Journal of Insect Conservation **5**: 187–196, 2001.

Short-term effects of harvest technique and mechanical site preparation on arthropod communities in jack pine plantations

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Received 8 August 2000; accepted 10 April 2001

Key words: arthropods, forest, jack pine, harvest technique, site preparation

Abstract

Arthropods play a key role in the functioning of forest ecosystems and contribute to biological diversity. However, the influence of current silvicultural practices on arthropod communities is little known in jack pine (*Pinus banksiana*) forests, a forest type comprising a major portion of the Canadian boreal forest. In this study, the effects of silvicultural treatments on arthropod communities were compared to identify those treatments that minimize ecological impacts on arthropods. The influence of harvesting techniques and mechanical site preparations on insect family richness and abundance of arthropods (total, by orders and by trophic groups) was examined in young (three-year-old) jack pine plantations of northern Ontario. Each of the following treatments were conducted in three plots: (1) tree length harvest and trenching; (2) full tree harvest and trenching; (3) full tree harvest and blading; and (4) full tree harvest and no site preparation. Arthropods were collected using sweepnets and pitfall traps over two years. Blading significantly reduced insect family richness, the total abundance of arthropods, abundance of Orthoptera, Heteroptera, Hymenoptera, Diptera, insect larvae, and plant feeders when compared to the other treatments. The use of either full tree or tree length harvesting had similar short-term effects on family richness and the abundance of arthropods. Arthropod diversity declined with increasing post-harvest site disturbance. These results suggest that arthropod communities in the understory and on the ground are reduced most on sites mechanically prepared by blading, but are similar under conditions immediately following either full tree or tree length harvesting. The implications for regenerating jack pine in the boreal forest are discussed.

Introduction

Current attempts to conserve biological diversity in forest ecosystems include the development of forestry practices that emulate critical aspects of natural disturbances (Franklin 1989; Noss & Cooperrider 1994). The effects of timber harvesting on forest ecology, however, differ from those of natural disturbances (Hunter 1993). Large areas of natural forests are being harvested and reforested, and although existing natural reserves are insufficient to maintain overall biodiversity, major expansions of the reserve network are unlikely (Hansen *et al.* 1991). Consequently, it is crucial to use ecologically sound silvicultural practices in the matrix of forested landscapes (Hansen *et al.* 1991; Niemelä 1997; Perry 1998).

Most studies examining the influence of forestry practices on invertebrate communities have emphasized the effects of logging and habitat fragmentation in boreal and tropical forests (Didham 1997; Niemelä 1997). There is evidence that certain types of forest management cause a general decline in insect fauna over time (Siitonen & Martikainen 1994; Michaels & Bornemissza 1999). Previous studies suggest that biodiversity in both the Palearctic and Nearctic boreal regions can be maintained by maximizing habitat diversity at the regional scale, and that knowledge of ecological processes at the local scale is essential to conserve specific assemblages (Niemelä *et al.* 1993*b*). Soil and litter micro and macrofauna were the main groups used to examine the effects of catastrophic disturbance (such as deforestation, harvesting and fire) on arthropods (Huhta *et al.* 1967; 1969; Huhta 1971; 1976; Vlug & Borden 1973; Seastedt & Crossley 1981; Bird & Chatarpaul 1986; Beaudry *et al.* 1997; Paquin & Coderre 1997; Michaels & Bornemissza 1999). Although prior studies addressing the effects of forestry practices on invertebrates have mainly focused on logging, the type of scarification and methods of plantation establishment can also influence insect diversity (e.g., Watt *et al.* 1997). The effects of harvesting technique (e.g., Bird & Chatarpaul 1986) and other silvicultural practices (e.g., Huhta *et al.* 1967; 1969; Beaudry *et al.* 1997; Duchesne *et al.*, 1999) on arthropod communities have been little studied in the boreal forest.

Forestry practices may affect both composition and function of arthropod communities. Changes in community composition, species richness and/or population abundance of arthropods have been documented following logging for a limited number of taxa including ants (Punttila *et al.* 1994), carabid beetles (Niemelä *et al.* 1993*a*; Spence *et al.* 1996), lucanid beetles (Michaels & Bornemissza 1999), moths (Holloway *et al.* 1992), and spiders (Pajunen *et al.* 1995). The functional approach to the study of insect communities, as a complement or alternative to the species diversity approach, analyses the changes in insect groups (representing different ecological roles) as influenced by forest management (Didham *et al.* 1996). Insect functional assemblages, such as trophic groups, change following habitat management and such shifts can affect ecosystem processes (Kruess & Tscharntke 1994).

