



Impacts of harvesting on insect community composition using water-pan traps in maple-beech trees, Haliburton forest, Canada

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Abstract

Insect communities respond to microhabitat changes caused by forest management. Therefore, it could be used to examine ecological changes following management. Differences in abundance, richness and composition of different insect assemblages at two different taxon levels (Order and family) were assessed. This was undergone at Haliburton Forest, Ontario, Canada dominated by maple-beech trees by setting water-pan traps at five sites. One of the sites has never been harvested while the others have been harvested at different times through the last two decades. Sampling also included locations (edge and center of each harvested site). There were 2270 insects caught in traps, out of them 1206 hymenopteran dominated by Diapriidae. Order Diptera represented by 625 individuals and Muscidae was the most abundant family. Both orders Coleoptera and Hemiptera represented by 241 and 127 individuals. Different cutting dates showed no influence on the structure of selected insect assemblages at the high-taxa level, while few hymenopteran and dipteran families showed some significant change along the time following cutting represented by Diapriidae, Platygasteridae and dipteran Muscidae. Regarding locations, there were no significant differences in abundance of different taxa levels. Jaccard index indicated relative similarity in hymenopteran family composition in the study sites and a high similarity (98%) among the two locations. Non-metric Multidimensional Scaling (NMDS) that used to perform ordinations has shown some evidence of segregation of hymenopteran families by site and location. The present study has shown that harvesting of forest tree has a little influence on the changes in associated insect community composition.

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Introduction

Forests are one of the most vital ecosystem components all-over the globe. They are engaged in the provision of complimentary services to both human being and nature. Forests are sustainably managed for a range of benefits. Strategies of management have been changed in the past decades to include the maintenance of biodiversity and wildlife populations along with timber extraction and recreation objectives. The periodic harvesting resulted in local-scale disturbances and change in the environmental conditions (Beaudet and Messier, 2002). In this regard, any forest management scenario requires suitable indicators that easily monitored to give real and precise impression beyond varying management regimes (Yi, 2007). Forest insect communities are considered as vital part relying on the complexity of the ecosystems and their response during any environmental changes can be exploited as a crucial tool for the altered forest habitats (Schowalter and Ganio, 1998, Hunter, 2002, Pohl *et al.*, 2007; Maleque *et al.*, 2009). This is due to their short generation time, small size and high sensitivity to environmental changes (Kremen *et al.*, 1993; Samways, 1994; New, 1998; Schowalter *et al.*, 2003).

Many studies in the forests showed that both hymenopteran and saproxylic insects are sensitive to gap formation and harvesting of the forest (Deans *et al.*, 2005; Muller *et al.*, 2007). Hymenopterans, in particular, have high diversity and play a vital role in the ecosystem that includes pollination, nutrient-cycling, herbivory, predation and parasitism (Smith *et al.*, 2012). The largest group in this order is the parasitic wasps, which includes major families like Braconidae, Ichneumonidae, and Chalcidoidea (Smith *et al.*, 2012). Parasitic wasps are highly dependent on host density, distribution, and host habitat-related factors like vegetation structure and foraging sites for herbivorous insects (Meiners and Obermaier, 2004; Kagata *et al.*, 2005; Zeipel *et al.*, 2006). Consequently, these wasps are sensitive to environmental changes due to their high

specialization beside their upper position in the trophic web (Smith *et al.*, 2012). In addition, the dipteran parasitoids of family Tachinidae, a large parasitoid group of forest insects found out of order Hymenoptera, has also shown response to forest management (Deans *et al.*, 2005). Such species are potentially sensitive to disturbances (Komonen *et al.*, 2000; Siitonen, 2001) and might serve as indicators of ecosystem changes and provide useful picture about the effects of different forestry practices. Both of these parasitoid assemblages have served as indicators in forests (Deans *et al.*, 2005; Pohl *et al.*, 2007). Similarly, the vital ecological role of dipteran and hymenopteran pollinators impose their use as bioindicators where they respond acutely to ecosystem changes (Hatfield and LeBuhn, 2007; Maleque *et al.*, 2009).

