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# Management of insect biodiversity by line thinning in Japanese cedar (*Cryptomeria japonica* D. Don) plantations, central Japan

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**Abstract**

We investigated the effects of line thinning on the biomass and diversity of common families of the two insect orders, Coleoptera and Hymenoptera, to evaluate the importance of line thinning for the management of insect biodiversity in Japanese cedar plantations in central Japan. In line thinning, 3- to 5-m-wide linear sections of the stand are harvested parallel to the slope and often perpendicular to the forest roads. Between the line-thinned sections, 5- to 12-m-wide stand sections are retained. We compared abundance and diversity of Coleoptera and Hymenoptera between line-thinned stand and an adjacent unthinned stand in two plantations: low-elevation Sugi site (four years since thinning) and high-elevation Kuchiotani site (six years since thinning). Biomass of both orders increased with increasing understory plant biomass across the two sites. Biomass of Coleoptera and Hymenoptera increased as high as 130% in the thinned and retained sections of the line-thinned sections of the line-thinned stand relative to the unthinned stand. The difference between the line-thinned stand and unthinned stands was greater for the Kuchiotani site, probably because this region supports more natural forests that serve as source habitats for various insect groups. Because arthropod diversity can be used as an indicator of ecosystem integrity, we conclude that line thinning is an effective silvicultural treatment for enhancing biodiversity of overstocked *C. japonica* plantations.

*Key Words*: Biodiversity, Ecosystem function, Forest management, Malaise trap

## Introduction

*Cryptomeria japonica* D. Don (Japanese cedar) plantations constitute about half of the plantation forest area in Japan. Many of these plantations were established 50 to 60 years ago and are now reaching harvesting age. However, because of high labor costs and low wood value in recent years, these plantations have remained unmanaged over the years (Japan for Sustainability 2003). This situation has resulted in overstocked stands with very dark understory environments, supporting low diversity of plants and other forest-dwelling organisms (Ito *et al.* 2003, Inagaki *et al.* 2003). It has been recognized that loss of plant and animal species from the plantation areas is a major concern in Japan (Government of Japan 2002). In response, we must evaluate and develop cost-effective silvicultural techniques for sustainable management of biodiversity in Japanese plantation forests.

In the USA, new forestry techniques are being evaluated that aim to enhance ecological functions as well as timber production (Kohm and Franklin 1997). Because conservation of biological diversity and timber production must be attained simultaneously (Hartley 2002, Nagaike 2002), new silvicultural techniques must realize both economic return as well as ecological objectives. Line thinning is a form of variable retention commercial thinning being practiced widely in Japan. It aims to enhance ecological functions as well as timber production. In this type of thinning, 3- to 5-m-wide linear sections of the stand are harvested parallel to the slope and often perpendicular to the forest roads. Between the line-thinned sections, 5- to 12-m-wide stand sections are retained. Line thinning is less labor intensive and more efficient for timber extraction than conventional single-tree thinning methods (Taniguchi 2003). For this reason, line thinning is an economically viable silvicultural treatment that can potentially enhance biodiversity of overstocked plantations.

The effects of line thinning on biodiversity of Japanese cedar plantations, however, have not yet been formally evaluated. Line thinning creates heterogeneous canopy structure, which creates more variable understory microenvironments and increases understory plant biomass (Maleque 2006). In this study, we investigated whether line thinning had increased the biomass and diversity of two important insect orders Coleoptera and Hymenoptera. The order Coleoptera, which includes beetles and weevils, is the largest order of the animal kingdom, and the order Hymenoptera, which includes ants, bees, sawflies, and wasps, is the third largest order of Insecta. Members of both orders play diverse ecological roles acting as herbivores, pollinators, predators, parasitoids, scavengers, decomposers, etc. (e.g., Gauld and Bolton 1988, Goulet and Huber 1993, Grimaldi and Engel 2005, Arnett Jr 2000).

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Recently, Maleque *et al.* (2006) proposed that arthropods can be used in forest management as indicators of ecosystem integrity because community structure of arthropods reflects the heterogeneity of forest habitats and the diversity of other forest-dwelling organisms. By creating canopy openings, line thinning would lead to a more heterogeneous microclimate in understory habitats and potentially support more diverse arthropod communities. To test this assumption, we compared biomass of understory plants, as well as biomass and diversity of Coleoptera and Hymenoptera families between line-thinned and unthinned stands in two *C. japonica* plantations in northern Hyogo Prefecture, central Japan.

