
15
ELSEVIER
Journal of
Asia-Pacific Entomology
Vol. 15, Issue 1
March 2012
ISSN 1226-8615
The official journal of the Korean Society of
Applied Entomology, the Taiwan Entomological
Society and the Malaysian Plant Protection Society

Journal of Asia-Pacific Entomology 17 (2014) 775–780

Contents lists available at ScienceDirect

Journal of Asia-Pacific Entomology

journal homepage: www.elsevier.com/locate/jape

Ground beetle community in suburban Satoyama — A case study on wing type and body size under small scale management

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A R T I C L E   I N F O

Article history:
Received 24 March 2014
Revised 9 July 2014
Accepted 26 July 2014
Available online 2 August 2014

Keywords:
Brachyptery
Carabidae
Environmental monitoring
Forest management
Macroptery

A B S T R A C T

A Satoyama landscape is an important reservoir of biodiversity; however, in post-industrial era traditional Satoyama management became economically unfeasible.
To maintain Satoyama, labor-saving management styles have begun to be implemented. In contrast to the traditional styles based on labor-intensive practices such as rotational tree clear-cutting, the labor-saving styles consist mainly in tree thinning and ground vegetation cutting within a small spatial range. The consequences of this new approach are unclear, and our study aimed at filling this gap in our knowledge by analyzing the effects of small scale management on ground beetle community in suburban Satoyama (Kashiwa city, central Japan). We applied labor-saving management at limited spatial range, and sampled and analyzed ground beetles both before and after management. Cluster analysis revealed three groups of beetle assemblages, corresponding to three habitats: forest, bamboo stand and grassland. Comparison of wing traits showed that, before management, brachypterous beetles dominated forest plots and macropterous beetles were more prominent in the grassland plot, while in the bamboo stand both types of wing morphology were evenly represented. This trend can be linked to habitat structural stability driven by vegetation regeneration cycles which reflect dominant plant longevity. After management, macroptery increased in all three habitats. Probably, habitat disturbance created by vegetation management gave advantage to macropterous beetles over brachypterous beetles. These results suggest that wing type can be linked to vegetation structural stability. In some species, decline in abundance was accompanied with decline in body size. Our study shows that small scale Satoyama management can have pronounced effects on beetle assemblages.

Introduction

A Satoyama landscape in Japan supports important habitats, where traditional vegetation management sustains a large variety of unique plant and animal species (Takeuchi et al., 2003). However, it became difficult to keep the traditional Satoyama management after the introduction of fossil fuels and chemical fertilizers in the 1960s and because of changing lifestyles in Japan. Satoyama has been abandoned and its landscape has been reduced in size and fragmented into small patches due to development of the land. This led the government of Japan to recognize that Satoyama landscapes are threatened by habitat alterations (Japanese Government, 2012). Nowadays, to maintain a Satoyama landscape, new management styles based on labor-saving approaches have begun to be implemented. These managements are mainly tree thinning and ground vegetation cutting within a narrow spatial range (Shigematsu, 1991; Terada et al., 2010). This is in contrast with the traditional management consisting in tree clear-cutting with 10 to 25 years of rotation (Moriyama, 1988; Takeuchi, 2003). The small scale management styles are feasible and sustainable with limited manpower; however, the effects of such management on Satoyama habitat have not been well studied yet. One of the reasons of our poor knowledge is that in most places the new management has been started without documenting the pre-management state of these habitats.

Here we assess the effects of the labor-saving forest management on ground beetles in typical suburban Satoyama habitats. Carabid beetles (Carabidae, Coleoptera) are an abundant and widespread group of insects, and are often suggested as suitable targets for monitoring environmental conditions due to their rapid responses to changes in their habitats (Ishitani, 1996; Sota, 2000; Rainio and Niemelä, 2003; Pearce and Venier, 2006; Yamashita et al., 2006; Maleque et al., 2009; Rusch