Old-growth forests supposed to support higher biodiversity (Okland *et al.*, 2003; Lindenmayer and Hobbs, 2004; Ohsawa, 2005) due to the presence of diverse tree species, variable age classes, large logs, snags, and vertical structural heterogeneity, which provide diverse habitat resources for forest-dwelling organisms (Ishii *et al.*, 2004; Humphrey, 2005). Natural forests are the reference state for sustainable management (Angelstam, 1998; Wesolowski, 2005). Forest management includes a large range of practices that supposed to have contrasting impacts on biodiversity (Stephens and Wagner, 2007). After management, forests will partially be able to restore its diversity through time. The aim of the current study was to compare insect communities between unharvested site and sites harvested at different dates in order to understand the dramatic changes happening in the natural communities after management. In addition, to evaluate the diversity recovery over time where estimation of the time needed for biodiversity recovery is crucial for conservation policy. Finally, to make sustainable management recommendations that will maintain biodiversity as forest management still threatens the survival of many species that depend on natural forest habitats.

Materials and methods

Study sites

The study sites were located at the Haliburton Forest, Ontario, Canada. The region dominated by maple-beech trees which is a climaxmesic closed canopy hardwood forest that is primarily composed of American beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.) trees which co-dominate the forest. The study sites are subjected to management through harvesting. During the present study, five sites were selected based on their harvesting dates. Sites 1& 2 represented maple-beech trees those have been harvested in 2011. Sites 3& 4 represented maple-beech trees those have been harvested in 2008 and 1998. Site 5 had never been harvested. Cut sites have "trails" running through them that are used by the loggers to haul the cut trees out of the forest. These are understandably very impacted and often have little to no canopy cover along their length. Some traps were set up on the skid trails ("Edge") and others in the forest proper a fair piece from the skid trails ("Center").

Insect sampling and identification

In order to collect flying insects in different study sites, units of water-pan traps were set at a height of 1 m above ground during 2013 summer. In sites (1, 2, 3) pan traps were set in both center and edge of each site to find out whether insect diversity will differ in the two locations due to the difference in their canopy cover. Traps were also set at sites 4&5 in order to compare the entomofaunal diversity in the five study sites of different harvesting dates. Each trapping unit composed of three colors (blue, yellow and white). Pan traps were filled with water containing some drops of detergent to make insects sink quickly. The traps were emptied after 48 hours. The collected insects per trap were pooled and kept in 75% alcohol. All captured Hymenoptera were identified to family following published identification guides (Grissell and Schauff 1990; Goulet and Huber 1993). Selected Diptera families were also identified using identification manuals, keys and guides (Mc Alpine *et al.* 1981, 1987; Oosterbroek 1998).

Data analysis

Water-pan traps were set at different five sites to study the effect of harvesting on insect communities. In three sites (1, 2, 3) the traps were set in the center and at the edge of each site to evaluate the effect of plant cover density on insects. Sampling occurred more than once during July and August 2013. Differences in trapping numbers and dates have no influence on the results since only the mean numbers of insects per trap site and location are compared. Abundance was estimated as the number of individuals caught per trap. Since many taxa were represented by very few individuals (rare taxa), the criteria used to run the ANOVA on a given taxon were to have more than 15 individuals as the total caught. Data were transformed as necessary to achieve assumption of normality. While data for some of the more common wasp families did not fulfill the requirements of normality and homoscedasticity, even after transformation, ANOVA is robust to departures from the assumptions of normality and homogeneity of variances when sample sizes are large enough and when experiments are balanced (Underwood, 1997). The ANOVA analysis was run using SPSSPASW Statistics ver. 18, GLM Univariate, Method= SSTYPE (3) which calculates the sum of squares of an effect F in the design as the sum of squares adjusted for any other effects that do not contain it, and orthogonal to any effects (if any) that does contain it. The Type III sums of squares have the major advantage of being invariant with respect to the cell frequencies as long as the general form of estimation remains constant. The effects of different harvesting dates and locations on number of taxa caught in traps and their diversity with Shannon index were performed using R version 3.2.2 (R Core Team 2015), vegan package (Oksanen *et al.* 2016). This was followed by t-test for locations and analysis of variance for sites. For illustration, means comparisons were visualized with box-plots.

