The effects of forestry practices on the abundance of arthropods (Acarina, Araneae, Collembola, Coleoptera and Diptera)

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Abstract

In 2000, an interdisciplinary SSAM (Systèmes Sylvicoles Adaptés à la forêt Mélangée) research project was initiated in the yellow birch and balsam fir dominated forest northwest of Quebec City. We studied the impact of nine forest treatments on the abundance/activity (measured by pitfall traps) of five arthropod orders: beetles (Coleoptera), springtails (Collembola), flies (Diptera), spiders (Araneae) and mites (Acarina). The treatments consisted of a clear-cut and three 35% thinning configurations, i.e. 2-, 4- and 8-openings (all trees and shrubs removed), ground scarification (scarified or not) crossed with all forest extraction intensities, plus a control (no thinning, no scarification). Arthropods were captured weekly in 120 unbaited pitfall traps from 5 June to 28 August. All the trapped specimens were counted and their numbers were analyzed statistically (total: 94390). Ground scarification and thinning treatments had a significant impact on arthropod abundance. This impact varied among groups and over the season. The 8- and 4-opening thinning treatments had the least negative effect on the abundance of beetles and mites. These latter treatments probably emulated the natural disturbances that occur regularly in forests caused by dying trees that create small openings in the forest canopy. The litter fauna is vulnerable to desiccation and is particularly sensitive to the moisture content in the forest floor. Small openings in the forest canopy permit less sunlight to reach the forest floor and allow more retention of litter moisture than do the large openings. The effects of scarification and other forest treatments on arthropod abundance were more visible from mid-July to the end of August. Scarification, in general, exposes various layers of the naturally stratified and compacted litter to sunlight and allows for faster desiccation. This process had a profound effect on the abundance of all the groups studied (except mites) by elimination of suitable habitats.

Keywords: arthropods, abundance, forestry practices, impact.

Résumé

En l'an 2000, un projet de recherche interdisciplinaire, Systèmes sylvicoles adaptés à la forêt mélangée (SSAM), a été entrepris dans la sapinière à bouleau jaune au nord-ouest de la ville de Québec. L'impact de neuf traitements sylvicoles sur l'abondance ou l'activité de cinq ordres d'arthropodes a été évalué à l'aide de pièges-fosses. Les ordres étudiés sont les coléoptères (Coleoptera), les collemboles (Collembola), les mouches (Diptera), les araignées (Araneae) et les acariens (Acarina). Les traitements comprenaient une coupe à blanc et trois formes d'une même intensité d'éclaircie (35 %), soit 2-, 4- ou 8- trouées. Deux niveaux de scarification (scarifié ou non) étaient croisés avec les quatre modes d'extraction. Il y avait aussi un témoin sans éclaircie ni scarification. Les arthropodes capturés dans les 120 pièges-fosses sans appât ont été récoltés toutes les semaines entre le 5 juin et les 28 août. Tous les spécimens capturés ont été comptés et leur nombre a été analysé statistiquement. La scarification et les éclaircies ont eu un effet significatif sur l'abondance de ces arthropodes, effet qui variait selon l'ordre des invertébrés et au cours de la saison. Les éclaircies de 4 ou de 8 trouées sont les traitements qui ont le moins affecté l'abondance des coléoptères et des acariens. Ces traitements ont sans doute eu un effet comparable à celui des perturbations naturelles de la forêt associées à la mort des arbres qui créent de petites ouvertures dans le couvert forestier. La faune de la litière de la forêt est vulnérable à la dessiccation et est particulièrement sensible à l'humidité du sol. De petites ouvertures dans le couvert forestier empêchent la lumière du soleil de pénétrer jusqu'au sol forestier, permettant ainsi une plus grande rétention de l'humidité de la litière que les ouvertures plus grandes. Les effets de la scarification et des éclaircies sur l'abondance des arthropodes étaient plus marqués entre la mi-juillet et la fin d'août. En général, la scarification expose au soleil des strates de la litière qui ne le sont pas normalement, favorisant ainsi une dessiccation plus rapide. En modifiant la qualité de leur habitat, ce processus a eu un effet marqué sur l'abondance de tous les groupes étudiés, à l'exception des acariens.

Introduction

There is a lack of trust in the general public and the scientific community towards forest practices, in particular large-scale clear-cutting, and perceived impacts on biodiversity and sustainable forest management. To solve these problems we need to improve our understanding of what occurs during these human interventions and what are the most negative impacts of past and present forest practices on current forest biodiversity and forest regeneration. Improved knowledge of these subjects may improve management practices by emulating natural disturbances rather than creating persistent biodiversity crises (BENGTSSON *et al.*, 2000). Several contributions have addressed forest biodiversity issues (BEAUDRY *et al.*, 1997; BOUTIN & HÉBERT, 2002; BUNNELL & HUGGARD, 1999; GREENSLADE, 1964; LOREAU, 1985; MITCHELL, 1963; NIEMELÄ, 1999; NIEMELÄ *et al.*, 1993; NOSS, 1999; SIMBERLOFF, 1999; VOLNEY *et al.*, 1999; WINCHESTER, 1997*a,b*). Most of these papers deal with the sampling methods, influence of some forestry practices on carabid beetles and do not treat the combined abundances of major arthropod groups. They are useful however, in getting familiar with some major efforts in these areas of research.

