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Comparison of moth communities following clear-cutting and wildfire disturbance in the southern boreal forest

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ABSTRACT

Nocturnal macrolepidopteran fauna (moths) of the southern boreal forest of Ontario, Canada, were compared between forests clear-cut or burned by wildfire approximately 5 years previously to assess whether their assemblages differed following disturbance. Moths were light-trapped for 27 days during the summer in three burned and three clear-cut sites that had been formerly mature mixed jack pine (*Pinus banksiana*) forest. The dominant species varied throughout the summer (*Protorthodes oviduca* dominated in June, *Orthodes cynica* in July and *Idia americalis* in August), but they were similar between disturbance types. Diversity indices were similar although ordinations showed significant differences between the two disturbance types. Nine species were more significantly abundant in burn than clear-cut sites (*Callopietra cordata*, *Cyclophora pendulinaria*, *Gluphisia septentrionis*, *Hyppa nr. xylinoides*, *Nemoria rubrifrontaria*, *Semiothisa neptaria*, *Spiramater lutra*, and *Tacparia deterrenta*), whereas the converse was true for three species (*Acronicta innotata*, *Phyllodesma Americana*, and *Euxoa comosa*). Vegetation composition, disturbance age, percentage of jack pine pre-disturbance, and amount of downed woody debris and snags were the most important environmental correlates of moth community composition. Our study supports that of previous work on the effects of forest disturbance and biodiversity suggesting that clear-cutting may emulate wildfire for some organisms, but not for others. Thus, forest managers must consider multiple aspects of forest structure in attempting to use clear-cuts to mimic fire.

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1. Introduction

Forest scientists and managers have long discussed the development of forest management strategies that attempt to emulate natural disturbances (Hunter, 1993; Haila et al., 1994; Wuerther, 1995; Delong and Tanner, 1996; Bergeron et al., 2002). If forestry practices produce similar environmental conditions (such as physical and structural aspects) to those resulting from natural disturbance, then they are considered to better maintain native flora and fauna diversity. In temperate and boreal forests of North America and Scandinavia, wildfire is perhaps the single most important natural disturbance (Barney and Stocks, 1983; Haila, 1994), and many organisms are adapted to recurrent fires (Rowe and Scotter, 1973; Schimmel, 1993). In those regions, commercial forest management is primarily under the clear-cut silvicultural system, although advances have recently been made to use retention-harvesting techniques (Bergeron and Harvey, 1997; Franklin et al., 1997; Sullivan et al., 2001). Clear-cut logging in the boreal forest may resemble fire in its periodicity, canopy removal, and light availability near the ground; however,

there are also distinct differences between clear-cut and wildfire, such as soil structure, tree species dominance, and understory composition of post-disturbance communities (see review by McRae et al., 2001).

In order to investigate whether clear-cutting emulates wildfire for biodiversity conservation purposes, it is necessary to test whether biological communities differ between the two disturbances over time (the natural disturbance hypothesis). Previous studies comparing the results of fire and clear-cutting in northern forests have focussed on various aspects of the ecosystem, such as size and shape of the disturbance (DeLong and Tanner, 1996; Gluck and Rempel, 1996), tree growth and chemistry (McCullough and Kulman, 1991; Lussier et al., 1992), soil nutrients (Simard et al., 2001), and plant (Noble et al., 1977; Abrams and Dickmann, 1982; Carleton and MacLellan, 1994; Johnston and Elliott, 1996), mammal (Zwolak, 2009), bird (Hobson and Shieck, 1999), and arthropod (Baker et al., 2004; Buddle et al., 2006) diversity. Most of those studies have found some difference between the effects of fire and clear-cutting, although not all results were consistent. Some found different, but not greater diversity under natural disturbance regimes (e.g. Naylor and Bendell, 1983; Carleton and MacLellan, 1994; Johnston and Elliott, 1996), whereas others found greater diversity in burned areas (Abrams and Dickmann, 1982).

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The few comparisons made between arthropod assemblages following clear-cut logging and wildfire in the boreal forest have focused on litter-dwelling arthropods such as beetles and spiders, and have showed differences between these two disturbance types (Saint-Germain et al., 2005; Buddle et al., 2006). Diversity of spiders following wildfire tended to be higher than in harvested stands, responding fast initially and then converging ca. 30 years after disturbance (Buddle et al., 2000). Ecological succession of litter-dwelling beetles seems to progress faster after clear-cutting than following wildfire (Buddle et al., 2006). Baker et al. (2004) found no differences between logging and wildfire for ground-active beetles at the site level 33-years after the disturbance, although spatial and temporal differences in the disturbance regimes were considered likely to create different habitat conditions at the landscape scale. There is evidence that edge effects differ between clear-cut and wildfire sites; Larrivée et al. (2008) found that ground-dwelling spiders penetrate from the forest into the disturbed site twice as far along edges created by wildfire (50 m) as through those created by clear-cutting.

Because most arthropod taxa are not targets for forest management planning, they can provide independent measures of how management practices will affect biodiversity (Spence et al., 1999). Unfortunately, a limited number of insect taxa have been studied in this regard, possibly due to the enormous task of taxonomic identification for most groups. The Lepidoptera is one of the most diverse insect orders (Powell et al., 1999) and a key component of the herbivore assemblage, as the larval stage of most species feed primarily on plants. The nocturnal assemblage of lepidopterans can be trapped relative easily and in large numbers by using attractive light-traps, and this approach has been used frequently in tropical ecosystems to assess the effects of human disturbance (Intachat et al., 1999; Kitching et al., 2000; Beck et al., 2002; Fiedler and Schulte, 2004). Here, we ask whether the nocturnal macrolepidopteran (moth) assemblage differs in the short-term following clear-cutting and wildfire in the southern boreal forest. We examine and compare habitat variables and attributes of the macro-moth assemblage 4–8 years following disturbance.

