Abundance and Diversity of Soil Macrofauna of Forests in Yanbaru, Northern Montane Part of Okinawa Island, with Special Reference to Removal of Undergrowth

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Abstract.

Soil macrofauna was studied in three forest areas of Yanbaru, northern part of Okinawa Hontô(Okinawa Island), each area includes natural forests, dominated by *Castanopsis sieboldii*, and forests from which undergrowth was completely removed by subsidies from the government. Thirteen species of Diplopoda, 23 species of Chilopoda and 1 species of Symphyla were found during five surveys carried out from 1995 to 1997. The numbers of Myriapoda, including these three Classes, occupied 29-85% (mean, 47%) of total numbers of individuals of all macro-soil animals. Among them, 5 species of Diplopoda and 8 species of Chilopoda are new records from the Ryukyu Archipelago.

In five surveys, numbers of individuals of Diplopoda and Chilopoda in forests from which undergrowth was removed (without-ug. forests) were smaller than those in natural forests, and numbers of species of Chilopoda

were also smaller than those of natural forests. Values of Simpson diversity, 1 - *D*, of Myriapoda in natural forests were 0.64 to 0.84 and those of all macro-soil animals were 0.72 to 0.83. When diversity values of natural forests calculated for each survey were compared with those of without-ug. forests, there was no significant difference between two forest types. However, when 1 - *D* values were calculated using combined data of the all five surveys, the values of without-ug. forests were significantly larger, showing high species diversity, than natural forests, although the difference was small. This result is different from results of studies of species diversity of insects, ants and oribatid mites in natural and without-ug. forests of Yanbaru, in all of them, 1 - *D* decreased in without-ug. forests. Notable decrease of some common diplopod species in without-ug. forests, effects of topography and place of survey plots and/or small sample size may be reason of this difference. But a general tendency of decrease of numbers of species and individuals in without-ug. forests as compared with with-ug. forests of the same area suggested harmful effects of undergrowth removal on species diversity of macro-soil animals.

Introduction

YANBARU, northern montane part of Okinawa Island (Okinawa Honto), is an important area for nature conservation, with many endemic and endangered species, such as the Pryer's woodpecker, *Sapheopipo noguchii* (Seebohm), the Okinawan rail, *Rallus okinawae* Yamashina et Mano, and the Yanbaru long-armed scarab beetle, *Cheirotonus jambar* Y. Kurosawa. All of these endemic animals are living in subtropical evergreen broad-leaved forests, dominated by evergreen oak or chinquapin, *Castanopsis sieboldii* (Makino), with other evergreen broad-leaved trees such as *Distylium racemosum* Sieb. et Zucc. Such evergreen forests are climax vegetation of this area. Even in Yanbaru, the endangered animals mentioned above do not breed in secondary forests, which include some pine trees, *Pinus luchuensis* Mayr, and some deciduous broad-leaved trees.

A large part of this climax forest has been recently destroyed by wide-scale clear-cutting (logging) and by elimination (cutting) of the undergrowth (tree seedlings, shrubs and herbs lower than 2 to 3 m above ground) under subsidies from the government. The both are supposed to increase risk of extinction of the endangered species (Itô, 1995).

To provide scientific basis for conservation of nature of Yanbaru forests, we have been working to evaluate species diversities of trees, insects, oribatid mites and macro-soil animals in natural forests of Yanbaru, and effects of elimination of undergrowth on the diversity (Azuma et. al., 1997 for insects, Itô, 1997 for trees). Although there are two reports on macro-soil animals of Yanbaru, that is animals falling into gutters of a forest road (Ômine et al., 1984) and numbers of taxa and individuals of soil macro-animals found in and outside of a natural forest (Azama, 1989), there was no detailed study on species diversity. This paper is the first report on the diversity of soil macrofauna of Yanbaru forests with reference to effects of the cutting of undergrowth.

Materials and Methods

Surveys were carried out in natural forests of three areas of Yanbaru, and forests in the same areas, from which undergrowth were completely removed (Fig. 1). The areas are western slope of Mt. Yonaha (498 m above sea level) (area A: A1 and A2), upper stream of Oku River (area B: B1 and B2), and southern slope of Mt.Nishime (420 m above sea