In 2000, an interdisciplinary research project known under the acronym of SSAM (Systèmes Sylvicoles Adaptés à la forêt Mélangée) was initiated in the yellow birch and balsam fir dominated boreal forest near Quebec City. The main objectives of this project are to study the impact of selected forest practices on the species composition and abundances of different biota and yellow birch regeneration. This paper presents preliminary results based on the total number of specimens captured in five groups of the most abundant arthropods in forest litter (Acarina: 7145, Araneae: 8930, Diptera: 15016, Coleoptera: 15866, and Collembola: 47433). They should be considered as working hypotheses that will be later tested on two beetle families, Carabidae and Staphylinidae, at the species level. The results presented here should be considered as a unique case study in Canada. In this paper, we investigate the impact of forest thinning treatment and forest floor scarification on the abundance/activity of five groups of arthropods: beetles (Coleoptera), springtails (Collembola), flies (Diptera), spiders (Araneae) and mites (Acarina). The abundance of the arthropods at the two sites was measured by the pitfall trap method and can also be referred to as the pitfall trap abundance (PTA). PTA reflects abundance as well as the degree of activity of trapped arthropods. However, for convenience, we will only use the term abundance but we mean PTA. MITCHELL (1963) studied two species of carabid beetles collected in pitfall traps and indicated that catches represented activity as well as abundance. LOREAU (1985) observed that high pitfall catches usually coincide with periods of reproduction in carabids. GREENSLADE (1964) pointed out that the vegetation immediately surrounding the trap also affects pitfall trap catches. Extensive discussions on pitfall trap methods may be found in several additional references (HAMMOND, 1997; LEMIEUX & LINDGREN, 1999; NIEMELÄ *ét al.*, 1986; SPENCE *et al.*, 1997; SPENCE & NIEMELÄ, 1994; WORK *et al.*, 2002).

Our objectives were to study the impact of forest thinning intensity (opening size), scarification and their interaction on: (*i*) the abundance of selected arthropods, and (*ii*) the evolution of the abundance curve of these arthropods over a growing season. In the second stage of the project (*iii*), we will investigate the impact of these factors on species composition and abundance of ground and rove beetles (Coleoptera) (KLIMASZEWSKI *et al.*, in prep.).

Materials and Methods

In 2000, two proximal sites in the yellow birch and balsam fir dominated forests were selected northwest of Quebec City in which experimental work was later conducted. The first site is in the Réserve faunique de Portneuf, a provincial wildlife preservation area near Lac Poissonneux (47°02' N, 72°07' W). The second site is located in the Zone d'Exploitation Contrôlée (ZEC) Batiscan-Neilson area near Lac des Étangs (46°58' N, 72°03' W). Two blocks (A and B at Lac Poissonneux, and C and D at Lac des Étangs), each composed of five 120 × 120 m experimental plots (main plots), were set up at each site

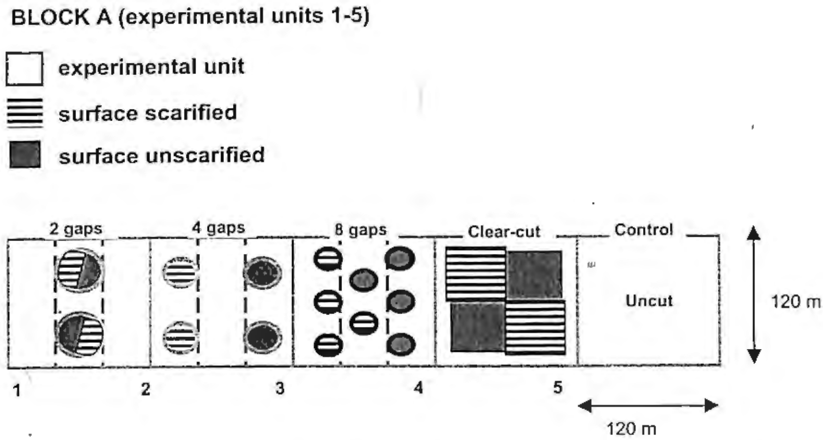

Fig. 1. Schematic presentation of one block with experimental units and different treatments.

(Fig. 1). Within each block, five thinning treatments were randomly allocated to the five main experimental plots: control (undisturbed forest), clear-cut (10000 m^2 or 70% of the plot area were cut leaving a border of standing trees around the perimeter of the square plot), partial thinning (approximately 35% of plot area) with two 2513 m^2 circular openings, four 1257 m^2 circular openings, or eight 628 m^2 circular openings. In the 4- and 8-opening thinned plots, half the openings were scarified. In the 2-opening thinned plots, one randomly selected half of each opening was scarified. In clear-cut plots, the cut area was divided into four squares and a randomly selected pair of diagonally opposed squares was scarified. Control main plots were not scarified.