2. Methods

2.1. Study design

Six sites were chosen in the study area, three in clear-cuts (C1–C3) and three in naturally-burned forests (B1–B3). The shortest distance between any two sites was 1.5 km, the furthest distance was 22 km, and the two treatment types were interspersed (see Table 1 for geographical coordinates). The sites were paired (B1–C1, B2–C2 and B3–C3) so that each pair had one cut and one burn site with a similar percentage of each tree species prior to disturbance (Table 1). Cutting or fire disturbance occurred 4–8 years prior to the study (Table 1). At each site, a sampling point was located to trap moths and to serve as a reference to record environmental variables. Location of sampling points was based on the distance to the nearest mature forest (>200 m), consistency of slope and aspect, distance to the original stand edge (>100 m), and ease of access. Previous studies indicated that few forest moths would be caught if light traps were more than 200 m away from the nearest forest (Baker and Sadovy, 1978; Moulding and Madenjain, 1979; Nieminen, 1996); besides, most light traps do not attract moths over a distance of 10 m (Frank, 1988, and references therein); this means that most moths collected in the traps were likely to have come from the research site and not be attracted from the edge or the surrounding forest. Environmental variables and attributes of the macro-moth assemblage were compared between clear-cut and wildfire sites.

2.2. Site description

The study was conducted at six sites in Roberts and Rhodes Townships, Sudbury District (Ontario, Canada) during the summer (Table 1). Stand size varied between 68 and 176 ha. Most sites faced west or southwest, had a slope of 8–10% and a gently undulating topography and occasional wet spots and ponds in low-lying areas (Table 1). Soils were examined at each site to determine whether soil type and moisture regime were similar for all sites

Table 1
Geographical coordinates, stand and disturbance characteristics, and the distance from trap to the nearest forest in three naturally-burned sites and three clear-cut sites used to sample moths in Sudbury District, Ontario, Canada.

	Burned sites			Clear-cut sites		
	B1	B2	B3	C1	C2	C3
Geographical coordinates	46°58'N 81°25'W	46°55'N 81°07'W	46°56'N 81°09'W	46°53'N 81°23'W	46°57'N 81°08'W	46°55'N 81°06'W
Stand size (ha)	100	176	108	100	124	68
Slope (%)	W 8	SW 10	NE 8	SW 9	W 1	SW 9
Moisture regime ^b	Moderately fresh	Moderately dry	Moderately fresh	Moderately fresh	Moderately fresh	Moderately fresh
Drainage ^b	Rapid	Rapid to well	Rapid to well	Rapid	Rapid	Rapid
Pre-disturbance stand composition (%)	Jack pine					
	80	50	30	80	50	40
	Black spruce	10	20	10	30	30
	White birch	10	20	10	20	20
	Poplar		10			10
	Red maple		20			
Stand density ^a	0.6	0.6	0.5	0.9	0.6	0.5
Stand age at disturbance (yrs)	117	108	128	75	129	119
Disturbed area (ha)	210	2000	2000	1700	48	222
Time since disturbance (yrs)	6	5	5	8	4	4
Site preparation (time since site preparation)				Trenched (7 years)	Windrowed (2 years)	Windrowed (2 years)
Regeneration technique (time)				Seeded (6 years)	Planted (1 year)	Planted (1 year)
Glyphosate				4 years ago	None	None
Distance from trap to nearest forest (m)	400	900	300	200	200	200

^a Based on Deholm and Scott (1993).

^b Proportion of the highest density that could grow on site as judged by the Ontario Ministry of Natural Resources (range 0–1).

regardless of disturbance type (Table 1). All sites had a humifibrimor humus form over shallow Ae and Bf mineral layers, and the bedrock was less than a metre below the surface.

Prior to disturbance, all sites were classified ecologically as Site Class 2, mature stands (over 100 years, except C1) of jack pine (*Pinus banksiana*), black spruce (*Picea mariana* Mill B.S.P.), white birch (*Betula papyrifera* Marsh.), and trembling aspen (*Populus tremuloides* Michx.) (Forest Resource Inventory (FRI), Ontario Ministry of Natural Resources 1974) (Table 1). The accuracy of FRI stand composition was assessed in the field and any deviations were recorded.

All harvested sites had been mechanically cut, delimiting and topped on site, then prepared with either a skidder (trenched) or a Young's teeth on a tractor (windrowed), and then seeded or planted (Table 1). The size of wildfires varied from 210 to 2000 ha, while the size of the clear-cuts ranged from 48 to 1700 ha (Table 1); thus, the disturbed area was larger than the original stand, except at one site.

2.3. Environmental variables

At each site, habitat variables were sampled along five 75-m transects located north, south, east, west and downhill from the sampling point where the light trap was located. The depth of organic material, the Ae and Bf mineral layers, and depth to bedrock (<25 cm) were recorded at 11 locations per site (one at the light trap, one at the end of each transect, and one at the centre of each transect). The number of logs (downed woody debris >2.5 cm diameter) that crossed each of the five transects were counted, and the number of standing deadwood snags (>10 cm dbh) per 100 m² was measured by recording the dbh and species of each snag in a 2 m-wide strip along each of the five transects.

