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ORIGINAL PAPER

Response of ground beetles (Coleoptera: Carabidae) to forest gaps formed by a typhoon in a red pine forest at Gwangneung Forest, Republic of Korea

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Abstract In Korea, damaging typhoons related to climate change have increased steadily since the 1990s. Red pine (*Pinus densiflora*) forests in Gwangneung Forest were greatly disturbed by typhoon Kompasu in 2010. A survey was carried out to clarify differences in ground beetle (Coleoptera: Carabidae) communities between forest gaps and undamaged forests. Ground beetles were sampled using pitfall traps from early May to late October 2011. Vegetation changes, litter layer, organic matter layer, and soil conditions were also measured. A total of 1035 ground beetles of 32 species were collected. Contrary to our expectation, species richness, abundance, and community structure of the ground beetles in forest gaps were similar to those in undamaged forests. Species richness and abundance of habitat type were also similar. However, species diversity and estimated species richness in forest gaps were significantly higher than in undamaged forests. These findings suggest that forest gaps formed by a typhoon did not lead to great change in ground beetle communities.

Keywords Climate change · Ground beetle · Forest gap · Red pine forest · Typhoon

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Introduction

Abnormal climatic events, such as typhoons, floods, and droughts caused by climate change are expected to occur more frequently in the future (IPCC 2007; Choi and Choi 2011). A typhoon is one of the most extreme natural disturbances in the northwest Pacific-east Asian region (Tu et al. 2009). Damage caused by typhoons according to global warming has increased in frequency and magnitude (Schelhaas et al. 2003; Hirao et al. 2008). In Korea, huge typhoons with heavy rains and high winds have been increasing steadily since the 1990s. In particular, Rusa in 2002, Maemi in 2003, and Kompasu in 2010 pounded the Korean Peninsula (Kim et al. 2007a, b; Youn et al. 2011). These typhoons caused wind damage to trees in forests (Youn et al. 2011). In 2012, four typhoons in 1 year directly damaged the Korean Peninsula for the first time since typhoon observations began. Forest gaps formed by typhoons become local biodiversity hotspots because wind-damaged trees provide important habitats for saproxylic species and the openings provide micro-habitats for various insects (Bouget and Duelli 2004). These changes affect forest organisms such as amphibians, reptiles, birds, and mammals. Therefore, there is a need to study how forest gaps formed by typhoons affect the distribution and abundance of forest organisms.

Insects are useful bio-indicators due to their rapid response to environment change (Rainio and Niemelä

2003; Stewart et al. 2007). Among them, ground beetles are considered to be valuable environmental indicators (Niemelä et al. 1993; Ribera et al. 2001; Villa-Castillo and Wagner 2002; Kotze et al. 2011). Ground beetles are diverse, taxonomically and ecologically well-known, and reflect biotic and abiotic conditions (Rainio and Niemelä 2003; Koivula 2011). Ground beetles are sensitive to environmental changes, such as temperature, soil moisture, and vegetation cover (Jukes et al. 2001; Perner and Malt 2003; Kotze et al. 2011). These beetles are relatively easy to collect in sufficiently large numbers using pitfall traps (Desender et al. 1994; Holland 2002). Ground beetles are also sensitive to openings created by forest disturbances, i.e., forest fires, logging, and windthrow (Niemelä et al. 1993; Kwon and Park 2005; Latty et al. 2006; Halaj et al. 2008; Bouget 2005).

Forests occupy 64.2 % (6.4 million ha) of land in Korea. Red pine (*Pinus densiflora*) forests are the most important type of coniferous forest and occupy more than 23.5 % (1.5 million ha) of Korean forest land (Forest Service 2006). Red pine forests are located from Jeju Island, Mt. Halla-san (33°20′N) to Jeungsan Hamgyongbu-do (43°20′N) except for the high mountainous areas (Yang 2002). Red pine forests have been declining due to insect pests, forest fires, and abundance of competitor trees related to climate change; thus, sustainable conservation and management are needed (Lee and Hong 2004; Lee et al. 2009). A red pine forest in Gwangneung Forest was damaged by typhoon Kompasu in 2010. Gwangneung Forest has been thoroughly protected and managed since it was designated as the mausoleum forest of King Sejo in 1468 (Korea National Arboretum 2008). This is a natural forest with high value, and 54 % of the forest has remained natural since late 1993 (Korea National Arboretum 2014). Most Korean forests are re-growth forests after being damaged by wars or reckless deforestation, but Gwangneung Forest has been consistently managed for about 450 years (Korea National Arboretum 2014). This study was carried out to clarify the response of ground beetles to typhoon-created gaps in a red pine forest that forms part of the protected Gwangneung Forest. We studied how typhoon disturbance affected ground beetles using analyses of changes in vegetation, litter layer, organic matter layer, and soil conditions.

