Changes in Insect Assemblages with Conversion from Old-Growth Evergreen Broadleaf Forests to *Cryptomeria japonica* Plantations on Yakushima Island, Japan

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Introduction

Recently, several studies have investigated the changes in insect assemblages after conversion from natural or secondary forests to plantations of conifers (primarily Japanese cedar, *Cryptomeria japonica*, and hinoki cypress, *Chamaecyparis obtusa*) in the temperate deciduous forests of Japan (e.g., Inada et al., 2006; Maeto & Makihara, 1999; Makino et al., 2007; Sayama et al., 2005; Sueyoshi et al., 2003). However, changes in insect communities in systems other than temperate deciduous forests in Japan have been less thoroughly examined (but see Maeto et al., 2002; Mizota & Imasaka, 1997). Thus, there is little information regarding shifts in insect assemblages in response to the conversion of evergreen broadleaf forests in Japan.

We examined the responses of insect assemblages to the conversion of an evergreen broadleaf forest to a *C. japonica* plantation. We compared the abundance and diversity of seven insect groups (tiger beetles, clerid beetles, longicorn beetles, leaf beetles, elephant beetles other than Curculionidae, hoverflies, and wasps) collected in old-growth evergreen broadleaf forests and *C. japonica* plantations in the lowlands on Yakushima Island, Japan.

Materials & Methods

1) *Study sites*

The study sites were located in lowland forests (150-250 m above sea level) on Yakushima Island, Kagoshima Prefecture, Japan. We selected two plantations of *C. japonica* (approximately 40 years old) in each of the eastern and western regions of the island and two old-growth evergreen broadleaf forests situated near the two plantations (Table 1). Each study site was located within a continuous stand at least 100 m from the boundaries of other forest types, although small patches of secondary stands of broadleaf forests were occasionally found in the vicinity of the plantations. Both old-growth sites are located in a National Forest, whereas both plantations are under private ownership. The forest floors of the plantations receive more light due to the process of tree thinning.

2) *Sampling and identification*

Townes-type, white Malaise traps (1.8 x 1.8 x 1.8 m) were used to capture insects. Within each site, three traps were haphazardly set, and the maximum distance between traps was < 100 m. Trapped insects were collected monthly from July to December 2006 and from March to May 2007. A mixture of 70 % ethanol and ethylene

glycol was added as a preservative to the insect containers in the traps. Collected insects were morphologically identified to species.

3) Target insect groups

Five coleopteran groups [Tiger beetles (Cicindelidae), clerid beetles (Cleridae), longicorn beetles (Disteniidae and Cerambycidae), leaf beetles (Chrysomelidae), and elephant beetles other than Curculionidae (Anthribidae, Brentidae, and Rhynchophoridae)], one dipteran group [hoverflies (Syrphidae)], and one hymenopteran group [wasps (Vespidae)] were examined. These insect groups consist of several functional feeding types. Tiger beetles, clerid beetles, and wasps are predators, whereas longicorn beetles, elephant beetles, and leaf beetles are herbivores. Adult hoverflies are pollen feeders (herbivores), and the larvae consist of two feeding types in the species examined: members of the subfamily Syrphinae are aphid-feeders (predators), and members of the subfamily Eristalinae are decayed-wood feeders (herbivores). We based guild assignment of hoverflies on larval feeding habits.

4) Data analyses

Data for each taxonomic group were pooled for each site throughout the season, and species with sample sizes > 20 individuals were analyzed using chi-squared tests. Data were compared between the two forest types (all individuals collected in old-growth evergreen broadleaf forests versus *C. japonica* plantations). Expected values were calculated by multiplying the number of total captures for each species by 0.5, because the number of individuals of all target species combined was nearly identical between the two forest types.

We calculated the logarithm of the inverse Simpson's index as an index of species diversity, as follows:

$$\log (1/D) = \log \Sigma \ [N (N\text{-}1)] \ / \ [Ni \ (Ni\text{-}1)]$$

where N is the total number of individuals, and Ni is the number of individuals of the ith species.

Results & Discussion

We collected 431 individuals of 51 species of target insect groups in the *C. japonica* plantations and 447 individuals of 76 species in the old-growth evergreen broadleaf forests (Table 2). Indices of species diversity calculated for each insect group were lower in the *C. japonica* plantations than in the old-growth evergreen broadleaf forests (Table 2).