## Material and methods

### Study areas

We conducted this study in two *C. japonica* plantations located at two different elevations: "Sugi" in Kanzaki Town (low-elevation site: 350 m asl, 35°24'N, 134°56'E) and "Kuchiotani" in Kami Town (formerly Muraoka Town) (high-elevation site: 700 m asl, 35°47'N, 134°50'E), northern Hyogo Prefecture, central Japan, during the period from April to October 2004. Mean annual temperature is 16.3°C and mean annual precipitation is 1487 mm in Kanzaki Town. Mean annual temperature is 14.5°C and mean annual precipitation is 1947 mm in Kami Town. The landscape surrounding the two study sites is different. In Sugi, plantation forests constitute over 80% of the forested area of Kanzaki Town. By contrast, the Kuchiotani area is part of the Hyonosen-Ushiroyama-Nagisan Quasi-national Park dominated by natural primary and secondary cool-temperate deciduous forests.

### Application of silvicultural treatment

The plantation in Sugi was 4.6 ha, located on a southeast-facing slope (mean inclination 25°). In 2000, when the stand age had reached 35 years, the plantation was line-thinned with an intensity of approximately 25% of the total number of trees. A total of twelve lines were thinned at a width of 3 m and a length of 120 m each. The retained areas between thinned lines were 9-m-wide. Tower yarder was used for removing cut stems. The study plot in the thinned stand (hereafter "treatment plot", measuring 15 x 50 m) included one line-thinned section and one retained section. The "control plot" (20 x 20 m) was located in an unthinned stand adjacent to the thinned stand on the same slope.

The plantation in Kuchiotani was 1.3 ha, located on a south-facing slope (mean inclination 12°). In 1998, when the stand age had reached 39 years, the plantation was line-thinned with an intensity of approximately 29% of the total number of trees. A total of five lines were thinned lines at a width of 3.6 m and a length of 65 m each. The retained areas between thinned lines were 5.4-m-wide. Swing yarder was used for removing cut stems. The treatment plot (20 x 30 m) included two line-thinned sections and two retained sections. The control plot (20 x 30 m) was located in an unthinned stand adjacent to the thinned stand on the same slope.

### Arthropod sampling, identification and biomass determination

For capturing arthropods, we used Townes-type white Malaise traps (height x width x length = 120 x 100 x 150 cm; Morpho, Czech Republic). The traps were set up in April 2004 in both study sites. In each site, eight traps were set up in the treatment plot (four traps each in the thinned and retained sections) and four traps were set up in the control plot. Traps were set up at random places in each plot. Collection bottles were 500 ml, about one third of which were filled with propylene glycol for preserving insect samples for one collection interval. Arthropod samples were collected at 14-20-day intervals from mid-April through the first week of October. Sampling had to be discontinued in the Sugi site after the third week of August due to typhoon damage.

Collected samples were brought back to the laboratory and preserved in 70% ethanol solution. We extracted all Coleoptera and Hymenoptera from the sampled arthropods. Then, we identified Coleoptera and Hymenoptera to families based on identification keys (Hayashi *et al.* 2002, Uéno *et al.* 1999, Kurosawa *et al.* 1998, Goulet and Huber 1993).

We measured understory plant biomass in each plot in September 2004. One 2 x 2 m quadrat was sampled near each Malaise trap. We harvested all vascular plants in the sample quadrats and transported them to the laboratory. All plant samples were oven-dried to constant weight to determine dry mass. Maleque (2006) gives detailed descriptions of understory plant species composition at each site.

### Statistical analyses

One-way ANOVA was used for comparing insect biomass among treatments considering each trap as replicate samples within each plot. As the data were positively skewed, log transformation was used to normalize the variance among treatments. Tukey's test was used for multiple comparisons of means. Regression analysis was used for analyzing biomass of Coleoptera and Hymenoptera in relation to understory plant biomass. Diversity indices were calculated for Coleoptera and Hymenoptera based on the *Shannon-Weiner function* (Krebs 1972). All statistical analyses were performed using SYSTAT 9.0.