Jack pine (*Pinus banksiana*) is one of the most important species used for timber and pulp production in Canada. Natural regeneration of jack pine occurs after fire has opened up the serotinous cones and the forest canopy (Cayford & McRae 1983). Clearcutting is the primary silvicultural system used to regenerate jack pine. Full tree harvesting is the most common technique currently used to harvest jack pine forests in northern and northeastern Ontario. It involves the removal of the entire tree from the site as opposed to tree length harvesting that removes only the commercially valuable timber, leaving branches and unwanted logs on the site. Harvesting is followed by scarification and planting or seeding. Site preparation in jack pine is conducted to provide the soil conditions required for seedling growth, reducing the level of organic matter, exposing the mineral soil, and reducing competing vegetation. Trenching is a commonly used mechanical site preparation in the jack pine forests, and it usually employs a disc to mix the organic matter of the forest floor with the mineral soil. Blading is primarily used when competing vegetation or slash is abundant on a site, and involves the removal of the organic layer and vegetation with a caterpillar bulldozer, thereby exposing the mineral soil completely.

Although jack pine forests managed within the clearcutting system cover extensive areas of the southern boreal forest in Ontario, little is known about the effects of current silvicultural practices on arthropod communities (Beaudry *et al.* 1997). In this paper, the short-term influences of harvesting technique (full tree and tree length harvesting) and mechanical site preparation (blading, trenching, and no site preparation) on arthropod communities in herbaceous vegetation and on the soil surface are examined in recently established jack pine plantations of northern Ontario. We identify the silvicultural practices that best promote insect diversity at the higher taxonomic level, and test the hypothesis that richness of insect families, total abundance of arthropods, and proportions of herbivores, predators, and parasitoids, vary depending on the silvicultural treatments.

Materials and methods

Study area

The study was conducted in a recently planted jack pine stand near Chapleau (47°50′N, 83°24′W), Ontario, Canada. The area was located in the southern boreal forest where jack pine is the dominant tree species in the forest community. The landscape showed large extensions of monospecific coniferous forest, ranging in age from 2 to over 60 years, resulting from natural or artificial regeneration after wildfire or clearcutting. Mixed coniferous-deciduous forests were also present in the area.

The study site was part of a larger project carried out by the Canadian Forest Service (Great Lake Forest Center) and the Ontario Ministry of Natural Resources. Prior to cutting, the site was an 82-year-old jack pine stand (composed by 90% jack pine and 10% black spruce) with the following characteristics: mean dbh, 22.9 cm; mean height, 17.0 m; and density, 706 stems/ha (Tenhagen *et al.* 1996).

The site was harvested using the clearcutting system that removes all standing trees and it was prepared and planted with jack pine seedlings in a 2 × 2 m spacing in 1994. Stock assessment revealed that seedlings had a good root growth potential, good conductivity (determines the presence of cell damage in shoot tissues), and an excellent chlorophyll florescence (indicates a healthy photosynthetic system). The soil at the site is sandy with variable texture, from very fine to very coarse. Stock assessment and soil analysis were conducted by the Canadian Forest Service (Tenhagen *et al.* 1996).

Experimental design

Forestry operations were carried out by the Canadian Forest Service and the Ontario Ministry of Natural Resources in cooperation with the local forest industry to examine the long-term impacts of silvicultural practices on jack pine growth and productivity. A completely randomized design was used for the experiment, with 12 plots established in the site described above prior to harvesting. Four harvest/site preparation treatments were randomly assigned to the plots for a total of three replications per treatment. Plots were 30 × 30 m, separated from each other by 20 m. Each plot was planted with 100 jack pine seedlings.

Treatments consisted of different combinations of harvest technique and mechanical site preparation within a clearcutting system. Two harvest techniques (full tree and tree length harvesting) and two mechanical site preparations (trenching and blading) were used in the experiment. Each one of the following combinations (treatments) of harvest technique and site preparation were conducted in three plots: (1) full tree harvest/no site preparation; (2) full tree harvest/blading; (3) full tree harvest/trenching; and (4) tree length harvest/trenching.

