Entomological Science

Entomological Science (2014) doi:10.1111/ens.12117

ORIGINAL ARTICLE

Annual fire resilience of ground-dwelling ant communities in Hiraodai Karst Plateau grassland in Japan

Shingo HOSOISHI[1], Wattanachai TASEN[1,2], Sang-Hyun PARK[1], Anh LE NGOC[1,3], Yuzuru KUBOKI[1] and Kazuo OGATA[1]

[1]*Institute of Tropical Agriculture, Kyushu University, Fukuoka, Japan;* [2]*Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand; and* [3]*Department of Entomology, Hanoi University of Agriculture, Hanoi, Vietnam*

Abstract

The fire resilience of ground-dwelling ant assemblages in grassland subjected to annual fire management was investigated. Study sites consisted of three burnt sites and three unburnt sites in grasslands on the Hiraodai Karst Plateau in Fukuoka Prefecture, Japan. Ground-dwelling ants were sampled by Winkler extraction and collected at 10 days and 1, 2, 3 and 6 months post-fire. In total 33 ant species belonging to 25 genera in six subfamilies were collected from the burnt and unburnt sites. Eight of the 29 ant species collected at burnt sites were restricted to burnt sites, while four of the 25 ant species collected at unburnt sites were restricted to unburnt sites. Non-metric multidimensional scaling and analysis of similarities revealed that the ant assemblages in the burnt sites at 10 days and 1 month post-fire were clearly separated from the assemblages observed at 2, 3 and 6 months post-fire. The results suggested that the ground-dwelling ant fauna in the study area were highly resilient to fire at 2 months post-fire and that the annual fire regime did not have a marked effect on species richness.

Key words: conservation, disturbance, Formicidae, management, *Plagiolepis flavescens*, seasonality, *Temnothorax spinosior*.

INTRODUCTION

Fire is a common disturbance in natural and agricultural environments. In natural areas, wildfires typically occur in dry regions, such as the savanna environments of Australia (Andersen *et al.* 2005) and Africa (Parr *et al.* 2004). However, fire has long been used to maintain areas in a semi-natural condition for agricultural activities such as grazing. Wildfires are relatively rare in Japan, but controlled burning is widely used in grassland areas to prevent forest succession, preserve wetlands, or manage areas for use as pastures.

Fire simplifies the ground surface and affects the distribution and ecology of the flora and fauna in the burnt regions. The biodiversity of fire-managed environments is generally regarded as being relatively low (e.g. Underwood & Quinn 2010). However, among semi-natural environments, grasslands are often biodiversity hotspots as many rare or endemic species are restricted to these habitats (van Swaay 2002; Batáry *et al.* 2007; Knop *et al.* 2010). Regular controlled burning can provide and maintain favorable environments for these grassland species (Woodcock *et al.* 2012). Consequently, assessing the community structure of the taxa in grasslands is important for the conservation biodiversity and sustainable management of grasslands generally.

Numerous studies have been conducted on the effect of fire on biodiversity (e.g. lizards by Hellgren *et al.* 2010; soil invertebrates by Wikars & Schimmel 2001; litter arthropods by Vasconcelos *et al.* 2009). While these studies revealed that fire generally decreased the diversity of these assemblages (Castaño-Meneses & Palacios-Vargas 2003), other studies have reported that ants are highly resilient to fire (e.g. Parr & Andersen 2008). Ants are ideal organisms for use in biodiversity studies because they typically constitute a major faunal component of almost all environments and are

Correspondence: Shingo Hosoishi, Institute of Tropical Agriculture, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan.
Email: hosoishi@gmail.com

Received 24 July 2013; accepted 9 July 2014.

considered to be keystone species (Hölldobler & Wilson 1990).