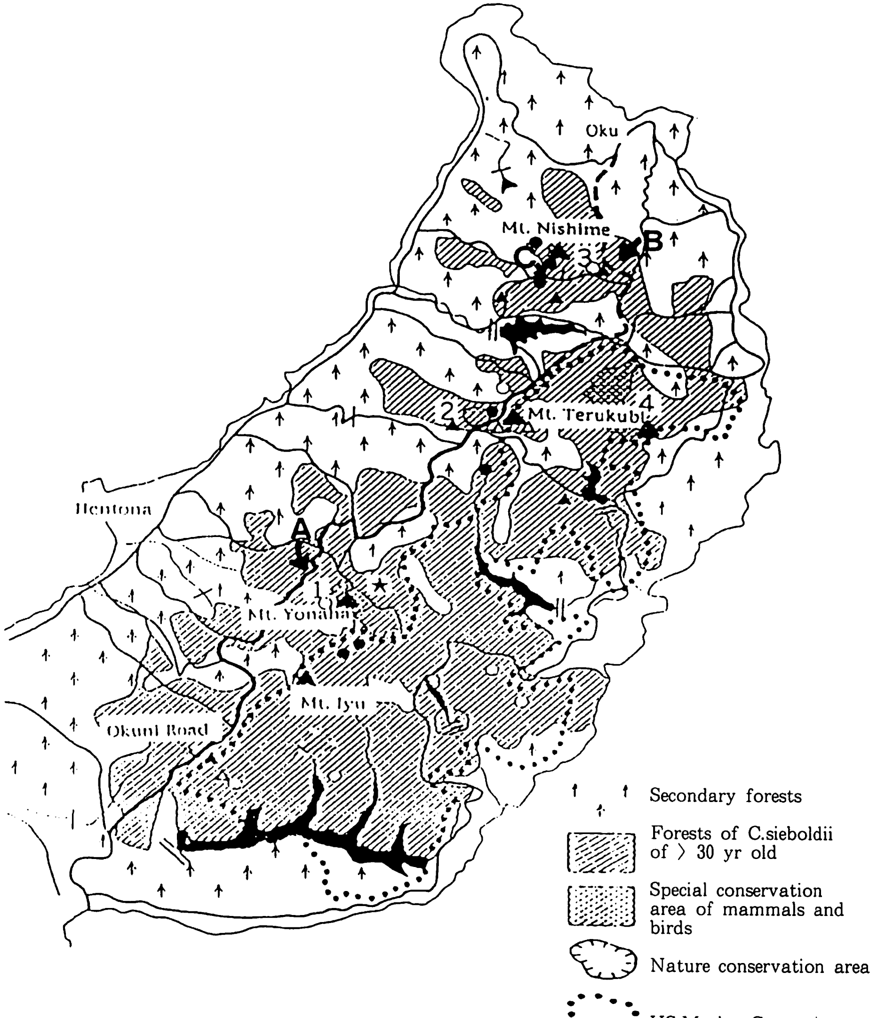

Fig.1 A map of Yanbaru, showing ‘natural forests’ (single striped area, forests dominated by *Castanopsis sieboldii* of > 30 year old), U.S.Marine Corps Area (area surrounded by dotts) and distribution of our survey area (A,B and C).

level) (area C: C1 and C2). Elevation of the three areas are about 350 m above sea level. Stations A1, B1 and C1 are intact natural forests (with-ug. forests, hereafter) while Stations A2, B2 and C2 are 'natural forests' from which undergrowth was completely cut (without-ug. forests). In 1997, another with-ug. forest was added. Although this forest lies in the area A, we coded this as D1 (see Tables 4, 5 and 6).

In each station, we set up two 50 × 50 cm quadrates, and litter and soil of humus-rich layer (A-horison) of these quadrates were collected and brought to nearby roads. Similar to the tropical rain forests (e.g. Olson, 1963), depth of the A-horison of subtropical rain forests in Yanbaru is quite shallow, only 10 to 20 cm from the soil surface. These litter and soil were carefully examined by eyes of two persons for collecting macro-soil animals. The animals collected were kept in bottles with 75% ethanol and later on, identified by the senior author. Although we brought litter and soil for sampling animals by Tullgren funnell, the results shall be published elsewhere.

Surveys were made five times in each station, during periods from July 8 to 9, 1995, October 19 to 20, 1996, January 10 to 12, 1997, June 21 to 22, 1997 and October 10 to 12, 1997.

Among collected animals, mites (mostly oribatid mites), spiders and ants were excluded from the calculation of diversity indices, because richness and species diversity of these animals will be reported in detail in other papers (Aoki et al. in preparation and Itô et al. in preparation for oribatid mites; Sasaki, in preparation for spiders; Takamine and Itô, in preparation and Itô and Takamine, in preparation for ants). In addition, we excluded insects, because classification of insects larvae in soil was quite difficult and the distribution of termites was quite contagious due to existence of nests or not.

Although there are many kind of species diversity indices, we used reciprocal of Simpson's index of concentration D (Simpson, 1949), that is $1/D$, Simpson diversity $1-D$, Shannon-Wiener function or MacArthur's index of diversity H' (MacArthur, 1955), and Pielou's equitability index J' (Pielou, 1969), because these do not need special distribution pattern. Original form of the Simpson's index is $D=\Sigma p_i^2 (p_i=n_i/N)$, where n_i and N mean number of individuals of species i and total number of individuals in the community, respectively, but we used an unbiased estimator of D, that is $D=\Sigma(n_i(n_i-1)/N(N-1))$. MacArthur's index is

$$H'= (n_i/N)\log_2(n_i/N),$$

and Pielou's equitability index is

$$J'=H'/H'_{max} \quad H'_{max}=\log_2 S,$$ where S is number of species.

Lande(1996) recommended to use $1-D$, but we used other indices also for comparison with other data (for characteristics of these indices, see Azuma et al. 1997 and Itô, 1997).

Results

Table 1 shows names of species or upper taxa (see below) of macro-soil animals found in Yanbaru, during our five surveys conducted from July 1995 to October, 1997. We found 13 species of Diplopoda, 23 species (including a taxon, *Mecistocephalus* spp.) of Chilopoda and a species of Symphyla. Among them, 5 species of Diplopoda and 8 species of Chilopoda (**in Table 1) are new records from Okinawa.

Table 1. List of macro-soil animals found in Yanbaru, northern montane part of Okinawa Hontô during five surveys carried out during a period from July, 1995 to October, 1997. *:Endemic to Okinawa Islands. **:New record from the Ryukyu Archipelago.

Dipropoda		Chilopoda	
Polyxenidae	*Eudigraphis* sp.*	Scutigeridae	*Thereuopoda clunifera*
Glomeridae	*Hyleogleomeris japonica***	Scolopendridae	*Otostigmus glaber*
Cambalopsidae	*Glyphiulus* sp.*,**[1]	Cryptopidae	Cryptopidae *sp.*
Julidae	*Anaulaciulus pinetorum*		*Criptops capillipedatus*
	A.yamashinai		*C.japonicus*
Pyrgodesmidae	*Cryptocorypha japonica*		*C.nigropictus*
Paradoxo-	*Oxidus gracilis*		*C.striatus*
somatidae	*Chamberlinius hualienensis*		*Cryptops* sp.**
	*Aponedyopus maculatus***		*Scolpocryptops curtus***
Xystodesmidae	*Riukiaria pugionifera*		*Sc.rubiginosus*
Polydesmidae	*Epanerchodus* sp.**	Lithobiidae	*Bothropolys asperatus*?[2]
Doratodesmidae	*Kylindogaster nodulosa**		*Bothropolys* sp.**
	Euconchylodesmus sp.**		*Monotarsobius purpureus*
Other animals			*M.crassips*
Annelida		Henicopidae	Henicopidae sp.**
Megascolecidae	*Pheretima* spp.	Geophilidae	*Cheiletha viridicans*?**[3]
Moniligastridae	*Drawida* sp.		*Cheiletha* sp.**
Enchytraeidae	*Enchytraeus* sp.	Mecistocephalidae	*Mecistocephalus takakuwai*
Arthropoda			*M.marmoratus*
Neobisidae	*Neobisida* spp.		*M.mirandus*
Porcellionidae	*Porcellio* spp.		*M.monotoriensis***
Armadillididae	*Armadillidium* spp.		*Mecistocephalus* sp.
			Scoliophanes sp.**
Entomobryonidae	Entomobryonidae sp.	Symphyla	
		Scutigerellidae	*Hanseniella* sp.
Talitridae	Talitridae sp.		
	Spalatorechestia sp.		

