PNFI Technical Reports

Petawawa National Forestry Institute, Chalk River, Ontario K0J 1J0, Canada

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Using Carabid Beetles (Coleoptera: Carabidae) as a Means to Investigate the Effect of Forestry Practices on Soil Diversity

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Abstract

Carabid beetles were collected through pitfall trapping from undisturbed stands of jack pine (*Pinus banksiana* Lamb.) and compared with carabid beetles from clear-cut sites and sites that had been clear-cut and burned-over. A total of 28 species of carabids was collected in this experiment. Species diversity was highest in burned-over sites and lowest in clear-cut sites. Carabid assemblages were found unique to each of the three treatments. Carabids were divided into four groups according to site preference: (1) burned-over sites, (2) clear-cut sites, (3) undisturbed sites, and (4) all three sites in similar proportions. Clear-cutting by itself and clear-cutting along with prescribed burning showed a trend toward increasing average carabid catches as compared to average carabid catches from undisturbed sites.

Introduction

Carabid beetles (Coleoptera:Carabidae) are an indicator of soil diversity after disturbance caused by forest fire (Holliday 1991a, 1991b), clear-cutting (Sustek 1981, 1984, Lenski 1982, Jennings et al. 1986, Langor et al. 1991), scarification (Parry and Rodger 1986), pollutants (Stubbe and Tietze 1982, Kolbe 1988), land reclamation (Day and Carthy 1988), management of primeval or old-growth forests (Niemelä et al. 1988, Terrel-Nield 1990), and climate change (Elias 1991). Carabids are good integrators of a substantial amount of ecological information about the biological communities to which they belong (Day and Carthy 1988) because they are important predators in forest soils. Moreover, they constitute a large fraction of the soil arthropod biomass and are efficient natural pest control agents (Edwards et al. 1979, Jennings et al. 1986, Sustek 1981, Weseloh 1985). Because carabids show different degrees of habitat selectivity, ranging from specialists to generalists (Niemelä 1990), carabid assemblages can be used to characterize disturbance in various habitats. Three aspects of carabid diversity are modulated by the environment: relative catches of each species within a particular forest site, absolute population size of individual species, and presence or absence of species within assemblages.

In North America, particularly in Canada, the effects of forest disturbance on carabid beetle diversity are not sufficiently documented. Preliminary work by Levesque et al. (1976) showed that carabid assemblages varied in individual species population size and in species diversity among nine different forest stands of the same forest region. However, these authors did not emphasize the effect of forest disturbance (Levesque et al. 1976). Langor et al. (1991) demonstrated that carabid assemblages differ between mature lodgepole pine stands and younger planted stands. Carabid species were grouped in three classes based on habitat preference: species with a preference for young stands, those that preferred mature stands, and the carabids present in both groups of stands. Similar results were found in aspen (*Populus*) and spruce (*Picea*) stands (Richardson

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and Holliday 1982, Holliday 1984, 1991a, 1991b) after wildfire. Furthermore, Holliday (1991b) found that carabid assemblages of burned-over aspen and spruce sites were similar to those of undisturbed aspen sites 11 years following fire (Holliday 1991b). However, to date the usefulness of carabids to compare sites treated by clear-cut logging and prescribed fire has not been documented. The objective of our study was to investigate the usefulness of carabid beetles as a means for assessing the effect of prescribed burning and clear-cutting. A jack pine forest was selected as a case study because of the importance of this species in the boreal forest.

Materials and Methods

Study site

The study area is located at Frontier Lake (latitude 46°00'N, longitude 77°33'W) in a *Pinus banksiana* Lamb. stand in eastern Ontario within the Middle Ottawa section (L.4c) of the Great Lakes St-Lawrence Forest region (Rowe 1972). Located near the Petawawa National Forestry Institute, the site is relatively flat, with a difference in elevation of approximately 4m over 1.0 km. The surface deposit is a fine-grained deep sand (10-30 m deep) (Gadd 1962) and the soil is a humo-ferric podzol (Weber 1988). The study site was selected because of its uniformity in tree composition and topography. Stand composition was determined before clear-cutting and is shown in Table 1. In addition to the tree species listed in Table 1, it is important to note that the understorey comprised *P. strobus* regeneration at a density of approximately 40 000 seedlings/ha. Other plant species observed on the site before clear-cutting were *Amelanchier* sp, *Comptonia peregrina* (L.) Coult., *Gaultheria procumbens* L., *Kalmia angustifolia* L., *Lycopodium complanatum* L., *Maianthemum canadense* Desf., *Polygonatum pubescens* (Willd.) Pursh., *Pteridium aquilinum* (L.) Kuhn, and *Prunus pumila* L. This site was harvested in 1942 and 1943 leaving behind standing timber with a stump diameter of 17.5 cm or less. Dendrochronological analysis of dominant trees and snags with multiple fire scars suggests that the study site sustained several fires, with the most recent in 1943, presumably from broadcast slash burning following harvesting (E. Stechishen, personal communication).