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http://dx.doi.org/10.1016/j.aspen.2014.07.013
1226-8615/

et al., 2013). In particular, we studied the changes in wing type (brachyptery versus macroptery) and body size of ground beetles in response to selective tree cutting and understory clearing. It is widely accepted that wing type is related to environmental stability, brachyptery being more common in stable and macroptery more common in disturbed habitats (Wagner and Liebherr, 1992; Gobbi et al., 2007). Accordingly, we explored the possible relationship between the wing type of beetles and the stability of the habitat by analyzing the wing type distributions among habitats both before and after management in a suburban Satoyama. At the same time, the body size of beetles is linked to management intensity (Blake et al., 1994; Ribera et al., 2001; Cole et al., 2006), and our second hypothesis, accordingly, was the following: body size can change in response to habitat alteration so that the mean body size of beetles decreases or increases when habitats become harsher or more suitable, respectively. Habitat alteration in food base also must cause changes in the abundance of beetle individuals via decreased or increased survival rates, and could prompt dispersal from scarce food to abundant food habitats. Our expectation was that changes in body size were possible to detect at least in some species.

Materials and methods

Study site

This study was conducted in a Satoyama landscape of a suburban area, Oaota-no-mori (100 ha, 35°54′N, 139°55′E, 18 to 25 m a.s.l.), Kashiwa city of Chiba Prefecture, central Japan (Fig. 1). Although Oaota-no-mori is not large, Kashiwa city preserves it as an important green area that provides habitats for various organisms (Kashiwa City, 2009). We set seven plots (50 m × 50 m each) as representatives of the suburban Satoyama within Oaota-no-mori (Fig. 1). Three plots were located next to each other: one of them (G) was set in grassland without canopy trees, and two plots (Fb1 and Fb2) were selected in broad-leaved forest dominated by deciduous *Quercus acutissima* Carruthers and *Quercus serrata* Murray (Fig. 1). Two other plots (Fc1 and Fc2) were chosen in coniferous forest dominated by evergreen species *Cryptomeria japonica* (Thunb. ex L.f.) D.Don and *Chamaecyparis obtusa* Sieb. & Zucc. and were set next to each other (Fig. 1). Finally, two other plots, also next to each other (B1 and B2), were set in a bamboo stand dominated by *Pleioblastus chino* (Franch. et Savat.) Makino (Fig. 1). After sampling ground beetles in 2011, we conducted the following small scale management: tree thinning (cut down approximately 30% of the original basal area) at plots Fb1 and Fc1, and bamboo mowing (100% clear cut) at plot B1. Plots Fb2, Fc2 and B2 were left without any manipulation in order to see whether the labor-saving management applied within a limited spatial range affected the adjacent parts of the habitat.

Ground beetles

Pitfall traps without bait (plastic cups with 102 mm top diameter and 123 mm deep with five 1–2 mm holes for drainage) were used for sampling ground beetles. Twenty four cups separated by 2–8 m were set in the center of each plot for five to six consecutive days. This sampling procedure was conducted once per month in June, July, September and November 2011. After vegetation management, sampling was repeated in June, July, September and October 2012. All collected beetles were brought back to the laboratory, identified and counted. The body length of all individuals was measured from the front margin of the labrum to the elytral apex using a vernier caliper (Ikeda et al., 2006; Yamashita et al., 2006). To examine the wing type, we opened the elytra of all individuals and checked whether the wing was macropterous or brachypterous except for three Carabinae species which are already known as brachypterous (*Carabus insulicola*, *Leptocarabus procerulus* and *Damaster blaptoides*, i.e. Ueno et al., 1985).