The total number of herbivorous species was much greater in the old-growth evergreen broadleaf forests (58 species) than in the *C. japonica* plantations (30 species). Herbivores depend directly on a wide variety of plants for food and shelter (Siemann, 1998). Therefore, the greater availability of more plant species in the old-growth evergreen broadleaf forests likely increased the species diversity of herbivores. In contrast, the total number of predator species did not significantly differ between the *C. japonica* plantation (21 species) and the old-growth evergreen broadleaf forest (18 species). These results suggest that the species diversity of predators was not greatly affected by the increased availability of plants in the old-growth evergreen broadleaf forest, because insect predators do not directly depend on a variety plants for food.

The numbers of trapped individuals of *Cicindela japonica*, *Stigmatium nakanei*, *Omadius nigromaculatus*, *Ceresium longicorne*, *Cryptocephalus perelegans*, and *Monolepta pallidula* were significantly greater in the

old-growth evergreen broadleaf forest than in the *C. japonica* plantations (Tables 3-6). The recorded host plants of *C. longicorne* and *C. perelegans* are primarily broadleaf trees and do not include Japanese cedar (Kimoto and Takizawa, 1994; Takeda, 2007). These six species include three predators, *C. japonica*, *S. nakanei*, and *O. nigromaculatus*; thus, some predators may indeed be affected by the conversion of old-growth evergreen broadleaf forests to *C. japonica* plantations.

In contrast, the number of trapped individuals of Alticinae gen. sp., *Sipalinus gigas*, *Episyrphus balteatus*, and *Chalcosyrphus frontalis* were significantly greater in the *C. japonica* plantations than in the old-growth evergreen broadleaf forest (Tables 6-8). In addition, *Milesia oshimaensis* (28 individuals) were collected only in the *C. japonica* plantations (Table 8). Although the host plants of Alticinae gen. sp. and *C. frontalis* are unknown, the recorded host plants of *S. gigas* and *M. oshimaensis* include Japanese cedar (Ikezaki, 1976; Morimoto, 1984). *Episyrphus balteatus* is a predator that may indirectly depend on *C. japonica*.

As has been previously recorded in temperate deciduous forests (e.g., Makino et al., 2007), our results indicate that the conversion of evergreen broadleaf forests to *C. japonica* plantations causes shifts in insect assemblages. Such conversions may lead to the impoverishment of insect herbivores. Insect predators may also be affected by the disappearance of evergreen broadleaf forests. However, several insect species were rarely collected in the evergreen broadleaf forests and may appear and/or increase explosively in the *C. japonica* plantations.

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Table 1 Location and forest type of the investigated sites in Yakushima Island

Site	Forest type	Site position	Altitude (m)
CE	Plantation of *C. japonica* (40 yr.)	Eastern part	150
CW	Plantation of *C. japonica* (40 yr.)	Western part	220
OE	Old-growth evergreen broadleaf forest	Eastern part	170
OW	Old-growth evergreen broadleaf forest	Western part	250

Table 2 Comparisons of number of species, number of individuals, and diversity indices [logarithm of inverse Simpson's index, log(1/D)] between plantation of cedar and old-growth evergreen broadleaf forest in Yakushima

	Plantation of cedar			Old-growth evergreen broadleaf forest		
	No. of species	No. of individuals	log(1/D)	No. of species	No. of individuals	log(1/D)
Tiger beetles	1	5	0.00	2	47	0.20
Clerid beetles	5	35	0.31	7	98	0.40
Longicorn beetles	8	17	0.92	26	94	0.96
Leaf beetles	8	145	0.12	12	123	0.76
Elephant beetles	7	40	0.22	16	39	1.07
Hoverflies	15	170	0.59	7	21	0.80
Wasps	7	19	0.20	6	25	0.47
All target groups combined	51	431	0.87	76	447	1.34

Table 3 The number of tiger beetles collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW *vs* OE+OW)
Cicindelidae						
Cicindela japonica	2	3	9	27	41	23.43*
Therates alboobliquatus			1	10	11	

*$P < 0.001$.

Table 4 The number of clerid beetles collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW *vs* OE+OW)
Cleridae						
Tillus igarashii				1	1	
Opilo carinatus		1	1	8	10	
Clerus postmaculatus				3	3	
Stigmatium pilosellum				1	1	
Stigmatium nakanei	2	22	25	34	83	14.75*
Stigmatium igai		2	1	7	10	
Omadius nigromaculatus		6	16	1	23	5.26**
Allochotes dichrous		2			2	

*$P < 0.001$; **$P < 0.05$.

