Diversity and structure of bee pollination system in different satoyama habitats

学 位 論 文 題 名

Diversity and structure of bee pollination system in different satoyama habitats

異なる里山環境におけるハナバチ類による送粉系の多様性と構造

学 籍 番 号　1123032334

氏 名　Windra Priawandiputra

(ウィンドラ プリアワンヂプトラ)

学位論文要旨

Abstract

This thesis, composed of two parts, dealt with the pollination system in Satoyama, a socio-ecological production landscape in Japan. Part 1 compared flowering plant-bee linkages between restored paddies in small valleys surrounded with forests and grasslands outside of forests in Kanazawa. All bees, which were observed to visit flowers, were collected from March-November, 2012 using sweeping net and abundance and flowering of plants were recorded. Results are: (1) totally 165 (133 native and 32 alien) plant and 61 bee species (5 families) were recorded, (2) species compositions of plants and bees largely overlapped in both habitats, (3) dominant plant and bee species and plant-bee linkages were different between habitats, reflecting the alien plants' dominance in grassland, (4) multivariate analyses showed the separation of species composition of plants and bees between both habitats. Part 2 reported abundance and diversity of bees collected monthly from May-October in 2009 and 2010 using window traps at canopy and ground levels from four types of Satoyama forests, predominated with deciduous and evergreen oaks, pine and sugi in Noto Peninsula. Results are: (1) totally 426 bee individuals in 25 species, 5 families were collected, (2) pine forests showed the highest number of individuals and species.

Satoyama is a socio-ecological production landscape (SEPL) managed by human activities such as agriculture and forestry in rural Japan. Biodiversity in well-managed satoyama is rich and plays important roles in providing a set of ecosystem services for human well being. Recently, biodiversity in satoyama has been deteriorating by under management of satoyama due to lowering and ageing human population. This thesis composed of two parts, dealt with the pollination system, which is one of most important biodiversity functions, in different satoyama conditions in Kanazawa and Noto Peninsula, Ishikawa Prefecture, Japan.

Part 1 compared the flowering plant-bee linkages between restored terraced paddies in small valleys surrounded with forests and the grasslands outside of forests in Kanazawa. All bees (Hymenoptera; Apiformes), which were observed to visit flowering plants, were collected monthly from March to November, 2012 using sweeping net. For the plants, abundance and flowering records were kept. Results indicated that (1) a total of 165 (133 native and 32 alien) plant species and 61 bee species (5 families) were recorded, (2) species make-ups of the flowering plants and bees largely overlapped in both habitats and no significant difference in the number of species and total abundance of the bees was found between both habitats, (3) dominant flowering plant species, bee species and plant-bee linkages were distinctly different between the two habitats, reflecting the alien plants' dominance in grasslands, (4) multivariate analyses on the species composition of flowering plants and bees, respectively, separated both habitats.

(1) Flowering plant assemblages

a. Species richness

A total of 165 flowering plant species were recorded in the flowering plant survey, accounted for 133 native species and 32 alien species. In each sampling site, the number

of native species (more than 55 species) was higher than that of alien species (less than 20 species) in each sampling site. No significant difference (P>0.05) was found in number of species for all, native and alien species between open grassland and small valley sites.

b. Occurrence rate

Occurrence rate is defined as number of sampling unit, where the plant species were observed divided by total number of the units. The rate for all plants was 969.4, and that for native and alien species were 722.7 and 246.6, respectively. No significant difference (P>0.05) was found in occurrence rate for all, native and alien flowering plant species between open grassland and small valley sites

c. Species ranking

Abundance ranking of the plant species was determined by the occurrence rate of the plants. *Polygonum thunbergii* (code no: FP128), *Impatiens platypetalla* (FP42) *Erigeron annuus* (FP21) were the species with rate > 40. Top rank species was different between grassland and small valley sites. The first ranking of flowering plant species in all open grassland sites was *E. annuus* (FP21). The first and second ranked were *P. thunbergii* (FP128) and *I. platypetalla* (FP42) in two sites of small valleys, while *V. persica* (FP155) was the first ranked in other site.

d. Species diversity and evenness

Shannon-Wiener diversity index was used to calculate species diversity. For each sampling site, the value for grassland and small valley sites was 4.08 and 4.08 for all species, and 4.01 and 3.86 for native species, and 2.37 and 2.44 for alien species, respectively. For each site, the value ranged from 3.64 to 4.08, 3.49 to 4.04 and 1.87 to

2.20 for all species, native and alien species, respectively.

