Activity of flying beetles (Coleoptera) at two heights in canopy gaps and intact forests in a hardwood forest in Quebec

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Abstract—We studied the effects of forest height and forest gap on assemblages of flying beetles in an American beech (*Fagus grandifolia* Ehrh. (Fagaceae) – sugar maple (*Acer saccharum* Marsh. (Aceraceae)) forest in Quebec. From June until August of 2005, beetles were collected in Lindgren funnel traps placed in the canopy (20–25 m height) and upper understorey (3–5 m height) in proximity to five forest gaps (15–30 m in diameter) (at the edge of the forest opening or within the closed-canopy forest). We collected 1852 beetles representing 38 families and 172 species. Based on rarefaction curves, species richness was significantly higher in the canopy than in the upper understorey. Nonmetric multidimensional scaling ordination revealed a change in species composition in relation to vertical stratification but not to the forest gaps. Our findings confirmed the importance of the vertical forest gradient to overall diversity of forest coleopterans.

Résumé—Nous avons étudié les effets de l'ouverture et de la structure verticale du couvert forestier sur la structure des assemblages de Coléoptères dans une hêtraie (*Fagus grandifolia* Ehrh., Fagaceae) – érable à sucre (*Acer saccharum* Marsh., Aceraceae) au Québec. Les Coléoptères ont été échantillonnés à l'aide de pièges Lindgren positionnés dans la canopée (20–25 m de hauteur) et en sous-couvert (5 m de hauteur) à proximité de 5 trouées de 15–30 m de diamètre (en bordure de la trouée *versus* forêt d'intérieur) et ce du début juin à la fin d'août 2005; 1852 individus appartenant à 172 espèces et 41 familles ont été collectés. La richesse spécifique, estimée à l'aide de courbes de raréfaction, s'est montrée plus élevée dans la canopée. Un cadrage non -métrique multidimensionel a démontré un changement au niveau de la composition spécifique en lien avec la position verticale des pièges, mais non au niveau de la proximité aux trouées. Notre étude confirme que la diversité structurelle fournie par le gradient vertical en forêt contribue de façon importante à la diversité des Coléoptères en milieu forestier.

Spatial heterogeneity conferred by forest gaps and vertical forest position is important to species diversity and community composition (Hoonbok and Moldenke 2005; Ulyshen and Hanula 2007), and diversity relates in important ways to ecosystem stability and function (Naeem 2002). The decline in American beech (*Fagus grandifolia* Ehrh. (Fagaceae) – sugar maple (*Acer saccharum* Marsh. (Aceraceae) (hereinafter beech–maple)) forests in parts of eastern Canada as a result of urban and agricultural encroachment, pollution, and tree diseases (Krasny and Whitmore 1992; Darveau *et al.* 1997) emphasizes the importance of documenting forest diversity, including the canopy. Beetles (Coleoptera) are a model study taxon, given their high diversity and key roles in forest ecosystems (Langor and Spence 2006).

In few studies of beetles in North American north-temperate forests have both the understorey and the canopy been sampled (but see Su and Woods 2001; Vance *et al.* 2003; Ulyshen and Hanula 2007). Research in the

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southeastern United States of America depicts a higher diversity of Coleoptera in the understorey than in the canopy, and distinct stratification of beetles in these two strata (Ulyshen and Hanula 2007). Vance *et al.* (2003) found differences between the Cerambycidae fauna in the canopy and that in the understorey. North-temperate forests are heterogeneous environments, and the effects of vertical stratification do not operate independently of other influences, including the effects of small forest gaps. We know little about the effects of forest gaps on Coleoptera communities in north-temperate forests, even though these openings are expected to have a significant influence (Ulyshen *et al.* 2006). With this framework, and using a north-temperate beech–maple forest as our study system, our objective was to compare species richness and community composition of flying beetles as a function of proximity to small canopy gaps and vertical forest position.

