研究資料 (Research record)

Trap-nesting bees and wasps and their natural enemies in regenerated broad-leaved forests in central Japan

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Abstract

Trap-nests are useful tools to monitor solitary bees and wasps that nest in tube-like cavities. We installed trap-nests made from internode tubes of bamboos and reeds in ten secondary deciduous broad-leaved stands of different ages of one to over 100 years after clear-cutting. Thirty-two species (eight families of Hymenoptera and one of Diptera) were obtained with the trap-nests: 20 host species and 12 of their natural enemies. The species richness of most families of hosts and natural enemies, except for Pompilidae, was higher in younger to middle-aged stands than in older ones over 70 years old. On the contrary, the family Pompilidae (spider wasps) proliferated in both young and old stands, with its relative abundance becoming greater with the increase in stand age.

Key words : cavity-nesting Hymenoptera, bamboo traps, monitoring, biodiversity, predator, pollinator

1. Introduction

Several groups of solitary bees and hunting wasps nest in pre-existing cavities, such as tubes or tube-like structures. These insects typically make cells in such cavities using various materials and store foods there to rear offspring (Krombein 1967). This behavior enables the study of the species compositions or relative densities not only of the cavity-dwelling bees and wasps but of their natural enemies in different environments by using tubes, such as bamboos or reeds, as “trap-nests.” As bees and hunting wasps play roles as pollinators and predators, respectively, using trap-nests is considered as a useful technique to study not only the biodiversity of bees and wasps but the possible ecosystem services they provide in various environments including forests (Sobek et al. 2009).

Although trap nests have been widely used for studies in various environments including agricultural landscapes (e.g.Tscharntke et al. 1998, Steffan-Dewenter 2002) or urban areas (e.g. Hashimoto and Endo 1994), attempts to use them in natural forests are relatively few (Suka et al. 2001, Taki et al. 2008, Sobek et al. 2009, Matsumoto and Makino 2011), and virtually no information is available on changes in trap-nesting insect communities with forest ages. Here, we present the results of trap-nests installed in deciduous broad-leaved forests along a chronosequence immediately after clear-cutting to over 100 years old in a cool temperate area in central Japan. As the plots of this monitoring have been used for the studies of various arthropod groups (Diptera: Sueyoshi et al. 2003; butterfly: Inoue 2003; nocturnal moths: Taki et al. 2010; cerambycid beetles: Makino et al. 2007; parasitic wasps: Maleque et al. 2010; bees: Taki et al 2013; soil animals: Hasegawa et al. 2006, 2013), our results will constitute a useful dataset for comparing responses of abundance and species diversity to forest age among the arthropods that are not only taxonomically different but also play varying roles in the ecosystem.

2. Methods

The study was conducted in a forested area in Ogawa (36º56′N, 140º35′E; 580–800 m a.s.l.), Kitaibaraki, Ibaraki Prefecture in central Japan. The area was situated at the southern edge of the Abukuma Mountains in Kitaibaraki and characterized by a mosaic-like landscape composed of conifer plantations of *Cryptomeria japonica* and *Chamaecyparis obtusa* and of secondary broad-leaved stands of various ages due to repeated small-scale clear-cutting over the years (Makino et al. 2007). The dominant canopy trees in the deciduous stands comprised *Quercus serrata, Q. mongolica* var. *grosseserrata,* and *Fagus crenata* (Masaki et al. 1992). The annual mean temperature and precipitation in Ogawa are 10.7 °C and 1910 mm, respectively (Mizoguchi et al. 2002). To learn the responses of trap-nesting bees and wasps to the stand age, we selected ten study plots of secondary broad-leaved stands that varied in age after clear-cutting from one to over 100 years (Table 1). The ten plots were distributed within an area of approximately 30 km^2 and at least 500 m apart from each other.

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Table 1. Stand characteristics of the study plots and the percentage of tubes of traps used for nesting or those producing adults

Plot code	Age[2)] (year)	Area (ha)	Average DBH (cm)	Basal area (m^2/ha)	% tubes used[1)]	% tubes producing adults[1)]
O1	1	3	0	0	45.0	27.8
O4	4	5	0	0	45.0	21.0
O12	12	4	7.3	9.5	29.4	19.4
O51	51	10	13.4	15.1	10.0	6.1
O54	54	14	17.1	22.4	46.7	36.7
O71	71	19	12.1	29.3	3.3	1.7
SA70	76	3	14.9	26.8	12.8	11.1
O128	>100	98	17.2	39.8	17.2	11.7
O174	>100	11	15.0	56.6	25.0	16.1
O178	>100	10	17.5	32.0	7.8	3.9

1) Total number of tubes examined was 180 from nine trap nests except in O4 (100 tubes) where four traps were lost before recovery. 2) For the stands older than 100 years old, only approximate ages are given because official logging records are not available.