Six 5-m² plots per site were used to measure vegetation (one at the light trap location, one at the end of each transect in the cardinal directions, and one 30-m from the light trap along the down-slope transect). All plants were identified to species, with the exception of grasses, mosses and lichens. The percentage cover of each taxa was estimated visually for each plot. The percentage of jack pine present prior to disturbance (from FRI maps) was also used as an environmental variable to represent the pre-disturbance vegetation.

Because nightly temperature could affect the number of moths caught (Hardwick, 1972; Persson, 1976; McGeachie, 1989), a hydrothermograph (Enercorp Instruments Ltd., Toronto, Ontario) was placed at ground level in one of the sites (B3) to record temperature and relative humidity throughout the night. Nightly temperature was calculated as a mean of the hourly temperatures recorded between 20:00 and 5:00 inclusive.

2.4. Moth sampling and identification

In each site, one light trap was placed on the ground at the sampling point at the same location throughout the summer to collect adult lepidopterans. Traps were located at least 200 m in all directions from mature forests (Table 1) to ensure their captures reflected the moth community in each disturbance type and not the surrounding area (as discussed in Section 2.1). The traps used in the study were 12-V DC Universal Black Light Traps that housed a 22-W Circline BL ultraviolet tube (BioQuip, Gardena, California) and were powered by portable rechargeable batteries (Booster Pac International Corp., St.-Jean-Sur-Richelieu, Quebec). A photoelectric switch (BioQuip) automatically turned the light on at dusk and off at dawn to conserve power. An 8 × 8-cm piece of Vapona[®] (with dichlorvos, a cholinesterase inhibitor) was placed in the bottom of each trap to kill moths as they were collected over the night.

Collection periods consisted of three 9-day periods across the summer (12–20 June (June); 1–9 July (July); and 29 July–7 August

(August)). Within each sampling period (June, July and August), each pair of sites (one cut and one burned) was sampled three times for one night in rotation. It was necessary to sample sites several times within a short time period because of the relatively brief flight period of each species of adult lepidopterans (Young, 1997). Thus, the sampling effort consisted of 3 traps/night per site in each month to give a total of 9 traps/night per site over the 3 months and a total of 54 samples collected during the study.

During sampling, traps were checked and emptied of specimens daily each morning. Moths were placed in paper envelopes and frozen until mounted or identified in the laboratory. All specimens from macrolepidopteran families were identified to species except those less than 13 mm in length (from tip of head to forewing apex with wings folded over the body) using several taxonomic keys (Lafontaine, 1969, 1987; McGuffin, 1972, 1977, 1981, 1987; Rockburne and Lafontaine, 1993; Service d'Entomologie et de Pathologie, Gouvernement du Québec, 1979; Covell, 1984; Ferguson, 1985; Lafontaine and Poole, 1991; Rings et al., 1992; Riotte, 1992; Poole, 1995; Handfield et al., 1997). Approximately 600 spread voucher specimens were used as a reference collection to identify the specimens of interest. Difficult specimens were taken to the Royal Ontario Museum, Toronto, for comparative identification and then to the Canadian National Collection (CNC) at the Eastern Cereal and Oil Seed Research Centre, in Ottawa, Ontario. The nomenclature used followed Handfield et al. (1997).

2.5. Data analysis

Shannon and Simpson diversity indices and the log series alpha (the Fisher's alpha parameter of a fitted logarithmic series distribution) (Colwell, 1997) were calculated for each site to provide diversity measures that would allow comparisons with future work. For each disturbance type, we estimated the proportion of rare species (those represented in the samples by two or three individuals) relative to the number of rare species caught at both disturbance types; a binomial Z test (Ostle and Mensing, 1975) was used to assess whether rare moth species were caught more than expected in a given disturbance type.

The multi-variable nature of the data led to the use of ordinations for further analysis. Each point on the ordination graphs represented one night's collection from one site. Thus, each site was represented by several points. When moth data throughout the whole summer were examined using a Detrended Correspondence Analysis (Lepš and Šmilauer, 2003), the points representing each collection night divided into three clusters representing the three collection periods as expected due to differences in moth phenology. Thus, ordinations were undertaken for each month separately. Two nights (C1 August 5 and C2 August 6) were excluded from the August ordinations because they were extreme outliers, as determined visually and by application of Chauvenet's criterion to the Detrended Correspondence Analysis (DCA) sample scores (Taylor, 1997). Despite relatively short gradient lengths (2–3 standard deviations), we used unimodal rather than linear approaches because they more easily interpreted (presumably due to the sparse nature of the moth matrices). All ordinations were undertaken using CANOCO 4.51 (see Lepš and Šmilauer, 2003). DCA's were used to avoid the arch effect found in some cases when Correspondence Analysis was used.

Variation among moth samples was correlated with the mean nightly temperature; specifically, permutation tests from canonical correspondence analyses (9999 randomizations) were significant with mean nightly temperature as a constraining variable for June and July, but not for August ($P = 0.008, 0.002, \text{ and } 0.140$, respectively). As a result, all moth ordinations were done with mean nightly temperature as a covariate (see Lepš and Šmilauer, 2003). The monthly ordinations were tested for differences between

clear-cut and burn treatments using permutation tests from canonical correspondence analyses (see Lepš and Šmilauer, 2003). In these tests, the constraining variable was a dummy variable indicating the treatment type of each sample. This test was temporally pseudoreplicated, hence it was indicative rather than conclusive.