We worked at the Morgan Arboretum (45°4′N, 73°9′W), a 245 ha forest on the Island of Montréal, Quebec. We selected five sampling locations that were dominated by mature American beech (*Fagus grandifolia* Ehrh. (Fagaceae)) and sugar maple (*Acer saccharum* Marsh. (Aceraceae)) trees (generally over 80 years old and >25 m in height), contained a naturally occurring forest gap (15–30 m diameter), were at least 50 m apart, and were accessible to our aerial lift platform. Beetles were sampled using four 8-stacked Lindgren funnel traps (Lindgren 1983) in each of the five locations (20 traps in total): (1) canopy–gap; (2) upper understorey–gap; (3) canopy–forest; and (4) upper understorey–forest. Light exposure was standardized by selecting trap locations close to the south edge of the forest opening. The two forest-gap traps were hung from a tree at the edge of the opening at heights of approximately 3–5 m (understorey) and 20–25 m (canopy). We could not hang the understorey traps lower because of animal disturbance, but felt that 3–5 m was representative of the sapling and upper shrub layer and in a relatively different stratum from the canopy. The other two traps were set up at similar heights but approximately 15 m into the forest, adjacent to the opening. The traps were hung from either American beech or sugar maple trees. It was beyond the scope of the study to investigate effects by tree species. To minimize this potential effect, traps were suspended several metres from tree boles.

Unbaited Lindgren funnel traps were installed with the use of a mobile aerial-lift platform (Larrivée and Buddle 2009), and because it requires a 2 m wide path for access, sampling locations were located along a footpath. Collection cups were filled with a mixture of water, soap, and propylene glycol. Traps were open for a continuous sampling period of about 10 weeks from the beginning of June until early August 2005. Beetles were sorted and identified to species whenever possible; 23% of the species (39 morphospecies) were determined only to genus or family level. Voucher specimens were deposited in the Lyman Entomological Museum, McGill University, Ste. Anne de Bellevue, Quebec.

Collection dates were pooled to focus on questions of vertical position and forest gaps, not phenology. To test the effects of gaps and vertical position on species richness, we generated individual-based rarefaction curves (Gotelli and Entsminger 2008) and compared estimates of species richness by trap location; this technique provides a less biased estimate of species richness than raw species richness or other indices (Buddle *et al.* 2005). The relative abundances of all species pooled, and of the most commonly collected species (determined as species abundances over 3% of the total number of individuals collected), were analyzed using a two-factor analysis of variance (ANOVA) with vertical position and proximity to forest opening as the two main factors. SAS (SAS Institute Inc. 1999) was used for ANOVAs. Data were log-transformed when assumptions for parametric statistics were not met.

To assess the effects of forest openings and vertical position of traps on community composition we analyzed beetle assemblages by means of nonmetric multidimensional ordination techniques using PCORD version 4.17 (McCune and Grace 2002). Abundance data were log-transformed to diminish the weight of the most commonly collected

Table 1. Species richness and relative abundances of beetle (Coleoptera) families and a subfamily collected in Lindgren funnel traps in the canopy and upper understorey of a beech–maple forest in southern Quebec from June to August of 2005.

Family	Species richness	No. of individuals
Cerambycidae	21	150
Elateridae	20	103
Melandryidae	11	53
Nitidulidae	11	131
Alleculidae	10	100
Cleridae	9	43
Scolytinae	3	89
Carabidae	2	100
Latridiidae	2	693
Other families*	83	390
Total	172	1852

*Anobiidae, Anthribiidae, Brentidae, Buprestidae, Cantharidae, Cephaloidae, Chrysomelidae, Ciidae, Coccinellidae, Corylophidae, Cucujidae, Curculionidae, Dermestidae, Elateridae, Erotylidae, Eucnemidae, Helodidae, Histeridae, Lampyridae, Lycidae, Mordellidae, Mycetophagidae, Nitidulidae, Phalacridae, Pyrochroidae, Ripiphoridae, Scarabaeidae, Silphidae, Sphinidae, Staphylinidae, Tenebrionidae, and Trogossitidae.

species, and we removed singletons and doubletons to reduce the influence of transient species. Six-dimensional ordinations were performed first to evaluate the optimum number of axes required. Final ordinations were compared with randomly derived matrices using Monte-Carlo simulations. A detrended correspondence analysis plot was first completed and the output from this was used as the starting coordinates for the final nonmetric multidimensional scaling ordinations.