Non-metric multidimensional scaling (NMDS) (Kruskal, 1964; Mather, 1976; Clarke, 1993) is an ordination method based on ranked differences.

It was used to explore further differences in the hymenopteran families by site (each site represent certain harvesting date) and location (at the edge of sites near the cutting gaps or at the center). It is particularly useful for ecological gradient studies because of its lack of assumptions about the distribution or type of data and its general robustness. With NMDS, the number of factors structuring a complex arthropod community can be determined so that the overall distribution of taxon assemblages may be qualitatively summarized across the gradients of different thinning dates. In addition, NMDS was used in lieu of other ordination methods because it avoids the zero-truncation problems of Beals smoothing. NMDS was conducted with vegan package (Oksanen *et al.* 2016).

To compare community composition between the places near the center and those at the edge of sites; abundance-based Jaccard index was estimated for hymenopteran taxa using Spade R package (Chao *et al.* 2016). This index varies from 0 (no similarity between both communities) to 1 (when all taxa are shared by both communities), and

high values indicate high similarity between communities (or low β -diversity). Adjusted Jaccard index of similarity is one of the recommended indices for quantitative data because they are not greatly affected by sample size (Krebs 2014). On the other hand, similarity of different sites thinned at different dates was estimated through the richness-based index (the classic N-community Jaccard index) (Chao *et al.* 2016).

Results

Insect composition, abundance and richness

In all, 2270 individual insects were caught in the water-pan traps, most of them belonged to 4 dominant orders (Hymenoptera, Diptera, Coleoptera, Hemiptera) and 71 of these individuals belonged to other orders. Total of 1,206 hymenopterans representing 22 families were collected. Six hymenopteran families have met the criteria of ANOVA analysis that has been run to test for differences between sites harvested at different dates and the effect of trapping location either at the center or at the edge of sites (Table 1).

Table 1. Mean numbers of individuals per trap from selected insect orders and families caught in the Center (C) and Edge (E) of different sites at Halliburton forest, Canada.

Order/Family	Site 1		Site 2		Site 3		Site 4	Site 5	p values	
	C	E	C	E	C	E	C		Sites	Locations
Hymenoptera										
Diapriidae	47.33	40.00	18.50	11.50	7.00	4.00	9.68	30.75	0.04	0.59
Ichneumonidae	7.00	14.00	9.50	13.50	5.99	8.00	5.25	5.25	0.15	0.07
Braconidae	0.25	0.20	0.19	0.30	0.47	0.00	0.46	0.26	0.53	0.20
Platygastridae	0.30	0.90	0.30	0.38	0.47	0.30	0.06	0.30	0.01	0.28
Ceraphronidae	0.30	0.20	0.30	0.00	0.30	0.00	0.16	0.23	0.84	0.12
Eulophidae	0.20	0.20	0.22	0.15	0.00	0.00	0.15	0.19	0.56	0.82
Total abundance ¹	60.00	66.33	34.50	35.75	18.00	13.00	22.00	40.75	0.09	0.95
Diptera										
Dolichopodidae	0.99	0.66	1.25	3.0	0.00	0.00	-	0.50	0.11	0.54
Muscidae	1.33	2.0	2.75	4.50	9.00	2.99	-	7.49	0.02	0.36
Syrphidae	0.33	1.00	0.25	3.0	0.00	0.99	-	1.49	0.67	0.16
OtherDiptera	29.66	21.00	24.50	38.50	4.00	4.00	-	38.50	0.31	0.87
Total abundance	33.66	26.0	30.5	50.74	12.99	7.99	-	49.99	0.19	0.82
Coleoptera	12.36	6.02	16.04	18.25	3.99	1.99	-	21.50	0.62	0.85
Hemiptera	4.33	8.33	5.00	9.00	2.99	1.99	-	13.99	0.52	0.55
Others	3.67	3.00	2.50	2.25	6.00	7.00	-	9.50	0.16	0.99

¹ Includes rare (less than 15 individuals caught) families not listed here.

Other families trapped (the total number of collected individuals in brackets) included: Scelionidae (14), Apiodea (13), Mymaridae (12), Pompilidae (12), Dryinidae (8), Halictidae (8), Eucolidae (7), Encyrtidae (6), Vespoidea (6), Megaspilidae (3), Formicidae (3), Chrysididae (2), Charipidae (1), Cynipidae (1), Colletidae (1), Megachilidae (1).

