Effects of two silvicultural practices on ground beetles (Coleoptera: Carabidae) in a northern hardwood forest, Quebec, Canada

Jean-David Moore, Rock Ouimet, Daniel Houle, and Claude Camiré

Abstract: The impact of selective cutting (6 and 8 years after treatment) and strip clear-cutting (12 and 13 years after treatment) on abundance and diversity of carabid beetles was evaluated in a northern hardwood forest of Quebec, Canada. A total of 1078 individuals belonging to 14 species were captured with pitfall traps from June to September 1996 during 2568 day-trap. Abundance of *Synuchus impunctatus* Say was significantly higher in clear-cut compared with uncut control strips. There were no within-species differences between selectively cut and uncut plots. None of these two silvicultural systems had any significant impacts on species diversity and richness 6–13 years after treatment. Although we observed an effect of strip clear-cutting on the abundance of *S. impunctatus* in this northern hardwood forest, the discrepancy between the response of carabids to forest disturbance in this study compared with other studies in different ecological regions suggests that the same carabid beetle species cannot be used as an indicator of forest disturbance over a large region. Our results suggest the use of carabid beetles as a disturbance indicator at the ecological-type scale (relatively similar soil and forest type) in a given region.

Résumé : L’impact de la coupe de jardinage (6 et 8 ans après le traitement) et de la coupe totale par bande (12 et 13 ans après le traitement) sur l’abondance et la diversité des carabes a été évalué dans une érablière à bouleau jaune des Basses Laurentides de la région de Québec (Canada). Un total de 1078 carabes, appartenant à 14 espèces, ont été capturés à l’aide de pièges à fosse de juin à septembre 1996, durant 2568 jours-pièges. L’abondance de *Synuchus impunctatus* Say était significativement plus élevée dans les bandes coupées, comparativement aux bandes témoins non coupées. Aucune différence d’abondance n’a été observée pour les différentes espèces entre les forêts jardinées et témoins. Aucune des deux pratiques sylvicoles n’a eu d’impact significatif sur la diversité et la richesse en espèces des carabes pour les périodes étudiées. Cette étude soulève aussi des questions concernant la niche écologique de certaines espèces de carabe. En effet, bien que nous ayons observé un effet de la coupe par bande sur l’abondance de *S. impunctatus* dans l’érablière de Duchesnay, les résultats divergeants entre notre étude et celles réalisées dans des régions écologiques différentes suggèrent qu’une même espèce de carabe ne peut être utilisée sur de grandes régions comme indicateur de perturbation en milieu forestier. Nos résultats suggèrent plutôt une utilisation des carabes à une échelle plus locale, par exemple à l’échelle du type écologique (sol et type forestier relativement semblables) dans une région donnée.

Introduction

Conservation of biodiversity, as a criterion of sustainable forest management, has increased in concern over the last decade (Government of Canada 1995; Dallmeier 1996), triggering an increasing need for the use of indicator taxa to assess and monitor the impact of forest practices.

Carabid beetles have been often used as indicators of forest disturbance in North America (Lenski 1982a; Jennings et al. 1986; Martel et al. 1991; Duchesne and McAlpine 1993; Niemelä et al. 1993, 1994; Bailey et al. 1994; Addison and Barber 1997; Beaudry et al. 1997; Duchesne et al. 1999; Werner and Raffa 2000) and Europe (Day and Carthy 1988; Baguette 1993; Butterfield et al. 1995; Magura et al. 1997, 2000, 2001). This is mainly related to their wide distribution in terrestrial ecosystems and to their sensitivity to environmental changes (Thiele 1977; Refseth 1980; Heijerman and Turin 1994; Langor et al. 1994; Eyre et al. 1996). Because carabid beetles show different degrees of habitat selectivity, they can be used to characterize habitat disturbance (Niemelä 1990). For this reason, they are often classified as forest specialists (species that are most abundant in closed mature forests), forest-habitat generalist (species that occur in various types of forest habitats, both open and closed for-
ests), and open-habitat generalists. Carabid beetles also fulfill many other criteria for being selected as bioindicators (Niemelä 2000; Rainio and Niemelä 2003). For instance, as predators of other soil fauna (Thiele 1977), carabid beetles integrate ecological information on the nature and structure of soil communities at lower trophic levels (Day and Carthy 1988).