Table 1. Characteristics of dominant overstorey vegetation at the study site, Frontier Lake, before clear-cutting

Species	Stems/ha	Age (years)	DBH+ cm	Volume m^3/ha
Pinus banksiana	505	53	17.1	81
Pinus resinosa	50	105	37.5	45
Pinus strobus	100	55	28.7	57

+ DBH: diameter at breast height

In the summer of 1990, an area of 150 m x 1000 m was clear-cut and the residual slash (limbs and treetops) left in place. The cutover area was divided into 40 plots, (Figure 1), each measuring 35 m x 70 m and with 8 m fireguards, around each plot. To establish the fireguards, the soil woody debris and organic layer were mechanically removed. In addition, 40 plots, each 35 X 70 m and surrounded by fireguards, were also established in standing timber as controls. Ten of the clear-cut plots were burned-over in 1991. For prescribed burning, pre- and post-burn fuel loads were measured for both slash and duff fuels (McRae et al. 1979). Fuel consumption was determined as the difference between these two values. On-site weather conditions were monitored with an automatic fire weather station to determine the component codes and indices of the Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1987, Van Wagner 1987). Wind was closely monitored on a minute-by-minute basis to correlate with the resultant fire behaviour. Fire rate of spread was measured with a pin grid network on each plot; fire arrival times at each pin were recorded to provide distance and time information. Fire intensity was calculated using Byram's (1959) intensity equation $I=HwR$, where I is the intensity of the fire (kW/m), H is the fuel low heat of combustion (assumed to be 18000 kJ/kg), w is the weight of fuel consumed in the active front (kg/m^2) (all fuel consumed was assumed to have been consumed in the active front), and R the rate of spread (m/sec).

For this study, adult carabids were collected from three burned-over plots, three clear-cut plots, and three locations in undisturbed stands as controls, for a total of nine plots. The three burned-over plots received prescribed burning under various fire intensity conditions common to those frequently encountered in *P. banksiana* stands and are optimal for their regeneration (Weber et al. 1987). Clear-cut sites contained woody debris from 1 mm to 20 cm diameter with a mean fuel loading of 3.5 ± 0.8 kg/m^2.

Carabid collection

Carabids were sampled using 18 unbaited pitfall traps for each of the nine plots. The traps consisted of plastic containers (350 mL; 8 cm diameter) that were buried in the soil with their lips flush with the soil surface (Figure 3). Traps were laid at 2 m intervals in a straight line in the middle of the plots (Figure 2). Beetles were harvested from the traps weekly from August 1, 1991 to October 15, 1991 and the beetles from each plot