To examine the similarity of species composition and abundance distribution in ground beetle assemblages, we performed cluster analysis of our seven plots using Group average distance as the measure of similarity (software PC-ORD5, McCune and Mefford, 2006). We used natural log-transformed (ln X + 1) numbers of beetle individuals as a measure of abundance. To analyze how wing type was associated with

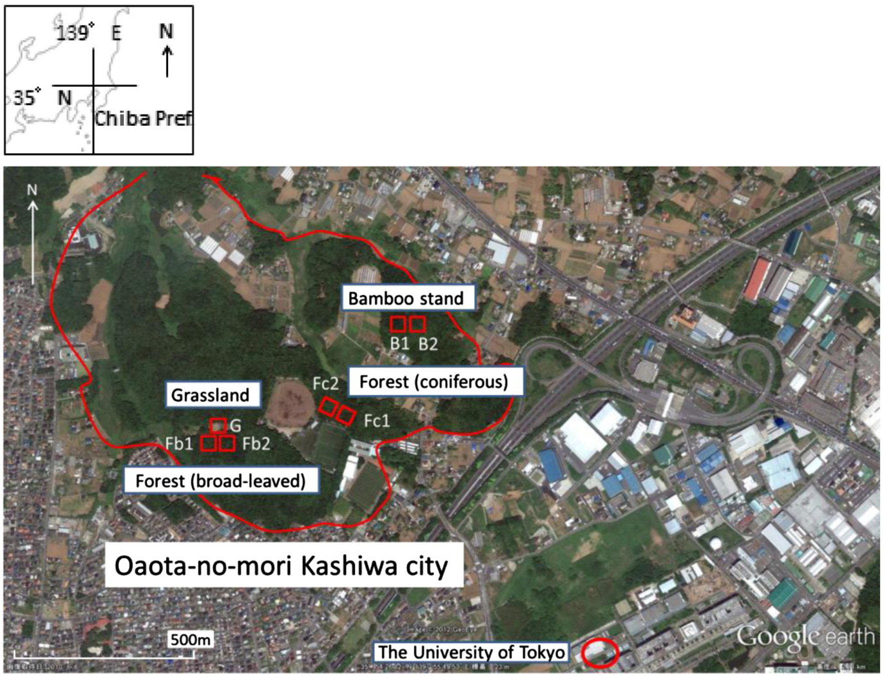

Fig. 1. Location of the study plots in Oaota-no-mori in Kashiwa city, Chiba prefecture. G: plot in grassland (adjacent to tree thinning). Fb1: plot in broad-leaved forest (center of tree thinning after 2011 survey). Fb2: plot in broad-leaved forest (adjacent to tree thinning). Fc1: plot in conifer forest (center of tree thinning after 2011 survey). Fc2: plot in conifer forest (adjacent to tree thinning). B1: plot in bamboo stand (center of mowing after 2011 survey). B2: plot in bamboo stand (adjacent to mowing).

Table 1
Abundance (number of individuals per plot) and wing type of ground beetles in 2011 and 2012.