In Canada and northeastern United States, some studies documented the effects of coniferous forest harvesting on carabid beetles (Jennings et al. 1986; Duchesne and McAlpine 1993; Niemelä et al. 1993; Addison and Barber 1997; Beaudry et al. 1997; Duchesne et al. 1999). Generally, species richness and diversity increased after forest harvesting. Although the effects of silvicultural practices on carabid beetle species have been assessed for coniferous forests, there were only two studies to our knowledge that concerned the northern hardwood forests of North America (Werner and Raffa 2000; Vance and Nol 2003). Werner and Raffa (2000) reported no difference in species richness or abundance and few differences in species diversity among even-aged (from selective cutting), uneven-aged (from clear-cutting), and old-growth forests in northern hardwood stands located in Michigan and Wisconsin. Vance and Nol (2003) observed significant reductions (>50%) in densities of carabids in recently (0.5–3 years postlogging) selective-cut forests in Ontario. Beetle communities in older, selective-cut forests (15–20 years postlogging) contained densities and species composition similar to uncut control stands. At Duchesnay (Quebec), Carabidae have been investigated with other soil organisms by Moore et al. (2002), but only at the family level. Given the potential of this group as indicators of forest disturbances, Carabidae have been further examined at the species level.

The objective of this study was to evaluate the effect of 6- and 8-year-old selective cutting and 12- and 13-year-old strip clear-cutting on relative abundance, species richness, and diversity of carabid beetles, compared with uncut controls, in a northern hardwood forest of the Lower Laurentians of Quebec. Consequently, we wanted to evaluate whether some carabid species were indicators of forest disturbance at this ecological-type scale.

**Materials and methods**

**Site description**

The Duchesnay forest station (46°57′N, 71°40′W) is located approximately 50 km northwest of Québec, Que., Canada (Fig. 1). Elevation varies between 200 and 400 m and average slope is approximately 10%. Mean annual temperature is 3.4 °C and annual precipitation is 1300 mm. Soils are classified as Orthic Ferro-Humic Podzol (Soil Classification Working Group 1998) or Typic Haplorthod (Soil Survey Staff 1998) and pertain to the stony loamy sand of the Ste-Agathe series and shallow St-Colomban terrain (Raymond et al. 1976). The humus is of mor type, and the main surface deposit is a very acidic and stony glacial till, locally derived from the underlying bedrock made of the Grenville quartzic gneiss.

Two silvicultural practices were examined in this study: selective cutting and strip clear-cutting. In the selective cutting and strip clear-cutting areas, the forest was dominated by mature (85–130 years old) sugar maples (*Acer saccharum* Marsh.) in association with yellow birch (*Betula alleghaniensis* Britt.) and American beech (*Fagus grandifolia* Ehrh.), making up a closed forest canopy. Strip clear-cutting was implemented in 1983 and 1984. The strips (cut and un-
cut) were 60 m wide and approximately 1000 m long, one cut strip alternating with an uncut strip (control) of mature sugar maple stands, repeated two times. One of the two uncut control areas was a forest patch adjacent to a clear-cut strip. Regeneration established rapidly in strip clearcuts, making up a dense stand of pin cherry (Prunus pensylvanica L. f.) and yellow birch of approximately 3.5 m height, 12 and 13 years after treatment.

In the selective-cut plots, small gaps were created in 1988 and 1990. Characteristics of the selective-cut sites may be found in detail in Majcen and Richard (1995) and Majcen (1996). In brief, each of the two selective-cut plots included a block of 2 ha in the treated area and a block of 1 ha in the untreated area (control). Blocks were surrounded by a protection strip of 50 m in width that were subjected to selective cutting in the same manner, and these strips were surrounded by forest vegetation of the same type. The selective-cut plots were declared protected areas for other research projects, and therefore, our study was done in the protection strips (see below). Whereas the strip clear-cutting areas were adjacent to each other, the distance between the two selective cutting areas was approximately 9 km. Basal area in the control plots in 1988 and 1990 were 26.4 and 24.7 m²·ha⁻¹, respectively. Basal area before and after cuts were, respectively, 25.6 and 17.5 m²·ha⁻¹ in 1988 (32% decrease) and 24.9 and 18.8 m²·ha⁻¹ in 1990 (25% decrease).