1)Species near G.septentrionalis.

2)There is some possibility that this is a new species near *B.asperatus.*

3)There is some possibility that this is a new species near *C.viridicans.*

Table 2 shows numbers of species or taxa and of individuals of the four groups (3 classes of Myriapoda and other animals) in natural forests (with-ug. plots; total of A1, B1, C1 and D1 (after January, 1997)), and forests from which undergrowth was removed (without-ug. plots; total of A2, B2 and C2), and totals of the both. As the number of with-ug. plots became 4 while that of without-ug. plots remained 3 after January, 1997, total number of three with-ug. plots, A1, B1 and C1, were also shown in parentheses. Total numbers of Myriapoda (here Diplopoda, Chilopoda and Symphyla) occupied about 29 to 85% (Mean ± s.d.= 47 ± 23%) of total number of individuals of all animals, showing large proportion of Myriapoda among soil macrofauna in Yanbaru forests.

In Diplopoda, although numbers of species in with-ug. plots were twice (2nd and 3rd surveys) larger, and once (5th survey) smaller than those of without-ug. plots, and twice equal to the latter, numbers of individuals of with-ug. plots were always larger than those of without-ug. plots (3 times more than 2-fold). In Chilopoda, the numbers of species of with-ug. plots were 4 times larger than those of without-ug. plots and the numbers of individuals of with-ug. plots were 3 times larger than those of without-ug. plots (twice more than 2-fold). Numbers of individuals of the soil animals other than Myriapoda in with-ug. plots were also larger than those of without-ug. plots.

Tables 3 to 6 show numbers of species or taxa and of individuals per taxa of macro-soil animals, and species diversity in with-ug. and without-ug. forests found in the first, third, fourth and fifth surveys. Results of the second survey carried out in October, 1996, were not shown, because, in this survey, small numbers of Myriapoda were collected (see Table 2).

Table 2. Numbers of species (or upper taxa in animals other than Myriapoda) and individuals of 4 groups of macro-soil animals in with-ug. and without-ug. forests in Yanbaru.

	Plots					
Time of survey	with-ug.1)		without-ug.		all plots	
	S	*N*	*S*	*N*	*S*	*N*
1(July, 1995)						
Diplopoda	8	117	8	82	9	199
Chilopoda	6	18	5	10	7	28
Symphyla	1	2	1	1	1	3
Others2)	7	157	7	85	8	242
Ratio of number of myriapod individuals to all animals = 48.7%						
2(October,1996)						
Diplopoda	3	6	1	2	4	8
Chilopoda	3	5	1	1	3	6
Others2)	3	26	1	8	3	34
Ratio of number of myriapod individuals to all animals = 29.2%						
3(January,1997)						
Diplopoda	5(4)	53(44)	3	19	5	72
Chilopoda	8(8)	57(49)	4	25	8	82
Symphyla	1(1)	1(1)	1	1	1	2
Others2)	6(6)	174(154)	7	45	7	219
Ratio of number of myriapod individuals to all animals = 41.6%						
4(June,1997)						
Diplopoda	7(6)	126(93)	7	90	9	216
Chilopoda	6(6)	18(18)	8	23	9	41
Others2)	3(2)	24(21)	5	21	6	45
Ratio of number of myriapod individuals to all animals = 85.1%						
5(October,1997)						
Diplopoda	4(4)	67(65)	5	25	8	92
Chilopoda	14(13)	28(27)	9	35	17	63
Others2)	7(4)	225(208)	6	107	7	332
Ratio of number of myriapod individuals to all animals = 31.8%						

1)Numerals in parentheses are values when D1 plot is excluded.

2)Macro-soil animals other than Myriapoda, Acarina, Araneae and Insecta.

For Myriapoda, the number of individuals of each species were described in the tables, but for other taxa, numbers of individuals were described under names of genus or family, such as *Drawida* sp. or Entomobryonidae sp., because of difficulty of identification of immatures and small number of individuals in most species. Although a few myriapod species were described by genus or family name, as *Epanerchodus* sp. (Table 1) or Cryptopidae sp. (Table 2), these, except *Mecistocephalus* spp., are certainly distinct species of which taxonomic status is not yet determined.

In with-ug. plots, total numbers of individuals per plot (total of two 50 × 50 cm quadrates, N_1 in the bottom sections of tables) were 32.1 ± 19.1 (3 to 69) for Myriapoda and 38.7 ± 38.6 (0 to 115) for other taxa. Total numbers of all soil animals in with-ug. plots (N in tables) were 70.8 ±47.9 (8 to 171). Corresponding values of without-ug. plots are 25.8±20.3, 21.5±19.0 and 47.3±28.1, respectively. However, there were variation in numbers between areas. In Myriapoda, differences between numbers of individuals and species of area A (4 surveys in A1 plot) and area C (4 surveys in C1 plot) or D (3 surveys in D1 plot) were significant, but those between area A and area B was not significant. If we compare numbers of individuals or species between with-and without-ug. plots using all values, the difference in numbers of individuals of Myriapoda (32.1±19.1 and 25.8±20.3) was significant (P=0.0128, U-test). There was no significant difference between numbers of species of Myriapoda and other animals and between numbers of individuals of other animals in with- and without-ug. plots.

Table 3. Number of individuals of different taxa (species in Myriapoda and species or upper taxa of other animals) and species diversity of soil macrofauna in natural forests with undergrowth (with-ug. A1,B1,C1) and forests from which undergrowth was removed (without-ug. A2, B2, C2) in Yanbaru.

