

Spatial Distribution of Two Bumble Bee Species in an Agro-Forestry Landscape

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Introduction

Bumble bees are important contributors to the pollination of temperate plants, including herbs, shrubs, and trees (Heinrich 1979; Yumoto 1987). They are important pollinators in both forests and open lands around artificially managed landscapes (Kato and Miura 1996; Walther-Hellwig and Frankl 2000; Osada et al. 2003; Yamazaki and Kato 2003), although little is known about their spatial distribution, i.e., habitat use, in these landscapes (Bhattacharya et al. 2003).

Forestry has changed natural forests into artificially structured forest landscapes. *Satoyama* forest is an east-Asian traditional forestry ecosystem in which many different human-managed landscape units, including both forest units (secondary forests, conifer plantations, and sometimes old-growth forests) and open-land units (cutover lands) are intermixed (Tabata 1997; Fukamachi et al. 2001). Different plant species compositions have been reported from different *satoyama* forest landscape units.

Two bumble bee species, the short-tongued *Bombus ardens ardens* Smith (*B. ardens*) and the long-tongued *B. diversus diversus* Smith (*B. diversus*), coexist and are dominant in *satoyama* forests (Kato and Miura 1996; Osada et al. 2003). *B. ardens* visits the simple-structured flowers of trees and shrubs (Yumoto 1987; Katayama 1996; Osada et al. 2003), whereas *B. diversus* generally prefers the complex floral structures of herbs, such as long corolla tubes (Washitani et al. 1994; Dohzono and Suzuki 2002). The local extinction of *B. diversus* because of habitat loss might reduce the sexual reproduction of plant species pollinated by this bee (Washitani et al. 1994). Eusocial *Bombus* species visit flowers of many plant taxa within a season. The diversity of woody species with shallow flowers is high in forests, whereas the diversity of herbaceous species with complex flowers is high both on the forest floor and in open lands. Thus, we predicted that within a given landscape, *B. ardens* would inhabit forests and *B. diversus* would inhabit both forests and open lands. Landscape units that lack flowering plant diversity, such as conifer plantation monocultures, would be avoided by both bumble bee species.

We used window traps to examine the spatial distribution (i.e., among several landscape units) of the two *Bombus* species in a *satoyama* forest. We also investigated the diversity of insect-pollinated plant species in five landscape units around the study area. We discuss the relationships between flower

preference and the spatial distribution of the two *Bombus* species. We also address the management of landscape units for the conservation of the bumble bee pollination system in *satoyama* in which the traditional forest management system has been changing.

Materials and methods

Bumble bee species

Bombus ardens is widely distributed in Japan and Korea, except for Hokkaido and the Ryukyu Islands. *B. diversus* is endemic to the Japanese islands. The average colony life span of the two species differs widely; *B. ardens* lives from early April to early July, whereas *B. diversus* lives from late April to mid-October (Katayama 1996; Nakamura and Toquenaga 2002).

Study area and landscape units

In 2003, we investigated five landscape units around Ogawa Forest Reserve (OFR; 36°56' N, 140°35' E; 610–660 m elevation), which is located in the southern part of the Abukuma Mountains near Kitaibaragi City, Ibaraki Prefecture, Japan. We investigated five landscape units in and around OFR; these consisted of four forest units and one open-land unit:

- Old-growth deciduous forest (>100 years old): The dominant tree species were *Quercus crispula*, *Q. serrata*, *Fagus crenata*, and *F. japonica* (all Fagaceae), *Carpinus* spp. (Carpinaceae), and *Acer* spp. (Aceraceae) (Nakashizuka and Matsumoto 2002);
- Remnant forest (>100 years old): This consists of a narrow belt (30–50 m wide) of old-growth forest preserved as a boundary or firebreak. The dominant species were similar to those of the old-growth forest;
- Secondary deciduous forest (11–24 years old): The four secondary forests that we investigated were used for the production of mushroom logs and wood chips (Suzuki 2002). The dominant species were *Q. crispula*, *Q. serrata*, and *Carpinus laxiflora* (Suzuki 2002);
- Conifer plantation (25–50 years old): Two Japanese cedar (*Cryptomeria japonica*) and two hinoki cypress (*Chamaecyparis obtusa*) stands were investigated;
- Cutover lands (secondary forest 5–7 years after clear-cutting): *Rubus* spp., *Aralia elata*, and *Stephanandra incisa* were abundant, with a vegetation height of 2–4 m.

Bumble bee collection

We used window traps to collect bumble bees. The bumbles tended to strike against plastic transparent panes (45 cm high x 36 cm wide) and drop into a tray filled with 2 L of water and a small amount of detergent (Inari 2003). At the OFR old-growth forest and remnant forest, we set up four trap sites ≥ 200 m apart. We also set up trap sites in four secondary stands, four plantations, and three cutover lands (two sites in one large stand and two sites in two small stands). In all, we set up 20 study sites within an area of approximately 90 ha.