Coarse woody debris were more abundant in treated plots than in controls given that noncommercial woody biomass was left on the plots after the cutting. However, there was no attempt to obtain a quantitative assessment of the coarse woody debris left on the sites.

Experimental setup
Pitfall arrays were established in June 1996 in two repetitions of the two silvicultural practices, each one associated to a control forest site, for a total of eight arrays and experimental units. Six pitfall traps were installed per array, for a total of 48 pitfall traps. No drift fences were used. In northern hardwood forests of Michigan and Wisconsin, Werner and Raffa (2000) indicated that only four pitfall traps were needed to capture 98% of all species.

In the strip clearcuts, the six pitfall traps were distributed every 15 m along a transect located at the center of the strips (or 30 m from the edge). In the selective cutting areas, traps were systematically placed in the middle of the protection strips (25 m from the adjacent forest), at the four corners of the plots, and in the middle of two opposite sides, with a minimal distance of 50 m between each trap. The pitfall traps were the “Multi-Pher” type (Jobin and Coulombe 1988). This slightly conical trap had a 20.5 cm height, with a diameter of 10.0 cm at the base and 13.0 cm at the top. A funnel of 4.0 cm diameter at the base was located in the top part of the trap. Some moist leaves were placed in the pitfall traps. No bait or preservative agents were used in the traps given the probable differential attractant or repellant effects on carabid species (Luff 1968; Greenslade and Greenslade 1971; Holopainen 1990, 1992). Opaque rain covers of 26 cm in diameter were placed at approximately 15 cm above pitfall traps.

Carabid beetles were collected every 2 days from June 26 to July 5, July 12 to August 16, and August 23 to September 2, 1996, for a total sampling effort of 57 days (or 2568 day-trap). Carabid beetles were identified to species using Larochelle (1976) and Bousquet and Larochelle (1993) identification keys. A small number (~20) of small carabid species (probably Bembidion or Trechus species) were damaged during storage before they could be identified.

Statistical analyses
For both the strip-cutting and the selective-cutting experiments, frequency tables of species abundance by block and treatment were constructed. We used the Cochran–Mantel–Haenszel $\chi^2$ statistic to test the association between species abundance in treated and control treatments, after adjusting for treatment replication. Diversity indices were also calculated for treatment replicates using the Shannon index to determine richness and evenness and the Simpson index as a measure of dominance (Magurran 1988). These indices were computed using the EstimateS program (Colwell 2000). Formulas used are as follows:

$$\text{Shannon index} = -\sum_{i=1}^{S} \left[ \frac{n_i}{n} \ln \left( \frac{n_i}{n} \right) \right]$$

$$\text{Simpson index} = \frac{\sum n_i(n_i - 1)}{n(n-1)}$$

where $n_i$ is the number of individuals in the $i$th species and $n$ is the total number of individuals for all species in the sample.

To facilitate interpretation of the results, we expressed Simpson indices as $1/$Simpson index, since low Simpson index values indicate high diversity (Magurran 1988). Indices were analysed with an ANOVA model with treatment replicates as blocks. Statistical procedures were performed using SAS v. 8.01 (SAS Institute Inc. 2000).

Results
Carabid beetles abundance
For all treatments, a total of 14 species and 1078 individuals of the Carabidae family were captured (Fig. 2). These included Pterostichus melanarius Ill., an introduced species. Catches were dominated by Synuchus impunctatus Say (42%), Pterostichus coracinus Newman (23%), Agonum retractum LeCompte (18%), and Pterostichus tristis Dejean (9%), amounting to 92% of the total catch. Other species caught are presented in Fig. 2.

Effects of silvicultural practices on species abundance
There was no significant difference in the abundance of carabid beetle species between treated and control stands for the selective cutting treatment (Table 1; Fig. 2a), except that one more species was found in the treated forest compared with the control areas: Pterostichus honestus Say.

In the strip clear-cutting areas, three more species were found in the selective cuts compared with the control areas: Platynus decensus Say, Pterostichus adoxus Say, and Trechus apicalis Motschulsky. Also, we found that Synuchus impunctatus was significantly more abundant in the strip clearcuts than in the adjacent undisturbed strips (Table 1;
No treatment effects were observed for the other species in the strip clearcuts (Fig. 2b).

### Species diversity
There was no difference for the different diversity indices between controls and strip clear-cutting (12 and 13 years after treatment) and selective cutting (6 and 8 years after treatment) (Table 2).