Materials and methods

Study site

The study was conducted in a red pine forest (37.77 N and 127.17 E) on Mt. Jukyeob-san in Gwangneung Forest (Fig. 1). Gwangneung Forest is home to over 2881 animal species including 20 endangered animals such as Korean

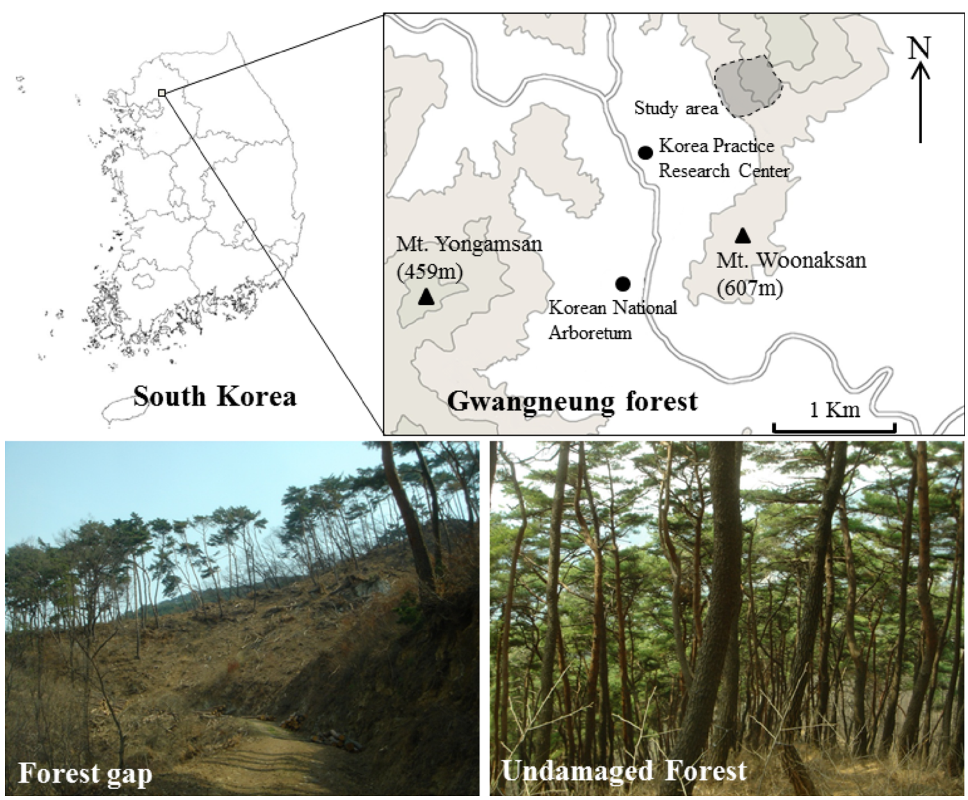

Fig. 1 Map of the study area in Gwangneung Forest, South Korea. *Photographs* show forest gap and undamaged forest

woodpeckers (*Dryocopus javensis richardsi*), black woodpeckers (*D. martius martius*), flying squirrels (*Pteromys volans*), and long-horned beetles (*Callipogon relictus*) (Korea National Arboretum 2014). Gwangneung Forest is also valuable from a historical perspective, as it is the burial place of King Sejong, the revered king of the Joseon Dynasty (Korea National Arboretum 2008). This forest (2240 ha) has been used as a research experimental forest by the Korea Forest Research Institute since 1929. Therefore, Gwangneung Forest comprises old natural forest (1200 ha, hardwood and pine) and plantations of diverse tree species (1040 ha, 52 tree species) (Korea Forest Research Institute 2012). Average annual temperature and rainfall in Gwangneung Forest are 11.3 °C and 1625 mm, respectively (Lim et al. 2010). Typhoon Kompasu damaged the middle part of the Korean Peninsula in 2010, and wind damaged many trees nationally. The highest average and maximum instantaneous wind speeds inside the forest were 3.4 and 8.7 m/s respectively, (Youn et al. 2011). Forest gaps in Gwangneung Forest caused by this typhoon were the first ever recorded since typhoon observation began.