To compare abundances of individual moth species between the two treatments, we used *t*-tests ($n = 3$ sites per treatment). Because of the high variability (and hence lack of normality) of moth numbers, we rank-transformed data prior to calculating the site-specific means for each species. Because of the relatively small number of sites and low power, we undertook two additional tests. In one, we used *t*-tests to compare the ranked abundances between the two treatments for each month, using the three nightly samples per site as replicates (i.e., $n = 9$ replicates per treatment per month). In a second test, we used the untransformed nightly samples as replicates for each month, but used mean nightly temperature as a covariate. These latter two tests were temporally pseudoreplicated and hence should be taken as indicative rather than conclusive.

A separate DCA ordination was performed on vegetation variables. The average first axis score of the six sites was used to derive a single number that represented the vegetation community. Two atypically wet plots (one at each of two sites) were excluded from the average score calculations because they were outliers in the ordination.

Environmental variables were examined passively in moth DCA to determine which were most important in determining variation in moth communities; we also used permutation tests in a Canonical Correspondence test (forward selection) to test their significance. Importance was confirmed by calculating the degree of correlation between the environmental variable for each site and the DCA axis score.

3. Results

3.1. Environmental factors

In our study sites, 26 woody plants and 29 herbaceous plant species were recorded (excluding grasses and sedges, which were uncommon). Plant species with a mean coverage greater than 10% in at least one site were: red maple (*Acer rubrum* L.), sweetfern (*Comptonia peregrina* (L.)), bush honeysuckle (*Diervilla lonicera* Mill.), jack pine, low sweet blueberry (*Vaccinium angustifolium* Ait.), bunchberry (*Cornus canadensis* L.), bracken fern (*Pteridium aquilinum* L.) and *Polytrichum* mosses. Green alder (*Alnus viridis* (Villars)), white birch, beaked hazel (*Corylus cornuta* Marsh.), trembling aspen, pin cherry (*Prunus pensylvanica* L. fil.) and velvet-leaf blueberry (*Vaccinium myrtilloides* Michx.) were also common and widespread. The vegetation tended to be similar between the two treatments, as indicated by the considerable overlap in point clusters of the plots from different sites in the DCA ordination on vegetation; however, plots from two of the clear-cut sites (C2 and C3) tended to cluster in the upper right quadrant of the plot (Fig. 1). Gradient length was 3.8, although once the two outliers were removed the spread between the points was reduced to 2.4. Plant species that were highly positively correlated (i.e., $P \leq 0.001$ from Spearman's correlations) with axis 1 were wild sarsaparilla (*Aralia nudicaulis* L.), bracken fern, red maple, and beaked hazel; high negative correlates with this axis were *Polytrichum* spp., black spruce, jack pine, and trembling aspen. High positive correlates of axis 2 were white birch, red raspberry (*Rubus ideaus* L.), and bush honeysuckle; the only high negative correlate of axis 2 was low sweet blueberry.

The average number of woody debris pieces on the ground was similar between disturbance types; there were 6 pieces/10 m of transect in the burn and 7.3 pieces/10 m in the cut sites ($t = -0.64$, $df = 4$, $P > 0.56$). The distribution of downed woody debris in the clear-cut sites was either spread evenly similar to the

burned sites, or clumped in piles of slash. As expected, there was a much larger number of snags in the burned (275/ha) than in the cut sites (7/ha) ($t = 9.04$, $df = 4$, $P < 0.0008$). In contrast, no standing live trees were recorded in the burn sites, whereas a few clumped, uncut trees had been left in the clear-cut sites (36/ha); although these differences were not significant ($t = -2$, $df = 4$, $P > 0.12$). The organic layer in soils of clear-cuts (2.9 cm) was shallower than in the burned sites (3.9 cm), but again the difference was not significant ($t = 0.98$, $df = 4$, $P > 0.38$). There seemed to be a greater mineral soil exposure in clear-cut sites (9 of 33 augers showed no organic layer) than in the burned sites (1 of 33 augers showed no organic layer).

3.2. Moth assemblages and environmental correlates

A total of 4070 individual adult moths representing 204 species was found in the burned sites, and 3455 individuals of 211 species in the clear-cut sites (Appendix 1). The number of species trapped was similar between disturbance types ($\chi^2 = 0.067$, $P > 0.4$); we did not use rarefaction because sample sizes and number of individuals caught in both disturbance types were similar.

Species abundance distributions showed that moth communities in both clear-cut and burned sites had a few, very abundant species and many uncommon or rare species (Fig. 2). Diversity was similar between treatments. There was non-significant differences between the mean log series alpha for burned (38.74 ± 3.61 , range of 32.90–45.34, $n = 3$) and clear-cut (42.83 ± 1.96 , range 39.85–46.53, $n = 3$) sites ($t = 0.995$, $df = 4$, $P = 0.38$); the Shannon index was also similar between burned (3.96 ± 0.13 , range of 3.70–4.12) and clear-cut (3.95 ± 0.11 , 3.79–4.15) sites ($t = 0.098$, $df = 4$, $P = 0.92$), as well as the Simpson index (burned sites: 28.70 ± 4.90 , range 19.71–36.59; clear-cut sites: 25.61 ± 5.57 , range 17.15–36.13) ($t = 0.416$, $df = 4$, $P = 0.70$).