One hundred and twenty unbaited pitfall traps, sixty per site (commercially produced by the BIO-CONTRÔLE company in Sainte-Foy, Quebec), each containing about 100 ml of 75% ethanol, were used to collect invertebrates weekly. The dimensions and design of the used traps were the same as the LUMINOC pit-light trap except for the lacking of the light producing components. Details on the LUMINOC pit-light trap are provided by JOBIN & COULOMBE (1992). It is important to note that the trapping container has a removable funnel near the top to reduce evaporation of ethanol or other killing solutions. We can say that the ethanol attraction to some invertebrates was kept to the minimum during our experiment but was not completely eliminated. In each treated plot, six pitfall traps were installed in cut areas: three in scarified ground and three in unscarified ground. In the control plots, all six traps were set in unscarified wooded areas. Samples were collected weekly for 13 weeks from 5 June to 28 August 2000. Each week, specimens were sorted into orders and their number was recorded for each trap.

The experimental design was a split-plot in four randomized blocks, two at each site, with thinning intensity as the main plot factor and scarification as the subplot factor. The treatment structure was a 4 × 2 factorial plus control. The design also involved three pitfall traps per subplot, all located in cut areas except those in control main plots of which there were six per plot (no subplots) all located in wooded unscarified areas. Finally, there were 13 repeated arthropod counts per week in each pitfall trap from 5 June to 28 August. Five response variables were the logarithms of the average number of specimens per trap (+0.1 to avoid logs of 0) of each of the five orders, per subplot, per week of sampling. The logarithm of the average number of specimens per trap (+0.1) of all five orders combined, per subplot, per week was also analyzed. We refer to this variable as total abundance. The variance of each variable was analyzed with the MIXED procedure of SAS according to a model based on the experimental design and treatment structure (SAS Institute 1999; LITTELL *et al.*, 1996). An autoregressive heterogeneous covariance structure was found adequate to model the variance of and dependence among residual errors on successive weeks. Mean abundances were computed on the logarithmic scale and back-transformed for presentation in the text and figures.

Results

Trap monitoring throughout the season showed that arthropods were, on average, more abundant at Lac des Étangs than at Lac Poissonneux. Each site constitutes a complex system of microhabitats, and physical and biotic components, which influence species abundance and composition and are responsible for between- as well as within-site variability.

Total abundance generally increased over the course of the season with a peak in the third week of July followed by a decrease and, subsequently, a steady increase until the end of August ($p \leq 0.0001$, Table 1, Fig. 2). The mean number of specimens per trap of the five groups of arthropods was 1.34 times as high in unscarified, thinned areas (mean: 52.4 specimens) as in scarified areas (mean: 39.2 specimens), on average over the season ($p \leq 0.0001$). There was some indication that the variation in total abundance over time was not the same in scarified and unscarified subplots ($p = 0.0349$). From 5 June to 3 July, scarification had no apparent effect on total abundance, while the discrepancy between scarified and unscarified subplots increased from early July to early August, and remained rather large through August (Fig. 3). On average over the season and over scarification levels, specimens of the five groups of arthropods were more abundant in pitfall traps from thinned plots with 8 small openings (mean: 56.5) than in thinned plots with 2 or 4 larger ones (mean: 42.3, $p = 0.0212$).

Beetles (**Coleoptera**) were trapped more frequently in June and August than in the middle of the season ($p \leq 0.0001$ for the effect of time, Table 1, Fig. 2). On average over the season, they were 2.80 times as abundant in pitfall traps from control plots as in those from unscarified, thinned subplots (mean numbers of specimens per trap: 16.5 and 5.9, respectively, $p \leq 0.0001$, Table 1). There was some indication that the difference between beetle abundance in control plots and thinned, unscarified subplots was not constant over time ($p = 0.0237$). Indeed, beetles were always more abundant in control plots than in treated unscarified subplots, but the difference was more substantial in August than in

Table 1. Analysis of variance of the log-transformed average abundance per trap per subplot per week for total abundance of the five orders considered, and for beetles, springtails, flies, spiders and mites separately. P-values in bold highlight significant effects at the 5% level.