Pielou's evenness index was used to calculate species evenness. For each sampling site, The value for the grassland and small valley sites was 0.47 and 0.44 for all species, and 0.56 and 0.42 for native species, and 0.40 and 0.60 for alien species, respectively. For each site, the value ranged from 0.46 to 0.57, 0.44 to 0.67 and 0.48 to 0.65 for all species, native and alien species, respectively

e. Similarity of species composition

Multivariate analysis using ordination plot (Principal Component Analysis) was used to analyze flowering plant species distribution among sampling sites. Based on Principal Component Analysis (PCA), the two sites of small valley were separately plotted with other site of small valley and the three sites of open grassland. The plotted was formed according to the distribution of alien and native species where the grassland sites dominated by alien species.

(2) Bee assemblages

a. Species richness

A total of 61 bee species from 6 families was collected where only 1 bee species (*Apis mellifera*) were recognized as introduced species. Number of bee species that visited native plant species (53 species) was higher than alien plant species (46 species). No significant difference ($P>0.05$) was found in number of bee species for all, native and alien flowering plant species between open grassland and small valley sites

b. Abundance

Overall, a total number of 1870 bee individuals were collected. Only 5 species were collected more than 100 individuals while 29 species were caught less than 5

individuals. The number of bee individuals collected in open grassland sites ranged from 220 to 399, 114 to 188 and 106 to 211 for all, native and alien plant species, respectively. Meanwhile, the number of bee individuals collected in small valley sites ranged from 252 to 377, 160 to 306 and 19 to 217 for all, native and alien plant species, respectively. No significant difference ($P>0.05$) was found in bee abundance for all, native and alien flowering plant species between open grassland and small valley sites.

c. Species ranking

Abundance ranking of the bee species was determined by the total number of bee individuals. In total sampling sites, *Andrena kaguya* (249 individuals) was the most abundant species in all sampling sites, followed by *Ceratina japonica* (214 individuals), and *Lasioglossum ohei* (167). A total of 19 species was collected singleton and doubleton in all sampling sites. Dominant bee species was collected differently in number of individuals among sampling sites. *C. japonica* (code no: B19) was the most abundant species in two sites of open grassland while *Halictus aerarius* (B39) was the most abundant in another site. *A. kaguya* (B5) were the most abundant bees in two sites of small valleys while *L. ohei* (B46) was the most abundant species in another site. In open grassland sites, *Andrena knuthi* (B06), *Colletes perforator* (B35) and *H. aerarius* (B39) were abundantly collected from native plant species while *H. aerarius* (B39) and *C. japonica* (B19) were abundant to visit alien plant species. In small valley sites, *L. ohei* (B46) and *A. kaguya* (B05) were abundantly collected from native plant species while *A. mellifera* (B10), *Xylocopa appendiculata* (B33) and *C. japonica* (B19) were mostly collected from alien plant species.

d. Species diversity and evenness

Shannon-Wiener diversity index was used to calculate species diversity. For each

sampling site, the ranged value of diversity index for bees that visited all, native and alien plant species was from 2.38 to 3.05, 2.24 to 3.03 and 2.08 to 2.89, respectively.

Pielou's evenness index was used to calculate species evenness. For each sampling site, the ranged value of evenness index for bees that visited all, native and alien plant species in each site was from 0.33 to 0.58, 0.39 to 0.69 and 0.37 to 0.73, respectively.

e. Species composition similarity

Multivariate analysis using ordination plot (Principal Component Analysis) was used to analyze bee species distribution among sampling sites. Based on Principal Component Analysis (PCA), three sites of open grassland are clearly separated from those of small valleys. Each site of small valley was distinctly formed each other.

(3) Flowering plant – bee linkages

a. Number of links

From 101 flowering plant species and 61 bee species, a total of 459 linkages was formed in all sampling sites. The linkages of native flowering plant species (311) were higher than alien flowering plant species (148). In each sampling site, the linkages ranged for all, native and alien plant species were from 92 to 142, 49 to 90 and 12 to 61, respectively.

b. Link ranking

Overall, *P. centigrana* - *A. kaguya* link (code no: link 38) was the highest number of interaction observed in all sampling sites combined. In two small valley sites, the most dominant link was *P. centigrana* - *L. ohei* link (41 times visit, link 343) and *P. centigrana* - *A. kaguya* link (48, link 38). Those links described dominant native flowering plant - bee links. Meanwhile other sites (all open grasslands sites and one site

of small valley) have more than 15 dominant alien flowering plant - bee link. The most dominant link in all open grassland sites and one site of small valley was between alien flowering plant - bee link, i.e. *E. annuus* - *H. aerarius* link (36 times visit, link 235), *S. altisima* - *A. cerana* link (22, link 72), *E. annuss* - *C. japonica* link (12, link 172), and *E. philadelpictus* - *C. japonica* link (42, link 173).

c. Linkage diversity and evenness

Shannon-Wiener diversity index can used to calculate linkages diversity where in this case the link was described as species. The linkage diversity index, which has value more than 4 was found in two site of grassland and one site of small valley. For each sampling site, the ranged value of diversity index for all, native and alien plant linkages was from 2.83 to 4.46, 3.38 to 4.20 and 2.23 to 3.60, respectively.

