FOREST EDGES ARE BIODIVERSITY HOTSPOTS
– ALSO FOR NEUROPTERA

DUELLI, P.[1], OBRIST, M. K.[1] and P. F. FLÜCKIGER[2]

[1]Swiss Federal Research Institute WSL, CH-8903 Birmensdorf, Switzerland
E-mail: peter.duelli@wsl.ch
[2]Naturmuseum Olten, Kirchgasse 10, CH-4600 Olten, Switzerland
E-mail: naturmuseum@stadt.olten.ch

In a research project investigating the contribution of forest ecotone structures to regional arthropod biodiversity, the neuropteran fauna was assessed at five differently-structured forest edges and, for comparison, 50 m inside the forest. Arthropods were collected from February to November by means of pitfall traps, window (interception) traps and yellow water pans. The traps were installed along transects, reaching horizontally from the open cultivated land into the forest and vertically, on scaffolds, from the ground up to the tree crowns.

For each of the species of the insect orders Neuroptera (59), Raphidioptera (3) and Mecoptera (2), spatio-temporal distribution patterns from open habitats into the forest can be generated from the available database. Only 3 species (5%) were equally or more numerous inside the forest than at the edges. Of particular interest is the distribution in space and time of three sibling species of the *Chrysoperla carnea* complex (*C. lucasina*, *C. pallida*, *C. carnea*).

Neuroptera and Raphidioptera showed their highest species numbers in the shrub belt and the forest mantle, while the Mecoptera preferred the herbaceous fringe. Traps located deepest inside the forest yielded the lowest number of species. In the forest interior, species numbers peaked in the canopy. However, the canopy yielded markedly fewer species than the forest edges. Steep forest edges contained 24% more species than the forest interior, sloped, structurally rich forest edges even 60% more.

Key words: Neuroptera, Raphidioptera, Mecoptera, biodiversity, forest edge, canopy

INTRODUCTION

It is generally assumed that forests harbour the highest proportion of the world's biodiversity, and that the larger the forests are, the higher is the biodiversity they contain. While this may be true for virgin rain forests in the tropics, the situation in managed forests in temperate climates seems to be quite different.

For numerous taxa of the invertebrates, which contribute world-wide with more than 73% of all described organisms most to biodiversity, we tested the following hypotheses:

– so called "forest species" are in fact mainly forest-edge species, i.e. species numbers decline towards the forest interior;

– highly structured forest edges contain more species than abrupt or steep forest edges, because the latter lack ecotonal structures such as a proper shrub belt and/or a forest mantle.

We here report on the Neuroptera and Raphidioptera, insect orders known to be prevalently arboreal, as well as the Mecoptera, which also are generally associated with forests.

MATERIAL AND METHODS

Arthropod biodiversity was measured 1994 and 1995 at five differently structured forest edges and, for comparison, 50 m inside one of the forests (FLÜCKIGER & DUELLI 1997, FLÜCKIGER 1999). In addition, the results of these transects were linked to the data of a 5km-transect through agricultural and seminatural habitats, which had been assessed in the same region in 1987 (DUELLI et al. 1992, DUELLI & OBRIST 1995, DUELLI & OBRIST 1998). All study sites were located along the slopes of the Jura Mountains in north-western Switzerland.

Arthropods were collected with standardized faunistic sampling methods from February to November by means of pitfall traps, window (interception) traps (Fig. 1), and yellow water pans (DUELLI et al. 1999). The traps at the forest edges were installed along transects, reaching horizontally from the open cultivated land into the forest and vertically, on metal scaffolds, from the ground up to the tree tops.

The horizontal transects on the surface consisted of one trap station in each of the following ecotone structures: (1) cultivated land, traps at a distance of 10 m from the herbaceous fringe of the forest edge; (2) herbaceous fringe: (3) shrub belt, just behind the herbaceous fringe, but traps were displaced side-ways to keep a distance of at least 10 m to the station in the herbaceous fringe; (4) not commercially used forest beneath the forest mantle, just 1 m behind the shrub belt; (5) not commercially used forest ecotone 10 m inside the herbaceous fringe.