Most fire and ant studies have focused on a comparison of burnt and unburnt areas (Andersen & Yen 1985; York 1994; Vanderwoude *et al.* 1997; Farji-Brener *et al.* 2002; Parr *et al.* 2002; Gunawardene & Majer 2005; Ratchford *et al.* 2005; Barrow *et al.* 2007; Parr & Andersen 2008; Philpott *et al.* 2010; Verble & Yanoviak 2013). While these studies examined the fire resilience of ants in naturally or managed burned areas, little is known about ants in areas where fire management is undertaken on an annual basis in the northern hemisphere (but see Ratchford *et al.* 2005; Verble & Yanoviak 2013).

The aim of this study was therefore to compare the ant species richness and species compositions in grassland areas that either were or were not subjected to burning as part of an annual fire management plan. In addition, the recovery time of different ant species in the field was determined.

MATERIALS AND METHODS

Study site

The study was carried out on the Hiraodai Karst Plateau (approximately 12 km^2) (33°45′N, 130°54′E) in Kitakyushu National Park in Fukuoka Prefecture, Japan (Fig. 1). The elevation at the site ranges from 370 m to 400 m a.s.l. The mean annual temperature in Iizuka (located 20 km from Hiraodai), Fukuoka Prefecture, is approximately 15.5°C and the mean annual precipitation is 1848 mm (Anonymous 2001). The Hiraodai Plateau measures 11 km from north to south and 2 km from east to west, making it one of the three largest karst formations in Japan (Anonymous 2001). The region consists of limestone hills and is dominated by grassland, but in order to maintain the area as semi-natural grassland, controlled burning is conducted every year in early spring, generally at the end of February. However, unfavorable weather conditions in 2010 meant that burning was postponed to the middle of March. The area selected as the study site was generally dominated by bamboo grass *Pleioblastus argenteostriatus* (Regel) Nakai, although Japanese pampas grass *Miscanthus sinensis* Andersson was also common. The trees were cut regularly, but without burning at the unburnt sites. The study sites consisted of three burnt and three unburnt sites. The area (approximately 3.8 km^2) of the burnt sites had been annually burnt for more than 40 years, whereas the area of the unburnt sites had been retained without burning for that time (Hiraodai Natural Observation Center, pers. comm., 2013). There was a single burnt area and a single unburnt area. However, within the burnt area, the residential area and small patches of forest developed in the doline (a depression in karstic terrain) had been unburnt. Fire frequency is once every year, with no area burnt more than twice. At each site (40 m × 40 m), two pseudo-replicated transects were placed 10 m apart from each other.

Ant sampling

In Western Japan, ants are relatively active and abundant from March to October. Sampling was therefore

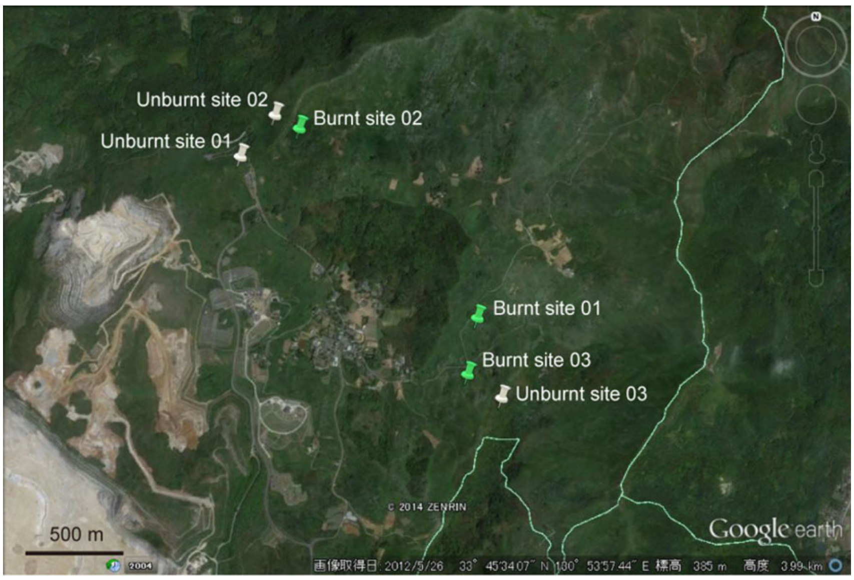

Figure 1 Map of the study site in the Hiraodai Karst Plateau Grassland, Fukuoka Prefecture, Japan (Courtesy Google Earth). The three burnt sites are marked in green, while three unburnt sites are marked in white.

conducted 10 days after burning in March 2010, and then after 1 month (April), 2 months (May), 3 months (June) and 6 months (October) in the burnt and unburnt sites. Sampling could not be conducted in November to February because of unfavorable weather conditions.