Table 5 The number of longicorn beetles collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW vs OE+OW)
Disteniidae						
Distenia gracilis gracilis				1	1	
Cerambycidae						
Lepturinae						
Leptura ochraceofasciata ochraceofasciata		1	1		2	
Cerambycinae						
Allotraeus sphaerioninus			2		2	
Stenodryas clavigera clavigera				1	1	
?Ceresium holophaeum				6	6	
Ceresium longicorne		3		25	28	17.28*
Ceresium sp.				2	2	
Comusia testacea				1	1	
Stenhomalus nagaoi				1	1	
Artimpaza setigera japonica				1	1	
Cleomenes takiguchii				4	4	
Callidiellum rufipenne	2				2	
Xylotrechus emaciatus		4	10	5	19	
Perissus kiusiuensis kiusiuensis			1	3	4	
Chlorophorus quiquefasciatus	1		2	1	4	
Chlorophorus muscosus			1	4	5	
Demonax transillis				2	2	
Anaglyptus arakawae kumagensis			2		2	
Clytini gen. sp.			1		1	
Lamiinae						
Mesosa longipennis			1		1	
Neosybra cribrella			1		1	
Sybra ordinata ordinata				3	3	
Pterolophia gibbosipennis subcristipennis				3	3	
?Pterolophia kyushuensis			1	1	2	
Uraecha bimaculata	1		2	2	5	
Xenicotela pardalina		1			1	
Mimectatina meridiana ohirai	1	3			4	
Rondibilis insularis			1		1	
Sciades fasciatus fasciatus				2	2	

*$P<0.001$

Table 6 The number of leaf beetles collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW vs OE+OW)
Chrysomelidae						
Cryptocephalinae						
Cryptocephalus perelegans		1	5	21	27	23.14*
Eumolpinae						
Acrothinium gaschkevitchii			5	8	13	
Basilepta hirayamai		1	4	5	10	
Trichochrysea okinawana				1	1	
Lypesthes fulvus				7	7	
?*Lypesthes itoi*	9	3	1		13	
Hyperaxis fasciata		2	2	5	9	
Demotina fasciculata			1		1	
Demotina sp.			13	1	14	
Galerucinae						
Fleutiauxia armata		1			1	
?*Monolepta pallidula*		1	9	30	40	36.10*
Alticinae						
Nonarthra cyanea				1	1	
?*Nonarthra tibialis*	1				1	
Alticinae gen. sp.	114	12		4	130	114.49*

*$P<0.001$.

Table 7 The number of elephant beetles (excluging Curculionidae) collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW vs OE+OW)
Anthribidae						
Ozotomerus nigromaculatus				1	1	
Mecotropis kyushuensis			1		1	
Stiboderes impressus stibinus	1				1	
?*Dendrotrogus japonicus*			2		2	
Sintor bipunctatus			2		2	
Sympaector rugirostris			1		1	
Acorynus asanoi		2	5	3	10	
Litocerus kimurai				1	1	
Litocerus tokarensis insensibilis			1	1	2	
Litocerus multiguttatus		1		1	2	
?*Phaulimia confinis*				1	1	
Phaulimia aberrans				2	2	
Oxyderes fastigatus		1	2	3	6	
Aphaulimia debilis		1	2	4	7	
Habrissus unciferoides		3	2	2	7	
Brentidae						
Baryrhynchus poweri				1	1	
Rhynchophoridae						
Sipalinus gigas	31			1	32	28.12*

*$P<0.001$.

Table 8 The number of hoverflies collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW *vs* OE+OW)
Syrphidae						
Syrphinae						
?*Allograpta iavana*				1	1	
Didea fasciata		1			1	
Episyrphus balteatus	42	25	3	4	74	48.64*
?*Ischiodon scutellaris*				1	1	
?*Parasyrphus aeneostoma*		1			1	
?*Syrphus torvus*	1				1	
Allobaccha nubilipennis	3	3			6	
Baccha maculata		1			1	
Chrysotoxum sp.	1				1	
Platycheirus sp.	2	2			4	
Eristalinae						
?*Eumerus japonicus*		1	1	3	5	
?*Mallota yakushimana*		1			1	
Milesia oshimaensis	18	6			24	
Milesia undulata	1		3		4	
Takaomyia johannis		5	1	1	7	
Chalcosyrphus frontalis	25	23	3		51	39.70*
Xylota sp.	6	2			8	

*$P < 0.001$.

Table 9 The number of wasps collected with 3 Malaise traps in Yakushima

	CE	CW	OE	OW	Total	χ^2 (CE+CW *vs* OE+OW)
Vespidae						
Polistes rothneyi	1				1	
Parapolybia indica	1	6			7	
Vespa mandarinia	2			1	3	
Vespa ducalis	2	1	1		4	
Vespa analis	1	2		1	4	
Vespa similima	1	1	3	9	14	
Vespula flaviceps			1		1	
Vespula shidai		1		9	10	