Species	2011								2012								Total	Wing form
	G	Fb1	Fb2	Fc1	Fc2	B1	B2	Total	G	Fb1	Fb2	Fc1	Fc2	B1	B2	Total		
Calosoma maximowiczi (Morawitz)	1							1									1	Ma
Carabus insulicola Chaudoir	198	188	205	139	130	74	35	969	73	34	39	31	23	90	57	347	1316	Br
Leptocarabus procerulus (Chaudoir)	40	88	63	81	167	7	10	456	29	50	34	37	30	9	7	196	652	Br
Damaster blaptoides Kollar	2			1		2		5	1				2	3		6	11	Br
Cosmodiscus platynotus (Bates)									1							1	1	Ma
Myas cuprescens cuprescens Motschulsky	3	2	1	2	9	6	3	26		1	1	6	3	3	2	16	42	Br
Lesticus magnus (Motschulsky)	23	53	67	23	31	30	4	231	25	25	43	5	3	17	7	125	356	Ma
Trigonotoma lewisii Bates	1	2	3	4	6	2	1	19	1		1	3	1	1	1	8	27	Ma
Pterostichus sulcitarsis Morawitz										1						1	1	Br
Pterostichus yoritomus Bates			1			1	1	3				4			2	6	9	Br
Pterostichus prolongatus Morawitz	1	1						2				1				1	3	Br
Pterostichus microcephalus (Motschulsky)	8	2	4	1	3			18	6	7	3	2	1	1		20	38	Br
Dolichus halensis (Schaller)	57				2	3	3	65	66				2	3	2	73	138	Ma
Synuchus nitidus (Motschulsky)	15	39	66	6	17	27	18	188	9	9	43	21	28	19	33	162	350	Ma
Synuchus cycloderus (Bates)		4	7				2	13	47	58	126	34	65	51	332	713	726	Ma
Synuchus dulcigradus (Bates)	5	1	3	4	3			16	5	3	6	4	2		1	21	37	Ma
Synuchus arcuaticollis (Motschulsky)	9		2					11	14	1		2				17	28	Ma
Amara congrua Morawitz	10					1		11	3							3	14	Ma
Amara chalcites DeJean	3					1		4									4	Ma
Amara simplicidens Morawitz	27							27	2							2	29	Ma
Amara macronota ovalipennis Solsky	7							7	6							6	13	Ma
Amara gigantea Motschulsky										1						1	1	Ma
Anisodactylus signatus (Panzer)									3							3	3	Ma
Anisodactylus punctatipennis Morawitz	3		1			1	1	6	2				1			3	9	Ma
Anisodactylus sadoensis Schauberger	4					5		9	3						1	4	13	Ma
Anisodactylus tricuspidatus Morawitz	1							1									1	Ma
Harpalus capito Morawitz	25							25	3						1	4	29	Ma
Harpalus griseus (Panzer)	25	1		1		1	2	30	27	1						28	58	Ma
Harpalus eous Tschitscherine	14							14	21			1		1	1	24	38	Ma
Harpalus tridens Morawitz	94			1		4		99	15			2				17	116	Ma
Harpalus sinicus Hope	5					1		6	4							4	10	Ma
Harpalus niigatanus Schauberger				1		1		2	7							7	9	Ma
Harpalus tinctulus Bates	2							2			1					1	3	Ma
Harpalus discrepans Morawitz	37	7	7	3	4		1	59	23	5	3	1	2	1		35	94	Ma
Oxycentrus argutoroides (Bates)	13	2	2	1	3		1	22	6	1	2	9	7	3		28	50	Br
Trichotichnus longitarsis Morawitz			1					1									1	Ma
Stenolophus quinquepustulatus (Wiedemann)	1							1									1	Ma
Diplocheila zeelandica (Redtenbacher)	7	2	1		4	1		15				2		1	1	4	19	Ma
Haplochlaenius costiger (Chaudoir)	2	9	13	3	9			36		4	1		1	1		7	43	Ma
Chlaenius variicornis Morawitz						1		1				1			1	2	3	Ma
Chlaenius pallipes Gebler						1		1							1	1	2	Ma
Chlaenius tetragonoderus Chaudoir				1	1			2						1		1	3	Ma
Chlaenius virgulifer Chaudoir	2			1	2	1		6	4	1			2	1		8	14	Ma
Chlaenius micans (Fabricius)									2	1				3		6	6	Ma
Chlaenius naeviger Morawitz	5	2	2	3		3	2	17	6	2	14	1	2	10	16	51	68	Ma
Chlaenius posticalis Motschulsky									4				1	6	10	21	21	Ma
Aephnidius adelioides (Macleay)	11							11	17			1				18	29	Ma
Brachinus scotomedes Redtenbacher	1	7	23	1	17	5		54	1		14	12	2	3	5	37	91	Ma
Total number of individuals	662	410	472	277	408	179	84	2492	436	205	331	180	178	228	481	2039	4531	
Total number of species	35	17	19	19	16	23	14	42	32	18	15	21	19	21	19	43	48	

Br: brachypterous and Ma: macropterous.

habitat types, we classified beetles into brachypterous and macropterous species (Table 1). The observed distribution of macroptery and brachyptery across the plots and years of sampling was compared to the distribution expected from the random model, and the differences were tested using Chi-squared test with subsequent multiple comparisons for proportions (Software Statistix9, Analytical Software, Tallahassee, FL, U.S.A.).