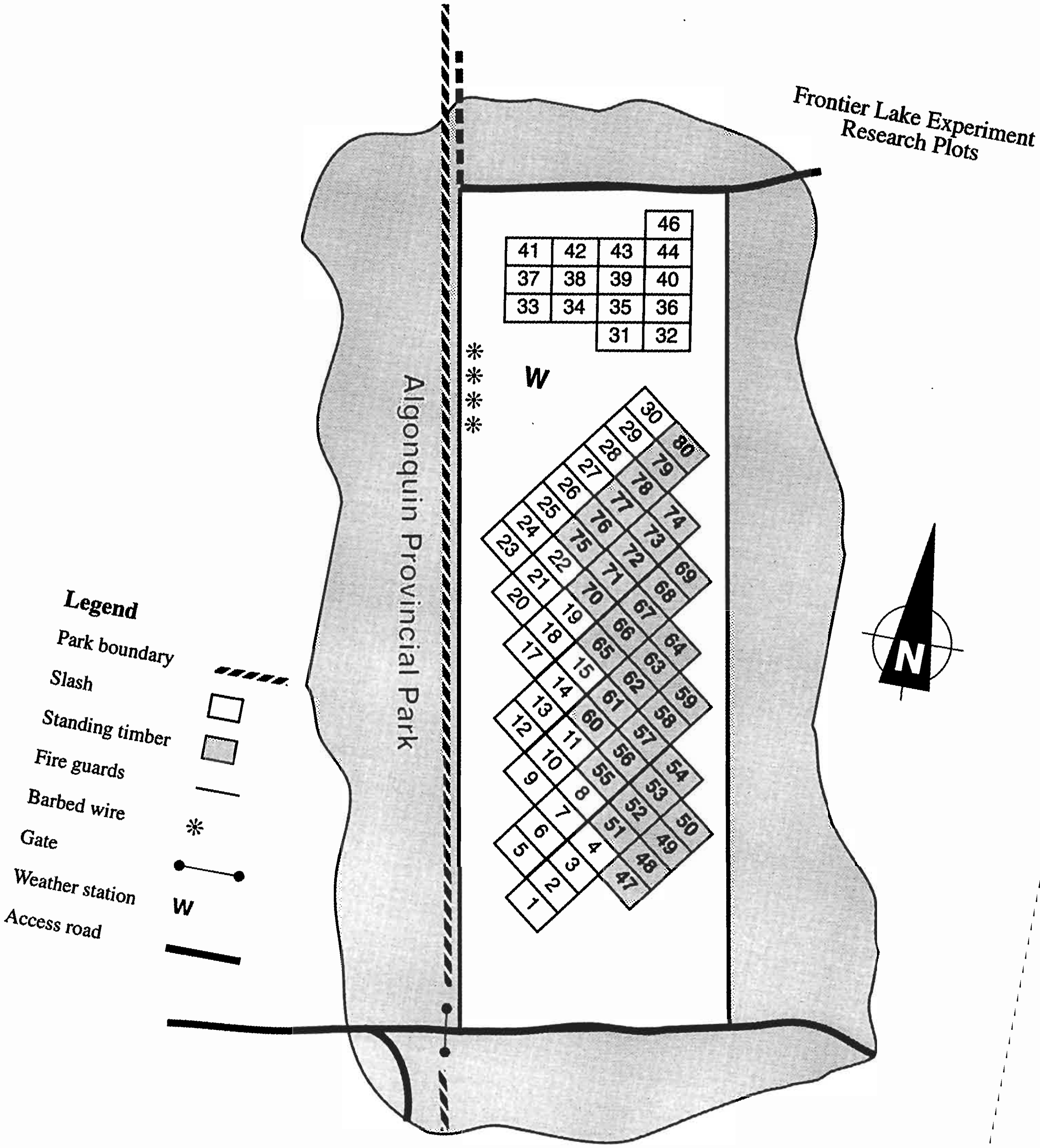

Figure 1. Layout of the Frontier Lake experiment.

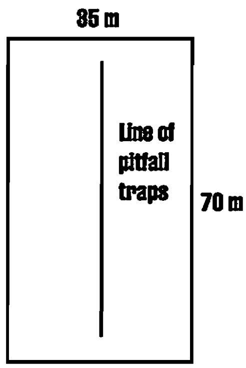

Figure 2. Layout of pitfall traps within plots. Traps were placed a\t 2 m intervals on a line in the centre of the plots.

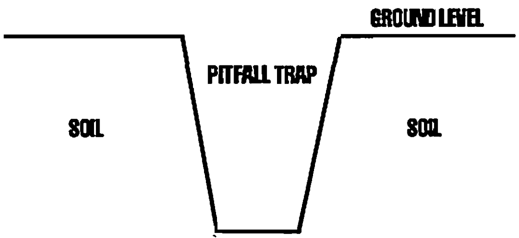

Figure 3. Pitfall trapping of carabid beetles. Traps were placed in the ground with their lips flush with the soil surface.

pooled. Beetle identification was carried out according to Larochelle (1976) and Gariépy et al. (1977). Species diversity for each plot was determined through the Shannon-Wiener formula (Pielou 1966) such as used by Refseth (1980). Species diversity was defined as:

$$-\sum_{i=0}^{s} p_i \times \ln p_i$$

where p_i = relative abundance in total catches of species number i and s=total number of species. Shannon's index has been shown to be normally distributed, and so it can be used to compare difference between treatments using analysis of variance (Magurran 1988). Table 2 shows an example of computation of the Shannon index.