## Results

### Biomass of Coleoptera and Hymenoptera

In Sugi, thinned and retained sections of the treatment plot hosted 104.8-128.7% more Coleoptera biomass, and 11.5-34.7% more Hymenoptera biomass over the control (Table 1), although trends were not significant (Coleoptera: $F = 1.31$, $P = 0.32$; Hymenoptera: $F = 1.86$, $P = 0.21$). In Kuchiotani, biomass of Coleoptera and Hymenoptera was significantly greater in the thinned and retained sections of the treatment plot than in the control (Coleoptera: $F = 15.81$, $P = 0.002$; Hymenoptera: $F = 18.34$, $P<0.001$). There were strong across-site positive relationships between biomass of understory plants and biomass of Coleoptera and Hymenoptera (Fig. 1).

Table 1. Biomass (mg per trap) of Coleoptera and Hymenoptera in the two line-thinned and unthinned stands of *Cryptomeria japonica* plantations in northern Hyogo Prefecture, Japan, during the period from April to October 2004.

| Insect order | Study site | Treatment | Biomass per trap (± SD)[1] | % Biomass exceeding control |
|---|---|---|---|---|
| Coleoptera | | | | |
| | Sugi | | | |
| | | Thinned | 1700 (± 1281.6) a | 104.8 |
| | | Retained | 1898 (± 1074.5) a | 128.7 |
| | | Control | 830 (± 409.7) a | - |
| | Kuchiotani | | | |
| | | Thinned | 4058 (± 570.1) a | 130.8 |
| | | Retained | 3373 (± 648.9) a | 91.9 |
| | | Control | 1758 (± 381.8) b | - |
| Hymenoptera | | | | |
| | Sugi | | | |
| | | Thinned | 164 (± 36.4) a | 11.5 |
| | | Retained | 198 (± 47.9) a | 34.7 |
| | | Control | 147 (± 24.5) a | - |
| | Kuchiotani | | | |
| | | Thinned | 510 (± 36.3) a | 128.7 |
| | | Retained | 452 (± 113.5) a | 102.7 |
| | | Control | 223 (± 30.2) b | - |

[1]Common letters denote no significant difference between treatments for each site (Tukey's HSD, $P>0.05$)

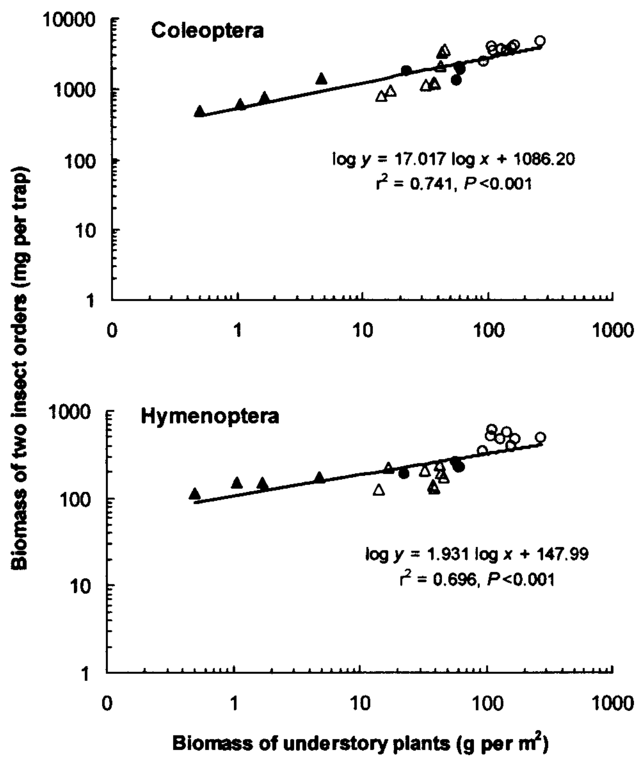


Fig. 1. Biomass of Coleoptera and Hymenoptera in relation to biomass of understory plants in the two *Cryptomeria japonica* plantations in northern Hyogo Prefecture, central Japan (note varied y-axis range). Triangular symbols indicate Sugi site and circular symbols indicate Kuchiotani site. Symbol patterns indicate sample quadrats in the thinned (open), retained (shaded) sections of the treatment plot and in the control plot (filled).