One of the horizontal transects through a highly structured forest edge ended with a trap station 50 m inside a beech forest. Here, a metal tower was placed for constructing a vertical transect, representing the forest interior. Trap stations were mounted on scaffolding at heights of 0 m (flight traps actually at 1.5 m above ground), 4 m, 12 m, 20 m, and 28 m.

The other vertical transects followed the smooth or steep slopes of the five forest edges. At the two highly structured (smooth) forest edges, traps were placed in steps of 4 m height up to the canopy. In the three steeper forest edges, the steps between heights were 8 m.

The data for all groups, including Neuroptera, Raphidioptera and Mecoptera, were processed in a faunistic data base, custom programmed in Oracle (Oracle Corporation, USA).

RESULTS

In the course of two years of collecting, 58 species of Neuroptera, 3 of the order Raphidioptera and 2 of the Mecoptera were collected. The family Hemerobiidae, with 26 species, contributed most to neuropteran diversity of forest edges, followed by the Chrysopidae with 18 species, and the Coniopterygidae with 13 species.
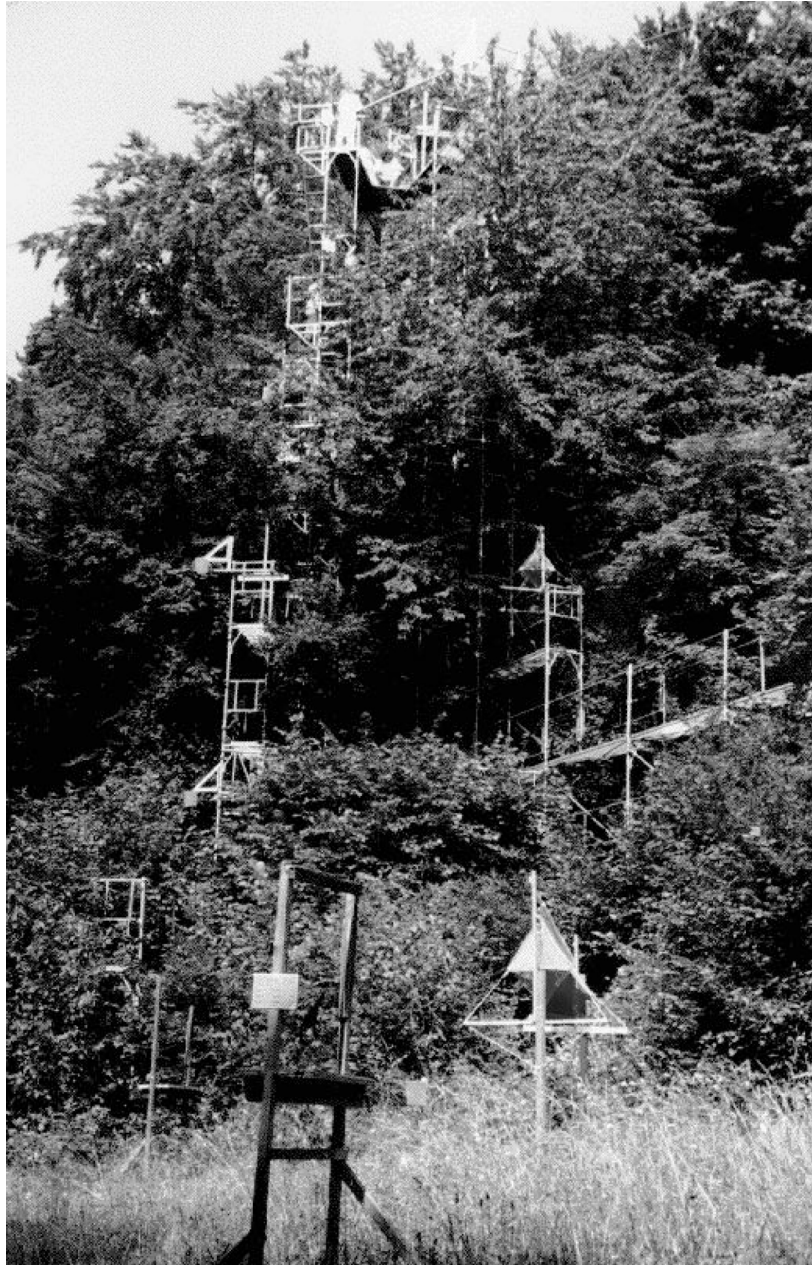
Fig. 1. Sloped, highly structured forest edge along a mixed beech forest at Rickenbach (Western Switzerland). One (horizontal) transect of trap stations (window interception trap in the foreground) started 10 m outside the herbaceous fringe of the forest edge and lead 50 m into the forest, the other (vertical) transect lead from the herbaceous fringe to the canopy