The 625 dipteran individuals included 11 families beside unidentified families caught at low numbers in the traps.

The ANOVA was run on the abundance of 3 families as well as the group of unidentified families as they have met the criteria of analysis. Other families included: Tachinidae (11 individuals), Anthomyiidae (6 individuals), Asilidae, Tipulidae, Calliphoridae (2 individuals for each of the three families), Empididae, Rhagionidae, Sarcophagidae were represented by only one individual. Both of orders Coleoptera and Hemiptera were represented by 241 and 127 individuals respectively in the trapping system.

Table 2. Pair wise similarity matrix of the Jaccard index for hymenopteran families in different sites at Halliburton forest, Canada.

Sites	1	2	3	4	5
1	1	0.73	0.55	0.83	0.64
2		1	0.36	0.74	0.45
3			1	0.46	0.69
4				1	0.56
5					1

Differences between sites harvested at different dates

Different cutting dates showed no influence on the structure of selected insect assemblages at the high-taxa level. There were no significant differences between sites of different harvesting dates in the total abundance of Hymenoptera ($F = 4.41, p = 0.09$), Diptera ($F = 1.86, p = 0.19$), Coleoptera ($F = 0.61, p = 0.62$), Hemiptera ($F = 0.80, p = 0.52$) and other insect orders ($F = 2.12, p = 0.16$) (Table 1). On the other hand, few hymenopteran and dipteran families showed some significant change along the time following cutting; Diapriidae ($F = 6.66, p = 0.04$), Platygastridae ($F = 4.07, p = 0.01$), Muscidae ($F = 4.92, p = 0.02$). Both Diapriidae and Platygastridae were most abundant in the first site, whereas Muscidae prevailed in the fifth site that has not been harvested. The low influences of cutting are shown in box plots (Fig. 1) which visualize the differences in family richness ($F = 3.46, p = 0.07$) and diversity (Shannon index) ($F = 0.02, p = 0.99$).

The Jaccard index (Table 2) indicated relative similarity in the composition of hymenopteran families between the site that has not been harvested

and the other sites those harvested at different times through the last two decades. Non-metric Multidimensional Scaling (NMDS) was used to perform ordinations of hymenopteran communities along sites of different cutting dates. It showed some evidence of segregation of hymenopteran families by site (Fig. 2).

Effects of gaps on insect communities

When setting water-pan traps at the gaps formed due to harvesting and near the center of three sites (1, 2, 3), the studied insect assemblages showed no differences. These insignificant differences were so clear in the high-taxa level, Hymenoptera ($F = 0.01, p = 0.95$), Diptera ($F = 18.16, p = 0.82$), Coleoptera ($F = 11.69, p = 0.85$), Hemiptera ($F = 15.47, p = 0.55$) and other orders ($F = 0.00, p = 0.99$). Abundance of lower taxa levels (Both hymenopteran and dipteran families) showed no significant differences as well (Table 1).

There was no significant interaction between sites and locations for any of the study taxa. The number of hymenopteran families (Fig. 1) caught in the traps

was insignificantly different ($t = -0.78$, $p = 0.4439$) as well as diversity of hymenopteran when using Shannon index ($t = -1.5814$, $p = 0.13$).

The Jaccard index showed high similarity (98%) in the composition of hymenopteran families among the

two locations either at the gaps and the center of study sites. NMDS plot (Fig. 3) has shown some separation between hymenopteran samples from center and those from the edge of the study sites.