Fig. 1. "Curtain type" trap nest used in the study.

We used "curtain type" (Matsumoto and Makino 2011) trap-nests, with each consisting of 20 tubes (Fig. 1). The tubes were 20 cm-long bamboos or reeds of four different inner diameters (approximately 6, 10, and 16 mm for bamboos and 4 mm for reeds), vertically tied with a thin wire in decreasing order of size from the top. This four-tube unit was repeated five times within a trap, with their openings directed to the same direction. The trap-nests were installed between April 9 and 16, 2002. In each of the ten plots, nine traps were set in a 3 × 3 grid pattern, with adjacent traps approximately 10 m apart from each other. The traps were tied with thin wires to trunks of trees at 1.5 m above the ground, although in the very young plots with no large trees present (O1 and O3), they were tied to the top of wood posts (5 × 5 × 150 cm) fixed on the ground. Except in O1 and O3, the traps were situated in the interior of the stand, at least 10 m from the stand edge. In O1 and O3, they were placed at least 50 m away from the nearest stand edge. The traps were recovered on November 5 or 6 of the same year, opened in the laboratory, and mapped for their tube contents. When a tube had immatures (cocoons or larvae) of trap-nesting bees and wasps or their natural enemies (parasitoids and kleptoparasites), or if it had any trace of successful or failed nesting (remains of nest material, vacant cocoons, etc.), it was counted as "used tube." All the cocoons and pupae were individually numbered and transferred in a small vial (20 ml) and kept under outdoor conditions with protection from the rain or direct sunlight until emergence of adults. All adults including the natural enemies were identified at the species level. The hosts of natural enemies were determined based on the maps. As four of the nine traps were lost before recovery in plot O4, we used the results from the remaining five traps. We used the number of adult-producing tubes as that of individuals when calculating abundance or diversity.

3. Results and discussion

We obtained 825 adults of 32 species from 320 (18.6%) out of the 1720 tubes (86 traps) that were recovered from the ten plots (Table 2). All the species were hymenopterans except for two dipteran parasites. A total of eight of the 32 species were singletons, that is, they were only produced from a single tube.

Among the 32 species, 20 constructed nests in the tubes (hosts), whereas the other 12 were natural enemies that took advantage of their hosts (Table 2). The host species comprised four families of hunting wasps (Pompilidae, Crabronidae, Vespidae, and Sphecidae) and two bee families (Megachilidae and Colletidae). The natural enemies consisted of a single family of parasitoid wasps (Ichneumonidae) and five families of kleptoparasites (wasps: Pompilidae and Chrysididae; bees: Megachilidae, flies: Sarcophagidae). The broods of the parasitoid wasps feed on host immatures, whereas those of kleptoparasites principally exploit food (prey or pollen) stored by the host adults.

The percentage of tube-producing adults varied from 1.7% to 36.7% among the plots, changing nearly in parallel with that of tubes used (Table 1). The total number of hosts and natural enemies also changed with these percentages (Fig. 2). These variables yielded higher values in the plots younger than 70 years old (except for O51) than in older plots. *Auplopus*

Table 2. Species collected with trap nests. Numerals represent the numbers of tubes that produed adults.