Statistical analyses

For statistical comparison, all catches from the 18 traps from the same plot were pooled. The data presented here show the averaged value for the three plots from the same treatment. Comparison of average carabid catches per treatment, average species number per treatment, and average carabid species diversity in each treatment was conducted. Moreover, average catches for each major species were also compared among the treatments. A major species constituted at least 2% of the total catches for a given treatment.

All comparisons were based on analysis of variance of the data from each plot after testing for homogeneity of variances (Sokal and Rohlf 1981). Heteroscedastic data were transformed and then tested for homogeneity of variances at $P<0.05$. For results that showed significant differences among treatments using ANOVA, pairwise comparisons of the means were conducted using the T-method (Sokal and Rohlf 1981).

Results

A total of 28 carabid beetle species was collected in the course of this investigation. Comparison of carabid assemblages among the three treatments showed differences in composition, number of catches,

Table 2. Example of computation of the Shannon biodiversity index for Carabid species collected in control plots at Frontier Lake, Chalk River, Ontario.

Species	Frequency	Proportion (pi)+	Ln Pi	-pi.ln(pi)
Calathus advena	53	.589	-0.529	0.312
Calathus ingratus	4	.044	-3.123	0.139
Carabus nemoralis	3	.033	-3.411	0.114
Harpalus pensylvanicus	3	.033	-3.411	0.114
Myas cyanescens	7	.078	-2.511	0.198
Pterostichus adoxus	3	.033	-3.411	0.114
Pterostichus mutus	8	.089	2.420	0.215
Synuchus impunctatus	9	.100	2.300	0.230
TOTAL BIODIVERSITY INDEX				1.436

+: the Shannon-Wiener formula for diversity is:
a

$$-\sum_{i=0}^{s} p_i \times \ln p_i$$

Table 3. Fire weather conditions, behaviour characteristics, and impact of three prescribed fires at Frontier Lake

Plot	Burn [a] date	Temp (° C)	Relative humidity	10-m wind (km/h)	Canadian Forest Fire Weather Index (FWI) System Components ([b]) FFMC	DMC	DC	BUI	ISI	FWI	Slash fuel consumption (kg/m²)	Depth of burn (cm)	Duff (forest floor) consumption (kg/m²)	Rate of spread (m/min)	Fire intensity kW/m
24	14-06-92	22.6	40	16.6	89	61	198	69	8.6	23.5	1.79	1.8	2.99	22.0	31 548
43	12-07-91	26.0	49	3.8	89	35	308	55	4.3	12.9	2.86	2.6	4.42	9.5	20 748
46	24-06-91	27.3	32	3.7	92	50	236	65	6.9	19.4	1.61	2.0	3.26	7.9	11 541

[a] Day - Month - Year
[b] FFMC, Fire Fuel Moisture Code; DMC, Duff Moisture Code; DC, Drought Code; BUI, Buildup Index; ISI, Initial Spread Index; FWI, Fire Weather Index

and species diversity. Forest disturbance affected carabid fauna composition because each treatment was colonized by an unique carabid assemblage characterized by one or more major species (Table 4, Figure 4). Burned-over sites were characterized by *Agonum obsoletum*, *Cicindela punctulata*, *Harpalus pensylvanicus*, and *Harpalus lewisi* (Table 4). Of these four species, the last three are typically found in fields and sandy expanses (Lindroth 1966, 1968, Gariépy et al. 1977) whereas *A. obsoletum* is attracted by forest fires (Lindroth 1966, Gariépy et al. 1977). Clear-cut sites were characterized by *Pterostichus lucublandus*, a species typical of wood margins, fields, and sandy expanses (Lindroth 1966, Gariépy et al. 1977) and *Calathus advena*, a species usually found in woods (Lindroth 1966, Gariépy et al. 1977). Control sites were characterized by *Myas cyanescens* and *Pterostichus adoxus* which are typically found in woods (Lindroth 1966, 1969, Gariépy et al. 1977). The other major carabid species, *Calathus ingratus*, *Carabus nemoralis*, *Pterostichus mutus*, and *Synuchus impunctatus* were found in similar proportions within each of the three treatments. These species have been observed in various habitats ranging from forests to fields (Lindroth 1966, Gariépy et al. 1977). In addition the following minor species were collected within the plots: *Agonum cupreum* Dej., *Agonum cupripenne* Say, *Agonum retractum* Lec., *Amara bifrons* Gyll., *Amara discors* Kby., *Amara laevipennis* Kby., *Amara littoralis* Mnh., *Anisodactylus nigrita* Dej., *Calosoma calidum* F., *Harpalus caliginosus* F., *Harpalus fallax* Lec., *Harpalus fuliginosus* Dft., *Harpalus laticeps* Lec., and *Harpalus pleuriticus* Kby.