In the ordinations, permutation tests comparing clear-cut versus wildfire sites were significant for all 3 months ($P = 0.018$, 0.048, and 0.040 for June, July, and August, respectively) and some clustering of the two treatment types was apparent in the DCA ordinations, especially for the June and July samples (Fig. 3). In June, moth samples from two of the cut sites (C2 and C3) tended to have high scores on the second DCA axis in comparison to the other sites; in July, they tended to have relatively high scores on the first DCA axis. In both cases, the cluster was most strongly associated with high scores on the first axis of the vegetation DCA.

Examination of species abundances revealed several differences between the burned and cut forest stands. The dominant species was similar between disturbance types, although it varied throughout the summer. In fact, the five most abundant moth species were the same in both disturbance types, with only slight differences in their rankings (Table 2). A few differences were apparent when examined on a monthly basis (Table 2). For example, in June, *Drasteria adumbrata* (Behr.) was the fourth most common species in the clear-cut sites, but ranked 17th in burned sites. When we used sites as replicates, of the 241 species caught by the trapping system, six differed in abundance between the two disturbance types. Two were more abundant in clearcuts than burned sites (*Acronicta innotata*, $P < 0.001$; *Phyllodesma americana*, $P = 0.047$) and four showed the converse (*Cyclophora pendulinaria*, $P = 0.009$; *Hyppa* nr. *xylinoides*, $P = 0.019$; *Spiramater lutra*, $P = 0.023$; *Tacparia detersata*, $P = 0.027$). When months were compared using nightly samples from each month, only August abundances of *Euxoa comosa* showed greater abundance in clear-cuts than burned sites ($P = 0.022$); however, June abundances showed the converse for three species (*Semiothisa neptaria*, $P = 0.029$; *Tacparia detersata*, $P = 0.031$; and *Nemoria rubrifrontaria*, $P = 0.040$). Analysis of covariance also showed significantly greater August abundances in clear-cuts compared to burns for *Euxoa comosa* ($P = 0.042$); species that had relatively greater

abundances in burns than clearcuts were June abundances of *N. rubrifrontaria* ($P = 0.031$), *Spiramater lutra* ($P = 0.038$), July abundances of *Gluphisia septentrionis* ($P = 0.038$), and August abundances of *Callopietra cordata* ($P = 0.017$). Additional taxa that were significant at the $0.05 < P < 0.10$ level in one or more of the above tests and had greater abundances in clear-cuts than burns were *Dypterygia rozmani*, *Feltia herilis*, and *Spilosoma dubia*; those showing the converse were *Cabera erythemaria*, *Lacinipolia lustralis*, *Polia purpurissata*, *Proxenus miranda*, and *Sicya macularia*.

Twenty-six species of moths were collected exclusively in the burned sites and 37 species exclusively in the cut sites. Most of these unique species were collected only once or in very low numbers, and it is possible that all of these species collected only two or three times could have been there solely by chance ($Z = 0.416$, $P = 0.68$). However, three of these unique species were very unlikely to have been found only in one disturbance type by chance: i.e. *Cyclophora*

pendulinaria (8 individuals found, $P = 0.008$) and *Hypanr. xylinoides* (7 individuals found, $P = 0.02$) were both found in burned sites exclusively, whereas *A. innotata* (8 individuals found, $P = 0.008$) was found in clear-cut forests exclusively. The probability of seven or eight individuals being found by chance in only one disturbance type (as for the three species above) was calculated using the equations $(.5)^7 \times 2$ and $(.5)^8 \times 2$, respectively. Four of the five *Euxoa* species collected were found in the cut sites only.

Vegetation score from the DCA, disturbance age, percentage of jack pine pre-disturbance, and amount of downed woody debris and snags were the most important environmental correlates (out of the nine variables examined) with moth community composition, whether analyzed over the whole summer or by month (Fig. 3, Table 3). Permutation tests (Canonical Correspondence Analysis, forward selection) indicated that log abundance and DCA scores were significant for June ($P = 0.012$ and 0.004 ,

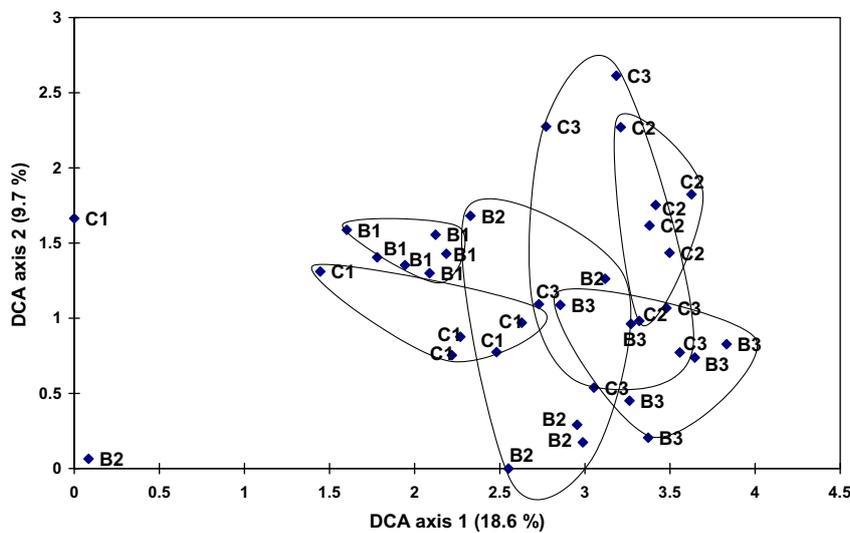


Fig. 1. DCA of vegetation data from six study sites where moths were collected in the southern boreal forest of Ontario. The letter “C” signifies clear-cut sites; the letter “B” signifies burned sites. Lines encircle six plots for each site except two wet outliers in C1 and B2. Into brackets is the percentage variance of species accounted for by respective axis.