Vegetation, litter, and soil properties

Vegetation at the study sites was investigated by a botanist (Dr. Cheon) who recorded the plants growing in a 400 m^2 plot (20 m width and 20 m length) where pitfall traps were set. The vegetation structure was surveyed according to the Braun-Blanquet method (1964). Coverage (%) of tree, subtree, shrub, and herb layers, and the gradient of slope were recorded. Depths of the litter and organic matter layers were measured in five replicates per study site (25 m^2), and average values were used for analysis. Five soil samples (ca. 100 ml) per plot were randomly sampled from the surface to a depth of 5 cm, using a small shovel after removing the litter layer, and samples from each plot were pooled. Soil samples were analyzed in the soil analysis laboratory of the Korea Forest Research Institute (KFRI) to determine pH, soil texture (i.e., composition of sand, fine sand, and silt), organic matter, total nitrogen, and cation exchange capacity (CEC, cmolc/kg). Vegetation, the litter and organic matter layers, slope gradient, and physicochemical properties of the soil samples are shown in Table 1.

Survey and ground beetle identification

Typhoon Kompasu made forest gaps near the top of Mt. Jukyeob-san. Reaching the survey area takes about two hours by walking from Korea Practice Research Center. The study was carried out in three forest gaps that measured 2800, 3200, and 2500 m^2. Three undamaged forest plots were sampled as controls at locations about 100 m from the forest gaps. Sampling plots (25 m^2) in forest gaps was set up in the center of gaps to avoid the edge effect (Magura 2002). Five pitfall traps were set for 14 days at the center and four corners of each plot. Traps were plastic cups (depth, 6.3 cm; mouth diameter, 8.5 cm; bottom diameter, 7 cm). Polyethylene glycol, a non-attracting and non-evaporating preservative, was added to fill each trap to one-third of the cup depth (Greenslade and Greenslade

Table 1 Vegetation, litter layer, organic matter layer, soil texture, and physicochemical property of soil in study sites

Site	Vegetation (%)				Litter layer (cm)	Organic matter layer (cm)	Soil texture (%)			Slope degree (°)
	Tree	Subtree	Shrub	Herb			Sand	Fine sand	Silt	
Forest gap 1	30	0	65	80	2.1	2.1	36	46.3	17.6	31
Forest gap 2	20	5	75	70	1.7	2	42.9	44.1	12.8	33
Forest gap 3	15	5	10	90	2.5	3.6	37.5	41.5	20.8	20
Undamaged forest 1	60	0	80	80	2.9	3.8	48.1	40.5	11.2	24
Undamaged forest 2	70	0	80	65	3	2.6	53.7	29.5	16.7	20
Undamaged forest 3	80	0	45	50	2.9	2.5	36.1	44.6	19.2	31

Site	Physicochemical property								
	pH	TN	P	CEC	K	Na	Ca	Mg	O.M.
Forest gap 1	4.8	0.28	5.3	18.7	0.39	0.09	2.94	0.33	6.9
Forest gap 2	4.7	0.48	25.1	18.2	0.36	0.08	1.58	0.24	10.9
Forest gap 3	4.6	0.3	13.5	4.8	0.15	0.05	0.76	0.09	11
Undamaged forest 1	4.3	0.23	19.8	14.7	0.2	0.04	1.11	0.22	8.3
Undamaged forest 2	4.5	0.19	14.4	17.8	0.23	0.04	1.43	0.2	6.8
Undamaged forest 3	4.4	0.36	24.3	16.2	0.37	0.1	2.58	0.51	10.8

1971). The survey was carried out 12 times from early May to late October 2011. The ground beetle specimens were identified using taxonomic keys (Ueno et al. 1989; Park and Paik 2001; Park 2004) to the level of species under a stereoscopic microscope. All specimens were deposited in the forest ecology laboratory of the KFRI.

Habitat type

Ground beetles were classified into two groups based on their location when collected. Forest species were recorded mainly in forests, such as broadleaf forests or pine forests, whereas openland species were recorded mainly on riverbanks, paddy fields, urban green areas, and urban parks. If a species was recorded in more than one habitat, the habitat where the species was more frequent was used. Habitat type was determined based on Ueno et al. (1989), Lee (2009) and Lake Biwa Museum (2014).