For more detailed analysis, we chose relatively abundant species (more than 30 individuals caught during each of 2011 or 2012 surveys). If the abundance of a given species increased or decreased significantly from 2011 to 2012, we categorized it as "increased" or "decreased" species, respectively. Then we calculated the mean body size of each species and their standard error, and tested the significance of difference in mean size between years using t-test (Software Statistix9, Analytical Software, Tallahassee, FL, U.S.A.).

Results

Ground beetle community

A total of 4531 ground beetle individuals representing 48 species (nine species were brachypterous and 39 were macropterous) were collected from pitfall traps; 2492 beetles representing 42 species were caught in 2011, and 2039 beetles representing 43 species were caught in 2012 (Table 1). All specimens were monomorphic in hind wing shape.

The results of cluster analyses in both 2011 and 2012 showed a similar pattern (Figs. 2a, b); four plots in the forest (plots Fb1, Fb2, Fc1 and Fc2) clustered into one group, and there was not quite measurable difference between broad-leaved and coniferous forests. Two plots from the bamboo stand (B1 and B2) were similar, and the grassland

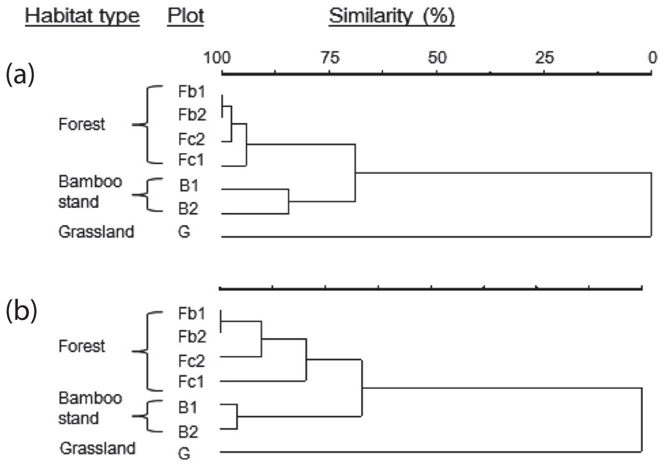

Fig. 2. Cluster dendrogram showing similarity of ground beetle assemblages among the seven plots from different habitat types in (a) 2011, and (b) 2012. The analysis was performed with the method of correlation using Group average distance as the measure of similarity.

assemblages (G) showed very low similarity to the forest and bamboo habitats in both 2011 and 2012 (Figs. 2a, b). After management, no striking difference between Fb1 and Fb2, Fc1 and Fc2, and B1 and B2 was found in species compositions (Fig. 2b). Hence, the consistent results of two-year cluster analyses of beetle assemblages enabled us to classify the plots as three habitat types: forest (uniting plots Fb1, Fb2, Fc1 and Fc2), bamboo stand (uniting plots B1 and B2) and grassland.

Wing type

The three habitat types distinguished by cluster analysis were further used to analyze the distribution of wing traits among these habitats. We found that the proportion of brachypterous individuals was high and that of macropterous was low from the forest habitat to bamboo stand to grassland in 2011 (Fig. 3a). The observed distribution differed from the expected proportions based on random distribution (Chi-square = 179.86, $P < 0.0001$). A multiple comparison test also showed significant differences among the three habitat types (Fig. 3a). In 2012 the proportion of macropterous beetles became significantly higher in all three habitats as compared to 2011 (Figs. 3a, b), although the proportion of brachypterous beetles in forest was still higher than that in bamboo and grassland (Chi-square = 30.51, $P < 0.0001$). A multiple comparison test also showed that the forest habitat differed significantly from bamboo and grassland (Fig. 3b).

Body size

We selected species with high abundance (over 30 individuals for each of 2011 or 2012), and, according to their change from 2011 to 2012, divided them into three groups. Group 1 represented five species with decreased abundance: *C. insulicola*, *L. procerulus*, *Lesticus magnus*, *Harpalus tridens* and *Haplochlaenius costiger*. Group 2 represented two species with increased abundance: *Synuchus cycloderus* and *Chlaenius naeviger*. Group 3 represented four species with no measurable increase or decrease: *Synuchus nitidus*, *Dolichus halensis*, *Harpalus discrepans*, and *Brachinus scotomedes*.