### Discussion
#### Carabid beetles abundance
The results of this study (14 carabid species and 1078 individuals; Fig. 2), combined with other studies in northern hardwood stands of Quebec, indicate a high variability of species richness and abundance of carabid beetles in these stands. In the Quebec Appalachian, Martel et al. (1991), over a 2-year period and using a similar day-trap number (~2600), reported that a total of 24 species (with a maximum of seven species captured by site for a given year) and 816 individuals were caught in 18 northern hardwood stands (72 sites) affected by canopy dieback, resulting in an opening of the canopy at various intensities. Levesque et al. (1976) captured 1288 and 355 carabid beetles representing 11 and 13 species, respectively, in two different sugar maple stands of the Lower Laurentides of Montréal (Quebec) over
a 3-year period and with a much higher day-trap number (50 000 day-trap for each stand).

When our total abundance data are compared with other Quebec studies, there is no emerging general pattern (Table 3). One or two of the four most abundant species in our study were also abundant in other northern hardwood stands of Quebec (Pterostichus coracinus and Synuchus impunctatus in Levesque et al. (1976) and in Martel et al. (1991); Agonum retracted and Pterostichus tristis in Levesque and Levesque (1986); Synuchus impunctatus in Saint-Germain and Mauffette (2001)). However, these species are not always abundant in this forest type (Agonum retracted in Levesque et al. (1976) and Martel et al. (1991); Pterostichus coracinus and Synuchus impunctatus in Levesque and Levesque (1986)). Also, some species considered as abundant in some Quebec northern hardwood stands were not abundant at our sites (Pterostichus pensylvanicus LeCompte in Levesque et al. (1976) and Levesque and Levesque (1986); Pterostichus adstrictus Eschscholtz in Martel et al. (1991)). Our collecting dates, however, may have affected the catch of some species, in particular Pterostichus adstrictus and Pterostichus pensylvanicus, given their higher abundance in spring (Levesque and Levesque 1986). Pterostichus pensylvanicus (Levesque et al. 1976; Levesque and Levesque (1986)) and Pterostichus adstrictus (Martel et al. 1991) could be abundant in sugar maple stands, so it is possible that a different catch result could be obtained over a complete sampling season (starting in May) for these two species.

Effects of silvicultural practices on species abundance

The absence of treatment effects on carabids abundance in the selective cutting areas suggests that the period of time since treatment (6 and 8 years) was long enough to restore habitat conditions suitable for the carabid beetles at Duchesnay or that low intensity, selective cutting have preserved habitat conditions that were similar to undisturbed forests. These observations are in agreement with previous studies in northern hardwood forests (Werner and Raffa 1991; Pearce et al. 2003). This result suggests that habitat conditions for these two species in managed sites at Duchesnay, 6–13 years after selective cutting or strip clear-cutting areas were as favourable as those prevailing in nontreated forests.

In the strip clear-cutting areas, abundance of Synuchus impunctatus was higher in the strip clearcut, as compared with the control forests, 12 and 13 years after treatment (Fig. 2b). This result is consistent with other Canadian studies that reported higher abundance of Synuchus impunctatus in regenerating coniferous or boreal stands when compared with mature forests (Table 3). Moreover, our results support the observations of Lindroth (1961–1969), who mentioned this species as an open-habitat species. These results, however, are inconsistent with other studies conducted in Quebec, Ontario, and northeastern United States, in which

<table>
<thead>
<tr>
<th>Carabidae (total)</th>
<th>Strip clear-cutting</th>
<th>P</th>
<th>Selective cutting</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>10.95</td>
<td>0.0009</td>
<td>1.51</td>
</tr>
<tr>
<td>Carabidae (without Synuchus impunctatus)</td>
<td>2.49</td>
<td>0.1145</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Carabidae (without Pterostichus coracinus)</td>
<td>13.37</td>
<td>0.0003</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Carabidae (without Synuchus impunctatus and Pterostichus coracinus)</td>
<td>0.14</td>
<td>0.7075</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 1. Analysis of frequency table of carabid beetle species using Cochran–Mantel–Haenszel \( \chi^2 \) statistics for managed and undisturbed sites.