Data analysis

The number of individual beetles collected was log transformed (ln N + 1) to achieve a normal distribution. Species richness (number of species), abundance (number of individuals), species richness and abundance of habitat type, vegetation coverage (tree, shrub, and herb layers) were normally distributed (Shapiro–Wilk test, $P > 0.05$). After *F* testing to compare variances, species richness, species richness of openland species, and litter layer were tested using the Welch two sample *t* test, whereas other parameters were tested by the two sample *t*-test (Zar 1999). Estimated species richness and species diversity were evaluated by Estimate S (Colwell 2005). Estimate S offers statistical tools for analyzing and comparing the diversity and composition of species assemblages, based on sampling data in studies of taxa from microbes to mammals in every biome (Colwell and Elsensohn 2014). Biotic inventory works are routinely biased by undersampling, even for intensive and carefully designed studies (Colwell and Elsensohn 2014). Estimate S computes expected species accumulation curves for rarefied reference samples (both sample-based rarefaction curves and individual-based rarefaction curves), with 95 % unconditional confidence intervals, using analytical formulas (Colwell 2013). Estimated species richness was computed by Chao 1 (Chao 1984) and species diversity was estimated by the Shannon diversity index (Shannon and Weaver 1949). Chao 1 is based on individual-based abundance data. Estimated species richness (Chao 1) and species diversity (*H*') were not normally distributed (Shapiro–Wilk test, $P < 0.001$). The difference of estimated species richness (Chao 1) and species diversity (*H*') were tested by Wilcoxon rank-sum test. Ground beetle communities were ordinated using non-metric multidimensional scaling (NMDS). The Sørensen distance measure was used for NMDS with log-transformed abundance (ln N + 1). The log-transformation was conducted to decrease data variance. Singleton species occurring on one site were excluded from NMDS ordination. The multi-response permutation procedure (MRPP) was used to test the impact of typhoon disturbance on community grouping. NMDS and MRPP were conducted using PC-ORD (ver. 5.17) (McCune and Mefford 1999) and further analyses were performed using R Studio version 0.98.1103- ©2009-2013 R Studio, Inc.

Results

A total of 1035 ground beetles representing 32 species were collected (Table 2). There were 618 individuals of 29 species in forest gaps and 417 individuals of 13 species in undamaged forests. Species richness and abundance in forest gaps were higher than in undamaged forests. *Synuchus cycloderus* was the most abundant species in forest gaps and undamaged forests. Cicindelinae, Nebriinae, and Lebiinae were collected only in forest gaps. *Calosoma cyanescens* and *C. maximowiczi* (Carabinae) were only collected in forest gaps. Forest species (907 individuals, 11 species) were dominated by *S. cycloderus*, which made up 61.4 % of all individuals. Openland species (128 individuals, 21 species) were dominated by *Harpalus pseudophonoides*, which made up 6.9 % of all individuals.

Species richness and abundance were similar in forest gaps and undamaged forests (Table 3). Species richness and abundance of forest species were similar across habitat types in forest gaps and undamaged forests. In terms of vegetation coverage, the tree layer was significantly lower in forest gaps than in undamaged forests. The shrub, herb, and litter layers were similar in forest gaps and undamaged forests.

The comparison of species richness (Chao 1) and species diversity (*H*') is shown in Fig. 2. Species richness and species diversity (*H*') were significantly higher in forest gaps than in undamaged forests (species richness: $W = 707$, $P < 0.001$; species diversity: $W = 749$, $P < 0.001$). Similarity relationships among ground beetle communities were visualized using two-dimensional NMDS ordination (Fig. 3). Axis 1 (1 %) and axis 2 (2 %) explained 3 % of all variation. Ground beetle communities in forest gaps and undamaged forests did not group separately. MRPP indicated similarity in community composition in forest gaps and undamaged forests ($A = 0.017$, $P = 0.33$).