Order	Family	Species[1)]	Food of brood	Plot code										
				O1	O4	O12	O51	O54	O71	SA70	O128	O174	O178	Total
Hymenoptera	Sphecidaee	*Isodontia harmandi* (Pérez)	katydids					33				13	2	48
	Crabronidae	*Rhopalum kuwayamai* Tsuneki	psocids		1									1
		Rhopalum succineicollare Tsuneki	psocids					2						2
		Trypoxylon malaisei Gussakovkij	spiders				2							2
		Trypoxylon nipponicum Tsuneki	spiders	1										1
		Trypoxylon varipes Pérez	spiders					2		2				4
	Pompilidae	*Auplopus carbonarius* (Scopoli)	spiders	3	6	11	1	6	3	9	11	10	3	63
		Auplopus pygialis (Pérez)	spiders										2	2
		Dipogon bifasciatus (Geoffroy)	spiders		1	1				1		1		4
		Dipogon conspersus (Pérez).	spiders				1	3						4
		Dipogon iwatai Ishikawa*	spiders			3		8		4	8			23
		Dipogon nagasei Ishikawa*	spiders	1	1	3		1						6
		Dipogon nipponicus (Yasumatsu)	spiders		1									1
		Dipogon romankovae Lelej	spiders			1						1		2
		Dipogon sperconsus Shimizu & Ishikawa	spiders		4	9	1	6		6		3	1	30
	Vespidae	*Anterhynchium flavomarginatum* (Smith)	moth larvae	12										12
		Discoelius zonalis (Panzer)	moth larvae	21		1					1			23
	Chrysididae	*Chrysis fasciata* Olivier*	moth larvae	2										2
	Colletidae	*Hylaeus transversalis* Cockerell	pollen/nectar	4	2									6
	Megachilidae	*Coelioxys hiroba* Nagase*	pollen/nectar	2	2									4
		Megachile sculpturalis Smith	pollen/nectar	2		1		1				4		8
		Megachile tsurugensis Cockerell	pollen/nectar	2	2	1								5
		Osmia cornifrons (Radoszkowski)	pollen/nectar		1									1
		Osmia taurus Smith	pollen/nectar				5	8			8			21
	Ichneumonidae	*Caenocryptus* sp. (*canaliculatus*?)**	host immatures			13		3		5			4	25
		Dihelus hylaevorus (Momoi)**	host immatures			1								1
		Ephialtes hokkaidonis Uchida**	host immatures			1								1
		Nematopodius oblongus Momoi**	host immatures					2						2
		Picardiella tarsalis (Matsumura)**	host immatures		2	1		1		1				5
	Leucospidae	*Leucospis japonica* Walker**	host immatures	1										1
Diptera	Sarcophagidae	*Amobia distorta* (Allen)*	moth larvae	8						1				9
		Oebalia rossica (Rohdendorf) or *cylindrica* (Falien)*	moth larvae									1		1
Total				59	23	47	10	76	3	29	28	33	12	320

1) Single aster (*) indicates kleptoparasites, and double aster (**) parasitoids.

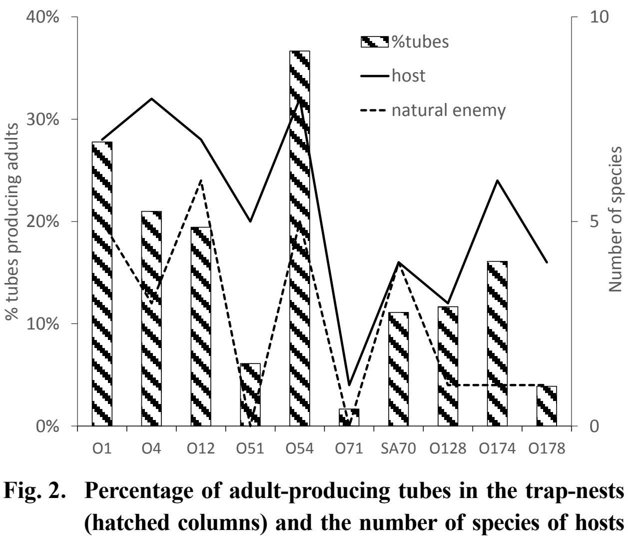

Fig. 2. Percentage of adult-producing tubes in the trap-nests (hatched columns) and the number of species of hosts (solid lines) and natural enemies (broken lines) in the ten plots of deciduous broad-leaved stands in temperate Japan.

carbonarius (Pompilidae) was the most frequent host species (19.7% of adult-producing tubes), followed by *Isodontia harmandi* (Sphecidae) (15%) and *Dipogon sperconsus* (Pompilidae) (9.4%) (Table 2). The two pompilids inhabited all or nearly all the plots irrespective of age, whereas *I. harmandi* was found only in the sites over 50 years old. Among the natural enemies, the parasitoid wasp *Caenocryptus* sp. (7.8%) and the kleptoparasite *Dipogon iwatai* (7.2%) were the most frequent, with both utilizing pompilids of the genera *Auplopus* or *Dipogon* as hosts (Table 3; Shimizu et al. 2012).

At the family level, Pompilidae showed prominence both in abundance and in species richness: 42% individuals and 28% species of all emerged adults were of this family. In particular, the genus *Dipogon* exhibited the highest species number (seven including two kleptoparasites) among all genera obtained in this monitoring. The dominance of Pompilidae was also demonstrated by its occurrence in the plots with a wide age range, as represented by *A. carbonarius*, which was the only species present in all the plots considered in this study. The ubiquity of *A. carbonarius* influenced the species assemblage

Table 3. Associations between natural enemies and hosts. Data of the frequency are pooled for all traps. All species are hymenopterans, execept for two dipteran kleptoparasites (*Amobia* and *Oebalia*).