At each forest site, we set three traps at different heights to cover different strata: forest floor, 0.5 m;

shrub layer, ~3 m; and under-canopy layer, 8–20 m above the ground, depending on forest height. Two traps per site were set at a height of ~1.5 m in the cutover lands. A total of 56 traps were used. All traps were set at least 15 m inside each landscape unit. The window traps were set once a month from April to October, and the bumble bees were collected 6 days later.

For statistical analyses, we pooled data from the cutover lands and the pasture because these landscape units had similar floras (Fig. 3). We compared the total numbers of *B. ardens* and *B. diversus* individuals collected among the landscape units using a chi-square test. The expected number of individuals was calculated assuming a uniform distribution among the traps (we considered the number of traps per landscape unit). The distribution pattern between castes (queens and workers) was analyzed for *B. diversus*. We also used the chi-square test to examine the vertical distribution of the two species among forest units (primary, remnant, secondary, and plantation forests).

Diversity of insect-pollinated plant species in the landscape units

We investigated the insect-pollinated (entomophilus) plant diversity in the old-growth OFR stand, the remnant forest, two secondary forests (12 and 24 years old), two conifer plantations (both 32 years old), cutover lands (5 and 6 years old), and two pastures near OFR. We delineated one 10 x 100 m plot in each stand, except in one secondary forest in which the plot was 10 x 90 m. We inventoried all tree stems ≥ 5 cm in diameter at breast height and identified all shrubs ≥ 200 cm in height in each 5 x 5 m subplot. We also laid out 40 1 x 1 m quadrats inside each plot (36 quadrats in the young secondary forest plot) and inventoried all herbaceous species within each quadrat. We counted the number of entomophilus tree, shrub, and herb species for each plot and further subdivided herbs into early bloomers (April–June) and late bloomers (July–October). The number of species in each category was compared among the landscape units.

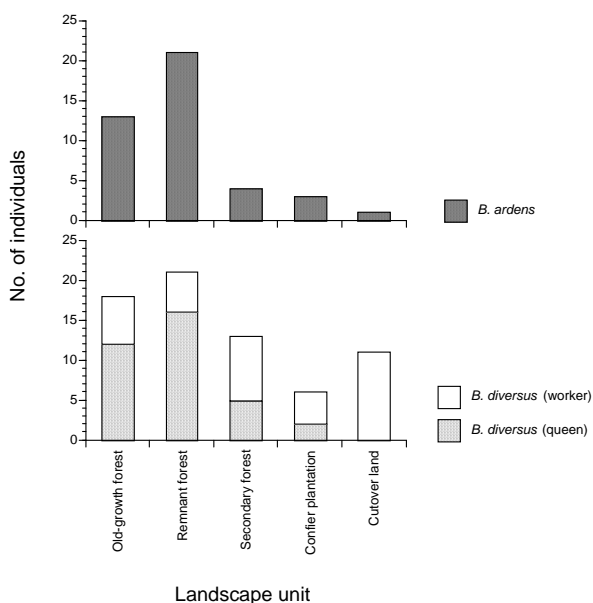


Fig. 1 Numbers of bumblebees collected in each landscape unit. *B. diversus* individuals were divided into two groups: queens (shaded bars) and workers (open bars).

Results

Bumble bee collection using window traps

The total trappings for the year comprised 16 queens and 26 workers of *B. ardens*, 37 queens, 34 workers, and three males of *B. diversus*, and two queens and three workers of *B. hypocrita*. *B. ardens* queens were collected from April to June and workers from May to August. *B. diversus* queens were collected from April to June, whereas workers were collected from June to October (Fig. 1).

The number of *B. ardens* collected was significantly greater in old-growth and remnant forests than in other landscape units ($\chi^2 = 28.7$, d.f. = 4, $P < 0.001$; Fig. 1), the distribution pattern was not different between queens and workers. However, there was no significant difference in the total number of *B. diversus* collected among landscape units ($\chi^2 = 8.9$, d.f. = 5, $P > 0.05$; Fig. 1). *B. diversus* queens were caught more frequently in old-growth and remnant forests than in other units, but more workers were collected in cutover lands than in forest units (queens, $\chi^2 = 22.2$, d.f. = 5, $P < 0.001$; workers, $\chi^2 = 10.3$, d.f. = 5, $P < 0.05$; Fig. 1).