Effects of silvicultural practices on species abundance

The absence of treatment effects on carabids abundance in the selective cutting areas suggests that the period of time since treatment (6 and 8 years) was long enough to restore habitat conditions suitable for the carabid beetles at Duchesnay or that low intensity, selective cutting have preserved habitat conditions that were similar to undisturbed forests. These observations are in agreement with previous studies in northern hardwood forests (Werner and Raffa 1991; Pearce et al. 2003). This result suggests that habitat conditions for these two species in managed sites at Duchesnay, 6–13 years after selective cutting or strip clear-cutting areas were as favourable as those prevailing in nontreated forests.

In the strip clear-cutting areas, abundance of Synuchus impunctatus was higher in the strip clearcut, as compared with the control forests, 12 and 13 years after treatment (Fig. 2b). This result is consistent with other Canadian studies that reported higher abundance of Synuchus impunctatus in regenerating coniferous or boreal stands when compared with mature forests (Table 3). Moreover, our results support the observations of Lindroth (1961–1969), who mentioned this species as an open-habitat species. These results, however, are inconsistent with other studies conducted in Quebec, Ontario, and northeastern United States, in which

<table>
<thead>
<tr>
<th>Species</th>
<th>Strip clear-cutting</th>
<th>P</th>
<th>Selective cutting</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synuchus impunctatus</td>
<td>9.5a</td>
<td>0.05</td>
<td>8.5a</td>
<td>0.05</td>
</tr>
<tr>
<td>Simpson*</td>
<td>4.12a</td>
<td>0.05</td>
<td>4.28a</td>
<td>0.05</td>
</tr>
<tr>
<td>Shannon index</td>
<td>1.62a</td>
<td>0.05</td>
<td>1.67a</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 2. Richness and diversity (treatment means) of carabid beetles for selective cutting and strip clear-cutting in 1996 at Duchesnay.

Synuchus impunctatus was reported as a forest-habitat generalist or a forest specialist species (Table 3). For instance, Saint-Germain and Mauffette (2001) observed a reduced catch of Synuchus impunctatus in a northern hardwood stand southeast of Montréal (Que., Canada) severely affected by the 1998 ice storm. In this study, Synuchus impunctatus was considered as a forest specialist species. Moreover, some studies reported no difference in the abundance of this species between treated and control forest stands within a few years after clear-cutting. In a study in northwestern Ontario, Pearce et al. (2003) showed that Synuchus impunctatus, as well as all other carabid species studied, were positively associated with coarse woody debris in clear-cut habitats. In our study, site observations indicated that coarse woody debris were more abundant in strip clear-cut than uncut control areas. This could explain, in part, the greater abundance of Synuchus impunctatus in strip clear-cut areas. This suggest that the same carabid beetle species may react differently to forest perturbation or have specific habitat requirements from one area to another depending on the ecological characteristics of this area (see below).

Another noticeable result in our study was the absence of treatment effects on the abundance of Agonum retracted and Sphaeroderus canadensis Chd. (Table 1). Indeed, these species have been generally reported as forest specialists in other studies (Table 3) whose abundance normally decreased shortly (5–10 years) after forest clear-cutting (Duchesne et al. 1999; Pearce et al. 2003). This result suggests that habitat conditions for these two species in managed sites at Duchesnay, 6–13 years after selective cutting or strip clear-cutting treatments, were as favourable as those prevailing in nontreated forests.

Given the relatively short distance (30 m) of the pitfall traps placed in the uncut control plots from the strip clear-cut area, it is possible that an edge effect occurred in the control sites. In a deciduous forest of Hungary, Magura et al. (2001) demonstrated that an edge effect can affect carabid assemblages as far as 50 m. However, Heliölä et al. (2001)
found that carabid assemblages in the edge were more similar to undisturbed forests than to clear-cut areas. Also, a study in coniferous forests of Alberta showed that no edge effect occurred for *Synuchus impunctatus* 2 years after clear-cutting (Spence et al. 1996). In this study, this species was clearly limited to a clear-cut area. Our study was not designed to test such an effect, and thus, we cannot make conclusions on the occurrence of an edge effect.