Carabid species diversity differed among catches of each treatment (Tables 4-5). Burned-over sites showed the greatest value for the diversity index whereas clear-cut sites showed the lowest value. There was no statistical difference in the number of species collected between the sites. Clear-cutting and prescribed burning increased carabid catches 3.9 times and 2.7 times, respectively, as compared to that of control sites (Tables 4-5). However, these results are not significantly different at $P<0.05$ because of the large standard variation in samples from clear-cut sites.

Discussion

Our results show clearly that carabid populations can be used as indicators of environmental changes associated with clear-cutting and prescribed burning. Numerous studies have documented the effect of ecosystem disturbance on carabid populations (Sustek 1981, Lenski 1982, Jennings et al. 1986, Parry and Rodger 1986, Day and Carthy 1988, Kolbe 1988, Niemelä et al. 1988, Holliday 1991a, 1991b, Langor et al.

Table. 4 Catches of major carabid species in pitfall traps from clear-cut, burned-over, and undisturbed sites at Frontier Lake, Ontario, 1991 (average of three plots per treatment)**

Species	Clear-cut	Burned-over	Control
Species abundant in burned-over sites:			
Agonum obsoletum Say	1.3 b[†]	21.0 a	0 b
Cicindela punctulata Ol.	0 b	4.0 a	0 b
Harpalus pensylvanicus DeG.	11.3 ab	18.3 a	1.0 b
Harpalus lewisi Lec.	0 b	2.0 a	0 b
Species abundant in clear-cut sites:			
Calathus advena Lec.	76.3 a	18.7 b	17.6 b
Pterostichus lucublandus Say	10.5 a	0.6 ab	0 b
Species abundant in control sites:			
Myas cyanescens Dej.	1.7 a	0 b	2.3 a
Pterostichus adoxus Say	0.3 b	0 b	1.0 a
Species abundant in all sites:			
Amara avida Say	0	1.7	0 NS
Amara obesa Say	0.3	1.7	0 NS
Calathus ingratus Dej.	0	1.3	1.3 NS
Carabus nemoralis Müll.	1.0	0	1.0 NS
Pterosticus mutus Say	5.7	3.3	2.7 NS
Synuchus impunctatus Say	3.7	4.0	3.0 NS
Catches (including minor species)	120.0 + 78	83.0 + 19	31.0 + 15.7
Number of species (including minor species)	11.3	10.3	4.1 NS
Species diversity index	0.95 b	1.52 a	1.27 ab

[†]: Within rows values followed by different letters are significantly different at P<0.05 using pairwise comparison of the means.
NS: ANOVA does not show significant differences at P<0.058. **1: A major species constitutes at least 2% of the total catches of a given treatment

Table 5. Relative abundance (percentage) of each major[1] carabid species within clear-cut, burned-over, and undisturbed (control) sites at Frontier Lake, Chalk River, Ontario.