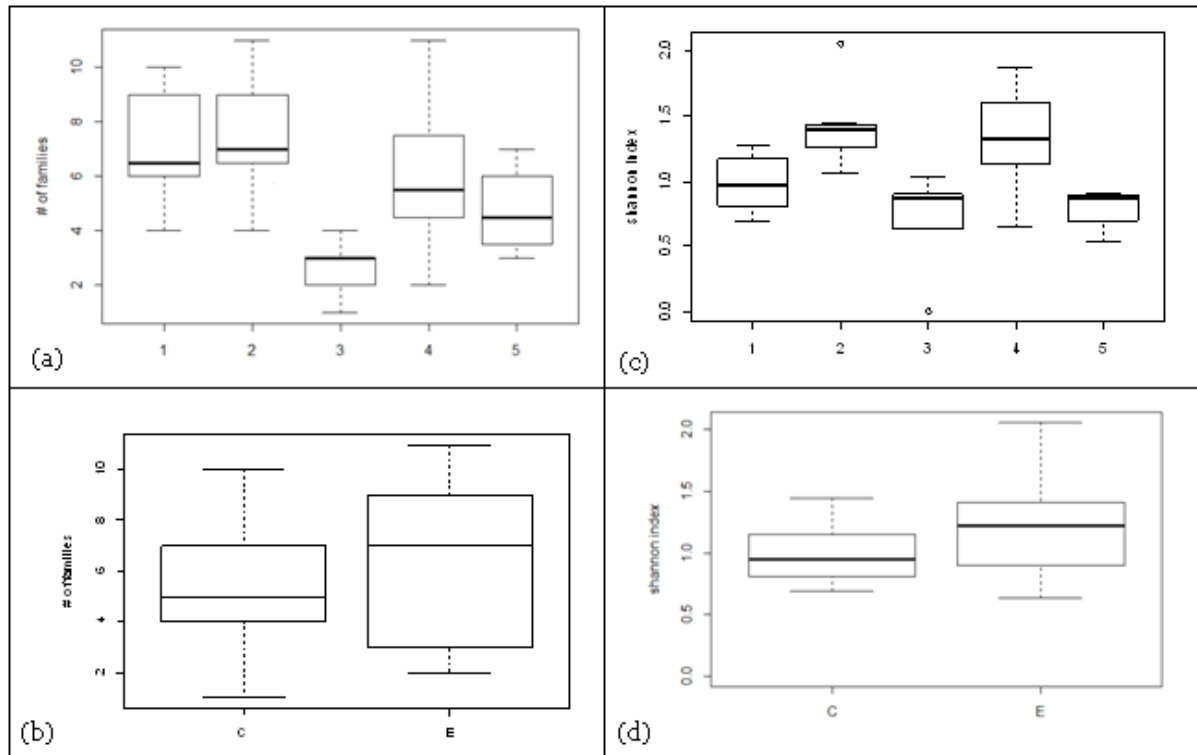


Fig. 1. Richness and diversity boxplots of hymenopteran families in different sites at Halliburton forest, Canada: number of families in sites (a) and locations (b); Shannon diversity index in sites (c) and locations (d).

Discussion

The present work aimed to study the change in forest insect communities over time that needed to return of old growth characteristics. Concerns focusing on the protection of biological diversity as well as forest health under management strategies require quantitative data to assess the change in environmental conditions through insect communities (Schowalter, 1995). The response of flying insects to such changes may provide the required data. Canopies of temperate forests are usually more exposed to harsh environmental conditions (high wind, radiation and temperature beside rainfall) and a lot of insect communities are more commonly found at lower levels (Lowman and Wittman, 1996) or in understory where survival rate is predicted to be higher, foraging easier because

chemical cues from hosts better detected (Smith *et al.* 2012). Therefore, insect community sampling in the understory using water-pan traps seemed to be more representative for the environmental changes under study.

Despite detailed examination of collected insects, few differences were found in the richness and abundance between unharvested site and the sites harvested over the last two decades. The obtained results suggesting that such activity of harvesting has little effect on the community structure. Although many authors (e.g. Progar *et al.*, 1999; Okland *et al.*, 2003; Yi and Moldenke, 2005) found that all insect taxa representing functional groups have shown significant reactions to thinning treatments, the influence of management of the time since last

management on biodiversity usually differ between monitored taxa and types of the forest (Chumak *et al.* 2015). In addition, Schmidt (2005) claimed that it

could not be confirmed that unmanaged forests in general contain more species than managed forests in several groups of organisms.