Plant cover was measured in the low (<10 cm, herbs), mid- (10–50 cm, shrubs), and upper (>50 cm, trees) strata of each plot by establishing a 10-m transect and measuring the distance covered by vegetation to the nearest cm along this line for the three strata. Thus, plots where there was no site preparation had the highest percentage cover in the upper stratum due to the growth of vegetation, whereas bladed plots had virtually no vegetation growth (Table 1).

Table 1. Mean percentage cover (±SE, $n = 3$) of the low, mid- and upper vegetation strata in recently established jack pine plantations subjected to different combinations of harvest technique and site preparation in northern Ontario.

	Low stratum (0–10 cm)	Mid-stratum (10–50 cm)	Upper stratum (>50 cm)
Full tree/no site preparation	0.7 ± 0.7	33.4 ± 11.6	70.8 ± 2.2
Full tree/ bladed	11.6 ± 1.6	3.7 ± 1.4	0.9 ± 0.3
Full tree/ trenching	25.5 ± 9.2	62.7 ± 9.6	37.3 ± 10.4
Tree length/ trenching	12.3 ± 4.7	32.6 ± 12.7	51.6 ± 5.5

Insect sampling

Arthropods were collected in pitfall traps and sweepnets during three sampling periods, 14–19 August 1996, 23–30 June 1997, and 29 July–7 August 1997. These sampling techniques were selected to focus on the ground (pitfall traps) and herbaceous understory of the stands where the greatest effects of harvesting and site preparation were expected. Although we sampled in three different periods, it is likely that the sampling system missed some insect species whose adult stages were not present at the time of sampling.

Pitfall traps consisted of 23 × 23 cm aluminium containers, 6 cm depth, 3/4-filled with water and a small amount of unscented detergent to prevent insects from escaping the trap. Five pitfall traps were set up in each plot. One trap was set in the center of the plot, and the remaining four traps were set 7.5 m from the center of the plot in the directions given between the center and each corner of the plot. Traps operated for four consecutive days during each sampling period. Captured arthropods were placed in labelled plastic bags and preserved in 90% ethanol for later identification in the laboratory.

Sweepnet samples were taken along five transects in each plot. A series of 10 sweeps per transect was carried out in 1996 while 20 sweeps per transect were done to increase the sample size in 1997. Captured arthropods were placed in labelled plastic bags and preserved as described above.

Arthropods were sorted and counted under a dissecting microscope, and adult insects were identified to family following Borror *et al.* (1989).

Data analysis

Abundance of arthropods was estimated as the number of individuals per 20 traps/day, or as the number of individuals per 20 sweeps. Weighted averages were calculated on sweepnet data to account for differences in sampling effort in 1996 and 1997. Family richness was estimated by counting the number of adult insect families captured by either pitfall traps or sweepnets in each plot.

Selected arthropod taxa were assigned to functional groups based on their position in the food web as evidenced by the feeding mode of the adult stages (following descriptions by Borror *et al.* 1989). We considered 19 herbivore taxa, 15 predator taxa, and 18 parasitoid taxa in our three trophic categories. We included in the analysis only those arthropod taxa which 90% or more of their members belonged to only one trophic category in Ontario. Taxa included in each trophic category are listed in Appendix 1.

One-way ANOVA was conducted to test for differences in the mean family richness and mean abundance of arthropods among silvicultural treatments. When data failed to reach homogeneity of variances even after transformation, the Kruskal–Wallis test was performed. Parametric (Tukey) and non-parametric (Nemenyi) tests were used for pairwise comparisons between treatments when appropriate. Most statistical tests were performed using the BIOMstat package. All means are presented ±1SE.

Results

General abundance and richness of arthropods

Over 6800 individual arthropods representing 122 families (excluding immature insects and spiders) were collected at the site. A total of 2640 arthropods were collected in sweepnets (692 in samples from August 1996, 833 in June 1997, and 1115 in August 1997) representing 97 families. Most common families found in the understory vegetation were Cicadellidae (Leafhoppers), Cercopidae (Spittlebugs) (in June), and Miridae (True bugs) (in August). In pitfall traps, 4171 arthropods were collected (2020, 1363, and 788 arthropods caught in August 1996, June 1997, and August 1997, respectively). Family dominance of ground-dwelling arthropods varied over time. Of the 98 families represented in pitfall samples, Acrididae (Grasshoppers) and Cicadellidae were most common in August 1996 and 1997, while Carabidae (Ground beetles) and Muscidae (Muscid flies) were most abundant in June 1997. Although twice as many arthropods were collected in pitfalls than in sweepnets, a similar family richness was represented in samples from both sampling techniques. Of the 122 families captured at the site, 25 were found only in sweepnet samples and 24 only in pitfall samples, including some fairly common Coleoptera, Diptera, and Hymenoptera.

