

Change in pollination system during restoration of satoyama terraced paddies

著者	Putra Ramadhani Eka
著者別名	プトラ ラマダニ, エカ
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氏名	PUTRA RAMADHANI EKA
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論文審査委員(主査)	中村 浩二(環日本海域環境研究センター・教授)
論文審査委員(副査)	岡澤 孝雄(留学生センター・教授), 川幡 佳一(人間社会研究域・教授), 木下 栄一郎(環日本海域環境研究センター・准教授), 都野 展子(理工研究域・准教授)

学位論文要旨

Changes in biodiversity of plants, insects, and their relationships due to the restoration practices in an abandoned satoyama forest was studied from May 2003 to November 2006 in Kanazawa University's Kakuma campus, Kanazawa, Japan. This study was carried out by regular census along the census routes set in Kitadan valley, a small valley located in Kakuma forest. This study focused on the recording and monitoring the changes on (1) flowering plant assemblages, (2) flower-visiting insect assemblages, (3) the analysis of links between flowering plants and flower-visiting insects, with special reference on wild bee assemblages. The variables recorded were changes in number of species, species composition, abundance, species turnover rate, species diversity, species evenness, and seasonal fluctuations in both flowering plants, flower-visiting insects and their links. A total of 120 flowering plant species, except Monocotyledoneae, belongs to 48 families were recorded during the study period and were categorized into six life forms. On the other hand, the total number of collected insects was 3407 individuals, which were identified into 258 species from 88 families and five orders. Of the five orders, Diptera was the most diverse and abundant (104 species, 1824 individuals), followed by Hymenoptera (90, 1401), Coleoptera (30, 91), Lepidoptera (24, 62), and Heteroptera (10, 29). In total, 86 flowering plant species and 258 flower-visiting insects formed 1183 interaction links (5.17 % of possible links), in which Diptera and Hymenoptera accounted for more than 80%, in Kitadan valley from 2003 to 2006.

(1) Flowering plant assemblages

a. Species composition

In this study, 122 plant species of 48 families flowered at Kitadan valley. Of all 48

families, Asteraceae was the most diverse family with 21 species, followed by Fabaceae, Labiatae, and Polygonaceae (all with 7 species). Total number of flowers produced by all species combined was 1,570,925, in which Polygonaceae was the highest in number of flowers (995,042 flowers, 63.34% of total). These species were categorized into 6 life forms with perennial herb as the most diverse life forms (61 species, 29 families), followed by annual herb (27, 15), shrub (13, 10), trees (8, 6), vine (7, 6), and biannual herb (6, 4).

b. Abundance

Both annual herbs and biannual herbs had highest average abundance levels from 2003 to 2006 (20.90% and 20.10%, respectively), followed by perennial herbs (17.10%), vines (14.60%), shrubs (8.70%), and trees (4.90%).

b. Species turnover rate

During the restoration, total number of flowered plant species changed from 64 species of 34 families in 2003 to 105 (44), 95 (43), and 84 (40) from 2004 to 2006, respectively. Among them, 48 species flowered all years, 32 in three years, 19 in two years, and 21 were flowering only in one particular year. Trees had the highest average species turnover rate (0.57; 0.5, 0.6, 0.6 from 2004 to 2006, respectively), followed by vines (0.22; 0.12, 0.2, 0.33), biannual herbs (0.2; 0.3, 0.15, 0.15), perennial herbs (0.2; 0.12, 0.14, 0.34), shrubs (0.16; 0.28, 0.07, 0.12), and annual herbs (0.14; 0.19, 0.09, 0.15).

c. Species diversity

Species diversity for all flowering plant species combined were relatively unchanged during the study years (0.97, 0.98, 0.98, and 0.97 from 2003 to 2006 respectively). However, each life form showed large changes in species diversity. Perennial herbs had highest average species diversity (0.95; 0.94, 0.96, 0.95, and 0.95 from 2003 to 2006, respectively), followed by annual herbs (0.90; 0.89, 0.91, 0.91, and 0.9), shrubs (0.82; 0.81, 0.83, 0.79, and 0.82), trees (0.81; 0.75, 0.85, 0.78, and 0.81), vines (0.70; 0.67, 0.73, 0.72, and 0.67), and biannual herbs (0.50; 0.70, 0.63, 0.16, and 0.50).

d. Species evenness

Average species evenness for all flowering plant species combined were quite low (0.45; 0.51, 0.45, 0.40, and 0.43 from 2003 to 2006, respectively). Among all identified life forms, trees had the highest average species evenness (0.76; 0.82, 0.68, 0.73, 0.82), followed by vines (0.69; 0.69, 0.52, 0.57, 0.97), biannual herbs (0.56; 0.62, 0.54, 0.60,

0.48), shrubs (0.54; 0.78, 0.45, 0.40, 0.52), annual herbs (0.51; 0.64, 0.53, 0.43, 0.45), and perennial herbs (0.45; 0.49, 0.46, 0.42, 0.44).

