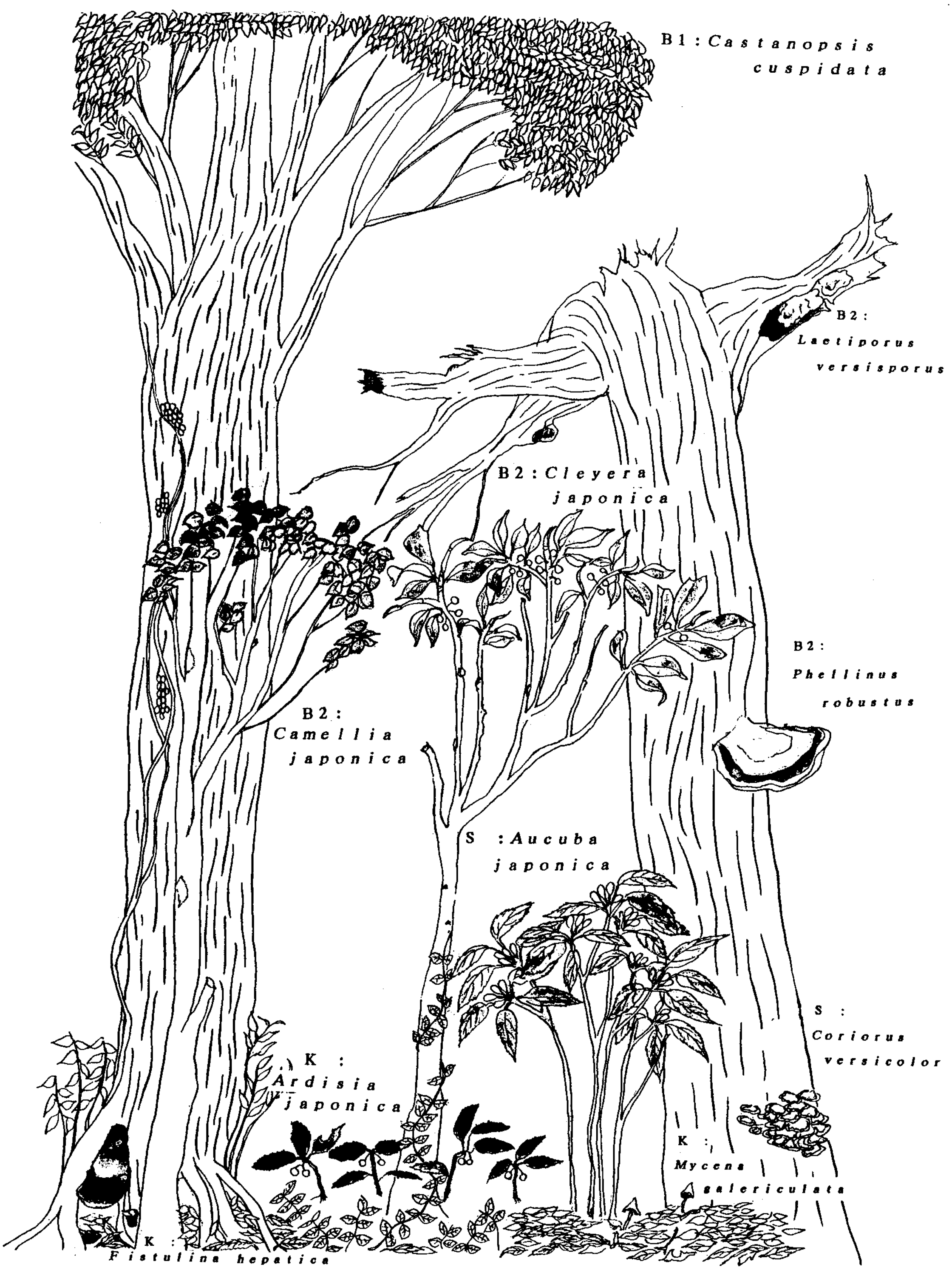

Figure 1. Schematic drawing of a typical and mature evergreen broad-leaved forest. Vertical structure of woody plants and mushrooms is recognizable. Woody plants are labeled in large letters. Mushrooms are labeled in small letters.

DISCUSSION

Vertical difference in fruit type and color: Forest has four layers in evergreen broad-leaved woodland. Yellowish green canopy is formed mainly by *Castanopsis* and *Quercus* trees. Under the canopy, green leaf stairs are formed by theaceae trees of *Cameria japonica* and *Cleyera japonica* and others. Deep green leaf shrub followed with leaves of *Aucuba japonica* and other shrubs. Finally, the grass layer is composed mainly of small dark green *Ardisia* trees of *A. crenata* and *A. japonica* and others. The changes of leaf color is easily seen from light to dark green. The change is caused by the difference in efficient absorption of sunlight having specific wave lengths. Most of the light having long wave lenghts is utilized by canopy trees. The trees under canopy develop supplementary photosynthetic pigments to catch the light having shorter wave lengths.

This niche separation is also reflected to the difference in mode of fruit type and its color shown in Table 3. Canopy trees have dry and brownish fruits. The trees under canopy have juicy and purple fruits. The trees in the shrub and grass layers have juicy and red fruits. The brownish color seems to have the same meaning to that of fallen leaves and decayed branches. It is criptic to them as well. Pollinaton by the wind and dispersion of seeds by the gravity force needs no specific contrivance. Wind is protected under the canopy, thus pollination and dispersion of seeds depends on some sort of insects and the other animals for the trees under canopy. Juicy purple fruits seem to be easily eaten by nocturnal animals or birds due to its good smell. Red juicy fruits are also eaten by birds and ground animals because of the complementary color pattern to green leaves.

Vertical difference in mushroom type and color: Vertical separation of niches in woody plants is expected also to be in fungi which live in the same wood. All the fungal species whose mushrooms appear in the undertree and shrub layers are saprophytic. Their biological energy is supplied from decaying woods. However, the majority of fungal species whose mushrooms on the ground are ectomycorhizal to the dominating host trees there. The mushrooms of the former are brownish in color and not so soft. Dispersion of their spores seems to be connected to the wind force. The mushrooms of the latter are variable in color pattern and generally soft and fragile. Some of *Russula* species are the typical members of them, and have reddish and fragile mushroom caps. The name of Russula has its origin in red coloring. Their spores must be dispersed with the aid of coloring such as snails and insects. Some purple mushrooms are seen in jelly fungi at the lower part of the undertree layer. The identical direction in fruit type and fruit color is observed in woody plants and mushrooms in mature evergreen broad-leaved forests. A schematic drawing of typical evergreen broad-leaved forest is shown in Figure 1.

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