For each species, the distribution of the yearly catches was displayed on a standard chart showing the trap locations of the five forest edges and the forest interior in schematic form (example of *Nothochrysa fulviceps* shown in Fig. 2). Similarly, the species numbers of selected families, or all the families, can be displayed on such charts (Fig. 3).

Generally, species numbers were higher in the gently sloped (structured) forest edges, as compared to the steep forest edges, where the forest mantle and/or the shrub belt was missing. In those steep edges, the herbaceous fringe usually was right at the base of the first row of tall trees. On average, species numbers per trap
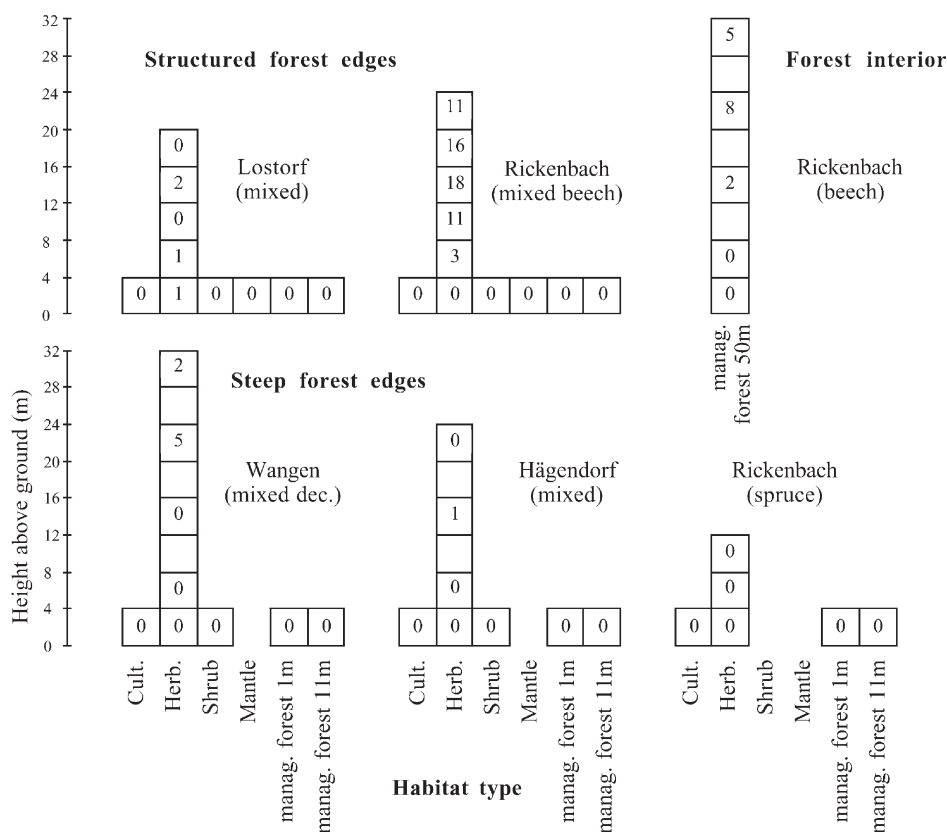
Fig. 2. Numbers of individuals of the chrysopid *Nothochrysa fulviceps* collected per year in the different trap stations of the two sloped, highly structured forest edges, the three steep edges, and the station in the forest interior, 50 m from the edge. The same distribution chart was performed for all 63 species collected during this project. Empty spaces in the horizontal transects mean that the particular forest structure was missing, empty fields in the vertical transects mean that there was no trap

height were lowest in the forest interior, 24% higher in the steep forest edges, and even 60% higher in the structured forest edges.