**Diversity of Coleoptera and Hymenoptera**

In Sugi, we identified fifteen common families of Coleoptera in the thinned and retained sections, whereas fourteen (excluding Cantharidae) were found in the control plot (Table 2). Curculionidae, Lycidae, Elateridae, Mordellidae, and Cerambycidae were the most dominant families. Plant feeder Chrysomelidae, polyphagous Lycidae, scavenger Tenebrionidae, wood borer Cerambycidae, predator Carabidae and Staphylinidae, were more dominant in the thinned and retained sections of the treatment plot than in the control. The predator Cantharidae was absent from the control plot. Elateridae, Mordellidae, Erotylidae, and Nitidulidae were more dominant in the control than in the treatment plot. In addition to Coleoptera in Sugi, we identified twelve families and two family series (Apiformes and Spheciformes) of Hymenoptera in the thinned and retained sections, whereas only ten families and two family series (Apiformes and Spheciformes) were found in the control plot. Ichneumonidae, Formicidae (ants) and Pompilidae were the most dominant families. Pollinator Apiformes (bees), parasitoid Braconidae, and predator Pompilidae were more dominant in the thinned and retained sections of the treatment plot than in the control. Herbivore Argidae and Tenthredinidae, parasitoid Bethylidae, Charipidae, and Tiphidae, were absent from the control plot. Diapriidae, Spheciformes and Formicidae (ants) were more dominant in the control than in the treatment plot. Ceraphronidae and Megaspilidae were absent from the treatment plot.

Table 2. Family-level relative abundance and diversity of the two insect orders Coleoptera and Hymenoptera in the line-thinned and unthinned stand of *Cryptomeria japonica* plantations in Sugi, during the period from April to October 2004.

| Families of Coleoptera | Relative abundance (%) | | | Families and family series of Hymenoptera | Relative abundance (%) | | |
|---|---|---|---|---|---|---|---|
| | Thinned | Retained | Control | | Thinned | Retained | Control |
| 1. Chrysomelidae | 3.8 | 5.3 | 2.8 | 1. Apiformes (bees)[1)] | 4.6 | 4.2 | 1.7 |
| 2. Curculionidae | 10.9 | 14.4 | 13.5 | 2. Argidae | 0.2 | 0 | 0 |
| 3. Lycidae | 11.0 | 8.4 | 7.8 | 3. Tenthredinidae | 0.5 | 0.7 | 0 |
| 4. Tenebrionidae | 6.6 | 6.2 | 4.2 | 4. Braconidae | 5.2 | 3.7 | 3.6 |
| 5. Oedemeridae | 7.6 | 3.3 | 4.6 | 5. Ichneumonidae | 37.2 | 38.9 | 35.4 |
| 6. Elateridae | 12.5 | 13.6 | 15.9 | 6. Bethylidae | 0.5 | 0.3 | 0 |
| 7. Scarabaeidae[1)] | 4.1 | 10.5 | 4.6 | 7. Ceraphronidae | 0 | 0 | 0.2 |
| 8. Mordellidae | 20.1 | 14.4 | 27.0 | 8. Charipidae | 0 | 0.2 | 0 |
| 9. Cerambycidae | 10.9 | 10.8 | 8.8 | 9. Diapriidae | 1.5 | 2.0 | 2.2 |
| 10. Scolytidae | 0.5 | 0.9 | 1.0 | 10. Megaspilidae | 0 | 0 | 0.5 |
| 11. Erotylidae | 0.6 | 1.6 | 1.8 | 11. Proctotrupidae | 0.8 | 0.9 | 0.3 |
| 12. Nitidulidae | 0.9 | 2.0 | 2.4 | 12. Scelionidae | 0.8 | 0.4 | 0.3 |
| 13. Scarabaeidae[2)] | 1.5 | 1.7 | 1.8 | 13. Tiphidae | 0.2 | 0.4 | 0 |
| 14. Carabidae | 4.9 | 2.6 | 1.8 | 14. Pompilidae | 19.6 | 14.9 | 10.0 |
| 15. Staphylinidae | 3.2 | 3.7 | 2.2 | 15. Spheciformes[2)] | 3.6 | 3.0 | 6.3 |
| 16. Cantharidae | 0.9 | 0.7 | 0 | 16. Vespidae | 1.5 | 0.9 | 0.9 |
| | | | | 17. Formicidae (ants) | 23.9 | 29.6 | 38.5 |
| Diversity index | 2.40 | 2.46 | 2.28 | Diversity index | 1.72 | 1.64 | 1.53 |