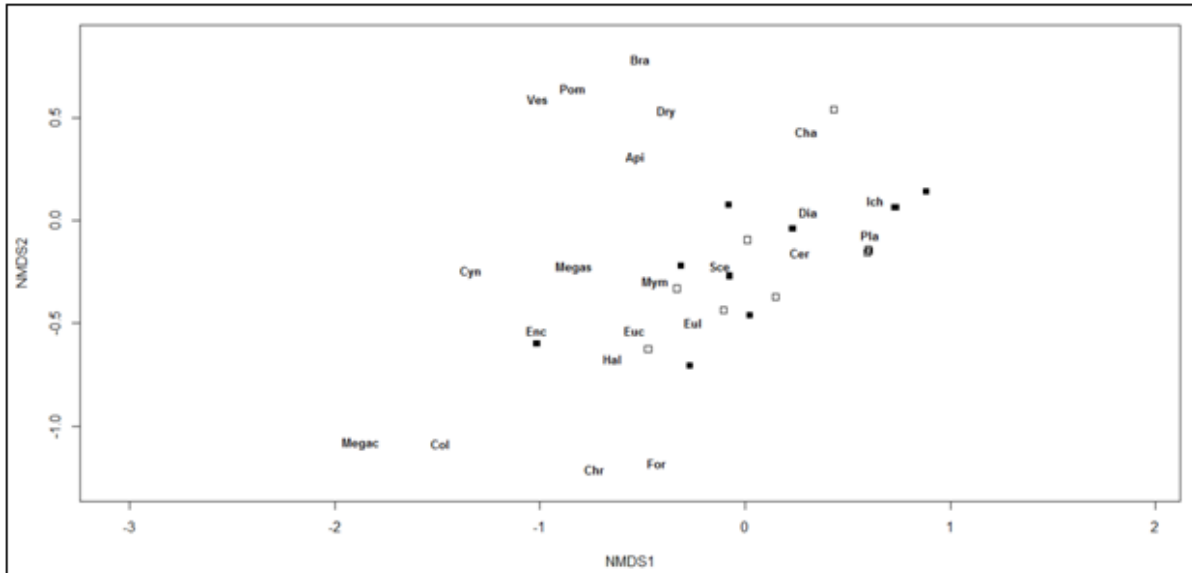


Fig. 2. Nonmetric Multidimensional Scaling for evaluation of hymenopteran families at center (square), edge (filled square), Halliburton forest, Canada.

The present findings coincided with some other researchers. Vance and Nol (2003) found that abundance and composition of carabid beetles were similar in the old forest that cut 15-20 years before and uncut forests in Ontario, while their abundance in the sites that cut 0.5-3 years before was lower than in old cut sites. In another study, Siira-Pietikäinen *et al.* (2003) reported that some harvesting techniques had no impact on taxonomic (species of Staphylinidae and Carabidae) and functional (such as predators, herbivores, fungivores, detritivores) arthropods at the boreal forest in Finland. Similarly, no differences were found in carabid beetles between 6-8 years after selective cutting (with small gaps) and unharvested sites in northern forests of Quebec (Moore *et al.* 2004). Muller *et al.* (2008) found no differences in the number of species and individuals of saproxylic beetles in beech forests. Chumak *et al.* (2015) found that arthropods from different families and trophic groups were insignificantly influenced by the management in beech forests. On the other hand, Bailey (1996) studied understory composition in

thinned and unthinned Douglas-fir stands and found that shrub cover, density and frequency were greater in thinned stands than in unthinned ones, which reflects the increase in available resources. Also, Nol *et al.* (2006) in northern temperate forests of Ontario, found more bees and hoverflies (syrphids) in the sites which recently harvested than in the sites unharvested at least for 40 years.

The relative to high similarity observed during the present study supports the previous interpretation. Out of the studied insect taxa, few hymenopteran and dipteran families differed between unharvested and harvested sites. In coincidence, Smith *et al.* (2012) examined the effects of harvesting on insects collected using Malaise traps in the temperate forests, and found that composition is the community attribute most sensitive to selection harvesting in these northern temperate forests. In our findings, insect compositions were distinctly similar in the vegetation at the gaps formed due to cuttings and at the center of the study sites.