For a general overview of the spatial distribution of neuropteran diversity in and around forested areas, the yearly species numbers collected in the Rickenbach transect (mixed beech forest, gently sloped, with the control tower 50 m in the forest interior) are combined here with that of an earlier transect (DUELLI *et al*. 1992, DUELLI & OBRIST 1998), in which exactly the same trap types and the same collecting period had been applied in a nearby area. Fig. 4 clearly shows a maximum of species in the shrub belt and mantle of the forest edge. Away from the forest edge, as well as towards the forest interior, the species numbers decline rapidly. Of
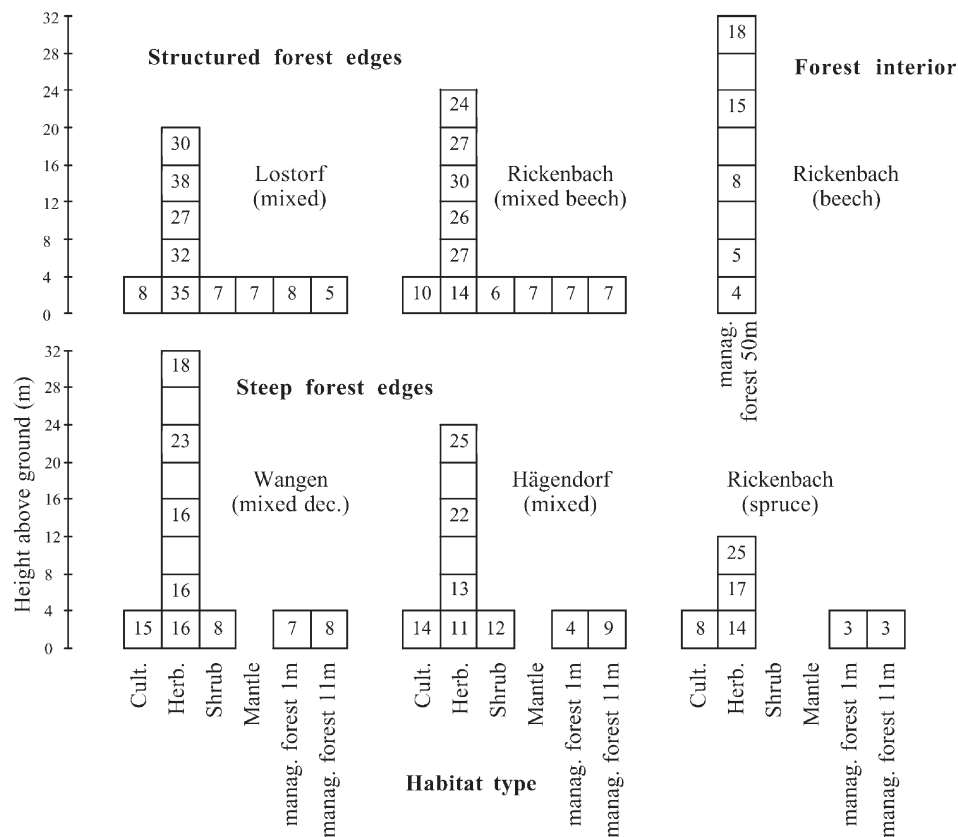

Fig. 3. The same format as shown in Fig. 2 can be used, as shown here, to display the species numbers per trap station per year (Neuroptera, Raphidioptera, Mecoptera). Empty spaces in the horizontal transects mean that the particular forest structure was missing, empty fields in the vertical transects mean that there was no trap

all the species of Neuroptera, Raphidioptera, Megaloptera and Mecoptera collected in this enlarged transect, only the two species of the order Megaloptera, *Sialis lutaria* and *S. fuliginosa*, were found to be more frequent outside the forest zone. All other species were most frequently collected in or along the forest. Within the forest, the canopy yielded the highest diversity (18 species), but still far less than the forest edge (30 species).