Ground-dwelling and cryptic ants were collected along two transects in each of the burnt and unburnt sites by Winkler extraction from leaf litter and soil. To reduce the influence of edge effects, all transects were situated at least 50 m from the edge of study sites. Winkler samples of leaf litter and soil (4×0.25 m^2; 0.5 m × 0.5 m, top 3 cm soil layer) were collected at least 10 m apart from one another. The litter was sifted using a sieve with a mesh size of 6 mm × 6 mm and left for extraction in a mini Winkler apparatus for two days. A total of 4 sampling points × 2 transects × 6 sites × 5 sampling times = 240 samples were collected and all specimens were identified to species using the Japanese Ant Image Database (Japanese Ant Database Group 2008). Voucher specimens were deposited at the Institute of Tropical Agriculture, Kyushu University, Japan.

Data analysis

Differences in the abundance and species richness between the burnt and unburnt sites were analyzed with repeated-measures ANOVA. Where we found significant differences for the main factor, post-hoc comparisons were carried out using Tukey HSD test. Multivariate analyses were carried out to examine differences in the ant assemblages between burnt and unburnt sites using non-metric multidimensional scaling (NMDS). All NMDS ordinations were performed based on the Bray–Curtis index, which is widely used in multivariate analyses of assemblage data based on sound biological reasons. Abundance data were fourth-root transformed to control for biases arising from the large number of collected specimens. The NMDS algorithm attempts to place data points in a coordinate system in which the ranked distances are preserved. As this method makes no assumptions, it is well suited for non-normal data and does not assume a linear relationship between variables. All statistical tests were done using the PRIMER software package v6 (Clarke & Gorley 2006).

Analysis of similarity (ANOSIM) was used to test whether ant assemblage composition differed between the burnt and unburnt sites over time. ANOSIM uses non-parametric permutation procedures applied to Bray–Curtis similarity matrices based on rank similarities between samples (Clarke & Gorley 2006). ANOSIM returns a global R-statistic, which gives a measure of how similar groups are; values range from −1 to +1. A value of ±1 indicates large differences between groups, while a value close to zero indicates there is little difference between groups (Clarke & Warwick 2001). A Bonferroni correction was applied to adjust the statistical significance for multiple comparisons.

The statistical significance of observed R is assessed by permuting (number of permutations = 999) the grouping vector to obtain the empirical distribution of R under a null-model.

In addition, the similarity percentage (SIMPER) procedure was used to determine which species were good discriminators of differences in composition between burnt and unburnt sites. SIMPER measures the percentage contribution of each species to the dissimilarity between samples (Clarke & Warwick 2001).

RESULTS

In total 33 ant species were collected by Winkler extraction (Table 1). The most abundant species were *Crematogaster osakensis* (56.7% of all 240 Winkler samples), *Carebara yamatonis* (55.4%) and *Nylanderia flavipes* (52.9%). Twenty-one species were recorded at both the burnt and unburnt sites. *Temnothorax spinosior* was only species with higher abundance than was recorded at burnt sites. Four species, *Ochetellus glaber*, *Myrmecina flava*, *Ponera scabra* and *Discothyrea sauteri*, were collected only from the unburnt sites.

A significant difference was observed in ant abundance between burnt and unburnt sites (repeated-measures ANOVA, $F_{4,20} = 31.76$, $P < 0.01$; Fig. 2), but no significant difference was observed between sampling periods (repeated-measures ANOVA, $F_{4,20} = 1.611$, $P = 0.210$). Post-hoc Tukey HSD tests revealed that ant abundance was significantly higher in the unburnt sites than in burnt sites.