Source of variation	**Ndf**[b]	**P-values**					
		Total	**Beetles**	**Springtails**	**Flies**	**Spiders**	**Mites**
Thinned vs control (C)[a]	1	0.1272	**<0.0001**	0.2983	**0.0361**	0.7643	**0.0017**
Thinnings (T) [C = thinned]	3	0.0917	**0.0048**	0.2637	0.5159	**0.0294**	**0.0021**
Clear-cut vs thinned	(1)	0.3286	**0.0393**	0.4791	0.1576	**0.0159**	0.1577
2 or 4 vs 8 openings	(1)	**0.0212**	**0.0120**	0.0692	0.7691	0.0779	**0.0149**
2 vs 4 openings	(1)	0.7807	**0.0233**	0.8019	0.9174	0.3309	**0.0016**
Scarification (S) [C = thinned]	1	**<0.0001**	**0.0399**	**0.0015**	0.1583	**0.0008**	0.1317
T×S [C = thinned]	3	0.3579	0.0922	0.0828	0.5014	0.1301	0.3487
Weeks (W)	12	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
C×W	12	0.4309	**0.0237**	0.2131	0.7431	0.5995	**0.0408**
T×W [C = thinned]	36	0.0942	**0.0333**	0.3143	**0.0181**	0.3407	**0.0034**
Clear-cut vs thinned*W	(12)	0.1117	0.3860	0.0907	**0.0574**	0.8791	0.5726
2 or 4 vs 8 openings*W	(12)	0.3559	**0.0438**	0.8213	0.1017	0.5904	0.4804
2 vs 4 openings*W	(12)	0.1157	**0.0406**	0.3537	**0.0403**	**0.0446**	**<0.0001**
S×W [C = thinned]	12	**0.0349**	**0.0166**	0.2807	0.2077	0.8361	0.5373
T× S×W [C = thinned]	36	0.8698	0.2602	0.7949	0.9589	0.5681	0.9844

[a] Unscarified only;

[b] Ndf: numerator degrees of freedom.

June or July (Fig. 4). On average over scarification levels, thinning treatments themselves also had important, diverse effects on beetle abundance ($p = 0.0048$). These effects were not constant throughout the season ($p = 0.0333$). In August, beetles in traps from the 8- and 4-opening thinning treatment plots were more abundant than those from traps set in 2-opening or clear-cut plots (Fig. 5). In June and July, there was no strong difference in beetle abundance between the thinning treatments. Scarification of thinned plots apparently had an effect on beetle abundance ($p = 0.0399$), but that effect varied over the season ($p = 0.0166$). In June, beetles were as abundant in traps from scarified openings as in those from unscarified areas, but the difference changed in July, and was most pronounced in August when beetle abundance was higher in unscarified subplots than in scarified openings (Fig. 6).

Springtails (**Collembola**) were the most abundant group in the pitfall traps over the entire season (47433 specimens), particularly in July and August when their numbers increased substantially ($p \leq 0.0001$ for the effect of time, Table 1, Fig. 2). This group was not affected by thinning treatments ($p = 0.2983$ for the comparison between control plots and thinned, unscarified subplots, and $p = 0.2637$ for differences between the thinning treatments themselves, averaged over scarification levels, Table 1), nor was there any indication that treatment effects were not constantly negligible over time ($p = 0.2131$ for the interaction between the control versus thinned (unscarified) contrast and time, and $p = 0.3143$ for the thinning treatment × time interaction). Scarification significantly

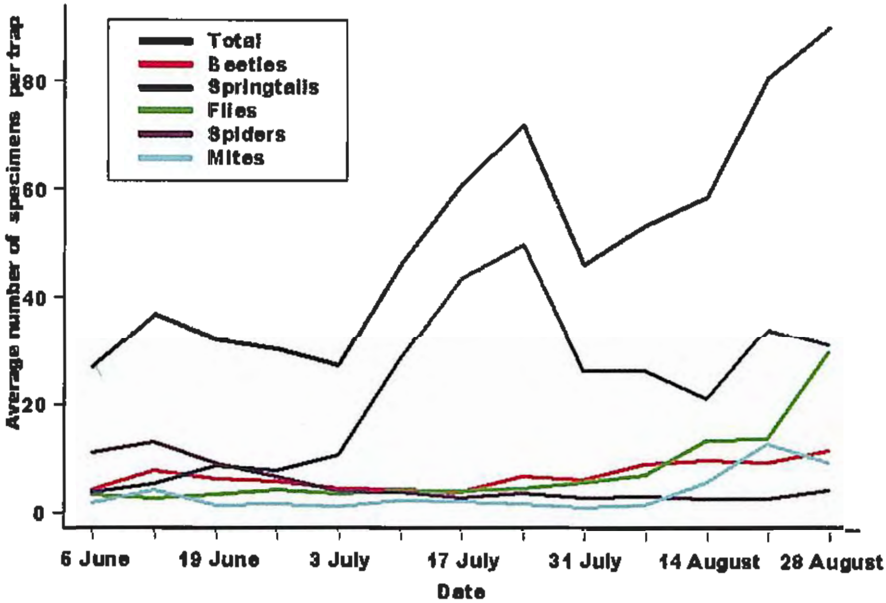

Fig. 2. Average number of beetles, springtails, flies, spiders, mites, and average total number of these invertebrates per trap from 5 June to 28 August.