I. Survey made on July 8 & 9, 1995.

		Stations					
Taxon	Species	A1	A2	B1	B2	C1	C2
Dipropoda							
Glomeridae	*Hyleogleomeris japonica*	0	0	0	3	0	0
Cambalopsidae	*Glyphiulus* sp.	1	1	2	0	20	1
Julidae	*Anaulaciulus yamashinai*	0	4	12	0	2	1
Paradoxosomatidae	*Chamberlinius hualienensis*	0	2	4	2	0	0
	Oxidus gracilis	40	27	9	20	2	4
Xystodesmidae	*Riukiaria pugionifera*	0	0	2	0	0	0
Polydesmidae	*Epanerchodus* sp.	0	3	0	0	20	2
Pyrgodesmidae	*Cryptocorypha japonica*	1	0	0	2	0	0
Doratodesmidae	*Kylindogaster nodulosa*	2	10	0	0	0	0
Chilopoda							
Cryptopidae	*Scolpocryptops curtus*	0	0	1	0	0	4
Lithobiidae	*Bothropolys asperatus*	2	0	0	0	3	2
	Monotarsobius purpureus	1	0	0	0	0	0
Geophilidae	*Cheiletha viridicans*	6	0	0	0	0	0
Mecistocephalidae	*Mecistocephalus monotoriensis*	1	0	3	1	0	0
	M.marmoratus	0	0	0	0	0	1
	M.mirandus	1	0	0	0	0	2
Symphyla							
Scutigerellidae	*Hanseniella caldaria*	1	1	1	0	0	0
Total of Myriapoda		56	48	34	28	47	17

Macro-soil animals other than Myriapoda, Acarina, Aranesae and Insecta

Annelida

Megascolecidae	*Pheretina* spp.	1	0	0	0	3	0
Moniligastridae	*Drawida* sp.	0	0	0	1	0	0
Enchytraeidae	*Enchytraeus* sp.	6	2	0	1	22	2
Arthropoda							
Pseudoscorpions	*Neovisida* spp.	2	0	2	7	0	2
Pocellionidae	*Porcellio* spp.	2	4	9	12	3	17
Armadillidiidae	*Armadillidium* spp.	1	0	0	3	0	3
Talitridae	Talitridae sp.	3	2	3	0	0	3
	Spratorchestia sp.	100	19	0	10	0	0
Total		115	27	14	34	28	24
Number of taxons S		17	11	11	11	8	13
Number of individuals N		171	75	48	62	75	41
N/S		10.06	6.82	4.36	5.64	9.38	3.15
$1/D$		2.52	4.72	7.37	5.73	4.46	4.97
$1 - D$		0.60	0.79	0.86	0.83	0.78	0.80
H'		1.99	2.65	2.95	2.80	2.37	3.20
J'		0.49	0.77	0.85	0.81	0.79	0.86
No. species of Myriapoda S_l		10	7	8	5	5	8
No. individuals of Myriapoda N_l		56	48	34	28	47	17
N_l/S_l		5.60	6.86	4.25	5.60	9.40	2.13
$1/D$ using data of Myriapoda		1.93	2.78	4.96	1.94	2.81	9.07
$1 - D$		0.48	0.64	0.80	0.48	0.64	0.89
H'		1.67	1.91	2.49	1.40	1.69	2.79
J'		0.50	0.68	0.83	0.60	0.73	0.93

Mean and s.d. of $1 - D$ values of all soil animals in A1,B1 and C1 (with-ug.forest):	0.75 ± 0.13
Ditto in A2, B2 and C2(without-ug.forests):	0.81 ± 0.05
Mean and s.d. of $1 - D$ values of Myriapoda in A1, B1 and C1:	0.64 ± 0.16
Ditto in A2, B2 and C2:	0.67 ± 0.21

Table 4. Number of individuals of different taxa (species in Myriapoda and species or upper taxa of other animals) and species diversity of soil macrofauna in natural forests with undergrowth (with-ug. A1,B1,C1,D1) and forests from which undergrowth was removed (without-ug. A2, B2, C2) in Yanbaru.
II. Survey made on January 10 to 12, 1997.

		Stations						
Taxon	Species	A1	A2	B1	B2	C1	C2	D1
Diplopoda								
Julidae	*Anaulaciulus pinetorum*	0	2	0	9	0	0	0
	A.yamashinai	4	0	11	0	2	0	7
Paradoxosomatidae	*Oxidus gracilis*	11	0	10	5	3	2	1
	Chamberlinius hualienensis	0	0	0	0	0	0	1
Doratodesmidae	*Enconchylodesmus* sp.	0	0	2	1	0	0	0
Pyrgodesmidae	*Cryptocorypha japonica*	1	0	0	0	0	0	0
Chilopoda								
Cryptopidae	*Cryptops japonicus*	0	0	4	0	0	0	0
	Cryptopidae sp.	0	0	5	0	0	0	0
	Cryptops sp.	3	0	1	1	0	1	0
Lithobiidae	*Bothropolys asperatus*	1	1	0	4	0	2	1
	Bothropolys sp.	7	0	8	0	2	0	0
	Monotarsobius crassipes	0	0	0	0	0	2	0
Geophilidae	*Cheiletha viridicans?*	3	0	0	0	0	0	0
Mecistocephalidae	*Mecistocephalus takakuwai*	1	0	0	0	0	0	4
	Mecistocephalus spp.	3	10	6	2	5	1	3
Symphyla								
Scutigerellidae	*Hanseniella caldaria*	0	0	0	0	1	1	0
Total of Myriapoda		34	13	42	22	13	9	17

Macro-soil animals other than Myriapoda, Acarina, Araneae and Insecta
Annelida

Megascolecidae	*Pheretima* spp.	1	1	12	0	0	7	9
Enchytraeidae	*Enchytraeus* sp.	7	7	4	0	2	2	1
Arthropoda								
Pseudoscorpions	*Neovisida* spp.	6	1	0	0	0	0	0
Porcellionidae	*Porcellio* spp.	60	10	14	0	34	8	4
Armadillidiidae	*Armadillidium* spp.	1	2	0	1	0	0	1
Amphipoda	*Entomobrya* spp.	0	0	0	3	0	0	1
	Entomobryonidae spp.	5	3	4	0	4	0	4
Total		80	24	34	4	40	17	20
Number of taxons S		15	9	11	8	8	9	11
Number of individuals N		114	37	76	26	53	26	37
N/S		8.77	4.11	7.60	3.25	6.63	2.89	2.84
$1/D$		3.38	5.74	9.85	5.80	2.36	6.13	8.08
$1-D$		0.70	0.83	0.90	0.83	0.58	0.84	0.88
H'		2.60	2.63	3.24	2.59	1.89	2.71	3.04
J'		0.66	0.83	0.90	0.86	0.63	0.85	0.88
No. species of Myriapoda S_l		9	3	7	6	5	6	6
No. individuals of Myriapoda N_l		34	13	42	22	13	9	17
N_l/S_l		3.78	4.33	6.00	3.67	2.60	1.50	2.83
$1/D$ using data of Myriapoda		6.16	1.70	6.76	4.36	5.20	12.0	4.00
$1-D$		0.84	0.41	0.85	0.77	0.81	0.92	0.75
H'		2.72	0.99	2.61	2.18	2.13	2.50	1.97
J'		0.86	0.62	0.87	0.84	0.92	0.97	0.84