**Coleoptera** (Left): 1-2, 5-6 = Plant feeders, 3 = Polyphagous, 4 = Scavengers, 7-8 = Rotten wood feeders/plant feeders, 9-10 = Wood or bark borers, 11-12 = Mushroom feeders, 13 = Dung feeders, 14-16 = Predators.
[1)]Excluding Scarabaeinae and Aphodiinae, [2)]Scarabaeinae and Aphodiinae.

**Hymenoptera** (Right): 1 = Pollinators, 2-3 = Herbivores, 4-13 = Parasitoids, 14-16 = Predators, 17 = Predators / Scavengers; [1)]Apoidea sensu strict; [2)]Sphecidae sensu lato. [1&2)]family series that include several families of Hymenoptera.

Table 3. Family-level relative abundance and diversity of the two insect orders Coleoptera and Hymenoptera in the line-thinned and unthinned stand of *Cryptomeria japonica* plantations in Kuchiotani, during the period from April to October 2004.

| Families of Coleoptera | Relative abundance (%) Thinned | Retained | Control | Families and family series of Hymenoptera | Relative abundance (%) Thinned | Retained | Control |
|---|---|---|---|---|---|---|---|
| 1. Chrysomelidae | 8.7 | 6.8 | 7.9 | 1. Apiformes (bees)[1] | 14.5 | 13.1 | 8.9 |
| 2. Curculionidae | 15.8 | 17.0 | 20.0 | 2. Cephidae | 0.1 | 0.1 | 0.2 |
| 3. Lycidae | 5.2 | 5.0 | 4.8 | 3. Tenthredinidae | 3.3 | 2.6 | 1.8 |
| 4. Tenebrionidae | 4.9 | 5.9 | 7.5 | 4. Braconidae | 7.7 | 10.7 | 7.0 |
| 5. Oedemeridae | 0.6 | 0.2 | 0.3 | 5. Ichneumonidae | 42.5 | 33.9 | 34.8 |
| 6. Elateridae | 10.3 | 9.0 | 8.5 | 6. Bethylidae | 0.1 | 0.2 | 0 |
| 7. Scarabaeidae[1] | 11.7 | 11.4 | 10.2 | 7. Diapriidae | 6.9 | 7.0 | 5.6 |
| 8. Mordellidae | 19.2 | 25.0 | 21.2 | 8. Dryinidae | 0.2 | 0 | 0 |
| 9. Cerambycidae | 4.0 | 3.3 | 3.3 | 9. Platygasteridae | 0.1 | 0.1 | 0.1 |
| 10. Scolytidae | 2.0 | 0.7 | 3.3 | 10. Proctotrupidae | 0.1 | 0.1 | 0 |
| 11. Erotylidae | 2.0 | 1.6 | 0.5 | 11. Scelionidae | 0.5 | 0.1 | 0.6 |
| 12. Nitidulidae | 3.2 | 3.1 | 2.3 | 12. Pompilidae | 4.9 | 6.9 | 5.6 |
| 13. Scarabaeidae[2] | 0 | 0.1 | 0 | 13. Spheciformes[2] | 1.3 | 1.3 | 0.4 |
| 14. Carabidae | 2.3 | 3.3 | 2.2 | 14. Vespidae | 0 | 0.1 | 0 |
| 15. Staphylinidae | 8.4 | 6.6 | 6.7 | 15. Siricidae | 0 | 0.1 | 0 |
| 16. Cantharidae | 1.7 | 0.7 | 1.3 | 16. Formicidae (ants) | 17.8 | 23.7 | 35.0 |
| Diversity index | 2.09 | 1.92 | 2.01 | Diversity index | 1.80 | 1.79 | 1.60 |

**Coleoptera** (Left): 1-2, 5-6 = Plant feeders, 3 = Polyphagous, 4 = Scavengers, 7-8 = Rotten wood feeders/plant feeders, 9-10 = Wood or bark borers, 11-12 = Mushroom feeders, 13 = Dung feeders, 14-16 = Predators.
[1]Excluding Scarabaeinae and Aphodiinae, [2]Scarabaeinae and Aphodiinae.