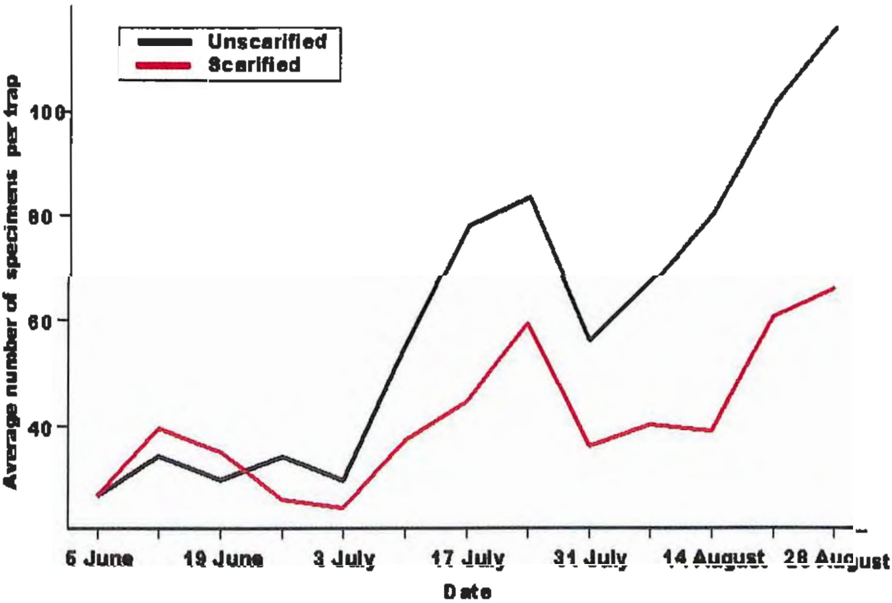

Fig. 3. Average number of specimens of the five groups of invertebrates per trap per scarification treatment (excluding control plots) from 5 June to 28 August.

reduced springtail abundance ($p = 0.0015$): the average number of springtail specimens trapped in unscarified, thinned subplots was 1.42 times as high as that in scarified subplots (means: 20.7 and 14.5 specimens per trap, respectively).

Flies (**Diptera**) were 1.46 times more abundant in control plots than in thinned, unscarified subplots (means: 8.3 and 5.7 specimens per trap, respectively, $p = 0.0361$, Table 1). Average abundance of flies did not differ strongly among thinning intensities ($p = 0.5159$), but the effects of the latter were not constant over time ($p = 0.0181$). Through most of the season, few flies were caught in the pitfall traps, but in August, the number of captured flies increased steadily in traps from all thinning treatments ($p \leq 0.0001$ for the effect of time, Fig. 2). This increase occurred one to two weeks earlier in traps from 8- and 4-opening thinning treatment plots than in the 2-opening thinning treatment or in the clear-cut (Fig. 7). The effect of scarification on fly abundance did not reach statistical significance (means: 5.7 in unscarified (thinned) subplots and 4.9 in scarified areas, $p = 0.1583$).

On average over time and scarification levels, spider (**Araneae**) abundance varied among thinning treatments ($p = 0.0294$, Table 1). Spiders were 1.23 times more abundant in traps from clear-cut plots than in those from partially cut plots ($p = 0.0159$). This is contrary to the abundance of beetles, springtails and flies, which were either less or equally abundant in clear-cut plots compared with partially cut plots. Spiders were 1.19 times as abundant in unscarified, thinned subplots as in scarified ones (means: 4.6 and 3.9 specimens per trap, respectively, $p = 0.0008$). There was no indication that the effects of thinning treatments and scarification varied over time ($p = 0.3407$ and 0.8361, respectively). Spiders were relatively more abundant in June than in July and August when their numbers were almost constant ($p \leq 0.0001$ for the effect of time, Table 1, Fig. 2).

Mites (**Acarina**) were 1.79 times as abundant in thinned, unscarified subplots as in control plots (means: 2.54 and 1.42 specimens per trap, respectively, $p = 0.0017$, Table 1). There was indication that this effect was not constant over time ($p = 0.0408$). Through June and July, mites were less abundant in control plots than in thinned, unscarified plots. In the last three weeks of August, however, they were more abundant in all plots and relatively more so in control plots than in treated ones (Fig. 8). The effect of the thinning treatment by time interaction on mite abundance was highly significant when comparisons were restricted to thinned plots ($p = 0.0034$, Table 1, Fig. 9). This interaction was mainly due to differences in the variation of mite abundance over time between the 2- and 4-opening thinning treatments ($p \leq 0.0001$ for this interaction). Mites were less abundant in plots with four openings than in those with two, for most of the season, particularly in the first two weeks of June, but in the last three weeks of August, average abundance was almost the same in these two thinning treatment plots. Early in the season, mites were, on average, more abundant in traps set in clear-cuts or in plots with two openings. From the middle of June to early August, mite abundance was generally low. Finally, in the August burst of mite activity or abundance, the number of captured specimens was larger in the