Silvicultural practices and arthropod abundance

The total abundance of arthropods differed significantly among treatments of site preparation, where bladed plots showed the lowest abundance in both pitfalls and sweepnet samples (Table 2). Plots with no site preparation supported the highest abundance in pitfall traps, whereas trenched plots and plots that were not site prepared showed the highest abundance in sweepnet samples. There was a significant treatment effect on the abundance of Heteroptera ($H = 8.062$, $P < 0.05$), Coleoptera ($F = 4.662$, $P < 0.05$), Diptera ($H = 7.294$, $P < 0.05$), and Hymenoptera ($F = 11.988$, $P < 0.005$) as revealed by sweepnet samples. Acarina and Diplopoda were only caught in full tree harvested and trenched plots and Thysanoptera in the trenched plots. Pitfall trapping showed significant differences among silvicultural treatments in the abundance of Aranea/Opilionida ($H = 7.845$, $P < 0.05$), Orthoptera ($H = 8.114$, $P < 0.05$), Heteroptera ($H = 8.729$, $P < 0.05$), Hymenoptera ($H = 8.460$, $P < 0.05$), and insect larvae ($H = 7.999$, $P < 0.05$). Plots that were not site prepared supported more Orthoptera, Heteroptera and Hymenoptera than plots subjected to other treatments. Insect larvae were most abundant in full tree harvested and trenched plots.

Fewer arthropods were collected in bladed plots than in plots subjected to any other treatment in both sweepnet and pitfall samples and in the three sampling periods (Table 3). Some differences, however, were not statistically significant. ANOVA and Kruskal–Wallis tests showed significant differences in the number of arthropods among silvicultural treatments in sweepnet samples in August 1996 and June 1997, and in pitfall samples during August 1996 and 1997. Arthropod abundance differed significantly between certain pairs of treatments involving bladed plots, as revealed by pairwise comparisons (Table 3). The use of either full tree or tree length harvesting had a similar effect on arthropod abundance after trenching.

Table 2. Mean number of arthropods (±SE, $n = 3$) caught per 20 sweeps and per 20 pitfall traps/day over three sampling periods in plots where different combinations of harvest technique and site preparation were used for the establishment of a three-years jack pine plantation in northern Ontario.