**Species diversity**

No difference was observed for the diversity indices in the selective cutting and strip clear-cutting areas when compared with their respective control forests (Table 2). This trend, however, is not consistent with previous studies that generally reported higher carabid species diversity in 1- to 19-year-old stands, when compared with mature control stands (Lenski 1982a, 1982b; Jennings et al. 1986; Niemelä et al. 1993; Beaudry et al. 1997; Duchesne et al. 1999). In this context, it is hypothesized that some characteristics of the managed sites contributed to buffer the effects of forest cutting on carabid communities. Among them, the presence of undisturbed forest areas near the treatments and the presence of many coarse woody debris left on site probably minimized the impacts of the silvicultural practices on soil fauna.

**Table 3. Habitat selection of carabid beetle species common to our study, based on other studies in Canada and northeastern United States**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Region and forest type</th>
<th>Time since perturbation* (years) or habitat study (HS)</th>
<th>Habitat selection†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addison and Barber 1997</td>
<td>Northern Ontario, boreal mixedwood</td>
<td>1–2 (PC, CC)</td>
<td>Agonum lutulentum</td>
</tr>
<tr>
<td>Bailey et al. 1994</td>
<td>Western Maryland</td>
<td>&lt;3, 20–30, 70–90, and &gt;100</td>
<td>Agonum retractum</td>
</tr>
<tr>
<td>Barlow 1970</td>
<td>Quebec, diverse habitats</td>
<td>HS</td>
<td>Platynus decentis</td>
</tr>
<tr>
<td>Beaudry et al. 1997</td>
<td>Ontario, conifer</td>
<td>1–2 (CC)</td>
<td>Pterostichus adstrictus</td>
</tr>
<tr>
<td>Duchesne and McAlpine 1993</td>
<td>Ontario, conifer</td>
<td>1 (CC)</td>
<td>(F?)</td>
</tr>
<tr>
<td>Duchesne et al. 1999</td>
<td>Ontario, boreal mixedwood</td>
<td>7 and 9 (CC)</td>
<td>Gariépy et al. 1977</td>
</tr>
<tr>
<td>Jennings et al. 1986</td>
<td>Maine, conifer</td>
<td>1–6 (SCC)</td>
<td>(n.r.)</td>
</tr>
<tr>
<td>Lenski 1982a</td>
<td>North Carolina, hardwood</td>
<td>1–6 (CC)</td>
<td>(n.r.)</td>
</tr>
<tr>
<td>Levesque et al. 1976</td>
<td>Quebec, diverse habitats</td>
<td>HS</td>
<td>(X)</td>
</tr>
<tr>
<td>Lindroth 1961–1969</td>
<td>Quebec, northern hardwood</td>
<td>HS</td>
<td>O</td>
</tr>
<tr>
<td>Martel et al. 1991¹</td>
<td>Quebec, northern hardwood</td>
<td>Forest dieback</td>
<td>(X)</td>
</tr>
<tr>
<td>Niemelä et al. 1993</td>
<td>Alberta, boreal</td>
<td>1, 2, 9, 14–19, and 27 (CC)</td>
<td>O</td>
</tr>
<tr>
<td>Pearce et al. 2003</td>
<td>Ontario, boreal (diverse)</td>
<td>5–10 (CC)</td>
<td>(n.r.)</td>
</tr>
<tr>
<td>Saint-Germain and Mauffette 2001</td>
<td>Quebec, northern hardwood</td>
<td>1 and 2, ice storm</td>
<td>X</td>
</tr>
<tr>
<td>Spence et al. 1996</td>
<td>Alberta, conifer</td>
<td>2, 8, 40, 60, &gt;120 (CC)</td>
<td>n.r.</td>
</tr>
<tr>
<td>Vance and Nol 2003</td>
<td>Ontario, northern hardwood</td>
<td>0.5, 3, and 15–20 (PC)</td>
<td>n.r.</td>
</tr>
<tr>
<td>Werner and Raffa 2000</td>
<td>Wisconsin–Michigan, northern hardwood</td>
<td>4–~100 (CC, PC)</td>
<td>n.r.</td>
</tr>
<tr>
<td>This study</td>
<td>Quebec, northern hardwood</td>
<td>6–13 (PC, SCC)</td>
<td>(n.r.)</td>
</tr>
</tbody>
</table>

*PC, partial cutting; CC, clear-cutting; SCC, strip clear-cutting.
†n.r., no response to treatment; O, open-habitat species; G, forest-habitat generalist species; F, forest specialist species; X, present; ?, tendency or pole stands of 20–30 years old.
²Given that the short-term response of forest-habitat generalist and forest specialist species is a decrease in abundance of the population (Beaudry et al. 1997), this study, all species (except *Pterostichus coracinus*) were pooled. It is thus impossible to know the response of carabid beetles to forest dieback at higher number in old-logged stands when compared with recently logged and reference stands.
³This species was affected by forest management that included partial cutting (no cutting had occurred for at least 4 years prior to the study) and clear-cutting.
Also, conservation of the major part of the forest canopy in the selective cut areas and the fast vegetation recovery in the strip clearcuts probably played a role as well. Unfortunately, it was impossible to compare our biodiversity data with data of other northern hardwood stands of Quebec, given their absence.