Table 2 Ground beetles collected at study sites in red pine forest, Gwangneung Forest

Species	Forest gap 1	Forest gap 2	Forest gap 3	Subtotal	Undamaged forest 1	Undamaged forest 2	Undamaged forest 3	Subtotal	Total	%	Habitat type
Cicindelinae											
Cicindela chinensis			6	6					6	0.6	O
Nebriinae											
Nebria chinensis	2		1	3					3	0.3	O
Nebria coreica			3	3					3	0.3	O
Pterostichinae											
Pristosia vigil			1	1					1	0.1	F
Pterosticus sp. 1		2		2	1			1	3	0.3	F
Synuchus cycloderus	176	85	82	343	177	47	69	293	636	61.4	F
Synuchus nitidus	13	2	1	16	13	3	2	18	34	3.3	F
Synuchus sp. 1	15	33	4	52	22		10	32	84	8.1	F
Trigonognatha coreana							2	2	2	0.2	F
Harpalinae											
Anisodactylus punctatipennis		1		1					1	0.1	O
Anisodactylus signatus		3		3					3	0.3	O
Anisodactylus tricuspidatus		1		1					1	0.1	O
Cyminidis daimio							1	1	1	0.1	O
Harpalus corporosus	2		1	3					3	0.3	O
Harpalus niigatanus	1	6	3	10	1	1		2	12	1.2	O
Harpalus pseudophonoides	25		22	47	23		1	24	71	6.9	O
Harpalus simplicidens	1			1					1	0.1	O
Harpalus sp. 1	1			1					1	0.1	O
Harpalus tridens	2		4	6					6	0.6	O
Zabrinae											
Amara congrua	1			1					1	0.1	O
Amara sp. 1	3			3					3	0.3	O
Amara sp. 2						1		1	1	0.1	O
Callistinae											
Chlaenius naeviger	3	7	17	27	1	8	4	13	40	3.9	F
Chlaenius ocreatus	1			1					1	0.1	O
Chlaenius posticalis	1	1		2		1		1	3	0.3	O
Chlaenius variicornis	1		1	2					2	0.2	O
Chlaenius virgulifer	1			1					1	0.1	O
Lebiinae											
Galerita orientalis	4			4					4	0.4	O
Carabinae											
Calosoma cyanescens	1			1					1	0.1	F
Calosoma maximowiczi	6			6					6	0.6	F
Coptolabrus jankowskii	23	14	12	49	6	4	11	21	70	6.8	F
Eucarabus sternbergi	9	7	6	22	1	4	3	8	30	2.9	F
Species richness	22	12	15	29	9	8	9	13	32		
Abundance	292	162	164	618	245	69	103	417	1035		

See text for classification methods of habitat type

Habitat type, *O* openland species, *F* forest species

Table 3 Species richness, abundance, species richness and abundance of habitat type, vegetation coverage, and litter layer at forest gaps and undamaged forests

Index	Forest gap (mean ± SD)	Undamaged forest (mean ± SD)	*t*-test		
			t	*df*	*P*
Species richness					
All species	16.3 ± 4.2	8.7 ± 0.5	2.571	2.051	0.121
Habitat type					
Forest species	7.3 ± 0.5	6.3 ± 0.9	1.341	4	0.251
Openland species	9.0 ± 3.7	2.3 ± 0.5	2.5	2.063	0.126
Abundance (N + 1)					
All species	5.3 ± 0.27	4.8 ± 0.52	1.231	4	0.286
Habitat type					
Forest species	5.1 ± 0.29	4.7 ± 0.50	0.895	4	0.421
Openland species	3.4 ± 0.58	1.9 ± 0.94	1.9473	4	0.137
Vegetation coverage (%)					
Tree layer	21.7 ± 6.2	70.0 ± 8.2	−6.653	4	0.003
Shrub layer	50.0 ± 28.6	68.3 ± 16.5	−0.786	4	0.476
Herb layer	80 ± 8.2	65.0 ± 12.2	1.441	4	0.223
Litter layer (cm)	2.1 ± 0.3	2.0 ± 0.0	−3.571	2.083	0.066