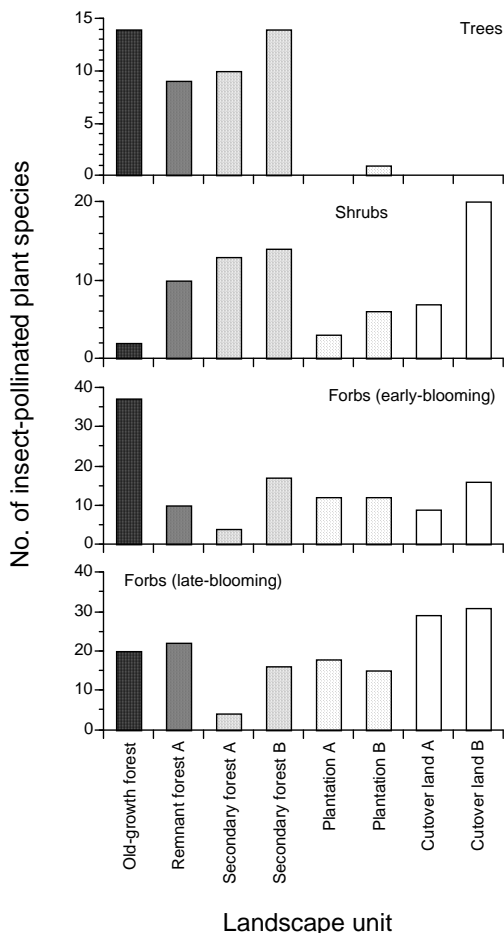


Fig. 2 Number of insect-pollinated plant species in five landscape types. Bumble bees were also trapped in the old-growth forest, remnant forest, secondary forest B, and cutover land A.

Diversity of insect-pollinated plant species in the landscape units

The diversity of entomophilus trees was high in old-growth, remnant, and secondary forests (Fig. 2). We

rarely found entomophilus tree species in the canopy or subcanopy strata of plantations. Entomophilus shrub diversity was high in one cutover area and in secondary forests, but was relatively low in old-growth and remnant forests and plantations (Fig. 2). Among all the landscape units, the number of early-blooming herbs was largest in the old-growth forest (Fig. 2). Late-blooming herbs were more abundant in open-land units than in forest units (Fig. 2).

Discussion

Around OFR, most *B. ardens* queens and workers were caught in old-growth and remnant forests. We rarely collected *B. ardens* in secondary forests, conifer plantations, or cutover lands. We predicted that *B. ardens* inhabits forest vegetation in which woody species diversity is high. However, the diversity of woody species, i.e., trees and shrubs, was also high in secondary forests and cutover lands, respectively. Why was *B. ardens* not caught more frequently in these landscape units? The population dynamics of *B. ardens* are strongly affected by the abundance of tree flowers (Inari 2003). However, many trees in secondary forests and cutover lands were not large enough to flower. *B. ardens* may respond not only to woody diversity, but also to the abundance of flowers in trees.

As predicted, *B. diversus* was distributed in both forest and open-land units. Interestingly, we found a large difference in spatial distribution patterns between castes. Like *B. ardens* individuals, *B. diversus* queens were concentrated in old-growth and remnant forests, whereas the workers were more often trapped in open-land units. The rich diversity of early-blooming herbs on the floor of old-growth forests may attract the queens. However, why *B. diversus* queens were rarely caught in open-land units, where entomophilus herbaceous flower diversity is as high as that in old-growth, remnant, and secondary forests, is difficult to explain. Flowering individuals of spring ephemerals (e.g., *Erythronium japonicum*, *Corydalis lineariloba*, and *Viola* spp.) and shrubs (e.g., *Rhododendron obtusum* var. *kaempferi* and *Kerria japonica*) visited by *B. diversus* were not abundant in open-land units (A. Ushimaru personal observation). This scarcity of spring ephemeral flowers may be one reason that queens infrequently visit open-land units in the spring. In contrast, late-blooming herbs were found more frequently in open-land units than in forest units, suggesting that *B. diversus* queens forage on the flowers of forest herbs and shrubs until early summer, and workers spread into open lands to seek summer- and autumn-blooming herbs. Thus, the seasonal shift in the distribution of floral resources within the *satoyama* landscape results in inter-caste differences in spatial distribution.

We seldom collected bumble bees of either species in conifer plantations. During and after World War II, old-growth forests were widely replaced by conifer plantations (Nagaike et al. 2005). However, conifer plantations have not been extensively managed because of high costs. Infrequent logging and thinning has created a very dark forest floor, with consequent low understory plant diversity (Nagaike et al. 2005). Although forest-floor plants were not necessarily rare in plantations, we found very few flowering individuals because of low light conditions (A. Ushimaru, personal observation). This lack of flowers may account for the rarity of bumble bees.

Our results showed that old-growth stands are important habitat for both bumble bee species and for early-blooming insect-pollinated plants. In contrast, open lands play a significant role in the mutualism between *B. diversus* and late-blooming herbs. However, during the past decades, changes in official forest

management policy have resulted in a rapid decrease in old-growth forests and cutover lands and an increase in conifer plantation monocultures (Fukamachi et al. 2001; Kato 2001; Inoue 2003; Nagaike et al. 2005). These landscape changes may have decreased the amount of habitat available for many plants and insects, including pollinators such as bumble bees (Tabata 1997; Kato 2001; Inoue 2003). The conservation of old-growth stands and the creation of new cutover lands by periodic logging are encouraged to conserve bumble bee–plant interactions.

Acknowledgements

We thank Naoki Inari for his suggestions on collecting bumble bees using window traps; Ryunosuke Tateno, Michiko Nakagawa, and Yuji Isagi for field assistance; and Takenari Inoue for valuable discussions on landscape use by bumble bees.

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