Species	Clear-cut	Burned-over	Control
Agonum obsoletum Say	1.1	26.0	0
Amara avida Say	0	2.0	0
Amara obesa Say	0.3	2.1	0
Calathus advena Lec.	64.3	23.1	61.6
Calathus ingratus Dej.	0	1.7	4.7
Carabus nemoralis Müll.	0.3	0	3.5
Cicindela punctulata Ol.	0	5.0	0
Harpalus lewisi Lec.	0	2.5	0
Harpalus pensylvanicus DeG.	9.6	22.7	3.5
Myas cyanescens Dej.	1.4	0	8.1
Pterostichus adoxus Say	0.3	0	3.5
Pterostichus lucublandus Say	11.0	1.2	0
Pterostichus mutus Say	4.8	4.6	9.3
Synuchus impunctatus Say	3.1	5.0	5.8
Other species	3.1	2.8	0
TOTAL	100	100	100

[1]A major species constitutes at least 2% of the total catches of a treatment.

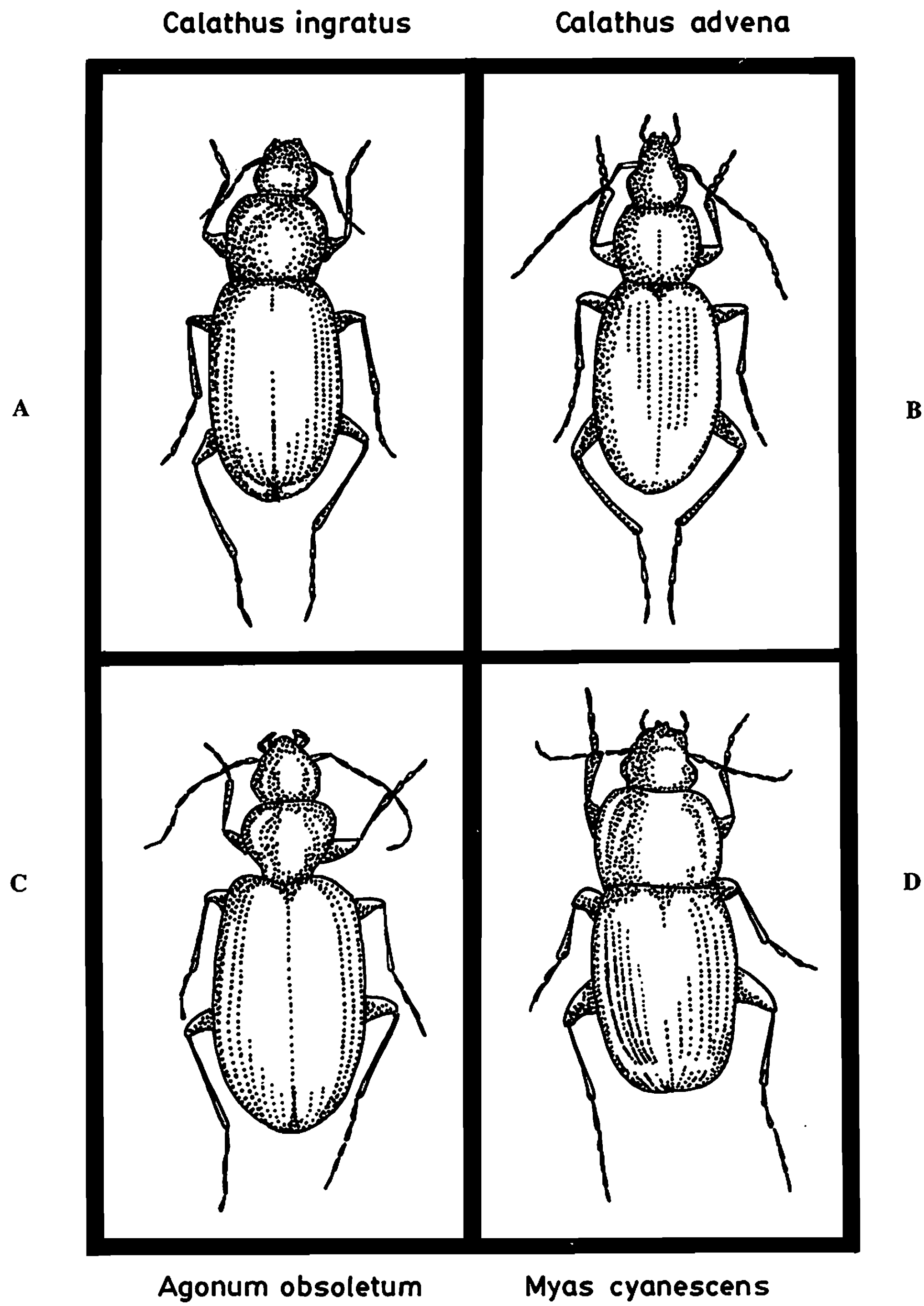

Figure 4. Representative species of carabids typical of each of the four groups: C: *Agonum obsoletum*, a species characteristic to burned-over plots; B: *Calathus advena*, a species characteristic to clear-cut areas; D: *Myas cyanescens*, a species characteristic to undisturbed plots; and, A: *Calathus ingratus*, a species found in equal proportions in all plots.