**Hymenoptera** (Right): 1 = Pollinators, 2-11 = Parasitoids, 12-14 = Predators, 15 = Decomposers, 16 = Predators / Scavengers; [1]Apoidea sensu strict; [2]Sphecidae sensu lato. [1&2]family series that include several families of Hymenoptera.

In Kuchiotani, we identified fifteen common families of Coleoptera in the retained section and fourteen common families (excluding dung beetles) in the thinned section and control plot (Table 3). Chrysomelidae, Curculionidae, Elateridae, Scarabaeidae, Mordellidae, and Staphylinidae were the most dominant families. Plant feeder Chrysomelidae, polyphagous Lycidae, scavenger Tenebrionidae, wood borer Cerambycidae, predator Carabidae and Staphylinidae, were more dominant in the thinned and retained sections of the treatment plot than in the control. The dung feeder Scarabaeidae was absent from the control plot. In addition to Coleoptera in Kuchiotani, we identified twelve families and two family series (Apiformes and Spheciformes) of Hymenoptera, and thirteen families and two family series (Apiformes and Spheciformes) in the thinned and retained sections of the treatment plot, respectively. However, only nine families and two family series (Apiformes and Spheciformes) were identified in the control plot. The families Ichneumonidae, Formicidae, and the series Apiformes were the most dominant families. Pollinator Apiformes, herbivore Tenthredinidae, parasitoid Braconidae and Diapriidae, predator Vespidae were more dominant in the thinned and retained sections of the treatment plot than in the control. Parasitoid Bethylidae, Dryinidae, and Proctotrupidae, and decomposer Siricidae were absent from the control plot.

In both sites, diversity of Coleoptera and Hymenoptera was higher in the thinned and retained sections of the treatment plot than in the control plot, as indicated by higher diversity indices (Table 2 and 3). In Sugi, diversity index of Coleoptera was highest in the retained section, while that of Hymenoptera was highest in the thinned section of the treatment plot. In Kuchiotani, diversity indices for both orders were highest in the thinned section of the treatment plot.

## Discussion

### Understory plants and insects in relation to thinning

Our results showed that line thinning markedly increased biomass and diversity of two important insect orders in the two *C. japonica* plantations. The strong across-site positive relationships between biomass of understory vegetation and biomass of Coleoptera and Hymenoptera (Fig. 1) suggest that increased habitat availability created by line-thinning contributes to increasing biomass of other forest-dwelling organisms.

The increase in the diversity of plant and insect communities after line thinning is likely to reflect increases of overall biodiversity in the plantation ecosystem (Maleque *et al.* 2006). Short-interval thinning can have negative impacts on the composition of understory vegetation cover such as decreasing diversity and biomass (e.g., Halpern *et al.* 2005, Beese and Bryant 1999). Several studies, however, have shown that thinning can increase diversity and biomass of understory vegetation given sufficient time intervals for recovery of understory vegetation after thinning (e.g., Clinton 2003, Kerr 1999). Southwood *et al.* (1979) found that 'taxonomic diversity' of plants and insects increased up to 16 months after thinning and thereafter, plant diversity decreased at higher rates compared to those of insect diversity. These results suggest that longer thinning interval creates higher 'plant structural diversity' (represented by higher plant biomass in this study) which maintains high biodiversity of insect communities. Many insect groups can quickly colonize a site after thinning. For example, Ohsawa (2005) found slightly higher abundance of Curculionidae in the middle-aged (21-45 years old) larch (*Larix kaempferi* Lamb.) plantations in only 1.5-2.5 years after thinning in the central mountainous region of Japan. Germain *et al.* (2005) found higher abundance of generalist Carabidae in only two years after logging in Canada.