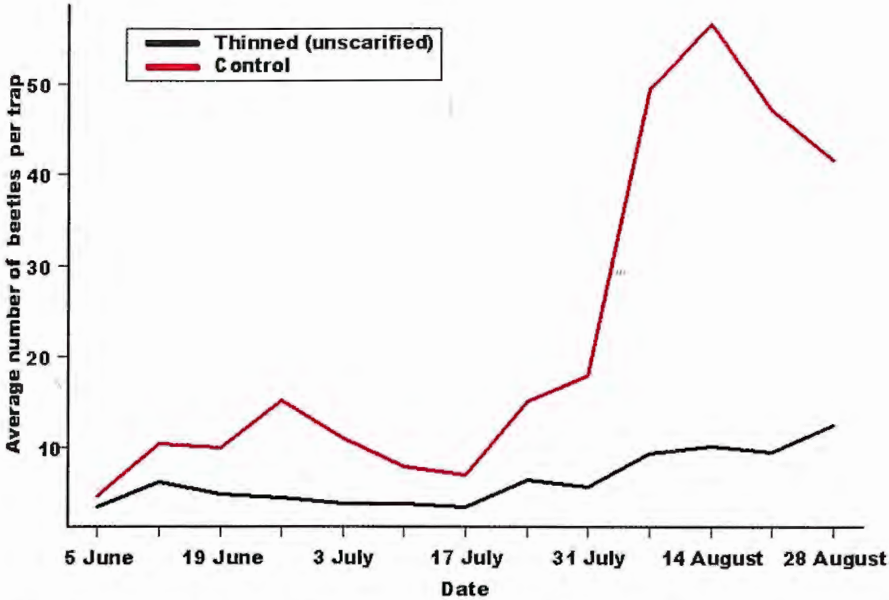

Fig. 4. Average number of beetles per trap in control plots and in thinned, unscarified subplots from 5 June to 28 August.

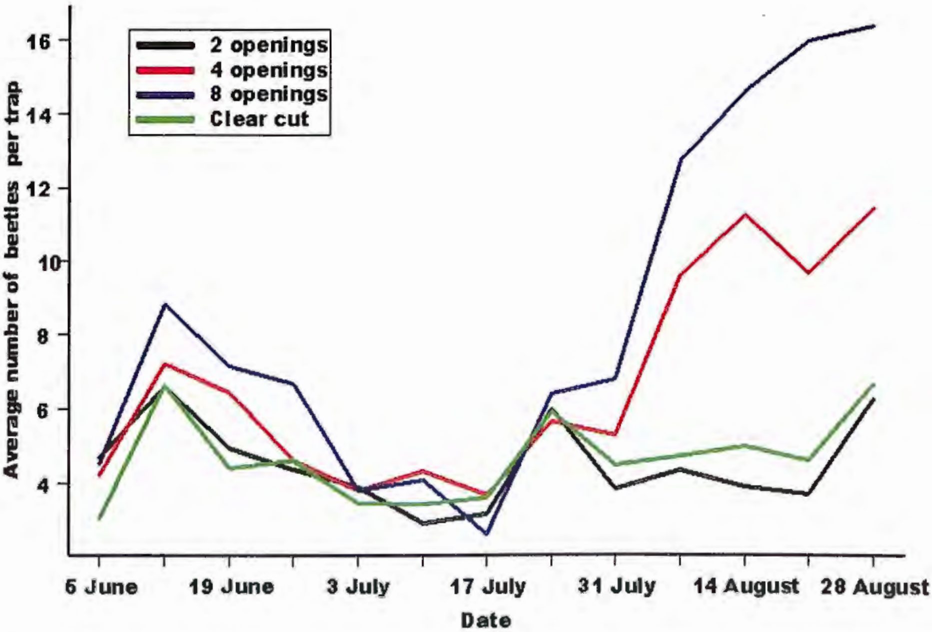

Fig. 5. Average number of beetles per trap, per thinning treatment (excluding control plots) from 5 June to 28 August.

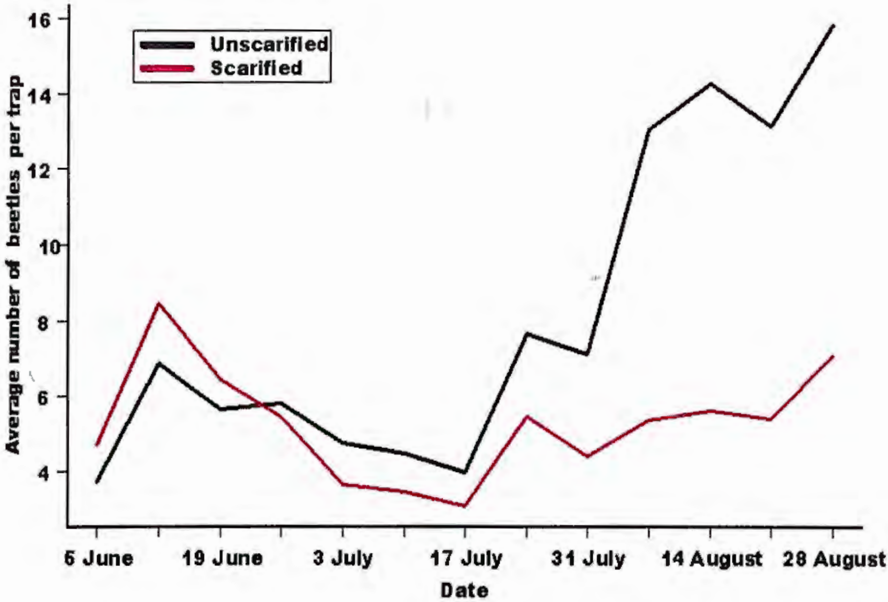

Fig. 6. Average number of beetles per trap, per scarification level (excluding control plots) from 5 June to 28 August.