The analysis of body size detected a statistically significant decrease in four species (*C. insulicola*, *L. procerulus*, *L. magnus* and *H. costiger*) out of five species of Group 1 (Fig. 4a). One species, *H. tridens* also became smaller, but the difference was not statistically significant (Fig. 4a). No significant difference was detected in the body size of *S. cycloderus* and *C. naeviger* of Group 2 (Fig. 4b). Finally, no significant difference in body size was detected among four species with no measurable increase or decrease in their numbers (Group 3).

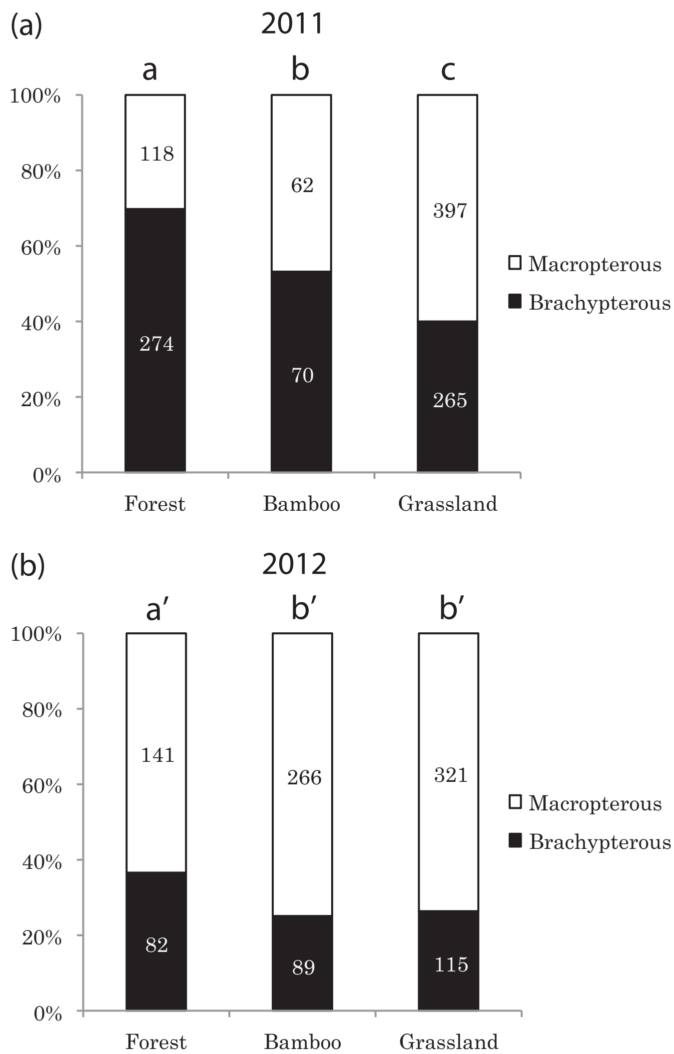

Fig. 3. Wing type distribution across three habitat types in (a) 2011, and (b) 2012. Letters above the bars (a, b and c in 2011, a′ and b′ in 2012) show significantly different proportions (by multiple comparison proportion test at $P < 0.05$). The numbers on the bars show the numbers of beetle individuals caught per plot. The proportion of macroptery of 2012 became significantly higher in all three habitats compared to 2011 (by multiple comparison proportion test at $P < 0.05$).