Although there was no significant difference in ant species richness between burnt and unburnt sites (repeated-measures ANOVA, $F_{4,20} = 0.750$, $P = 0.397$), significant differences were observed in species richness between sampling periods (repeated-measures ANOVA, $F_{4,20} = 19.13$, $P < 0.01$; Fig. 3). Post-hoc Tukey HSD tests revealed that ant species richness was significantly higher at 2, 3 and 6 months post-fire than at 10 days and 1 month post-fire.

NMDS ordination revealed considerable separation in species composition of plots in burnt and unburnt sites, and that the data for 10 days and 1 month post-fire were separated from the data for 2, 3 and 6 months post-fire in burnt sites, also the data for 10 days and 1 month post-fire were separated from the data for 2, 3 and 6 months post-fire in unburnt sites (Fig. 4). SIMPER analysis indicated that *Strumigenys lewisi* (8.53%) and the dominant species, *Nylanderia flavipes* (7.99%) and

Table 1 List of ant species collected by Winker extraction in Hiraodai Karst Plateau Grassland, Fukuoka Prefecture, Japan

Species	Burnt sites 10 days (March)	Burnt sites 1 month (April)	Burnt sites 2 months (May)	Burnt sites 3 months (June)	Burnt sites 6 months (October)	Unburnt sites 10 days (March)	Unburnt sites 1 month (April)	Unburnt sites 2 months (May)	Unburnt sites 3 months (June)	Unburnt sites 6 months (October)
Amblyoponinae										
Amblyopone silvestrii			X	X	X				X	
Dolichoderinae										
Ochetellus glaber						X				
Formicinae										
Acropyga sauteri		X						X		
Camponotus japonicus				X	X					X
Formica japonica			X							
Lasius japonicus	X		X							
Lasius talpa		X								
Nylanderia flavipes	X	X	X	X	X	X	X	X	X	X
Nylanderia sakurae	X	X	X	X	X			X	X	
Plagiolepis flavescens					X				X	X
Myrmicinae										
Aphaenogaster japonica			X					X	X	
Carebara yamatonis	X	X	X	X	X	X	X	X	X	X
Crematogaster osakensis	X	X	X	X	X	X	X	X	X	X
Monomorium chinense			X	X	X				X	
Monomorium intrudens				X	X			X	X	X
Myrmecina flava							X	X	X	
Myrmecina nipponica		X	X				X		X	X
Pheidole fervida			X	X	X					
Pheidole noda			X	X	X					
Pristomyrmex punctatus				X				X	X	
Pyramica canina			X			X	X	X	X	X
Pyramica hexamera				X	X		X		X	X
Solenopsis japonica	X	X	X	X	X			X	X	X
Strumigenys lewisi		X		X	X	X	X	X	X	X
Temnothorax spinosior	X	X	X	X	X					
Tetramorium tsushimae	X	X	X	X	X				X	X
Ponerinae										
Hypoponera nippona				X						
Hypoponera sauteri			X		X			X	X	X
Pachycondyla chinensis					X	X	X	X	X	X
Pachycondyla pilosior					X					
Ponera scabra						X	X		X	X
Proceratiinae										
Discothyrea sauteri									X	
Proceratium itoi			X	X				X	X	X
Total number of species	8	11	18	18	19	8	10	15	22	16