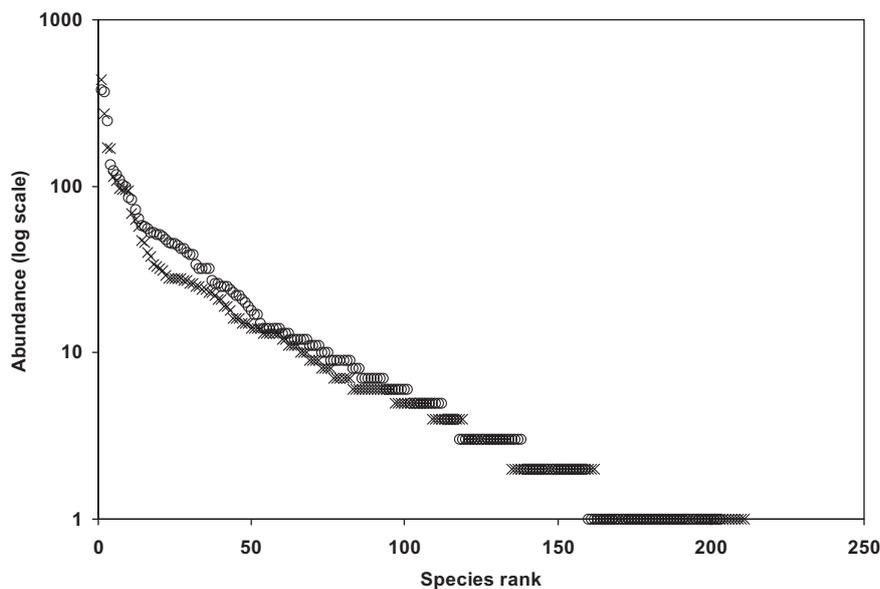


Fig. 2. Rank abundance curves of adult moths collected in light traps in recently burned (O) or clear-cut (X) mixed jack pine forests in the southern boreal forest of Ontario, Canada.