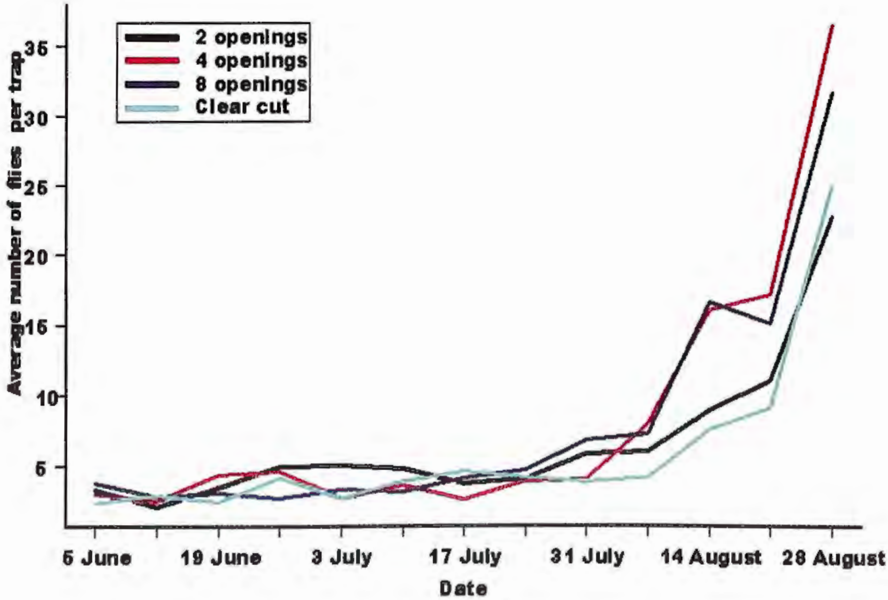

Fig. 7. Average number of flies per trap, per thinning treatment (excluding control plots) from June to 28 August.

2-, 4- and 8-opening thinned plots than in clear-cut areas. Scarification has not strongly affected mite abundance ($p = 0.1317$ for the main scarification effect and $p = 0.5373$ for its interaction with time). Among the studied groups of arthropods, flies were the only other group that seemed unaffected by scarification.

Discussion

The abundance of each of the five groups of arthropods showed some order specificity and variability over the season (Fig. 2). Springtails were always the most abundant but particularly so in July. Spiders were relatively more abundant in June. The large abundance of beetles, flies and mites in August is likely associated with the emergence of a variety of fungi, which serve as food and shelter for many adults and larvae (KLIMASZEWSKI & PECK, 1987), and with increased adult activity. Some species only emerged later in the season, contributing to population increases (KLIMASZEWSKI & PECK, 1987).

The analysis indicated that scarification and type of forest thinning (size and number of openings) had a significant impact on the abundance of arthropods and that this impact often varied among orders and over the season (Figs 3-9). Thinning treatments did not significantly affect population abundance of springtails, but it did affect populations of beetles, flies, spiders and mites at least at some time during the season. In June and July, mite abundance was positively affected by some thinning treatments, but the trend was reversed in August. The 8- and 4-opening thinning treatments had the least impact on the abundance of beetles, flies and mites (Figs 5, 7, 9). These thinning treatments most likely emulated disturbances that occur naturally in every forest when dying trees create small openings in the forest canopy. The litter fauna is generally vulnerable to desiccation and is therefore particularly sensitive to the moisture content of the forest floor. Small gaps in the forest canopy do not expose the forest floor to the sun and to desiccation as much as large ones. Scarification had a profound, mostly negative influence on the abundance of three groups of arthropods out of five: beetles, springtails and spiders. When the effects of scarification or forest thinning intensity on abundance of the five groups of arthropods varied with time, they were usually larger from the middle of summer onwards than in the first half of the season (Figs 3-9). Scarification exposes various layers of the naturally stratified and compacted litter to sun and air, which allows for faster desiccation. This in turn has a profound effect on arthropod abundance and diversity by diminishing the numbers of suitable habitats and prey species. On a larger scale, groups of mobile arthropods, such as many beetle and fly species, would be less impacted by scarification and large forest clear-cuts, because they can fly away to find a suitable habitat elsewhere in the intact forest if this type of forest is within their reach. The less mobile groups however, and those less capable of adapting to dry conditions, would probably be eliminated by desiccation. Examples of such groups are many arthropod larvae, flightless or poorly flying adults, and many other insect species.