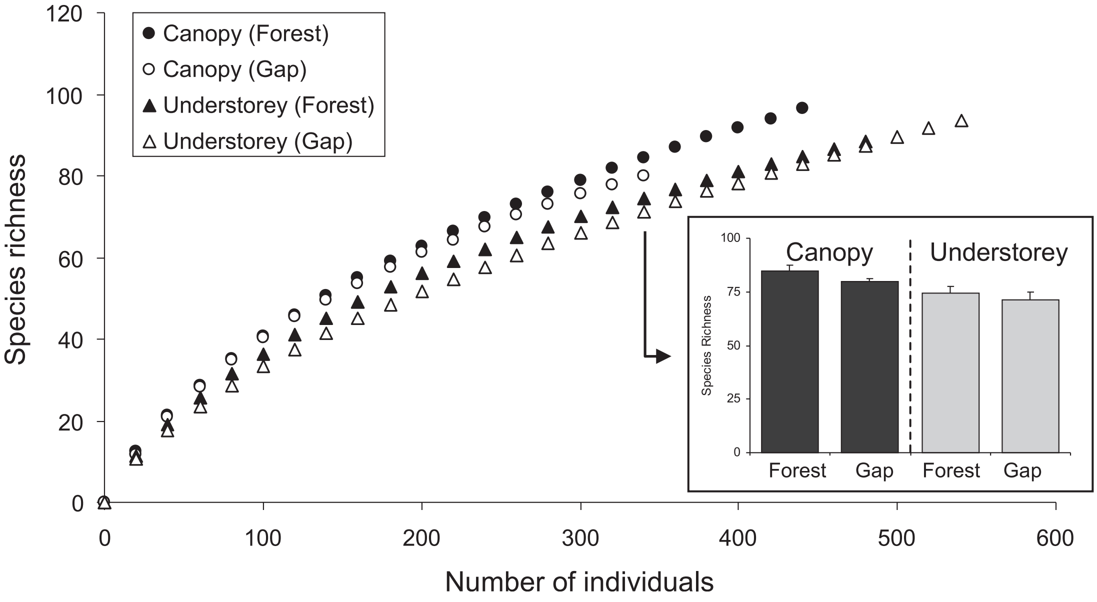
A total of 1852 individuals representing 172 species from 38 families was collected (Table 1). Of the total collection, 37% (690 individuals) belonged to a single species of *Corticaria* Marshall (Latridiidae). Other commonly collected species were *Cymindis cribricollis* Dejean (Carabidae, 90 individuals), *Xyleborus sayi* Hopkins (Curculionidae: Scolytinae, 87 individuals), and *Glischrochilus quadrisignatus* Say (Nitidulidae, 79 individuals). Forty-two species were unique to the canopy (27 collected once); 49 species were unique to the upper understorey layer (36 collected once). Most of the remaining species were infrequently collected (*i.e.*, fewer than 8 individuals), except for *Glischrochilus sanguinolentus* (Olivier) (23 individuals), which was never collected in the canopy. Forty-one species were collected only next to openings; 38 species were unique to the forest traps.

Rarefaction analyses depicted a significant difference (*i.e.*, non-overlapping standard deviations) in estimated species richness between assemblages located in the canopy and those in the upper understorey (the inset graph in Fig. 1 compares 340 individuals), but no difference between those in forest gaps and in the interior (Fig. 1). Two-factor ANOVAs showed no significant differences by main effects, nor were interaction terms significant for any response variable tested (P values ranged from 0.103 to 0.848). The final three-dimensional nonmetric multidimensional scaling ordination solution explained 70.8% of species variation by sample matrix and had a final stress value of 16.9 (30 iterations). Each axis was significantly different from random generation (Monte-Carlo simulation, $n = 100$; $P < 0.05$ for all axes). This ordination depicts few effects of forest location (interior *versus* gap), but does show an effect of vertical position (Fig. 2); most samples from canopy traps occupied a different ordination space than those from traps placed in the upper understorey.

The difference between communities along the vertical gradient is likely due to differences in physical and biological characteristics. The heterogeneity in primary producer species (Davidson 1997; Van Bael *et al.* 2003), predator species (Van Bael *et al.* 2003), and spatial patterns conferred by vertical forest position may act in combination to producethe observed patterns in arthropod community composition. Owing to the difference due to the vertical gradient, each type of forest structure may provide unique habitat and food sources, leading to differences in community composition and habitat specialization.

The difference in forest structure offered by the vertical gradient may explain the higher diversity in the canopy that we found: in our

Fig. 1. Individual-based rarefaction estimates of species richness of beetles (Coleoptera) as a function of sampling effort (number of individuals collected). Collections represent samples from Lindgren funnel traps placed in the forest interior and in gaps in both the canopy (25 m height) and upper understorey (3–5 m height) of a beech–maple forest in southern Quebec from June to August of 2005. The inset graph shows species richness (±1 SD) for a subsample of 340 individuals.