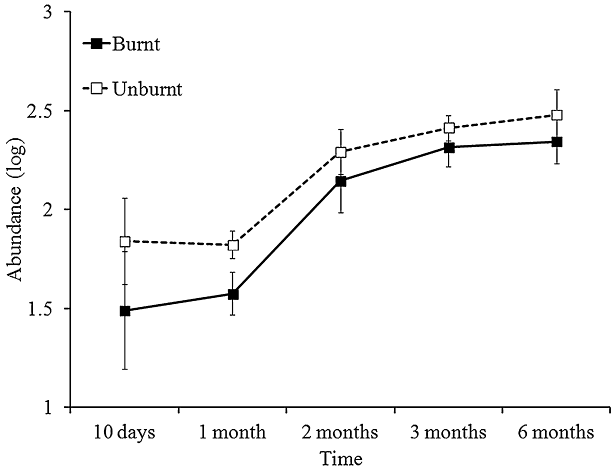

Figure 2 Mean logarithmic abundance of ants at burnt and unburnt sites in Hiraodai Karst Plateau grassland. Error bars show standard error. The *x*-axis shows the time elapsed after the fire, which is given as 10 days post-fire = sampled in March 2010, 1 month post-fire = sampled in April 2010, 2 months post-fire = sampled in May 2010, 3 months post-fire = sampled in June 2010 and 6 months post-fire = sampled in October 2010.

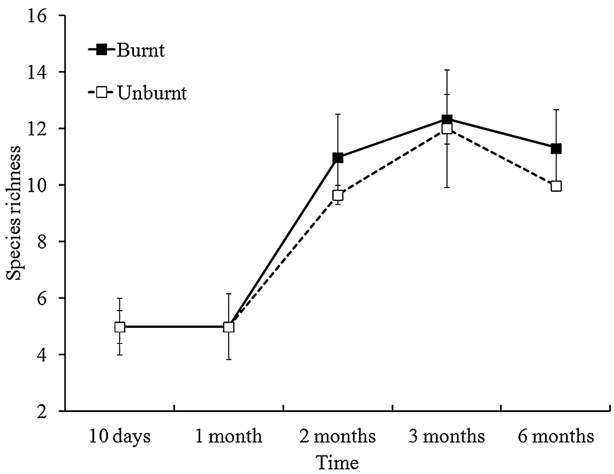

Figure 3 Mean species richness of ants at burnt and unburnt sites in the Hiraodai Karst Plateau Grassland. Error bars show standard error. The *x*-axis shows the time elapsed after the fire, which is given as 10 days post-fire = sampled in March 2010, 1 month post-fire = sampled in April 2010, 2 months post-fire = sampled in May 2010, 3 months post-fire = sampled in June 2010 and 6 months post-fire = sampled in October 2010.

Carebara yamatonis (7.87%), were the main contributors to the observed dissimilarity between burnt and unburnt sites.

The ANOSIM did not reveal a significant difference in ant assemblage composition in relation to sampling period based on a Bonferroni correction.

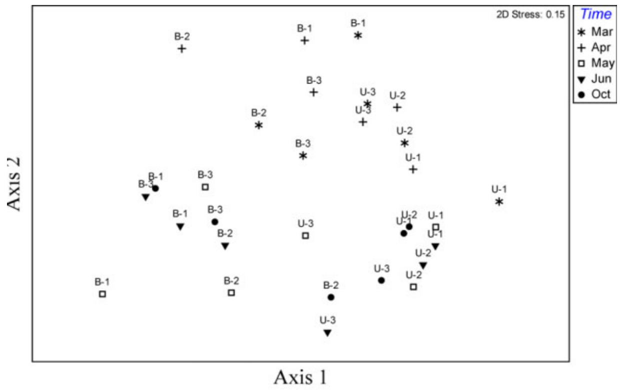

Figure 4 Non-metric multidimensional scaling ordination for burnt and unburnt sites in the Hiraodai Karst Plateau Grassland. Sampling periods are shown as March (10 days post-fire), April (1 month), May (2 months), June (3 months) and October (6 months). (B = burnt site, U = unburnt site).

DISCUSSION

No marked differences in ground-dwelling ant species richness were observed between the study sites, which suggests that controlled burning on an annual basis does not have a negative effect on ant species richness in the study area. Ant abundance was higher in the unburnt sites than in the burnt sites. This finding may be because the unburnt sites still had enough leaf litter for ant settling, but the burnt sites did not. While slight differences in the composition of ant assemblages were observed between burnt and unburnt sites in March and April (10 days and 1 month post-fire), these differences seemed to increase by 2 months post-fire and did not change dramatically thereafter, even at 3 and 6 months post-fire, but it is noted that there were no significant differences in the statistics using a Bonferroni correction (Fig. 4).