Pielou's evenness index can used to calculate linkages evenness where in this case the link was also described as species. For each sampling site, the ranged value of evenness index for all, native and alien plant linkages was from 0.45 to 0.76, 0.44 to 0.77 and 0.50 to 0.77, respectively.

d. Linkages similarity

Multivariate analysis using ordination plot (Correspondence Analysis) was used to analyze linkages distribution among sampling sites. CA ordination revealed a clear separation of linkages between two groups: 1) two small valley sites and 2) three open grassland sites and one small valley site along second axes. The alien flowering plant - bee links were closely formed in second groups while the native flowering plant species - bee links were closely formed in first group.

e. Linkages structure

The structure of linkages usually represented by connectance, level of specialization (H_2) and nestedness. Connectance describes possible link in linkages system and usually represents how generalize the interaction in system. For each sampling site, the ranged value of connectance for all, native and alien plant linkages was from 0.07 to 0.109, 0.077 to 0.119 and 0.19 to 0.293, respectively. The level of specialization (H_2) represents the ratio of specialized species availability in the pollination linkages. For each sampling site, the ranged value of the level of specialization (H_2) for all, native and alien plant linkages was from 0.35 to 0.55, 0.44 to 0.63 and 0.31 to 0.78, respectively. Nestedness is used to calculate perfect interaction, which is the subset between generalist with generalist and generalist with specialist, but absent of specialist and specialist. For each sampling site, the ranged value of nestedness for all, native and alien plant linkages was from 5.79 to 11.97, 7.56 to 16.7 and 16.14 to 43.48, respectively.

The differences of habitat condition among sampling sites could be presumably considered as the main factor effect to the vary flowering plant and bee assemblages. As a result of vary habitat condition in each sampling site, the existence of alien flowering plants appeared to strongly affect the floral preferences of bee and lead to the replacement of dominant links. Mostly alien plant species confirmed as generalized species because it presumably offers good and high resources with high attractiveness. Although alien species usually associated to threat biodiversity, the negative effect of this condition in this study on linkages is not clear yet. However, alien and native plant species were preserved for bee food resources in these non-forested habitats.

Part 2 reported the abundance and diversity of bees collected monthly from May to October in 2009 and 2010 using window traps at canopy and ground levels from four

types of satoyama forests, which were predominated with deciduous oak, evergreen oak and red pine and sugi plantations,in Noto Peninsula. Results showed that (1) a total of 426 individuals of bees in 25 species, 5 families, were collected, (2) the highest number of individuals and species were recorded in red pine forests, where no significant difference was found between managed and unmanaged pine forests, and (3) number of bees collected were generally larger at canopy than at ground level. These results were compared, first, with those of three preceding studies of bee assemblages (including Part 1 of this thesis), conducted in various Satoyama habitats of Noto Peninsula and Kanazawa and second, with beetle assemblages, collected in the same traps and reported in the previous article.

(1) Species richness

The number of species observed for all forests combined and that for pine forests were the same (25 species), followed by deciduous (12), evergreen (9) and sugi forests (4). The Jackknife1 estimates were 31.4 (all forests combined), 32.3 (pine forests), 18.4 (deciduous forests), 12.7 (evergreen forests) and 5.8 (sugi forests). Sampling ratios, calculated as a/b x 100, were 79.6, 77.3, 65.2, 70.8 and 68.9 for these categories. In pine forests, the sampling ratios in managed and unmanaged types were 71 and 75.7, respectively.

(2) Abundance

A total of 426 bee individuals (9.7 individuals per trap) were collected from all forests. Almost 70% of individuals of all samples were collected from pine forests (297 individuals and 12.4 individuals/trap). In pine forests, the number of bees collected at canopy level (172 and 14.3) was larger than at ground level (125 and 10.4). The number of bees collected from managed pine forests (155 and 12.9) was higher than that from

unmanaged ones (142 and 11.8). The numbers of bees collected per trap in other forest types were smaller than in pine forest, namely, 11.2 at canopy and 5.5 at ground levels in deciduous forests, 8.7 and 5 in evergreen, and 2 and 0 in sugi.