Taxa	Full tree harvest			Tree length harvests
	No site preparation	Blading	Trenching	Trenching
Sweepnet samples				
Araneae/opilionida (ns)	3.13 ± 1.45	0.60 ± 0.31	2.40 ± 0.99	1.27 ± 0.44
Acarina	—	—	0.27 ± 0.27	—
Diplopoda	—	—	0.07 ± 0.07	—
Collembola	2.40 ± 1.83	0.27 ± 0.27	1.07 ± 0.53	0.67 ± 0.27
Orthoptera (ns)	2.27 ± 0.55	1.40 ± 0.61	4.60 ± 0.90	2.67 ± 0.47
Psocoptera	2.27 ± 1.43	—	0.53 ± 0.07	0.87 ± 0.59
Homoptera (ns)	19.23 ± 3.51	2.80 ± 0.53	23.20 ± 2.66	21.27 ± 5.78
Heteroptera*	14.40 ± 0.72	1.73 ± 0.27	10.13 ± 3.60	7.13 ± 1.00
Thysanoptera	—	—	0.13 ± 0.13	0.13 ± 0.07
Coleoptera*	1.53 ± 0.37	0.40 ± 0.20	1.47 ± 0.47	2.73 ± 0.41
Diptera*	14.20 ± 1.92	3.93 ± 1.07	20.60 ± 5.89	10.80 ± 0.76
Lepidoptera	0.13 ± 0.07	—	0.47 ± 0.13	0.67 ± 0.24
Hymenoptera*	5.93 ± 0.94	1.73 ± 0.55	5.53 ± 0.47	3.67 ± 0.37
Insect larvae (ns)	2.87 ± 0.59	0.40 ± 0.11	3.07 ± 1.57	3.73 ± 1.24
Total*	68.40 ± 2.90	13.27 ± 2.74	73.53 ± 9.82	55.60 ± 7.76
Pitfall samples				
Araneae/opilionida*	51.7 ± 6.7	22.0 ± 3.2	54.7 ± 9.7	38.0 ± 4.6
Acarina	0.3 ± 0.3	—	—	—
Diplopoda	0.7 ± 0.4	—	—	—
Collembola	0.7 ± 0.4	—	—	0.3 ± 0.3
Odonata	1.0 ± 0.6	0.3 ± 0.3	0.7 ± 0.7	0.7 ± 0.7
Orthoptera*	107.0 ± 14.2	12.0 ± 3.6	74.0 ± 18.6	78.0 ± 6.8
Psocoptera	1.0 ± 1.0	—	0.3 ± 0.3	—
Homoptera (ns)	65.3 ± 9.9	8.7 ± 3.5	40.3 ± 11.9	39.7 ± 4.3
Heteroptera*	31.0 ± 2.6	2.3 ± 0.7	15.0 ± 0.6	16.0 ± 7.8
Coleoptera (ns)	55.7 ± 14.8	31.7 ± 4.9	37.7 ± 6.1	39.3 ± 5.4
Diptera (ns)	105.7 ± 13.0	50.7 ± 14.4	85.3 ± 19.4	62.7 ± 4.8
Lepidoptera	3.2 ± 1.7	1.3 ± 0.7	2.3 ± 1.5	1.3 ± 0.3
Hymenoptera*	92.7 ± 21.8	23.7 ± 6.1	40.0 ± 7.8	51.7 ± 7.2
Insect larvae*	2.7 ± 0.9	0.3 ± 0.3	19.0 ± 5.5	8.7 ± 6.2
Total*	520.0 ± 42.2	153.0 ± 23.5	369.3 ± 34.5	336.3 ± 17.0

*Significant treatment effect, $P < 0.05$; (ns) non-significant treatment effect.

Abundance of ground-dwelling arthropods seemed to decrease with increasing disturbance after harvesting (Table 3). In pitfall samples from all sampling periods, plots where there was no site preparation showed the highest number of arthropods followed by trenched plots and finally by bladed plots. This pattern was not consistent in samples collected by sweeping in the understory vegetation.

Silvicultural treatments influenced the composition of the arthropod community and the abundance of the populations. Some families, such as Nabidae, were caught in all plots except the three bladed plots ($H = 9.239$, $P < 0.05$) or were less abundant in bladed plots than in other treatments (Acrididae, $H = 8.128$, $P < 0.05$; Cicadellidae, $H = 7.667$, $P < 0.05$). Other families were more abundant in specific treatment plots than in others; for instance, 42 individual Cicindelidae were caught in bladed plots, whereas four individual were trapped in the other plots all together.

Silvicultural practices and insect family richness

Family richness of adult insects differed depending on the silvicultural treatment. The mean number of families caught in sweepnets and pitfall traps differed significantly among treatments for the three sampling periods (except pitfalls in August 1997) (Table 4). Multiple comparisons between pairs of means revealed that the number of arthropod families differed significantly

Table 3. Mean number of arthropods (±SE, $n = 3$) caught per 20 sweeps and per 20 pitfall traps/day in plots where different combinations of harvest technique and site preparation were used to establish a jack pine plantation in northern Ontario.

	Sweepnet samples			Pitfall traps		
	August 96	June 97	August 97	August 96	June 97	August 97
Full tree/no site preparation	34.5 ± 3.8a	13.2 ± 3.1ab	20.7 ± 3.4a	280.0 ± 44.0a	145.0 ± 30.2a	100.0 ± 16.1a
Full tree/blading	3.9 ± 3.4b	5.1 ± 1.1b	4.3 ± 0.3a	33.0 ± 6.6b	91.3 ± 19.3a	33.7 ± 5.4b
Full tree/trenching	33.4 ± 6.3a	20.5 ± 4.3a	19.7 ± 1.7a	184.7 ± 33.1a	115.0 ± 17.0a	70.3 ± 4.4ab
Tree length/trenching	20.2 ± 0.4ab	16.7 ± 2.2a	18.7 ± 5.7a	175.7 ± 5.5ab	103.0 ± 18.1a	58.7 ± 2.2ab
Statistic tests	$H = 9.45^{*}$	$F = 8.00^{**}$	$H = 6.27$	$H = 8.68^{*}$	$F = 1.12$	$H = 9.76^{*}$

$^{*}P < 0.05$. $^{**}P < 0.01$; within columns, means followed by different letters are significantly different at $P < 0.05$ (Tukey's or Namenyi's pairwise comparisons; critical values are 4.529 and 3.633, respectively).