Some factors may explain the differences between our study and other studies, such as habitat preferences and sampling intensity.

**Habitat preferences** — Habitat selection by carabid beetles may depend on many factors, such as vegetation composition and structure (Martel et al. 1991; Niemelä et al. 1992a; Magura 1997, 2000, 2001; Werner and Raffa 2000), edaphic conditions (e.g., humidity, acidity, litter thickness, soil type) (Szyszko 1974; Paje and Mossakowski 1984; Baguette 1993; Eyre and Luff 1994; Rykken et al. 1997; Guillemain et al. 1997; Magura et al. 2000; Pearce et al. 2003; Vance and Nol 2003), and the presence of coarse woody debris (Koivula and Niemelä 2003; Pearce et al. 2003). Werner and Raffa (2000) reported on the importance of microsite features in their study. Moreover, some studies mentioned that prey availability (Lenski 1982a; Loreau 1987; Niemelä et al. 1986; Guillemain et al. 1997; Magura et al. 2000) and the

<table>
<thead>
<tr>
<th>Pterostichus coracinus</th>
<th>Pterostichus honestus</th>
<th>Pterostichus melanarius</th>
<th>Pterostichus pensylvanicus</th>
<th>Pterostichus tristis</th>
<th>Sphaeroderus canadensis</th>
<th>Sphaeroderus lecontei</th>
<th>Synuchus impunctatus</th>
<th>Trechus apicalis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n.r.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>G</td>
<td>F</td>
<td>n.r.</td>
<td>F</td>
<td>n.r., G?</td>
<td>n.r.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n.r.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>G</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>G</td>
</tr>
<tr>
<td>n.r., F or G?³</td>
<td>(n.r.)</td>
<td>(n.r.)</td>
<td>(n.r.), F?</td>
<td>(n.r.), F?</td>
<td>(n.r.), F?</td>
<td>n.r.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>O</td>
<td>G</td>
<td>(F)</td>
<td>(G)</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>F</td>
<td>O</td>
<td>O?</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>O</td>
<td>G</td>
</tr>
<tr>
<td>n.r.</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n.r.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td>(F)</td>
<td>(F)</td>
<td></td>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X³</td>
<td>(X)</td>
<td>n.r.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X⁴</td>
<td>n.r., G?</td>
<td>n.r., G?</td>
<td>n.r., G?</td>
<td>n.r., G?</td>
<td>n.r., G?</td>
<td>n.r., G?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n.r., O?</td>
<td>(n.r.)</td>
<td>(n.r.)</td>
<td>(n.r.)</td>
<td>n.r., O?</td>
<td>(n.r.)</td>
<td>O</td>
<td>(n.r.)</td>
<td></td>
</tr>
</tbody>
</table>

authors’ opinion; parenthesis indicates a nonabundant species.

1997), we cannot distinguish with certainty which group they represent. the species level.

cutting (originated from a clearcut around the turn of the 1900s).