(3) Abundance at species level

The four most abundant species collected were *Bombus diversus* (53.28%), *B. ignitus* (7.98), *Lasioglossum japonicum* (6.8) and *Andrena kaguya* (5.63) (the percentages in parentheses are the proportions of the total number of individuals in the sample). *B. diversus* was also the most abundant species in all forest types, i.e. in pine (162 individuals and 6.75 per trap), deciduous (34 and 4.25), evergreen (28 and 3.5) and sugi forests (3 and 0.75). In total, the abundance of *B. diversus* was also higher at canopy than at ground level (94 and 68 individuals, respectively).

(4) Species composition similarity

The inclusion relation of species richness was established among the four forest types. A number of bee species in the three forest types (12 species in deciduous, 9 in evergreen and 4 in sugi forest) were also identified in pine forests. The NMDS ordination showed overlapping of bee assemblages among the four forest types. No significant difference was found in bee species compositions among the four forest types (ANOSIM, r=0.1, P=0.07).

Mostly bee species that collected in satoyama forest in Noto Peninsula were also found in satoyama non-forested habitats in Noto Peninsula and Kanazawa. It is reflected that most bee species have to utilize not only forests but also non-forested habitats of satoyama. Almost all comparisons between bees and beetles were showing different pattern except for comparison between managed and unmanaged pine forests. No

significant difference was found in abundance and species richness in both bee and beetle assemblages between managed and unmanaged pine forests because sites of these two types were located nearby, within easy reach considering the flight ability of bees and beetles.

Results from part 1 and part 2 show that the satoyama landscape systems can play crucial role in the conservation of biodiversity and ecosystem services, whereas the importance of connectivity between non-forested and forests habitat, which are intermingled as a mosaic satoyama, could support resources for bee pollination system. The present study emphasizes that conservation planning of the management in satoyama habitat carefully prepared because the effect is very fundamental for flowering plant and bee existence on a landscape scale. I hope this study can raise awareness of the importance of satoyama landscape conservation in preserving the diversity of flowering plants and bees in particular and a whole biodiversity in general in Kanazawa and Noto Peninsula area.

平成　26 年 7 月 29 日

学位論文審査報告書（甲）

1．学位論文題目（外国語の場合は和訳を付けること。）

Diversity and structure of bee pollination system in different satoyama habitats

（異なる里山環境におけるハナバチ類による送粉系の多様性と構造）

2．論文提出者　(1) 所　　属　生命科学専攻

(2) 氏（ふり）　名（がな）　Windra Priawandiputra（うぃんどら・ぷりあわんぢぷとら）

3．審査結果の要旨（600～650 字）

（第１部）ハナバチ送粉系を明らかにするために、金沢大学角間キャンパス内の里山ゾーンとその周辺に調査地を設置し、道沿いの草原と森林に囲まれた棚田跡において各 3 か所、2012 年 3～11 月に調査を行った。送粉系を群集レベルで定量把握するために，一定の調査ルート上で開花した全植物種と訪花した全ハナバチ種を対象として，種類相，数量，開花植物と訪花ハチ類のリンクを調査した。その結果、(1) 開花植物は合計 165 種（55 科、133 在来種と 32 外来種）、ハチ類は 61 種（5 科、外来種はセイヨウミツバチ１種）を記録した、(2) 植物とハチ類には、植物 101 種とハチ類 61 種が関与する合計 459 リンクが記録され、(3) 調査地毎の植物とハチ類の種類相、リンクを多変量解析したところ、草原と棚田の２グループに分かれた（ただしオープンな棚田は草原と同様に外来植物種の出現頻度が高く、同じグループに属した）、(4) 優占ハナバチ類は選好性が広く、在来種、外来種の区別なく、場所毎に出願頻度が高い開花植物とリンクを形成した。

（第２部）能登半島の里山のアカマツ林、コナラ林、常緑林、スギ造林地におけるハナバチ類の多様性を、生息環境（主要樹種の違い、林内の高度）、管理活動の影響に注目して IBOY 式の衝突板つき水盤トラップを使用して、2009 と 2010 年 5 - 10 月に月１回調査し、種組成が森林タイプごとに区別できることを明らかにした。

本研究は、里山のハナバチ類の送粉系に関する重要な新知見を多数含んでおり、本委員会は博士（学術）に値すると判断した。

4．審査結果　(1) 判　　定（いずれかに○印）（合　格）・　不合格

(2) 授与学位　博　士（　学術　）