Table 4. Mean number of families of adult insects (±SE, $n = 3$) caught by sweepnets and pitfall traps in plots treated with different combinations of harvest technique and site preparation in a young (three-year-old) jack pine plantation of northern Ontario.

	Sweepnet samples				Pitfall traps			
	August 96	June 97	August 97	Total	August 96	June 97	August 97	Total
Full tree/ no site preparation	23.7 ± 1.3a	25.3 ± 3.5a	24.0 ± 0a	46.0 ± 1.0a	27.3 ± 1.8a	27.7 ± 2.3a	17.0 ± 2.0a	46.7 ± 1.8a
Full tree/ blading	5.7 ± 1.8b	12.7 ± 1.8b	10.3 ± 0.9b	23.3 ± 1.8b	12.0 ± 1.7b	17.0 ± 2.3b	13.7 ± 2.2a	29.7 ± 1.7b
Full tree/ trenching	19.7 ± 2.7a	27.0 ± 2.1a	26.3 ± 2.9a	44.7 ± 1.8a	24.3 ± 3.2a	25.7 ± 2.3ab	18.0 ± 2.3a	43.3 ± 3.3a
Tree length/ trenching	19.3 ± 2.3a	27.0 ± 1.1a	22.3 ± 5.2ab	47.0 ± 2.1a	23.7 ± 2.6a	25.3 ± 2.6ab	18.0 ± 1.7a	43.3 ± 1.2a
F	13.650^{**}	9.061^{**}	6.030^{*}	43.100^{***}	7.916^{**}	3.882^{*}	0.987	12.603^{**}

$^{*}P < 0.05$.$^{**}P < 0.01$.$^{***}P < 0.001$; within columns, means followed by different letters are significantly different at $P < 0.05$ (Tukey's pairwise comparisons; critical value is 4.529).

only between the bladed plots and all other treatments (with exceptions for sweepnet samples in August 1997 and for pitfall samples in June 1997). These results showed that the bladed plots had a less rich insect fauna at the high taxa level than either trenched plots or plots where no site preparation was performed. Mean family richness was similar between all other pair combinations of harvest technique/site preparation. This showed that the use of either full tree or tree length harvesting resulted in similar family richness, and that trenching following harvesting did not affect the expected family richness based on plots where no site preparation was conducted.

Silvicultural practices and trophic categories

Of the selected taxa, a higher proportion of herbivores than either predators or parasitoids was collected in the sweepnet samples in all treatment plots except the bladed plots where more predators were captured (Table 5). Most differences in the proportion of insects by trophic category were not significant between treatments. In pitfall samples, more predators were collected in all treatment plots except in August 1997 when herbivores were more abundant. The percentage of herbivores was significantly lower in bladed plots than in plots that were not site prepared in June 1997 and August 1997 (pitfalls). The use of either full tree or tree length harvesting did not influence arthropod abundance by trophic group.

Discussion

The techniques used to log and prepare the sites for reforestation influenced the composition of the arthropod community and the abundance of some families shortly after jack pine re-establishment. Some herbivore families were not caught (e.g., Nabidae) or were collected in relatively low numbers (e.g., Acrididae) in plots that had been bladed and in which the vegetation cover of the mid-stratum (low shrubs) was low.

Table 5. Average percentage of the number of individuals by trophic category collected using sweepnets and pitfall traps in plots subjected to different harvest/site preparation treatments in a young (three-year-old) jack pine plantation of northern Ontario.