Discussion

We conducted our study in a Satoyama suburban area, and we found that beetle assemblages were grouped by vegetation type: forest (habitat under a tree canopy), bamboo stand and grassland. The strong relations between vegetation and beetles have been shown by previous studies highlighting the importance of trees (Niemelä and Spence, 1994) and/or ground vegetation (Magura, 2002; Shibuya et al., 2011). Actually, the assemblages from the grassland and the broad-leaved forest habitat were considerably distinct from each other, even though spatial distance between the grassland and the broad-leaved forest plots was closer than that between the coniferous and broadleaved forest plots. Management of vegetation caused similar changes in both central plots and adjacent plots. This means that management at a small spatial scale could have effects on the whole habitat of beetle assemblages. Actually, vegetation management even at a small spatial scale alters the surrounding environment and has pronounced effects on abiotic factors such as light, temperature and soil moisture (Shibuya et al., 2008a). Our results suggest that labor-saving forest management can have enough effects to the entire habitat of beetle assemblages. In Japan, a Satoyama landscape consists

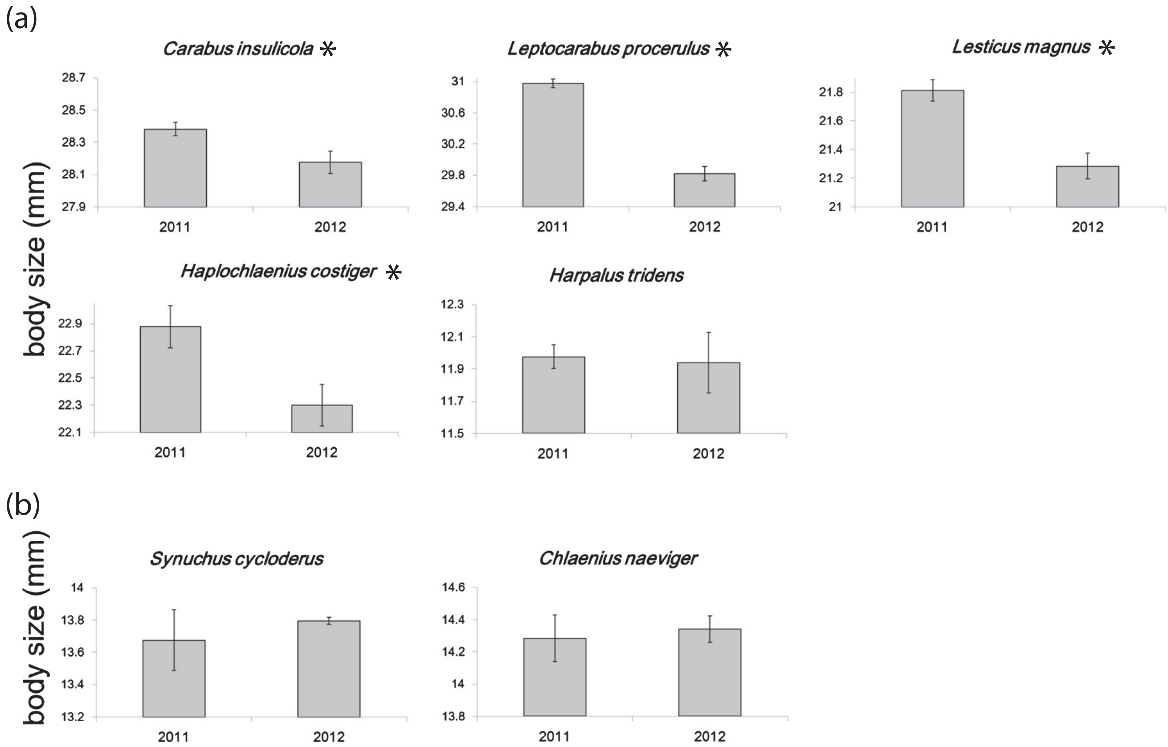

Fig. 4. Mean body size in 2011 vs. 2012. Error bars represent SE. The scale of the Y-axis differs among the panels. (a) Species with decreased abundance: body size of four out of five species marked with asterisk reduced significantly and (b) species with increased abundance showed no significant difference.

of the patchy mosaic of various habitats with a narrow spatial range and thus small scale management can be effective.