Mean and s.d. of $1-D$ values of all soil animals in A1,B1,C1 and D1:	0.77 ± 0.15
Ditto in A2, B2 and C2:	0.83 ± 0.01
Mean and s.d. of $1-D$ values of Myriapoda in A1,B1,C1 and D1:	0.82 ± 0.05
Ditto in A2,B2 and C2:	0.70 ± 0.26

Table 5. Number of individuals of different taxa (species in Myriapoda and species or upper taxa of other animals) and species diversity of soil macrofauna in natural forests with undergrowth (with-ug. A1,B1,C1,D1) and forests from which undergrowth was removed (without-ug. A2, B2, C2) in Yanbaru.
Ⅲ. Surveys made on June 21 and 22, 1997.

		Stations						
Taxon	Species	A1	A2	B1	B2	C1	C2	D1
Dipropoda								
Glomeridae	*Hyleogleomeris japonica*	0	0	0	1	0	0	1
Julidae	*Anaulaciulus pinetorum*	4	0	8	7	1	2	1
	A.yamashinai	0	0	0	0	0	4	0
Paradoxosomatidae	*Oxidus gracilis*	18	0	13	0	0	1	31
	Chamberlinius hualienensis	37	0	0	2	2	1	0
	Aponedyopus maculatus	0	0	0	58	0	13	0
Xystodesmidae	*Riukiaria pugionifera*	2	0	0	0	1	0	0
Pyrgodesmidae	*Cryptocorypha japonica*	0	0	1	0	0	0	0
Doratodesmidae	*Enchonchylodesmus* sp.	2	0	3	0	1	1	0
Chilopoda								
Cryptopidae	*Cryptops japonicus*	0	2	6	6	0	0	0
	C.nigropictus	0	1	0	0	2	3	0
	Cryptopidae sp.	2	0	0	0	0	0	0
Lithobiidae	*Bothropolys asperatus*	1	0	0	0	0	0	0
	Monotarsobius crassipes	0	0	0	1	0	0	0
Mecistocephalidae	*Mecistocephalus takakuwai*	0	1	3	2	0	0	0
	M.mirandus	0	2	0	0	0	0	0
	M. spp.	3	1	0	2	1	1	0
	Scoliophanes sp.	0	1	0	0	0	0	0
Total of Myriapoda		69	8	34	79	8	26	33

Macro-soil animals other than Myriapoda, Acarina, Araneae and Insecta

Annelida								
Megascolecidae	*Pheretima* spp.	3	0	7	0	0	0	1
Enchytraeidae	*Enchytraeus* sp.	8	0	0	5	0	3	0
Arthropoda								
Porcellionidae	*Porcellio* spp.	3	0	0	5	0	2	2
Armadillidiidae	*Armadillidium* spp.	0	0	0	2	0	2	0
Entomobryonidae	*Entomobrya* sp.	0	0	0	0	0	1	0
	Entomobryonidae sp.	0	0	0	1	0	0	0
Total		14	0	7	13	0	8	3
Number of taxons S		11	6	7	12	6	12	5
Number of individuals N		84	8	41	92	8	34	36
N/S		7.55	1.33	5.86	7.67	1.33	2.83	7.20
$1/D$		3.87	14.0	5.54	2.44	14.0	6.03	1.27
$1-D$		0.74	0.93	0.82	0.59	0.93	0.83	0.21
H'		2.34	2.50	2.51	1.89	2.50	2.97	0.85
J'		0.68	0.97	0.89	0.53	0.97	0.83	0.37
No. species of Myriapoda S_I		8	6	6	8	6	8	3
No. individuals of Myriapoda N_I		69	8	34	79	8	26	33
N_I/S_I		8.63	1.33	5.67	9.88	1.33	3.25	11.0
$1/D$		2.77	14.0	4.42	1.82	14.0	3.69	1.06
$1-D$		0.64	0.93	0.77	0.45	0.93	0.73	0.06
H'		1.75	2.50	2.23	1.48	2.50	2.27	0.39
J'		0.58	0.97	0.86	0.49	0.97	0.76	0.25

Mean and s.d. of $1-D$ values of all soil animals in A1,B1,C1 and D1:	0.68 ± 0.32
Ditto in A2, B2 and C2:	0.78 ± 0.17
Mean and s.d. of $1-D$ values of Myriapoda in A1,B1,C1 and D1:	0.68 ± 0.30
Ditto in A2,B2 and C2:	0.70 ± 0.24

Table 6. Number of individuals of different taxa (species in Myriapoda and species or upper taxa of other animals) and species diversity of soil macrofauna in natural forests with undergrowth (with-ug. A1, B1, C1, D1) and forests from which undergrowth was removed (without-ug. A2, B2, C2) in Yanbaru.
Ⅳ. Surveys made on October 10,11 and 12, 1997.