at Duchesnay (Moore et al. 2002). Also, conservation of the major part of the forest canopy in the selective cut areas and the fast vegetation recovery in the strip clearcuts probably played a role as well. Unfortunately, it was impossible to compare our biodiversity data with data of other northern hardwood stands of Quebec, given their absence.
presence of other predators (Niemelä et al. 1992b; Koivula and Niemelä 2003) may play an important role in the distribution of carabid beetle species and may thus influence their abundance, depending on the sensitivity of prey and other predators to forest disturbances. Finally, geographical location is important for the occurrence of species and the composition of communities (Eyre and Luff 1994; Heijerman and Turin 1994). Given that forest management may affect some of these factors, it is possible that a carabid species reacts differently after disturbance in a given area, depending on the ecological characteristics of this area and of the importance of the perturbation on the ecological features mentioned above. However, it is difficult to determine which factors carabid beetles were the most sensitive to, given the number of factors that can simultaneously affect carabids (Baguette 1993; Koivula 2002; Koivula and Niemelä 2003) and the possible interactions among these factors. In our study, the greater number of collembolans (Moore et al. 2002) and coarse woody debris observed in clear-cut strips, as compared with uncut areas, may have played a role in abundance of *Synuchus impunctatus*. Also, in the same area, carabid beetles were, by far, the main predators (Moore et al. 2002). This suggests that competition with other predator groups, as observed for example in other studies dealing with red wood ants (Niemelä et al. 1992b; Koivula and Niemelä 2003), was not a factor affecting carabid beetle community in our study. However, interspecific competition in carabid beetle assemblages is not well understood (Niemelä 1993).

A lack of knowledge on the ecology of carabids was noted recently by some researchers (Baguette 1993; Bailey et al. 1994; Spence et al. 1996; Magura et al. 2000; Werner and Raffa 2000; Pearce et al. 2003). In this context, it seems that the ecological requirements of some carabid beetles are not as well understood than previously reported in the scientific literature (Niemelä et al. 1994; Desender 1996; Dufrêne et Legendre 1997; Niemelä 2000). This may explain the different responses of carabid beetle species among studies (Table 3).

**Sampling intensity** — When interpreting our results and those of other studies, it should be kept in mind that relatively low numbers of replicates or short sampling periods were often used (Lenski 1982a; Jennings et al. 1986; Duchesne and McAlpine 1993; Bailey et al. 1994; Spence et al. 1996; Addison and Barber 1997; Beaudry et al. 1997; Duchesne et al. 1999; Pearce et al. 2003; Vance et al. 2003). Year-to-year variations in carabid population have been reported (Jennings et al. 1986; Bailey et al. 1994; Martel et al. 1991; Werner and Raffa 2000; Kotze and Niemelä 2002) because of, for example, climatological variations (Kotze and Niemelä 2002). Therefore, it is possible that a longer sampling effort may have yielded different results. Temperature and rain during our sampling period, however, were typical of long-term averages at the studied site (Moore et al. 2002).

One or a combination of factors may thus explain the contradictory results observed in the scientific literature. It seems, therefore, that carabid beetles must be used with caution as indicators of forest disturbances. Rykken et al. (1997) criticized the use of carabids as bioindicators in northern hardwood forests of Vermont, since they mainly have as forest-habitat generalist species. Moreover, our results, when compared with those of other studies made in relatively close forest areas (Table 3), suggest that carabid beetles cannot be used as indicators of forest disturbances over large regions, but should rather be used at a smaller scale (e.g., forest type). Similar findings were made by Rykken et al. (1997) in three ecological land types of Vermont, where the most significant effects on the relative abundance of carabid beetles were observed at the site scale. In this context, we recommend that long-term studies should be undertaken to better characterize the ecological requirements of carabid beetles and their sensitivity to forest disturbance at different ecological scales.

**Conclusion**

Overall, low intensity, selective cutting and strip clear-cutting had few impacts on carabid beetles abundance and diversity in the northern hardwood stands of Duchesnay, 6–13 years after cutting. However, the abundance of *Synuchus impunctatus* significantly increased 12 and 13 years after treatment in the strip clear-cutting area, suggesting that this species is a sensitive indicator of forest disturbance in the Duchesnay area. The contradictory results found in the literature for *Synuchus impunctatus* and for other carabid species suggest that habitat selection of many carabid beetles and, therefore, their response to forest management practices may differ from one region to the other. This interpretation questions the scale at which carabid beetles can be used as indicators of forest disturbances. Our findings suggest they could be used at the ecological-type scale (relatively similar soil and forest type over a given area) in a given ecological region (relatively similar climatic condition over a given area). Further studies will be needed, however, to confirm this hypothesis.

**Acknowledgements**

We are grateful to Maxime Pelletier and Danny Johnston for their invaluable assistance in the identification and preparation of the carabid beetles. We also thank Christian Hébert of the Laurentian Forestry Centre (Canadian Forest Service) for his technical support and the two anonymous reviewers for their constructive comments.

**References**


including Cicindelini) of America north of Mexico. Mem.


© 2004 NRC Canada