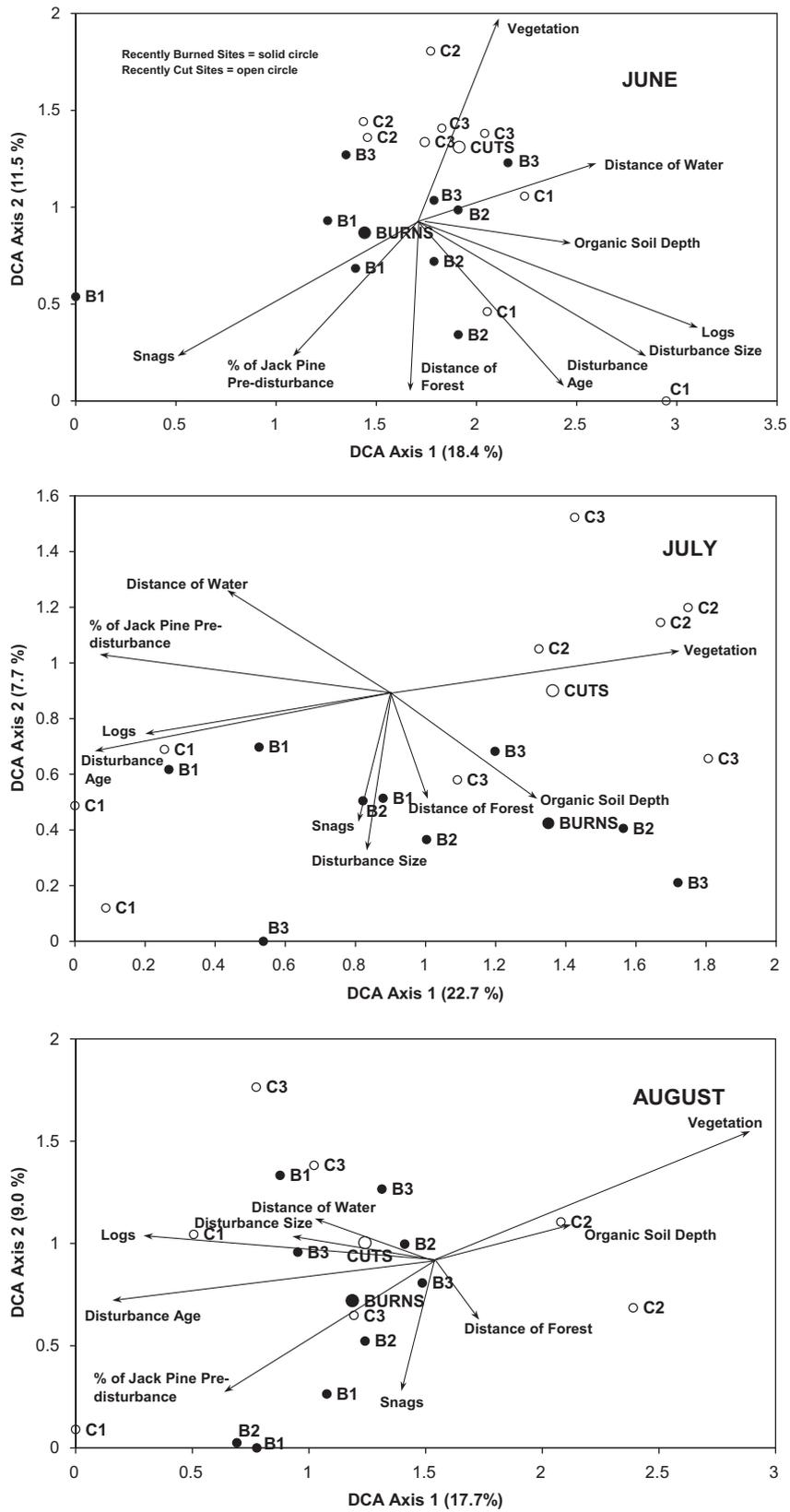


Fig. 3. Site scores and environmental variable biplot scores of passive DCA ordinations of adult moths found in recently clear-cut (open circle) and burned (solid circle) sites in the southern boreal forest of Ontario, Canada. BURNED and CUTS are disturbance type centroids. Into brackets is the percent variance of species accounted for by the respective axis. The various points for a single site represent communities from different sampling nights.

respectively), jack pine pre-disturbance, log abundance, and snag abundance for July ($P < 0.001$ for all three), and log abundance,

DCA scores, and jack pine pre-disturbance for August ($P = 0.026$, 0.027 , and 0.006 , respectively).

Table 2

Ranking of the five most abundant adult moth species found during the summer, in burned by wildfire or clear-cut mixed jack pine forests, in the southern boreal forest of Ontario, Canada.

		Burned sites	Clear-cut sites
Overall	1	<i>Orthodes cynica</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
	2	<i>Callopietra cordata</i> (Noctuidae)	<i>Protorthodes oviduca</i> (Noctuidae)
	3	<i>Protorthodes oviduca</i> (Noctuidae)	<i>Callopietra cordata</i> (Noctuidae)
	4	<i>Petrophora subaequaria</i> (Geometridae)	<i>Idia americalis</i> (Noctuidae)
	5	<i>Idia americalis</i> (Noctuidae)	<i>Petrophora subaequaria</i> (Geometridae)
June	1	<i>Protorthodes oviduca</i> (Noctuidae)	<i>Protorthodes oviduca</i> (Noctuidae)
	2	<i>Petrophora subaequaria</i> (Geometridae)	<i>Petrophora subaequaria</i> (Geometridae)
	3	<i>Spilosoma congrua</i> (Arctiidae)	<i>Spilosoma congrua</i> (Arctiidae)
	4	<i>Homochlodes fritillaria</i> (Geometridae)	<i>Drasteria adumbrata</i> (Noctuidae)
	5	<i>Lasionycta albinuda</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
July	1	<i>Orthodes cynica</i> (Noctuidae)	<i>Orthodes cynica</i> (Noctuidae)
	2	<i>Callopietra cordata</i> (Noctuidae)	<i>Callopietra cordata</i> (Noctuidae)
	3	<i>Polia detracta</i> (Noctuidae)	<i>Peridea ferruginea</i> (Notodontidae)
	4	<i>Sphinx gordius</i> (Sphingidae)	<i>Sphinx gordius</i> (Sphingidae)
	5	<i>Scopula spp.</i> (Geometridae)	<i>Polia detracta</i> (Noctuidae)
August	1	<i>Idia americalis</i> (Noctuidae)	<i>Idia americalis</i> (Noctuidae)
	2	<i>Polia purpurisata</i> (Noctuidae)	<i>Zanclonatha jacchusalis</i> (Noctuidae)
	3	<i>Eurois astricta</i> (Noctuidae)	<i>Eueretagrotis attenta</i> (Noctuidae)
	4	<i>Eueretagrotis attenta</i> (Noctuidae)	<i>Xestia normaniana</i> (Noctuidae)
	5	<i>Xestia normaniana</i> (Noctuidae)	<i>Polia purpurisata</i> & <i>Eurois astricta</i> (both Noctuidae)

Table 3

Correlations between environmental variables and DCA axis scores (of the axis lying closest to vector) for recently burned or clear-cut forests where moths were light-trapped in the southern boreal forest of Ontario, Canada.

Environmental variable	Month		
	June	July	August
Disturbance age	−0.72	−0.85	−0.69
Vegetation	0.72	0.75	0.61
Logs	0.53	0.72	−0.66
Pre-disturbance % of jack pine	−0.58	−0.68	−0.42
Snags	−0.50	−0.32	−0.30
Disturbance size	0.46	−0.45	−0.28
Distance of water	0.35	−0.48	−0.25
Distance of forest	−0.38	−0.38	−0.34
Organic soil depth	0.25	0.29	0.27

4. Discussion

Although both disturbance types seemed to be able to provide habitat for the majority of early-successional moth species, we found several differences in moth communities between the two disturbance types. We suspect that clear-cutting emulates wildfire relatively well for this community and forest type early in succession; however, differences between the two may be problematic for several species. It is unlikely that our methodology contributed significantly to these results as light traps were placed well beyond the minimal distance documented to draw moths from surrounding forests (Nieminen, 1996). Vegetation seemed to be particularly influential for nocturnal macrolepidopteran communities in our study, which is not surprising given that moths are primarily herbivores in their larval stage and adults do not consume large amounts of food (only nectar or honey-dew for about a week of their short adult lifespan, Young, 1997). Our work supports the hypothesis that plants are a prime determinant of moth diversity, and moreover that the primary distinction between clear-cut and post-fire sites was due to vegetation differences, and suggests that for moths, vegetation management following harvesting will be critical in determining the extent to which it emulates wildfire.