		Stations						
Taxon	Species	A1	A2	B1	B2	C1	C2	D1
Myriapoda								
Dipropoda								
Polyxenidae	*Eudigraphis* sp.	0	0	0	6	0	0	0
Glomeridae	*Hyleogleomeris japonica*	0	0	1	0	0	0	2
Julidae	*Anaulaciulus pinetorum*	3	0	4	0	3	3	0
	An.yamashinai	0	0	0	1	0	0	0
Paradoxosomatidae	*Aponedyopus maculatus*	18	0	0	0	0	0	0
	Chamberlinius hualienensis	17	3	8	0	2	11	0
Xystodesmidae	*Riukiaria pugionifera*	6	0	0	0	2	0	0
Doratodesmidae	*Enchonchylodesmus* sp.	0	1	1	0	0	0	0
Chilopoda								
Scutigeridae	*Thereuopoda clunifera*	0	0	1	0	0	0	0
Cryptopidae	*Cryptops capillipedatus*	0	0	0	0	3	0	0
	Cryptops nigropictus	0	0	0	0	0	1	0
	Cryptops sp.	0	0	0	0	1	0	0
	Scolpocryptops curtus	0	0	0	0	1	2	0
	S.rubiginosus	0	0	5	0	0	0	0
Lithobiidae	*Bothropolys asperatus*	0	0	1	7	0	0	0
	Monotarsobius purpureus	0	0	1	7	0	4	0
	M.crassipes	3	0	0	3	0	6	0
Henicopidae	Henicopidae sp.	0	0	1	0	0	0	0
Geophilidae	*Cheileta* sp.	0	0	0	0	0	1	0

Mecistocephalidae	*Mecistocephalus takakuwai*	4	0	0	0	0	1	0
	M.monotoriensis	1	2	3	0	0	0	0
	M.marmoratus	0	0	1	0	0	0	0
	M.mirandus	0	0	0	0	0	0	1
	M. sp.	0	0	1	0	0	0	0
	Scoliophanes sp.	0	1	0	0	0	0	0
Total of Myriapoda		52	7	28	24	12	29	3
Macro-soil animals other than Myriapoda, Acarina, Araneae and Insecta								
Annelida								
Megascolecidae	*Pheretima* sp.	7	15	38	0	4	3	4
Moniligastridae	*Drawida* sp.	1	0	0	0	0	0	0
Enchytraeidae	*Enchytraeus* sp.	51	0	6	32	2	1	0
Arthropoda								
Pseudoscorpions	*Neobisida* sp.	0	0	0	2	0	1	2
Isopoda	*Porcellio* sp.	9	0	74	30	16	8	7
Armadillidiidae	*Armadillidium* sp.	0	0	0	6	0	1	3
Entomobryonidae	*Entomobrya* sp.	0	5	0	3	0	0	1
Total		68	20	118	73	22	14	17
Number of taxons S		11	6	15	10	9	13	7
Number of individuals N		120	27	146	97	34	43	20
N/S		10.9	4.50	9.73	9.70	3.78	3.30	2.85
$1/D$		4.30	2.95	3.05	4.61	4.15	8.14	5.94
$1 - D$		0.77	0.66	0.67	0.78	0.76	0.88	0.84
H'		2.60	1.90	2.22	2.60	2.51	3.17	2.03
J'		0.75	0.73	0.56	0.78	0.79	0.86	0.72
No. species of Myriapoda S_l		7	4	12	5	6	8	2
No. individuals of Myriapoda N_l		52	7	28	24	12	29	3
N_l/S_l		7.42	1.75	2.33	4.80	2.00	3.63	1.50
$1/D$ using data of Myriapoda		4.12	5.25	8.04	4.60	8.25	5.08	3.00
$1 - D$		0.76	0.81	0.88	0.78	0.88	0.80	0.67
H'		2.28	2.35	3.08	2.10	2.43	2.50	0.92
J'		0.81	0.92	0.86	0.91	0.94	0.83	0.92

Mean and s.d. of $1 - D$ values of all soil animals in A1,B1,C1 and D1: 0.76 ± 0.07
Ditto in A2, B2 and C2: 0.77 ± 0.11
Mean and s.d. of $1 - D$ values of Myriapoda in A1,B1,C1 and D1: 0.80 ± 0.10
Ditto in A2,B2 and C2: 0.80 ± 0.02

Although numbers of species or taxa (S and S_l) in A1 plot were always larger than A2 plot, those in C1 were smaller than C2. There was no consistent tendency in area B. D1 showed sometimes large and sometimes very small values (only 3 species of Myriapoda in the fourth survey).

Tables 3 to 6 also show values of four species diversity indices. Larger values of $1/D$, $1 - D$ and J' show higher diversity or equitability. In Myriapoda, mean values of $1 - D$ in natural forests (with-ug. forests) in four surveys lied from 0.64 to 0.84, when values of D1 plot (for the reason, see below) were omitted. In all animals $1 - D$ values in with-ug. plots in four surveys were 0.72 to 0.83. In Myriapoda, $1 - D$ values of B1 were larger than B2 and those of A1 were smaller than A2 in all of four surveys shown in Tables 3 to 6, but there was no consistent tendency in area C. D1 plot once showed an extremely low value (0.06 in the fourth survey, when only 3 myriapod species were found) but in other surveys showed median values (0.75 and 0.84 for Myriapoda and 0.67 and 0.88 for all animals). The similar tendency was seen in J', that is, values of B1 were larger than B2 except the fifth survey (Table 6), but no consistent tendency in areas A and C. Order of $1- D$ and J' between with-ug. and without-ug. plots was sometimes reversed (e.g. in Myriapoda of Table 4, $1 - D$ of B1 and B2 were 0.88 and 0.78, respectively, but J' of them were 0.86 and 0.91). This reversal may be due to the nature of indices, that is, number of individuals of the dominant species strongly influences to value of $1 - D$, but not to J' (Peet, 1974).

Table 7 shows results of calculation based on combined data of all surveys, including the second survey. $1 - D$ values for Myriapoda were 0.82 to 0.90 (mean ± s.d.:0.86 ± 0.04) in with-ug. plots and 0.82 to 0.92 (0.86 ± 0.06) in without-ug. plots, and the difference was not significant. However, $1 - D$ values for all animals were 0.85 to 0.88 (0.86 ± 0.02) for with-ug. plots and 0.89 to 0.91 (0.90 ± 0.01) for without-ug. plots; here diversity of without-ug. plots was significantly higher than with-ug. plots, although difference was not large (only 4.7% of with-ug. value).

The commonest species of Diplopoda was *Oxidus gracilis* and that of Chilopoda was *Mecistocephalus* sp.

Table 7. Number of species or upper taxa(S), total number of individuals (N) and diversity indices of soil animals of Yanbaru. Combined data of five surveys (July, 1995, October, 1996, January, 1997, June, 1997 and October, 1997) were used for calculation, but data for D1 plot were omitted because this plot was set up after January, 1997.