Parr and Andersen (2008) also reported that *Iridomyrmex reburrus* abundance increased immediately after burning in the Australian savanna, and they suggested that this might have resulted from increased foraging in the disturbed areas. In this study, the disturbance-associated ant species *Temnothorax spinosior* was only collected at burnt sites. This species is usually found in dry open areas, such as grasslands and bare areas (Japanese Ant Database Group 2008). The fire-induced habitat simplification of the ground surface made it easier for *T. spinosior* to settle (Andersen & Yen 1985).

Some leaf litter-associated species, such as *Pyramica canina* and *P. hexamera*, were collected at the burnt sites several months after the fire, but *Myrmecina flava*, *Ponera scabra* and *Discothyrea sauteri* were not collected at the burnt sites, even at 6 months post-fire. These five ants are litter-associated species, but *M. flava*, *P. scabra* and *D. sauteri* showed a different response to microhabitat conditions changed post-fire (York 2000; Castaño-Meneses & Palacios-Vargas 2003). Moreover, *D. sauteri* is a specialized predator of spider and centipede eggs (Masuko 1981), suggesting that it also needs suitable environment for such larger sized arthropods to exist.

In a study of ants in Japanese red pine forests, Touyama (1996) classified ant species into three groups based on their recovery patterns after a forest fire. His Group I species consisted of silvicolous species that disappeared in response to the primary (heat and smoke) and secondary (fire-induced habitat devastation) disturbances associated with the forest fire; Group II consisted of species that disappeared temporarily after fire, but which then reappeared after 2–4 years; and Group III consisted of species that were commonly found in post-fire stands. Although Touyama (1996) classified *Carebara yamatonis* as a Group I species, we collected this species 10 days after fire, and then again at 1, 2, 3 and 6 months post-fire. Based on the findings of this study, we would therefore consider this species to be included in Group III.

Since the Hiraodai Grassland is subjected to controlled burning in the early spring (end of February) of every year, Touyama's (1996) Group II category is not applicable in our study; however, some species exhibited similar behavior to Group II, albeit over a shorter period. For example, according to Touyama's (1996) classification, *Pachycondyla chinensis* and *Hypoponera sauteri* belong to Group I. However, in this study, *P. chinensis* and *H. sauteri* were collected at burned sites 6 and 2 months after fire, respectively (Table 1). The temporary disappearance of these species might have been attributed to the habitat simplification associated with burning. As in Touyama's (1996) Group III, *Solenopsis japonica*, *Crematogaster osakensis* and *Nylanderia flavipes* were also very common in burnt sites in our study. *Monomorium intrudens*, which was belonged to Touyama's (1996) Group III, was not collected after 10 days or 1 month after fire, but it reappeared at 2 months post-fire. The reappearance is due to the seasonal activity of each species (Parr & Andersen 2008).

The increase in species richness and abundance recorded in May (2 months post-fire) might have been due to active foraging of ants in that season. As suggested by Parr and Andersen (2008), seasonality plays an important role in ant species richness, abundance and assemblage characteristics. Since the experimental sites were burnt at the end of winter when ant activity is still low, using the pre-fire data from our study sites was difficult. Ant activity at our study sites was highest around June to October, which is typical for temperate regions.

Interestingly, ant abundance in burnt sites was higher at 1 and 2 months post-fire than it was at 10 days post-fire (Fig. 2). A similar delay in response to fire was observed in spiders by Underwood and Quinn (2010), but no such delay was observed in their ant observations.

The study sites were limited to only three burnt sites and three unburnt sites in our experimental design. It is important to note that the lack of site replication has limitations on the inferences. Therefore it is difficult to conclude whether the resilience we observed was a general pattern or caused by sampling bias. However, the changes in ant communities may be sustained at a regional scale for short-term periods as in plants of the grassland. Increasing the number of replicates will contribute towards clearer understanding of the resilience of grassland ants in the future.