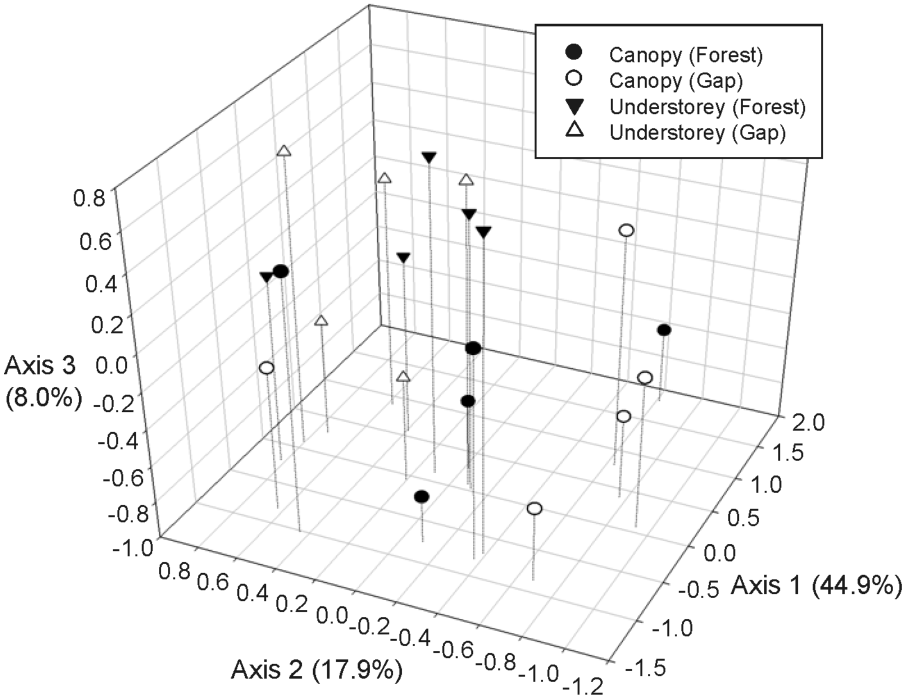


study forests, the canopy has a high leaf/branch density and may yield more fungal fruiting bodies than the shrub layer (personal observation). So more habitat and structure may be available to beetles in the canopy, at least compared with the upper understorey, and this may translate to higher species richness. Unlike tropical systems, where the presence of epiphytes may explain the elevated diversity of canopy arthropods, in temperate forests plant diversity is highest in the understorey, and we predicated higher beetle diversity in this stratum. However, our results did not support this, perhaps because our shrub-layer traps were located above the ground vegetation and we did not sample the fauna associated with the lower herbaceous layer. If we had sampled closer to the ground, understorey beetle diversity would have been higher (Hill and Cermak 1997), a finding reported by Ulyshen and Hanula (2007).

The lack of a strong difference in species richness between the forest openings and the interior may have been due to spatial scale: the interior traps may not have been far enough away from the forest openings. Insect communities are affected by the unique habitat characteristics (structure, microclimate, and plant type/quality) of forest openings, and the degree of difference varies with age, size, and origin of the opening (Ulyshen *et al.* 2005). Also, we recognize that our sample was small, and broader sampling (*i.e.*, more traps, longer time period) may reveal stronger effects.

Overall beetle diversity in this small forest on the Island of Montréal was impressive. Over 170 species were collected and most were rare in our traps. These data provide important baseline information for future biodiversity studies and illustrate how diversity can be readily discovered in Canada's "urban" forests. Our findings may serve to supplement future entomological studies and shed light on the role of the structural diversity offered by the vertical forest gradient in determining patterns of forest beetle diversity.

Fig. 2. Three-dimensional solution for nonmetric multidimensional scaling ordination of samples (Lindgren funnel traps, *n* = 20) placed in the forest interior and in gaps in both the canopy (25 m height) and upper understorey (3–5 m height) of a beech–maple forest in southern Quebec from June to August of 2005. Ordination was based on 62 species of Coleoptera (singletons and doubletons were removed prior to analysis) and relative-abundance data were log-transformed prior to analysis. Values in parentheses show percent variation explained by each axis.



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