	A1	A2	B1	B2	C1	C2	All stations
I. Myriapoda							
S	23	17	24	17	15	19	33
N	217	78	143	154	78	81	345
S/N	9.43	4.58	5.96	9.06	5.20	4.26	
$1/D$	5.51	6.12	9.52	5.33	6.95	13.0	
$1-D$	0.82	0.84	0.90	0.81	0.86	0.92	
H'	3.17	3.19	3.70	2.86	3.20	3.81	
J'	0.70	0.78	0.81	0.70	0.82	0.90	
Mean and s.d. of $1-D$ values in A1, B1 and C1 (with-ug.forests): 0.86 ± 0.04							
Ditto in A2, B2 and C2 (without-ug.forests): 0.86 ± 0.06 (NS)							
II. All animals.							
S	32	26	30	25	19	26	43
N	507	156	317	279	180	147	1569
S/N	15.84	6.00	10.57	11.16	9.47	5.65	
$1/D$	8.25	11.60	6.78	9.23	6.74	11.44	
$1-D$	0.88	0.91	0.85	0.89	0.85	0.91	
H'	3.52	3.82	3.49	3.68	3.08	4.00	
J'	0.70	0.81	0.71	0.79	0.72	0.85	
Mean and s.d. of $1-D$ values in A1, B1 and C1: 0.86 ± 0.02[a]							
Ditto in A2, B2 and C2: 0.90 ± 0.01[b]							

a,b : Significant difference (*t-test*, P=0.023).

Discussion

Ômine (1984) listed 36 species of Diplopoda and 51 species of Chilopoda which were collected in the Ryukyu Archipelago until that time. Of these, 25 and 36 species of Diplopoda and Chilopoda were found in Okinawa Islands (Okinawa Hontô, Kume Island, Kerama Islands and small islets near Okinawa Hontô), respectively.

Ômine (1987a, 1987b) also reported results of surveys of Diplopoda and Chilopoda in Yanbaru, which were carried out during 1985 and 1986. Fifteen species of Diplopoda and 20 species and 2 subspecies of Chilopoda were recorded. Among them, *Chamberlinius hualienensis* (introduced species), *Riukiaria pugionifera, Kiussiunum nodulosum* and *Hyleoglomeris* sp. (Diplopoda), and *Scolopendra subspinipes subspinipes* and *Thereunonema tuberculata* (Chilopoda) were new record from the Ryukyu Archipelago and *Orthomorpha coarctata* and *Riukiaria variatus* (Diplopoda) and *Otostigmus striatus* (Chilopoda), were new record from Okinawa Islands in that time.

In the present study, we collected 13 species of Diplopoda and 23 species of Chilopoda and 1 species of Symphyla. Among them, 5 Diplopoda species (*Hyleoglomeris japonica*, *Aponedyopus maculatus*, *Epanerchodus* sp., *Glyphiulus* sp. and *Euchonchodesmus* sp.) and 8 Chilopoda species (*Cheiletha viridicans?*, *Mecistocephalus monotoriensis*, *Bothropolys* sp., *Cheiletha* sp., *Cryptops* sp., *Scoliophanes* sp., *S.curtus* and Henicopidae sp.) are new record from the Ryukyu Archipelago. *Kylindogaster nodulosa* (Diplopoda) and *Scolpocryptops curtus* (Chilopoda) are new record from Yanbaru. *Riukiaria pugionifera* and Glyphiulus sp. are endemic to the Ryukyu Archipelago.

Kitazawa et al. (1967) described the number of individuals of soil animals in forests of three areas in Japan. The numbers of myriapod individuals per 1 m² soil surface of a subalpine coniferous forest, a cool temperate deciduous forest and an evergreen broad-leaved forest were 63, 93 and 91, respectively. The value of subalpine forest was about the same with our value (64.2 ± 38.2 per m²) but values of temperate forests were larger than our value. Niijima (1995) described the number of individuals of macro-soil animals in two temperate coniferous (*Cryptomeria japonica*) forests. The numbers of myriapod individuals per 1 m² were 337 ± 149 and 517 ± 285, far larger than our value. Unfortunately they did not report on the number of species.

Shimada and Yoshida (1988) reported species and number of individuals of macro-soil animals collected by Tullgren funnell from six soil and litter samples of 25 × 25 cm (7.5 cm depth.), taken in winter in pine forests of Ibaraki Prefecture, the central part of mainland Japan. They surveyed three ' natural ' pine forests, which had not been controlled by foresters for long years and 5 pine forests of which undergrowth had been removed. As they took 6 samples from each plot, the total area of soil/litter per plot is 3750 cm², 75% of total area of soil /litter per our plot (5000 cm²). In three plots in 'natural' forests (11250 cm² in total), they collected 15 species of macro-soil animals (except mites, spiders and insects) including 9 species of Myriapoda, as compared with 20 species of macro-soil animals including 14 species of Myriapoda in our winter collection (Table 2, January,1997). Numbers of species and individuals of Myriapoda in their "natural" forest are 5.3 ± 0.6 and 41.3 ± 22.1, respectively. Although difference is not significant, the number of myriapod individuals of their pine forests tends to be larger than the number of individuals in our winter survey (26.5 ± 13.8). On the other hand, the number of myriapod species in our winter survey (6.8 ± 1.7) is significantly larger than that in their pine forest. Values of 1 - *D* and J' calculated by us for their data except mites, spiders and insects are 0.73 ± 0.11 and 0.70 ± 0.13 for 'natural' pine forests, and 0.58 ± 0.08 and 0.66 ± 0.06 for without-ug. pine forests, respectively. These values are lower than values of our winter survey (Table 4). Although difference between values of with-ug. pine forests and our with-ug. forests in January was not significant, values of without-ug. pine forests are significantly lower than our data of without-ug. forests ($P<0.01$ both in t-test and U-test).

In tropical rain forests of Peruvian Amazonia. Lavelle and Poshanasi (1989) took 10 samples of 25 × 25 × 30 cm soil and litter, and counted number of individuals and taxonomic units (order or families) of soil macrofauna. Surveys were made in the rainy season (May and June). The number of individuals per m^2 was 3,748 except ants, far larger than our results (239 ± 164 per m^2), but in the Amazonian rain forest termites occupied 86% of soil fauna (3,2340 individuals), showing a common feature of the tropical rain forest areas. If termites are excluded, the total number is 508, about two-fold of our values. The number of taxonomic units of soil macrofauna of Amazonian rain forest was 41, while that of Amazonian secondary forests (15 years) was 27. Number of families in our surveys was 24, except spiders and insects.