Grasslands are widely considered to be biodiversity hotspots for plants and insects because many rare or endemic species have been reported in these areas (van Swaay 2002; Batáry *et al.* 2007; Knop *et al.* 2010). In Japan, grasslands are decreasing in area as land is developed or abandoned, resulting in a marked decrease in, or local extinction of, the grassland species in these areas (Anonymous 2001). Hiraodai Plateau is known to support rare species such as the cerambycid beetle *Thyestilla gebleri* (Anonymous 2001), and care needs to be taken to ensure their conservation. In the case of ants, probably grassland-associated species, such as *Plagiolepis flavescens*, were collected in this study for the first time in Hiraodai Plateau, as the community ecology of the grassland insects has not been studied in detail before. *Plagiolepis flavescens* is typically distributed along the margins of woodland and open land in northern Kyushu and southern Tsushima Island in Japan (Japanese Ant Database Group 2008). This species is rare and sparsely distributed elsewhere in Kyushu (Ogata 1986). In the absence of active habitat management, it is relatively easy for grasslands to develop into forest, as they are considered to be one of the first stages of forest succession. Dekoninck *et al.* (2007) suggested that measures such as grazing or mowing were necessary to conserve rare species inhabiting calcareous grasslands in Belgium. In the same way, we propose that annual controlled burning could be used to maintain the semi-natural grassland habitat and, in so doing, conserve the associated species on the Hiraodai Plateau.

ACKNOWLEDGMENTS

We thank staff at the Hiraodai Natural Observation Center and Hiraodai Countryside Park for their assistance with the field surveys in this study. We also thank the officials of the Fukuoka Prefectural Government for granting us permission to conduct this study in Kitakyushu National Park. We thank Dr Martin Pfeiffer for his valuable comments on this paper. Thanks are also due to Mark Lorenz (Forte Inc.) for improving the English. This work was supported in part by the Global COE Program (Asian Conservation Ecology as a Basis of Human-nature Mutualism) of MEXT (The Ministry of Education, Culture, Sports, Science and Technology), Japan, and JSPS KAKENHI (Grant-in-Aid for Scientific Research (C)) Grant Number 26440221.

REFERENCES

Andersen AL, Yen AL (1985) Immediate effects of fire on ants in the semi-arid Mallee region of north-western Victoria. *Australian Journal of Ecology* **10,** 25–30.

Andersen AN, Cook GD, Corbett LK *et al.* (2005) Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* **30,** 155–167.

Anonymous (2001) *Fukuoka Prefectural Red Data Book*. Fukuoka Prefecture, Fukuoka.

Barrow L, Parr CL, Kohen JL (2007) Habitat type influences fire resilience of ant assemblages in the semi-arid tropics of Northern Australia. *Journal of Arid Environments* **69,** 80–95.

Batáry P, Báldi A, Szél G, Podlussány A, Rozner I, Erdős S (2007) Responses of grassland specialist and generalist beetles to management and landscape complexity. *Diversity and Distributions* **13,** 196–202.

Castaño-Meneses G, Palacios-Vargas JG (2003) Effects of fire and agricultural practices on Neotropical ant communities. *Biodiversity and Conservation* **12,** 1913–1919.

Clarke KR, Gorley RN (2006) *PRIMER V6: User Manual/Tutorial*. PRIMER-E, Plymouth Marine Laboratory, Plymouth.

Clarke KR, Warwick RM (2001) *Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation*. PRIMER-E, Plymouth Marine Laboratory, Plymouth.

Dekoninck W, De Koninck H, Baugnee J-Y, Maelfait J-P (2007) Ant biodiversity conservation in Belgian calcareous grasslands: active management is vital. *Belgian Journal of Zoology* **137,** 137–146.

Farji-Brener AG, Corley JC, Bettinelli J (2002) The effects of fire on ant communities in north-western Patagonia: the importance of habitat structure and regional context. *Diversity and Distributions* **8,** 235–243.