Diversity of both Coleoptera and Hymenoptera increased in abundance and diversity in response to line thinning. Dominance of plant feeder Chrysomelidae, Curculionidae, polyphagous Lycidae, scavenger Tenebrionidae, root feeder Elateridae, wood borer Cerambycidae, and pollinator Apiformes (bees) increased in the thinned and retained sections presumably because these sections hosted microclimatically heterogeneous habitats due to presence of more understory vegetation (Weisser and Siemann 2004, Siemann 1998). The presence of more understory vegetation in the line-thinned stand is likely to have contributed to greater dominance of flower-visiting beetles of Chrysomelidae, Curculionidae, and Cerambycidae (Maeto and Fukuyama 1995). Ohsawa (2004) found that thinning increased wood borer Cerambycidae in larch (*L. kaempferi*) plantations in the central mountainous region of Japan. Because predator Carabidae prefers open habitats (e.g., Magura *et al.* 2002, Magura *et al.* 2000), line-thinned stand, which included open habitats, hosted more abundant Carabidae (Maleque *et al.*, unpublished data). A group of similar studies have shown that thinning increased herb and shrub cover, which lead to high species richness of Carabidae (Magura 2002, Magura *et al.* 2001, Magura *et al.* 2000).

Overall, unthinned stands supported lower diversity of Coleoptera and Hymenoptera. Notably, some important families were missing from the unthinned stand. For example, the absence of various herbivores and parasitoids from the unthinned stand in Sugi suggested that important ecological interactions such as herbivory and parasitism may not be functioning in this site. The absence of the decomposer Siricidae from the unthinned stand in Kuchiotani suggested that deleterious chemicals in the decomposed conifer foliage in the unthinned stand may directly reduce insect diversity and indirectly reduce nutrient cycling (review by Kerr 1999).

**Possible mechanisms for enhancing biodiversity of plantation forests**

Although this paper reports on two case studies of line thinning, we can make some inferences about the underlying mechanisms for enhancing biodiversity of plantation forests. We contend that both landscape- and stand-level aspects are important factors contributing to differences in insect diversity between the two sites. The landscape of the Kuchiotani area comprised of primary and secondary cool-temperate deciduous forests that provided source habitats for insect immigration into the thinned stand. In addition, widths of the line-thinned sections were wider, slope was gentler and time since thinning was longer in this site. These factors are likely to have contributed to increasing insect biomass in Kuchiotani. In contrast, the landscape of the Sugi area comprised more than 80% even-aged, structurally homogeneous conifer plantations, which limited source habitats for plant and insect immigration into the thinned stands. Line-thinned sections were narrower, slope was steeper, and time since thinning was shorter in Sugi than in Kuchiotani. These factors are likely to have contributed to the lower insect biomass found in Sugi compared with Kuchiotani.

The difference in the climatic conditions between the two sites may also have caused the difference in the biodiversity of the two plantations. The Kuchiotani site, located at a higher elevation with cool and humid climatic conditions, hosted many insect groups that prefer cooler and more humid habitats. For example, the families Staphylinidae, Scarabaeidae, Mordellidae, Erotylidae, and Nitidulidae, of the order Coleoptera, and the families Ichneumonidae and Braconidae of the order Hymenoptera, were more abundant in the Kuchiotani site (Uéno *et al.* 1999, Kurosawa *et al.* 1998; Hawkins *et al.* 1992, Goulet and Huber 1993).

In agreement with the above findings, Kerr (1999) shows that landscape patterns exert great influences on biodiversity conditions in managed forests. Thus, landscape-level influences on insect biodiversity need to be considered when applying silvicultural treatments to enhance biodiversity.

**Conclusion**

Several studies have shown that thinning simultaneously increases timber growth rate, maintains wood quality, creates more sun-exposed understory conditions, increases diversity, biomass and cover of understory plants (Griffis *et al.* 2001, Thomas *et al.* 1999). Overstocked plantations in Japan must be thinned to increase timber production and economic gain as well as ecosystem functions (Inagaki *et al.* 2003, Halpern *et al.* 1999). Line thinning is a cost-effective and easily executable silvicultural treatment for plantation management in Japan (Taniguchi 2003). Our study showed that line thinning also enhanced biomass and diversity of important insect groups in the overstocked plantations. Because arthropod diversity reflects overall ecosystem integrity, as well as diversity of other forest-dwelling organisms, we conclude that line thinning is an economically and ecologically effective silvicultural treatment for ecosystem management in *C. japonica* plantations in Japan.

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