Dangerfield (1997) took samples of 17 × 23 × 20 cm of soil and litter in dry forests of Botsuwana, and counted the number of soil macrofauna greater than 2 mm body length (almost the same with us). In wet season, numbers of individuals per m^2 were 512 to 916, and numbers of orders per sample were 4.39 to 6.33. In our survey, the number of individuals per m^2 was about a half or one-third of Botsuwana and the number of orders was 15 (including 5 orders of Diplopoda and 4 orders of Chilopoda), larger than values in Botsuwana.

Although methods to count taxa were different, these values indicate relatively high diversity of soil macrofauna in Yanbaru forests, which lie in the wet subtropics. A possible reason of smaller number of myriapod individuals in our forests than temperate forests may be smaller amount of litter and thinner humus layer of soil in our forests, due to higher decomposition rate of organic materials as compared with tremperate forests. These are common characteristics of tropical rain forests. Notwithstanding this, the number of myriapod species in our forests is larger than that in temperate pine forests.

In data of each survey (Table 3 to 6), there was no significant difference between values of species diversity indices between with-ug. and without-ug. plots. However high diversity of Myriapoda and soil macrofauna is notable. Mean and s.d. of J' for Myriapoda (27 samples shown in Tables 3 to 6) is 0.79 ± 0.18 and those for all animals is 0.76 ± 0.15. Kaneko (1995) reported J' values of oribatid mites in six forests of central Japan. The values are 0.73 ± 0.04.

There was no clear difference in values of species diversity indices between with-ug. and without-ug. plots, when we calculate the values for each survey. When we use combined data of five surveys, without-ug. plots had significantly larger $1-D$ value than with-ug. plots, although the difference was not large. This situation is different from species diversity of other animals in Yanbaru.

In insects living lower layer of forests (Azuma et al., 1997), soil inhabiting oribatid mites (Aoki et al., in preparation; Itô et al., in preparation), and ants (Takamine et al., in preparation;Itô et al.,inpreparation), values of species diversity indices of with-u.g. forests in Yanbaru were remarkably high, and those of without-u.g. forests were, almost always, significantly lower than with-u.g. forests. As shown before, $1 - D$ values for 'natural' pine forests of Ibaraki Prefecture were somewhat larger than values for without-ug. pine forests, although difference was not significant (P=0.06 in t-test). Reason of insignificant difference of diversity values of soil macrofauna between with-u.g. and without-u.g. plots in Yanbaru is not clear, but a possible reason is notable decrease of some myriapod species in without-ug. plots, as compared with with-ug. plots of the same area. For example, in *Oxidus gracilis*, numbers of individuals in A1 and B1 were 11 and 10 in the third survey and 18 and 13 in the fourth survey, respectively, but the numbers in A2 and B2 in these surveys were 0, 5, 0 and 0, respectively. Similar trend was seen in *Chamberlinus haulienensis*. Small sample size in our surveys and difference in topographical conditions in our plots can be another reason of insignificant difference in species diversity. More detailed studies are necessary to clarify this point.

However, it must be noted that the species diversity indices used here represent only one aspect of the biodiversity. Decreases in species richness (number of species) and in number of individuals are also important. Values of S_I and N_I (numbers of species and individuals of Myriapoda; Table 3-6) in without-u.g. plots were smaller than those of with-ug. plots in 7 of 12 cases and 9 of 12 cases, respectively. If we use total numbers of species and individuals in three survey areas (Table 2), numbers of individuals of Diplopoda were always smaller in without-ug. plots than in with-ug. plots, and those of Chilopoda in without-ug. plots were smaller than with-ug. plots in 3 of 5 surveys. Number of individuals of other soil animals always decreased in without-ug. plots. Decrease of the number of individuals in without-ug. plots was sometimes drastic (less than a half of with-ug. plots in 4 of 8 cases in Myriapoda and 3 of 4 cases in other animals). These may affect the increase of 1 -D in without-ug. plots.

Thus elimination of undergrowth by governmental subsidies is supposed to play harmful effects to the soil macrofauna in Yanbaru forests.

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和 文 摘 要

沖縄やんばるの森林におけるマクロ土壌動物の個体数と多様性
ー森林下生えの刈り取りとも関連してー

大嶺哲雄・伊藤嘉昭

沖縄やんばるの３地域の、スダジイを優占種とする自然林および育成天然林整備(改良)という補助金により下生えを完全に刈り取られた森林のマクロ土壌動物を調査し、得られたデータを多様度指数を用いて解析した。１９９５年から１９９７年にかけて行った５回の調査で、ヤスデ綱１３種、ムカデ綱２３種、コムカデ網１種が採集された。これらを合わせた多足類は、ダニ、クモ、昆虫を除くマクロ土壌動物相の２９－８５％（平均４７％）を占めていた。このうち琉球列島から初めて記録されたのは次の１３種である。

ヤマトタマヤスデ、ブチダケヤスデ、オビヤスデ属の一種、リュウキュウヤハズヤスデ、ウチカケヤスデの一種、ミドリジムカデ？、ミドリジムカデ属の一種、シゴナガズジムカデ、ケナガトゲアシムカデ、イッスンムカデ属の一種、メナシムカデ属の一種、スコリジムカデ、トゲイシムカデ科の一種。

ヤスデ綱とムカデ綱では下刈り区の個体数は自然林にくらべて減少していた。また後者では種数の減少も見られた。自然林の多足類の種多様度指数１－Ｄは、0.64－0.84、全マクロ土壌動物の指数値は0.72－0.83であった。各回別の計算では自然林と下刈り林の１－Ｄの値に有意差はみとめられなかったが、全データをまとめて計算したところ、下刈り林における全マクロ土壌動物の指数値は自然林のそれより有意に大きかった(ただし差は小さい)。この結果は同地区の昆虫、アリ、カブリダニにおいて下刈り林で種多様度が低下したという結果と異なる。この原因のひとつは、個体数の多いヤスデに下生え刈り取り区で激減した種があるとも考えられるが、サンプル数が小さいので調査区の地形、場所的条件などの影響も考えられ、今後の調査が必要である。