	August 1996			June 1997			August 1997		
	Herbivores	Predators	Parasitoids	Herbivores	Predators	Parasitoids	Herbivores	Predators	Parasitoids
Sweepnet									
FT/ No SIP	67.4 ± 11.4a	18.2 ± 8.6a	14.2 ± 4.7a	78.3 ± 4.9a	17.3 ± 4.9a	3.9 ± 0.4ab	61.9 ± 2.5a	31.5 ± 1.2a	6.5 ± 3.6a
FT/B	38.3 ± 21.7a	57.5 ± 25.3a	4.2 ± 4.0a	47.8 ± 7.8b	52.2 ± 7.8a	0 ± 0b	35.6 ± 9.9a	45.6 ± 13.7a	18.9 ± 11.6a
FT/T	83.4 ± 6.3a	10.0 ± 4.4a	6.6 ± 4.4a	67.7 ± 3.5ab	15.3 ± 8.6a	16.9 ± 5.5a	49.8 ± 8.3a	22.4 ± 5.2a	27.7 ± 3.1a
TL/T	84.5 ± 5.7a	9.5 ± 3.0a	6.0 ± 2.7a	69.6 ± 3.8ab	14.8 ± 3.9a	15.5 ± 2.3ab	64.0 ± 5.3a	20.4 ± 3.5a	15.5 ± 3.3a
H	5.038	3.615	3.563	8.013**	6.590	9.461*	6.513	5.154	5.397
Pitfall samples									
FT/ No SIP	36.3 ± 3.0a	57.3 ± 1.6a	6.3 ± 1.9a	38.0 ± 4.2a	55.9 ± 3.0a	6.1 ± 1.2a	76.7 ± 1.3a	22.8 ± 1.2a	0.5 ± 0.5a
FT/B	13.1 ± 4.5a	79.5 ± 3.8a	7.3 ± 2.0a	12.3 ± 4.1b	80.6 ± 8.4a	2.9 ± 2.0a	28.1 ± 11.0b	52.5 ± 11.3a	19.2 ± 2.9a
FT/T	32.8 ± 10.3a	65.7 ± 11.1a	1.5 ± 0.8a	20.5 ± 4.6ab	73.4 ± 6.5a	6.1 ± 2.2a	59.4 ± 6.8ab	29.5 ± 4.4a	11.2 ± 2.6a
TL/T	40.8 ± 2.0a	49.8 ± 5.8a	9.4 ± 3.8a	23.8 ± 3.3ab	66.8 ± 4.8a	9.3 ± 1.6a	67.9 ± 5.3ab	25.4 ± 3.0a	6.7 ± 3.4a
H	6.076	5.820	5.667	8.226**	5.674	5.423	8.231**	6.615	6.085

$^{*}P < 0.01$. $^{*}P < 0.05$; within columns and sampling techniques, means followed by different letters are significantly different at $P < 0.05$ (Nemenyi's multiple comparisons; critical value is 3.633). FT: full tree harvesting; TL: tree length harvesting; No SIP: no site preparation; B: blading; T: trenching; H: Kruskal–Wallis test values.

In turn, Cicindelidae (Tiger beetles) were collected almost exclusively in the bladed plots. Members of this family are indicators of degradation of tropical forests (Rodríguez *et al*. 1998), and occur typically in open sunny sites and sandy soil in Canada, a situation similar to that in bladed plots where removal of the organic layer exposed the sandy soil and reduced vegetation.

Both full tree and tree length harvesting resulted in similar richness and abundance of the arthropod community in the understory and on the ground. Few comparisons have been made between arthropod communities following different harvesting techniques. Bird and Chatarpaul (1993) compared the effects of full tree harvesting (removal of all aboveground biomass of trees) and conventional harvesting (some stems and slash were left at the site) on soil microarthropods in a mixed conifer-hardwood forest in central Ontario. This study showed that conventional harvesting had less impact on soil microarthropods than full tree harvesting. The high availability of decaying wood usually associated to areas recently regenerating after logging promotes species richness and abundance of saproxylic arthropods in the short-term (e.g., Michaels & Bornemisszza 1999). Although probably more arthropods directly associated with the slash piles and woody debris were present (or more abundant) after tree length harvesting than after full tree harvesting, this was not apparent from our sweepnet or pitfall samples. In Cameroon tropical forests, complete clearance, partial mechanical clearance (some soil compaction), and partial manual clearance (minimal soil compaction) reduced species richness of all arthropod groups studied (butterflies, leaf-litter ants, arboreal beetles, and termites) after complete forest clearance (Watt *et al.* 1997); however, species richness of some groups increased and that of other groups decreased after partial clearance.