(2) Flowering-visiting insect assemblages

a. Species composition

During the study, 258 flower-visiting insect species from 88 families and five orders were collected. Of all five orders, Diptera was the most diverse order (104 species, 23 families), followed by Hymenoptera (90, 18), Coleoptera (30, 15), Lepidoptera (24, 12), and Heteroptera was the least diverse insect order (10 species, 9 families).

b. Abundance

During the study, total number of collected insects was 3407 (1011, 857, 791, 748 from 2003 to 2006, respectively). Diptera was the most abundance order (538, 499, 400, and 387 from 2003 to 2006, respectively), followed by Hymenoptera (403, 317, 343, 338), Coleoptera (31, 18, 33, 9), Lepidoptera (20, 18, 14, 10), and Heteroptera (19, 5, 1, 4).

c. Species turnover rate

During the restoration, total number of insect species changed from 140 species (55 families) in 2003 to 144 (49), 112 (34), and 84 (35) from 2004 to 2006, respectively. Among them, around 35 species were collected in all years, 23 species in three years, 57 species in two years, and 143 species collected only in one particular year. Heteroptera had the highest average species turnover (0.93; 0.78, 1, 1, from 2004 to 2006 respectively), followed by Coleoptera (0.76; 0.77, 0.65, 0.86), Lepidoptera (0.71; 0.62, 0.81, 0.71), Hymenoptera (0.49; 0.56, 0.41, 0.50), and Diptera (0.46; 0.44, 0.46, 0.47).

c. Species diversity

Species diversity of total flowering plant species combined were relatively unchanged (0.97, 0.97, 0.96, and 0.90 from 2003 to 2006 respectively). At order level, Diptera had highest average species diversity and relatively the values were relatively unchanged (0.92; 0.93, 0.93, 0.90, and 0.93 from 2003 to 2006, respectively), followed by Lepidoptera (0.90; 0.89, 0.94, 0.95, and 0.81), Hymenoptera (0.84; 0.90, 0.95, 0.90, and 0.62), Coleoptera (0.84; 0.92, 0.85, 0.78, and 0.70), and Heteroptera (0.77; 0.77, data on 2002 to 2006 were not available due to lack of second species).

d. Species evenness

Average species evenness for all flowering plant species combined were very low (0.19; 0.20, 0.22, 0.20, and 0.12 from 2003 to 2006, respectively), indicating that a few species highly dominated with large numbers of singleton species in the assemblage. Among all insect orders, Lepidoptera had the highest average species evenness (0.72; 0.71, 0.65, 0.85, 0.68), followed by Coleoptera (0.63; 0.77, 0.69, 0.42, 0.65), Heteroptera (0.46; 0.46, data on 2002 to 2006 unable to count due to lack of second species), Diptera (0.26; 0.26, 0.22, 0.24, 0.30), and Hymenoptera (0.21; 0.22, 0.35, 0.20, 0.10).

(3) Flowering plant – insect relationships

a. Flowering plants and its insect visitors

In total, 86 flowering plant species were visited by insect in Kitadan Valley from 2003 to 2006. The number of visited plant species increased gradually from 2003 to 2005 and decreased in 2006 (44, 60, 62, and 48 from 2003 to 2006, respectively). Most flowering plant species were visited for four years (26 species, 30.23%), followed by for only one year (24 species, 27.91%), two years (22 species, 25.58%) and three years (14 species, 16.28%).

Proportion of visited flowering plant species by each insect order changed from 2003 to 2006. Both Diptera and Hymenoptera accounted for more than 70% of total visited flowering plant species (73%, 77%, 83%, and 86% from 2003 to 2006 respectively). Even though Heteroptera had the lowest number in individuals and species, it visited more diverse flower than Lepidoptera and Coleoptera in 2003 and 2006.

b. Number of links between flowering plants and flower visiting insects

In total, 86 flowering plant species and 258 flower-visiting insects formed 1183 interaction links (5.17 % of possible link) in Kitadan Valley from 2003 to 2006. Total number of the interactions gradually decreased from 346 in 2003 into 343, 274, and 220 in 2004-2006, respectively. Of all 1183 links recorded, both Diptera and Hymenoptera accounted for more than 80% of total interaction links and the number increased gradually from 2003 to 2006 (86%, 89%, 90%, and 94% from 2003 to 2006, respectively) (Fig. 202).