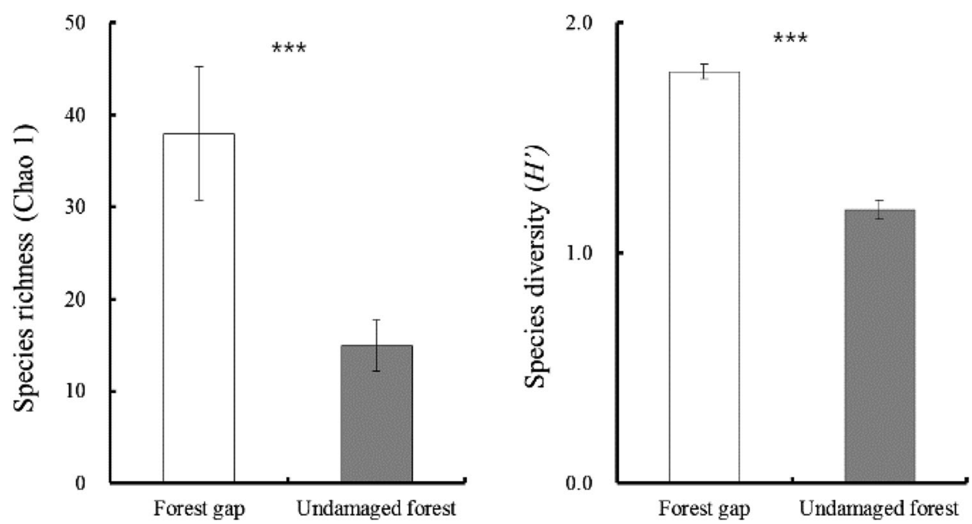

Fig. 2 Estimation of species richness (Chao 1) and species diversity (*H'*) of ground beetle at forest gap and undamaged forest in red pine forest. Species richness and species diversity were obtained using Estimate S (Colwell 2005). *Error bars* of species richness (Chao 1) indicate one standard deviation. Significance, ***$P < 0.001$

Discussion

Contrary to our expectation, species richness, abundance, and habitat type of the ground beetles in forest gaps were similar to those in undamaged forests. Furthermore, community structure of ground beetles was similar in forest gaps and undamaged forests, although estimated species richness and species diversity were significantly higher in forest gaps than in undamaged forests. In vegetation, the herb layer was similar but the tree layer was significantly lower in forest gaps compared to undamaged forests. The similarity in herb layer may have been due to the effect of the shrub layer. In addition, it is likely that community structure was similar in gaps and undamaged forest due to rapid inflow into gaps of ground beetles from the surrounding undamaged forests. However, Bouget (2005) reported that windthrow considerably decreased carabid abundance. Skłodowski and Garbalińska (2007) showed that carabidae assemblages markedly declined in abundance, although species richness was significantly higher in damaged stands compared to control stands after a hurricane in Puszcza piska pine forests. Skłodowski and Garbalińska (2011) emphasized that carabidae assemblages in the disturbed and control stands were different but no clear signals of recovery of carabidae assemblages were observed during a 6 year follow-up. Duelli et al. (2002) found that a hurricane significantly increased carabid species richness in gaps. They reported that species richness of