Comparison of wing traits showed that brachyptery dominated the forest habitat. On the other hand, macroptery was more pronounced in the grassland habitat, and in the bamboo stand brachyptery and macroptery were evenly represented in 2011. This trend can be linked to habitat structural stability driven by vegetation regeneration cycles which reflect dominant plant longevity. In our study forest, the canopy was built by 50-year old trees, while grassland was represented by annual and perennial herbaceous species. Hence, the forest habitat is structurally more stable than that of grassland, where vegetation cover is renewed every year. The bamboo stand is dominated by 7–8 year old individuals, and, with respect to natural regeneration cycles of vegetation, can be placed between the forest and grassland habitats. In 2012 (after the management), the proportion of macropterous individuals has increased in all three habitat types. We suspect that the management caused a collateral disturbance also by trampling and affected the stability of habitat. Macropterous insects are more common in less stable habitats where effective dispersal ability is crucial for beetles to survive (Roff, 1990). Flying capability gives macropterous beetles an important advantage in such habitats over brachypterous species, which are in disadvantage because of their inability to fly. Overall, our results suggest that wing type can be linked to habitat structural stability as reflecting the regeneration cycles of vegetation.

Generally, species composition of ground beetle assemblages is sensitive to changes in their environment (Thiele, 1977; Niemelä et al., 2000; Scott and Anderson, 2003). We found that five relatively abundant species (*C. insulicola*, *L. procerulus*, *L. magnus*, *H. costiger* and *H. tridens*) declined in their numbers in response to habitat change after the management. For these species this new habitat probably was not suitable and their abundance may have dropped due to reduced survival rates and/or emigrations in search of more suitable environment. We also found that the body size of four out of five species that decreased in abundance became significantly smaller. Although this decline was relatively small in magnitude, it was statistically significant. These four species are relatively large in body size, and the largest beetles (*L. procerulus*) declined the most in their body size. This result conforms to the report of Cole et al. (2006), which concluded that intensively managed habitats disfavor large carabids. Scarce diet has a negative effect on body size (Jiménez-Cortés et al., 2012), so the food base of these species might deteriorate after the management. However, other interpretations are also possible because we did not directly measure resource availability. Besides, the relationships between resource availability and body size may not be so simple (Blake et al., 1994). By contrast, two species (*S. cycloderus* and *C. naeviger*) increased in numbers, but this was not associated with the significant change in their body size. These two species are characterized by small size, and probably, their abundance increased mostly by immigrations as they responded positively to the management. If the management will continue, it might be expected that species with small body size will become dominant in these managed sites, because disturbance often favors small body sizes in carabid beetles (Blake et al., 1994), and because the decrease in ground beetle body size was observed after habitat disturbance (Braun et al., 2004). Our results additionally indicate that body size can decrease in the beetle species which become less abundant at least just after management. The generality of these phenomena as well as the specific mechanisms behind them is yet to be established and hence requires further studies also in other habitats.

Ground beetles can be good bioindicators (Irmler, 2003; Rainio and Niemelä, 2003; Scott and Anderson, 2003; Niemelä et al., 2007). In order to monitor the biodiversity of Satoyama, it is important to identify certain sensitive species as appropriate biological indicators (Shibuya et al., 2008b). In particular, *S. cycloderus* can rapidly increase in its abundance after vegetation management, as it was found also in another study on Satoyama management (Shibuya, 2008). The use of diversity indices alone may lead to a loss of important information associated with biologically meaningful traits (such as wing type and body size). Hence studying these traits can prevent the risks of oversimplification or misreading the field data. Our study documents the state of beetle community both before and after management at the same site; thus it provides valuable baseline for analyzing the effects of the forest management in the future. However, there are also certain potential limitations to our study, because it was conducted at one site and genuine replication was not possible. Again, further studies will be needed to document whether similar or different changes are produced by the labor-saving management in other locations too. Overall, analyzing beetle wing type and monitoring certain sensitive species potentially can help identify environmental changes more efficiently. Consequently, more detailed studies scrutinizing wing morphology of ground beetles and their relations to environment types are needed.

Acknowledgments

This study was supported by the project: Development Funds for Leading Creative Science and Technology, Promotion of Social System Reformation Integrated with Research and Development by MEXT, Japan. We thank M. Yokohari, our section leader in this project, for his support. We are also grateful to two anonymous reviewers for valuable comments.

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