Gunawardene NR, Majer JD (2005) The effect of fire on ant assemblages in the Gibson Desert Nature Reserve, Western Australia. *Journal of Arid Environments* **63,** 725–739.

Hellgren EC, Burrow AL, Kazmaier RT, Ruthven DC (2010) The effects of winter burning and grazing on resources and survival of Texas horned lizards in a Thornscrub Ecosystem. *Journal of Wildlife Management* **74,** 300–309.

Hölldobler B, Wilson EO (1990) *The Ants*. Harvard University Press, Cambridge, MA.

Japanese Ant Database Group (2008) *Japanese Ant Color Image Database*. CD-ROM. The Myrmecological Society of Japan, Tokyo.

Knop E, Herzog F, Schmid B (2010) Effect of connectivity between restoration meadows on invertebrates with contrasting dispersal abilities. *Restorian Ecology* **19,** 151–159.

Masuko K (1981) [Predatory behavior of some forest floor dwelling ants]. *The Nature and Insects* **16,** 19–25. (In Japanese.)

Ogata K (1986) [On the ant genus *Plagiolepis* collected from Tsushima Island and mainland Kyushu]. *Pulex* **74,** 355–356. (In Japanese.)

Parr CL, Andersen AN (2008) Fire resilience of ant assemblages in long-unburnt savanna of northern Australia. *Austral Ecology* **33,** 830–838.

Parr CL, Bond WJ, Robertson HG (2002) A preliminary study of the effect of fire on ants (Formicidae) in a South African savanna. *African Entomology* **10,** 101–111.

Parr CL, Robertson HG, Biggs HC, Chown SL (2004) Response of African savanna ants to long-term fire regimes. *Journal of Applied Ecology* **41,** 630–642.

Philpott SM, Perfecto I, Armbrecht I, Parr CL (2010) Ant diversity and function in disturbed and changing habitats. In: Lach L, Parr CL, Abbott KL (eds) *Ant Ecology*, pp 137–158. Oxford University Press, New York.

Ratchford JS, Wittman SE, Jules ES, Ellison AM, Gotelli NJ, Sanders NJ (2005) The effects of fire, local environment and time on ant assemblages in fens and forests. *Diversity and Distributions* **11,** 487–497.

Touyama Y (1996) Myrmecofaunal change under fire disturbance. *Edaphologia* **56,** 25–30.

Underwood EC, Quinn JF (2010) Response of ants and spiders to prescribed fire in oak woodlands of California. *Journal of Insect Conservation* **14,** 359–366.

van Swaay CAM (2002) The importance of calcareous grasslands for butterflies in Europe. *Biological Conservation* **104,** 315–318.

Vanderwoude C, Andersen AN, House APN (1997) Ant communities as bio-indicators in relation to fire management of spotted gum (*Eucalyptus maculata* Hook.) forests in south-east Queensland. *Memoirs of the Museum of Victoria* **56,** 671–675.

Vasconcelos HL, Pacheco R, Silva RC *et al.* (2009) Dynamics of the leaf-litter arthropod fauna following fire in a Neotropical woodland savanna. *PLoS ONE* **4,** e7762.

Verble RM, Yanoviak SP (2013) Short-term effects of prescribed burning on ant (Hymenoptera: Formicidae) assemblages in Ozark forests. *Annals of the Entomological Society of America* **106,** 198–203.

Wikars L-O, Schimmel J (2001) Immediate effects of fire-severity on soil invertebrates in cut and uncut pine forests. *Forest Ecology and Management* **141,** 189–200.

Woodcock BA, Bullock JM, Mortimer SR, Pywell RF (2012) Limiting factors in the restoration of UK grassland beetle assemblages. *Biological Conservation* **146,** 136–143.

York A (1994) The long-term effects of fire on forest ant communities: management implications for the conservation of biodiversity. *Memoirs of the Queensland Museum* **36,** 231–239.

York A (2000) Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests of southeastern Australia. *Austral Ecology* **25,** 83–98.