Contrasting responses of various taxonomic assemblages to the two disturbances may reflect other habitat variables as well. Standing deadwood or snag abundance is a feature of disturbed forests that often differs between burned and clear-cut sites

(Hutto, 1995, this study). Both log and snag abundance was a correlate of moth composition in our study. In Scandinavia, fire suppression in recent years has meant a lack of young post-fire forests (Niemi, 1997) and a decline in several insects associated with this habitat. However, the focus of these studies was on Coleoptera or Heteroptera (Heliövaara and Väisänen, 1984; Ahnlund and Linhe, 1992; Muona and Rutanen, 1994), and no work has considered lepidopterans such as we observed here. The rarity of some species seen in the Scandinavian studies implies that, at least for them, clear-cuts were not a suitable replacement for burned sites. Many of the insects associated with snags are saproxylic and solely dependent on dead wood suggesting a difference in either the quantity or quality of wood in post-fire versus post-logged sites. It is unclear why moth composition was correlated with dead wood abundance in our study. Possibilities include an influence of habitat complexity on predation by birds or bats, CWD-associated differences in plant germination, and effects of micro-site characteristics and overwintering success. The correlation with snags may have been spurious given the high contrast for this variable between the two disturbance types.

In other studies comparing arthropod communities between clear-cut and fire sites, diverse results have been obtained. Ground beetle (Coleoptera: Carabidae) assemblages from southern Quebec (Canada) were not highly specific to either clear-cut or burned sites, but diverged in abundance and species dominance following disturbance (Saint-Germain et al., 2005). Buddle et al. (2006) found that diversity and composition of litter-dwelling assemblages in clear-cut and burned sites differed from the beginning 1–2 years after disturbance. Thus, although a few years seem to be enough for some assemblages to converge after disturbance, other arthropod assemblages may take longer. For example, Buddle et al. (2006) found that most taxa of ground beetles, rove beetles (Coleoptera: Staphylinidae), and spiders (Arachnida: Araneae) from clear-cut and wildfire sites converged ca. 30 years after disturbance, although they were always more abundant in pyrogenic than in post-harvest sites.

A relatively small proportion of the species were significantly more frequent in either burned or clear-cut sites. This relative lack of significance must be tempered, however, with the relatively low number of replicates in this study and hence the low power. As well, it should be noted that our sampling focussed on species on the wing in summer. Species whose primary flight periods were

in May to early June and in mid-August to early September were underrepresented by our sampling.

Among these significant species, more were likely potential burn than clear-cut specialists (8 of 12 species). We found no obvious common features among the potential burn specialists; i.e. they did not feed on the same plant species nor fly at the same time of the year. Other moth diversity studies carried out in various parts of North America recorded all of the species we found except *N. rubrifrontaria*. These other studies took place in diverse forested sites including balsam fir-red maple forests of New Brunswick (Thomas, 1996), mixed oak forests of West Virginia (Butler and Kondo, 1991), and riparian zones within coniferous forests of Oregon (Grimble et al., 1992). Thus, it seems unlikely that these moth species are burn specialists, except for *N. rubrifrontaria*. According to Ferguson (1985), the two main food plants of *N. rubrifrontaria* are sweetfern and sweetgale (*Myrica gale* L.). Sweetgale was not found in our study sites, but sweetfern was common in two of our three burned sites and rare in the cut sites. It has been documented that sweetfern increases in abundance after fire (Vogl, 1971; Boerner, 1981), which may explain the differences we observed and support the idea that these species, while not burn specialists, are favoured through conditions that support growth of their host plant. Another moth species that has been previously noted to be a burn specialist, *Actebia fennica* (Tauscher) (Noctuidae) and which responds to fire smoke (J. McNeil, Biology, Laval University, Quebec City, pers. comm.), was not captured in our study.

Among the species that were significantly more abundant in clear-cut compared to burn sites, *A. innotata* was found in all three of our clear-cut sites, but not in any of our burned sites. The reason for this is unclear particularly as this moth is a member of the *Betula–Alnus–Populus–Salix* feeding group (Covell, 1984; Rings et al., 1992) and might be expected in both site types. Another taxon of note in our clear-cut sites was from the *Euxoa* genus; four out of the five *Euxoa* captured were found only in our cut sites. This species-rich genus is characteristic of dry temperate habitats (Lafontaine, 1987), and although food plants for many species in this genus are not known, they are thought to be generalist feeders (Lafontaine, 1987). *Euxoa* overwinters as eggs or sometimes as first-instar larvae, with eggs being placed just below the surface of the soil (Lafontaine, 1987). Lafontaine (1987) hypothesized that soil conditions such as moisture, texture, and exposure are more important in defining the range of *Euxoa* than its food plants. The prevalence of *Euxoa* in our cut sites might be explained by a preference for it to lay eggs in drier mineral soil, similar to that found on the surface of our clear-cut sites.

Our study supports that of previous work on the effects of forest disturbance and biodiversity suggesting that clear-cutting may emulate wildfire for some organisms, but not for others. Forest managers must consider multiple aspects of forest structure in attempting to use clear-cuts to mimic fire. In the case of mobile, winged species such as the macrolepidopteran studied here, little difference in the effect of disturbance may be detected early after disturbance, especially when adults can move rapidly across the landscape in search of suitable mates and host plants and provided that vegetation communities in the various disturbance types follow similar successional trajectories.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.foreco.2011.08.021.

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