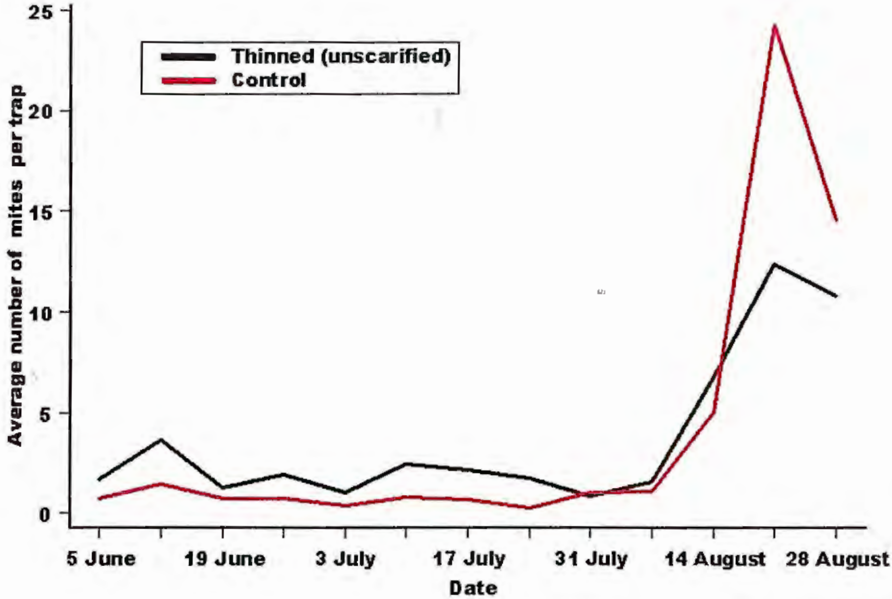

Fig. 8. Average number of mites per trap in control plots and in thinned, unscarified subplots from 5 June to 28 August.

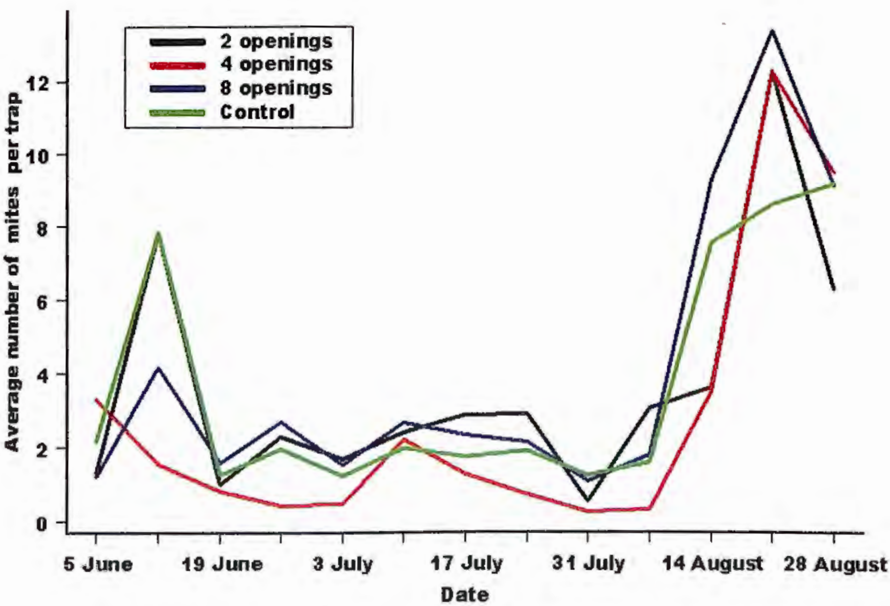

Fig. 9. Average number of mites per trap, per thinning treatment (excluding control plots) fro 5 June to 28 August.

Conclusion

The preliminary results presented above and based on the total abundance of captured specimens should be considered as a robust working hypothesis, which will be later tested at the species level on selected groups of beetles. Forest thinning had a significant impact on the total abundance of beetles, spiders and mites, and some effect on litter affiliated flies. Scarification affected the abundance of spiders, springtails and beetles. The abundance of spiders decreased by 19%, that of springtails by 42%, and that of beetles reached 129% in late August. The negative impact of forest thinning and scarification was clearer in the second half of the season than in the first. All groups of arthropods were not affected in the same way. Scarification, in general, exposes various layers of the naturally stratified and compacted litter to sun and air and allows for faster desiccation. This has a profound effect on arthropod abundance and diversity because it eliminates their suitable habitats.

Selective cutting or variable retention forest extraction methods are probably the most viable alternatives to extensive clear-cutting. These methods will have the least negative impact on forest ecosystems and the abundance and diversity of arthropods, which are important components of a complex web of litter processors that allow faster circulation of nutrients.

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