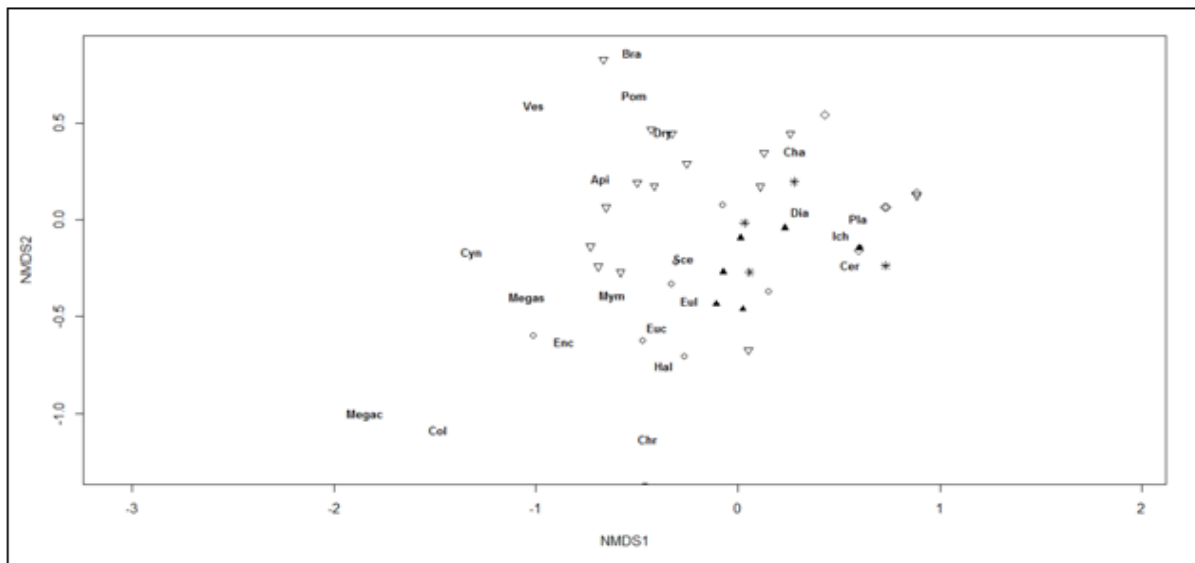


Fig. 3. Nonmetric Multidimensional Scaling for evaluation of hymenopteran families at Site 1 (filled triangle point up), site 2 (circle), site 3 (diamond), site 4 (triangle point down), site 5 (star), Halliburton forest, Canada.

Both order and family taxon levels were used to detect possible differences between insect communities after harvesting in northern temperate forests. A variety of studies have used high-taxon levels or/and functional groups in order to monitor different environmental changes in the forest ecosystems. This is due to species identification is not easy, very time-consuming and needs experts especially in highly diverse groups (Williams and Gaston 1994; Belloq and Smith 2003). On the same trend, Williams and Gaston (1994) reported family richness as a suitable predictor of species richness in insect taxa. In northern forest ecosystems, insects have been shown to respond to gradients of forest retention during harvesting at both high- and low-taxon levels (Siira-Pietikainen *et al.* 2003; Deans *et al.* 2005).

Hymenoptera is a very rich taxonomic group, and consequently intensive sampling and systematic experts are required to detect possible responses to environmental changes. Although Muller *et al.* (2008) recommended to avoid the use of total numbers of species to estimate the degradation in species composition in the forest, but better to focus on rare and threatened species. Because many of the families collected were only found once, future work should be conducted throughout the summer season

in the understory where structural diversity and plant species as well as lepidopterans that act as a host resource to parasitic wasps will enhance diversity. This study lends further support to the use of high taxon levels within forest management planning as this approach helps to rapidly identify areas of high insect diversity and conservation value while at the same time allowing for the necessary development of better taxonomic keys and expertise.

The present study shows that harvesting carried out in these northern temperate forests has minimal structural effect immediately after cutting as well as through time. Although harvesting clearly leads to changes in understory development and light intensity, which in turn may account for some of the minor compositional shifts we observed, the insect assemblages studied here displayed few responses to these effects within the first few years after cutting.

Thus, this work provides support for harvesting as a management strategy that has a little impacts on diversity of insect communities in the forests. In addition, further studies are recommended in order to learn more about the species interactions taking place in the forest ecosystem which will help to improve conservation-oriented measures.

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