The type of site preparation influenced the abundance of arthropods in recent jack pine plantations. Silvicultural treatments used on a site can affect arthropod abundance in temperate forests. For example, the type of disturbance regime (burn, logged, and natural regenerated; clearcut, roller chopped, and broadcast seeded; and clearcut and bracke seeded) changed the abundance of some ground-dwelling arthropod taxa (e.g., Opilions, Gryllacrididae) in sand pine forests of Florida (Greenberg & McGrane 1996). In the coniferous forests of Finland, changes in the abundance of soil microarthropods and ground-dwelling arthropods were also evident after burning (springtails, mites), fertilizing (springtails, mites) and reforestation (springtails, larvae and adult beetles, spiders, mites) (Huhta *et al.* 1967; 1969). Similar results were found in eucalypt forests in Australia, where high taxa richness and abundance of many litter-dwelling arthropods were lower in areas subjected to frequent fire than in unburned areas (York 1999). We found that blading reduced the number of insect families and abundance of herbivores compared to the other treatments three years after plantation establishment. Associations between plant and insect diversity may partially explain these results. The low number of families represented in the bladed plots compared to other treatments was more evident in the understory vegetation (sweepnet samples) than on the ground (pitfall samples). Furthermore, the abundance of herbivores (unlike predators or parasitoids) was reduced in the bladed plots where soil removal made the site inhospitable for many plant species.

We found no significant differences in family richness between trenched plots and the control plots that were not prepared. Our results are consistent with findings by Beaudry *et al.* (1997) at the species level for carabid beetles one year after clearcutting of jack pine. These authors found that species richness and diversity of carabid beetles was similar between trenched plots and plots that were not site prepared but higher in plots subjected to prescribed burning.

Arthropod abundance declined with increasing intensity of post-harvest mechanical disturbance to the site. In general, species richness declines with increasing disturbance in tropical forests (e.g., Lawton *et al.* 1998). In the boreal forest, logging can decrease both richness and abundance of arthropods (e.g., Paquin & Coderre 1997). Our results showed that a further decline in arthropod abundance occurred following mechanical site preparation. Mixing (trenching) or removal (blading) of the soil organic matter reduced the abundance of arthropods shortly after treatment, especially on the ground. This suggests that mechanical site preparation techniques that cause the least disturbance to a site will minimize the ecological impact of such a treatment on arthropod communities in the short-term. In jack pine forests, clearcutting and the use of different site preparation techniques in a matrix of mature and old-growth forest would favour conservation of old-growth species while promoting habitat heterogeneity and thus arthropod diversity, as it has been suggested for carabid beetles (Beaudry *et al.* 1997). However, mechanical site preparation techniques that involve high soil degradation (such as blading) significantly reduce richness of insects at the higher taxon level and its use should be limited. Investigating the responses

of individual species and arthropod communities over longer periods of time should reveal further specific effects of silvicultural practices in jack pine forests.

Acknowledgements

We thank K. Kloosterman and C. Edwards for their technical assistance in the field and the Canadian Forest Service (Sault Ste. Marie) and E.B. Eddy Forest Products for providing logistic support. T. Blake, J.R. Spence, R. Westwood and two anonymous reviewers made valuable comments to the manuscript. This research was sponsored by the Forestry Canada Green Plan and the Ontario Ministry of Natural Resources.

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Appendix 1. Arthropod taxa considered in each trophic category based on the primary feeding mode of adult forms.

Herbivores	Predators	Parasitoids
Acrididae	Araneae	Aphelinidae
Aphididae	Asilidae	Aulacidae
Berytidae	Carabidae	Bethylidae
Cecidomyiidae	Cicindelidae	Braconidae
Cerambycidae	Dolichopodidae	Ceraphronidae
Chrysomelidae	Dytiscidae	Chrysididae
Cicadellidae	Empididae	Diapriidae
Curculionidae	Histeridae	Eulophidae
Elateridae	Lampyridae	Eupelmidae
Lagriidae	Nabidae	Ichneumonidae
Lonchaeidae	Pompilidae	Megaspilidae
Lygaeidae	Reduviidae	Mymaridae
Meloidae	Saldidae	Perilampidae
Membracidae	Sphecidae	Pipunculidae
Pentatominae	Vespidae	Platygasteridae
Rhopalidae		Proctotrupidae
Scutelleridae		Pteromalidae
Therevidae		Scelionidae
Thripidae		