1991). However, the results presented in this investigation are unique since a comparison of the effect of prescribed burning and clear-cutting on carabid beetle populations has not been documented elsewhere.

In our experimental system prescribed burning increases diversity of carabid assemblages as compared to clear-cutting, although more carabid species were found in the clear-cut sites. Because the Shannon-Wiener formula of diversity deals with relative abundance of species within sites, it allows for a standardized comparison of species diversity. This explains why a comparison of diversity index values does not necessarily reflect species number. In practical terms most of the species unique to clear-cut sites were found in frequencies too low to influence the diversity index, and so the diversity index of burned over sites was greater than that of clear-cut and control sites.

In general, food webs display scale invariance, that is, the number of species at higher trophic levels is a constant proportion of the number of species at lower trophic levels (Briand and Cohen 1984). Therefore, the results from this experiment suggest that the overall number of species of all taxa at trophic levels lower than that of the carabids differ among the three treatments and presumably reflects different levels of diversity in soil microbial and invertebrate populations. Our results also suggest that the microbial populations differ in size among treatments because clear-cutting and burning showed number of catches that were greater than at control sites. More investigation is needed to verify this hypothesis. Furthermore it will be important, in future, to determine the survival and colonization rates of carabid and microbial populations in burned-over areas.

The differences observed in carabid assemblages among the treatments may be caused by the direct influence of physical and chemical site factors such as soil water content, vegetation cover, and temperature (Butterfield and Coulson 1983) or by the influence of these site conditions on carabid prey (Parry and Rodger 1986, Holliday 1991a). Forest fire and logging affect physical and biological soil characteristics such as soil temperature, moisture content, soil fertility, albedo, available light, microbial composition and biomass, plant cover, decomposition rates, and nutrient turnover (MacLean et al. 1983, Weber 1985, 1988, Bird and Chartapaul 1988, Brand and Penner 1990, Cancela Da Fonseca 1990, Brand 1991). Prescribed burning removed a large proportion of the humus layer in the study area as well as the fine woody debris left on the soil surface after clear-cutting (Table 3). However, our results do not provide indications regarding which biotic and abiotic site factors, critical for the modulation of carabid assemblages are unique to each of the disturbed sites.

Forest management impacts forest fauna (Welsh 1988, Beauchesne et al. 1991). While a great deal of work has been conducted to define forest management practices that take wildlife into consideration, emphasis has usually been given to game species; little attention has been given to non-game wildlife diversity. The present investigation provides new information about the effects of forestry practices on soil biodiversity. Investigation of the effect of disturbance on other types of forest ecosystems is needed before such information can be included in forest management programs.

Acknowledgments

Thanks to M. Hobbs, A. Johnson, and M. Wotton for technical help, E. Stechishen for support in establishing field plots, and F. Pinto, Dr. S. M. Smith, Dr. M. Strome, Dr. M.G. Weber, and A. Yapa for revising this manuscript. Thanks are also extended to anonymous reviewers.

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CANADIAN CATALOGUING IN PUBLICATION DATA

Duchesne, Luc Clément, 1960-
Using carabid beetles (coleoptera: carabidae) as a means to investigate the effect of forestry practices on soil diversity

(PNFI technical report ; 16)
Includes bibliographical references.
ISBN 0-662-21014-X
DSS cat. no. Fo29-26/16E

1. Forest soils -- Ontario. 2. Forest site quality -- Ontario.
3. Carabidae -- Ontario.
I. McAlpine, R.S. II. Petawawa National Forestry Institute. III. Title. IV. Series.

SD390.305D82 1993 631.4'6'09713 C93-099685-2

Ce rapport est aussi disponible en français

ISSN 1180-2618
ISBN 0-662-21014-X
Catalogue No. Fo29-26/16E