The most important plant families for flower-visiting insects were Polygonaceae, Rosaceae, Asteraceae, Cruciferae, and Amaranthaceae, which accounted for 69.68% of all flower visiting insects collected in Kitadan Valley. Among all flowering plant species, *Polygonum thunbergii*, a common herb growing in wetland and the surrounding farming areas was considered as one of the “keystone species” for flower-visiting insects in Kitadan Valley. Other important plant species were *Potentilla centigrana*, a light-loving

herb that became abundant in number and flower production during the restoration and *Erigeron philadelphicus*, a common weed in dry area. Among flower-visiting insect species, *Paragus haemorrhous* (Syrphidae, Diptera), *Lasioglossum ohei* and *L. japonicum* (both Halictidae, Hymenoptera) were the most important for flowering plants.

(4) Special reference to wild bees

a. Wild bees abundance and species richness

A total of 1322 foraging bees, belonging to 63 species in 24 genera of 9 families were collected. Halictidae was the most dominant wild bee family in Kitadan valley (646 individuals, 14 species), followed by Apidae (307, 8), Anthophoridae (177, 12), Andrenidae (67, 8), Megachilidae (48, 4), Scollidae (31, 5), Eumenidae (28, 5), Vespidae (12, 2), and Colletidae (6, 4).

b. Total species diversity and assemblage changes

Total richness increased from 35 species in 2003 to 48, 45, and 23 species in 2004 to 2006, respectively. Simpson diversity index in Kitadan valley was high from 2003 to 2005 (0.89, 0.94, 0.89, respectively). Restoration activities in 2006 lowered, which effected negatively on the wild bee diversity as the value decreased into 0.596 from average value of 0.906 in three previous years. Similarly, the species evenness also showed the same pattern with the value of 0.29, 0.37, 0.21, and 0.12 from 2003 to 2006, respectively.

c. Insect visitation to flowering plant species

Total number of visited flowering plant species was not highly different among the study years. The number changed from 31 species (48.44 % of total plant that produced flowers) in 2003 to 42 (40%), 45 (47.37%), and 38 (45.24%) from 2004 to 2006, respectively. On average, number of visited plant species for each wild bee species were rather stable, ranged from 3 to 4 flower species, from 2003 to 2006. Of 34 flowering plant families that were visited by wild bees, four flowering plant families that received wild bee visitation more than average in all study years (2.94 visits per flowering plant family). The four families included Rosaceae (average from all year 26.47%), Polygonaceae (16.63%), Asteraceae (13.50%), and Balsaminaceae (8.87%).

学位論文審査結果の要旨

本研究では、金沢大学角間キャンパス内の里山ゾーンにある棚田跡（約1.5ha、約20年間の放置後、2002年5月から現在まで棚田復元作業が進行中）において、4年間（2003～2006年、3～11月まで週1～2回）の送粉系の変化を記録した。調査では、全長約250mのルートを設定し、その両側1mに出現する植物種（単子葉植物をのぞく）の開花時期、開花数を記録するとともに、訪花した全昆虫を捕獲し、植物種ごとに種、個体数を記録した。その結果、(1)植物は、調査期間中に合計120種（48科）が開花し、多年草（29科61種）、1年草（15科27種）が種の73%を占めた。4年間の開花種数は、64種（36科）、105種（44科）、95種（43科）、84種（40科）であり、48種は4年間、32種は3年間、19種は2年間、21種は1年間のみ開花した。(2)訪花昆虫は、調査期間中に合計3407個体（5目88科258種）が採集され、ハエ目（23科104種）、ハチ目（18科90種）、コウチュウ目（15科30種）、チョウ目（12科24種）、カメムシ目（9科10種）の順であった。ハエ目とハチ目は、それぞれ全個体数の54%、41%を占めた。2003～2006年までの各年に140種（55科）、144種（49科）、112種（34科）、84種（35科）が採集され、そのうち35種は4年間、23種は3年間、57種は2年間、143種は1年間のみ採集された。(3)調査した4年間に開花植物（86種）と昆虫種（258種）の間に合計1183のリンクが記録された（可能な組合せの5.2%）。各年のリンク数は、346、343、274、220であり、リンクに占めるハエ目とハチ目の割合は、86%～94%へと年を追って上昇した。(4)調査期間中に植物と昆虫の種構成と相対量、植物と訪花昆虫のリンク等の変化を通じて、送粉系が大きく変化した。これには棚田復元作業により、調査地の日当たりが良くなり、乾燥したことが影響したと思われる。

本研究は、里山の生物多様性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。