Type of parasite	Natural enemy species [Family]	Host species [Family]	Frequency
kleptoparasite	*Dipogon iwatai* [Pompilidae]	*Auplopus carbonarius* [Pompilidae]	14
		Dipogon sperconsus [Pompilidae]	2
		Dipogon romankovae [Pompilidae]	1
		unknown	5
	Dipogon nagasei [Pompilidae]	*Dipogon sperconsus* [Pompilidae]	2
		unknown	4
	Chrysis fasciata [Chrysididae]	*Anterhynchium flavomarginatum* [Vespidae]	1
	Coelioxys hiroba [Megachilidae]	*Megachile tsurugensis* [Megachilidae]	2
		unknown	2
	Amobia distorta [Sarcophagidae]	*Anterhynchium flavomarginatum* [Vespidae]	4
		Discoelius zonalis [Vespidae]	3
		unknown	3
	Oebalia rossica or *cylindrica* [Sarcophagidae]	unknown	1
parasitoid	*Caenocryptus* sp. *(canaliculatus?)* [Ichneumonidae]	*Auplopus carbonarius* [Pompilidae]	10
	Dihelus hylaevorus [Ichneumonidae]	*Auplopus carbonarius* [Pompilidae]	1
	Ephialtes hokkaidonis [Ichneumonidae]	*Megachile tsurugensis* [Megachilidae]	1
	Nematopodius oblongus [Ichneumonidae]	*Trypoxylon nipponicum* [Crabronidae]	1
		unknown	1
	Picardiella tarsalis [Ichneumonidae]	*Auplopus carbonarius* [Pompilidae]	5
	Leucospis japonica [Leucospidae]	unknown	1

of natural enemies: four out of 12 natural enemy species totally or partly depended on *A. carbonarius,* which, in turn, was the most frequently used host species by natural enemies (Table 3).

Megachilidae and Crabronidae followed Pompilidae in terms of species richness (five species each), although their abundance was much lower compared with that of Pompilidae. In addition, hunting wasps other than Pompilidae and bees were absent in the plots over 70 years old, except for *Isodontia harmandi* (Sphecidae), *Megachile sculpturalis*, and *Osmia taurus* (Megachilidae).

We point out two main findings in the results of trap-nests installed in secondary deciduous broad-leaved forests. First, the abundance and species richness of trap-nesting species were higher in younger stands than in older ones. This is closely related with high rates of usage of traps by these species. For trap-nesting bees and wasps, in general, younger stands are suitable places to collect pollen or nectar for bees and herbivorous insect prey for hunting wasps, as these sites are rich in herbaceous plants on forest floors (Matsumoto and Makino 2011). *Isodontia harmandi* was the only non-pompilid host that mainly existed in older plots. This result was observed possibly because the species constructs cells in nests using mosses, which were more easily available in dark and humid forest floors in older plots than in younger ones. Second, Pompilidae was a dominant family in terms of both abundance and species richness, with its relative frequency increasing with aging of forests. In particular, *Auplopus carborarius,* which was the most abundant from this family, was present in every plot. Matsumoto and Makino (2011) showed a similar result showing that the species trap-nested in a sunlight-rich cherry forest and in a darker, secondary broad-leaved forest. The genus *Dipogon,* as represented by *D. sperconsus,* also nested in both young and old plots. The reason for the predominance of Pompilidae in forests remains unclear at present. One possible reason is the relative abundance of their prey (spiders), which may be distributed more evenly along the forest age compared with food resources of other trap-nesting bees or wasps. A quantitative study should be conducted on the relationship between the abundance of food resources and frequency of trap-nesting hymenopterans.

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関東北部の落葉広葉樹二次林に設置した営巣トラップによって得られたハチ類とその天敵

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要 旨

営巣トラップは、筒状の隙間に営巣する借孔性ハナバチ類やカリバチ類のモニタリングに有効な手法である。伐採から 1 ～ 100 年以上が経過した、林齢の異なる 10 地点の落葉広葉樹二次林に竹筒およびヨシ筒製の管住性ハチ類用営巣トラップを設置したところ、20 種の寄主および 12 種の天敵、合計 32 種 (ハチ目 8 科ならびにハエ目 1 科) が得られた。寄主および天敵のほとんどの科では、林齢 70 年を超える林分にくらべて、より若い林分で種数と個体数が多かった。これに対して、クモバチ科は若齢でも老齢でも見られ、その結果、林分が老齢になるほど全種に対するクモバチ科の個体数の割合が増加した。

キーワード：借孔性ハチ類、竹筒トラップ、モニタリング、生物多様性、捕食者、送粉者

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