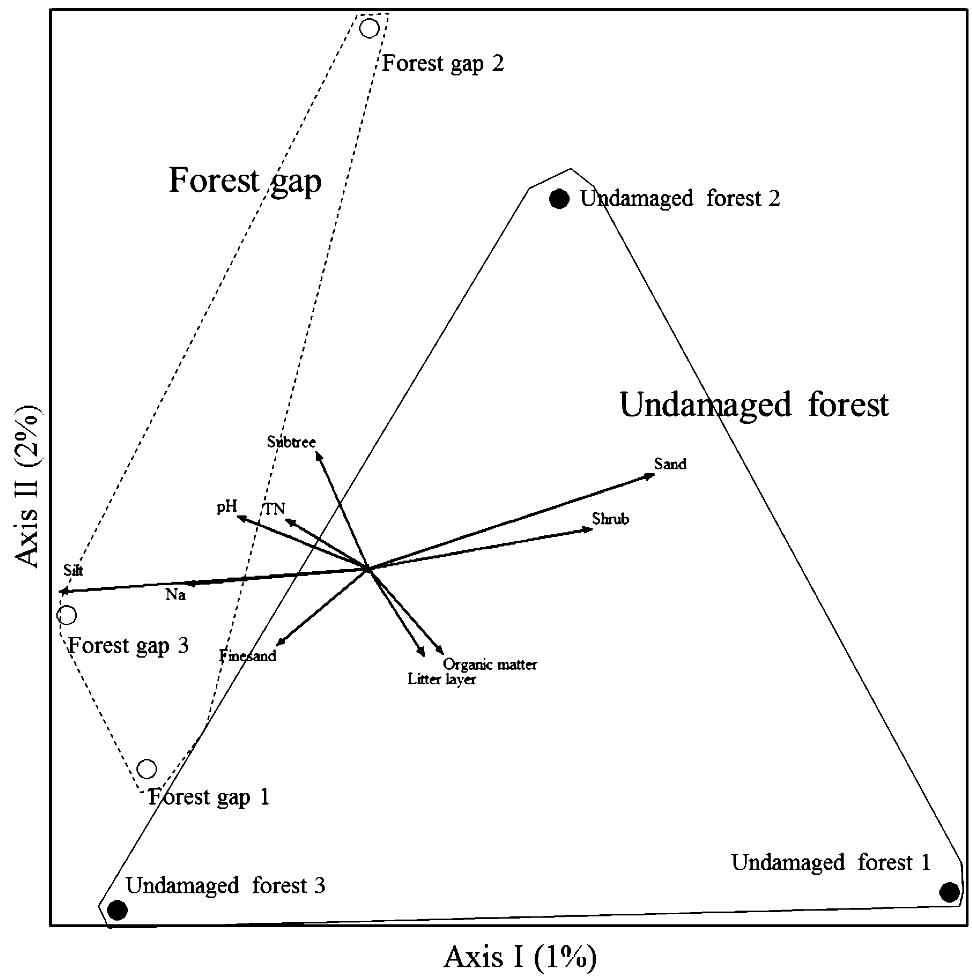

Fig. 3 Non-metric multidimensional scaling (NMDS) ordination of ground beetle communities. The *two axes* explained 3 % of all variation. Angles of the *two axes* were moved slightly to visualize the ground beetle communities. Singleton species occurring at one site were excluded from the NMDS ordination. Study site, *open circle* forest gap, and *dark circle* undamaged forest

all animal taxa was 50 % higher in gaps than in neighboring plots of an intact forest. Our results differ from those of several previous studies. The difference seems to be due to forest gap size or sample size. The size of the forest gaps in our study was under 1 ha. Bouget (2005) reported that the increase in carabid species richness in stands affected by hurricane was positively correlated with gap size. In addition, species richness of ground beetles and openland species did not overlap in forest gaps and undamaged forests. Yet they were statistically similar. This result may be due to small sample size. Our study site was located on a mountain top. On this site it was impossible to demarcate many study plots because of the limited area. Future study should increase sample size to enhance statistical rigor.

Food habits may be one of the reasons why ground beetle assemblages were similar in forest gaps and undamaged forests. Ground beetles are generally polyphagous predators (Kotze et al. 2011). Predators may be less affected by environmental changes than herbivores, fungivores, wood borers, and detritivores, because predators can change their food resources according to the environmental situation. Duelli and Obrist (1999) found that ground-foraging predators in salvaged and unsalvaged spruce gaps were equally species rich. Beetles with different food habits will show different responses to environmental change. Herbivores would increase with an increase in the herb layer, whereas fungivores and wood borers would increase with an increase in dead wood. Detritivores would decrease with increasing sun exposure. Therefore, further studies are required to define the roles of forest gaps in forest ecosystems using Coleoptera beetles.

Although many species are dependent on natural openings, modern forestry creates dense forests to harvest timber. Forest gaps formed by typhoons change the structure of forest ecosystem, increase openings, and this promotes the herb layer. Forest gaps provide many micro-habitats for flower-visiting, herbivorous, and ground insects (Bouget and Duelli 2004). The environmental changes caused by a typhoon will more strongly affect ground beetles that favor early successional habitats and their food sources than late successional habitat. *Harpalus* species, *Amara* species, and

Chlaenius species were more abundant in forest gaps than in undamaged forests. *Harpalus* species are seed-eating as larval instars and omnivorous as adults (Luff 1980; Holland 2002). *Amara* species feed on aphids and insects as well as seeds of *Stellaria* species, *Capsella* species, and *Taraxacum* species (Jonson and Cameron 1969; Holland 2002; Lee 2009). *Chlaenius posticalis*, *C. variicornis*, and *C. virgulifer* are mainly found in early successional habitats such as riverbanks, paddy fields, and urban parks (Lee 2009). Our results support those of several previous studies.

Conclusions

The heterogeneity of forest gaps would be expected to contribute to higher species richness and abundance of ground beetles in disturbed forest compared to those in undamaged forests. However, this study showed no difference in species richness, abundance, or ground communities between forest gaps and undamaged forests. This result differed from results of previous studies. It is possible that this study was affected by limited sample sizes caused by topographic constraints. Future studies are needed to sample in more wide gaps and many more gaps to clarify the change of forest biodiversity caused by typhoon.

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