To test the hypothesis, that most species are in fact forest edge species, and not real forest (interior) species, the spatial distribution of each single species was qualified in a standardized chart cumulating and weighing the information from all forest edges and the forest interior. For each trap location in the idealized transect depicted as an example in Fig. 5, the number of specimens collected had to be divided by the number of traps available at that location. This procedure is only an approximation to the real distribution of a species, since not all trap sites in the chart of Fig. 5 had the same probability to collect at least one specimen. Some structures were lacking in certain forest edges, or the structure had been sampled for two years instead of only one.

The distribution of each species shown in the idealized transect of Fig. 5 led to an interpretation of the favourite habitat of that species. The relative figures (in %) allow for an arbitrary threshold (here 20%) to decide, which of the forest structures are preferred by the species in question. According to Fig. 5, *Phaeostigma*
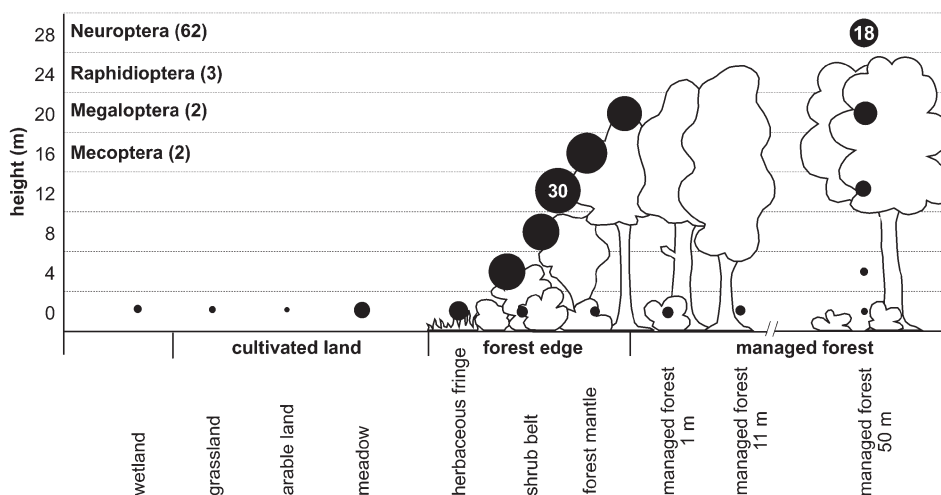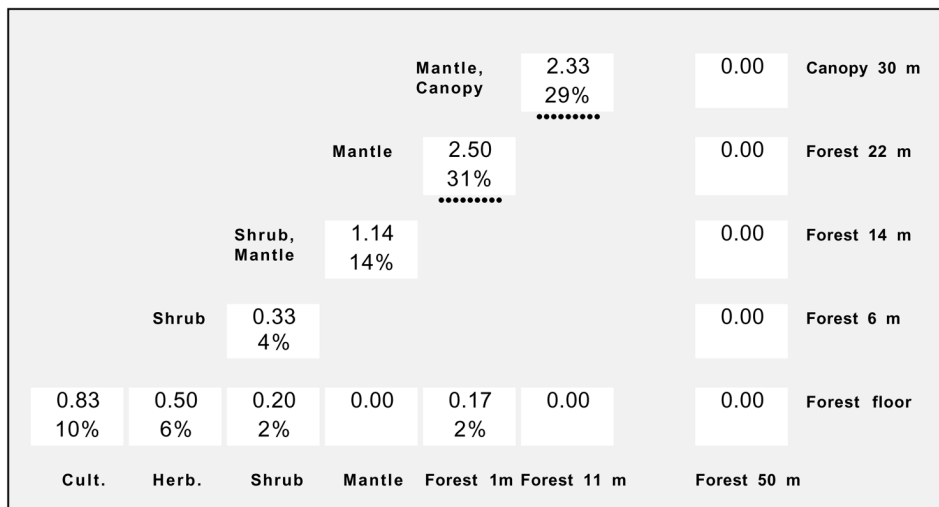

Fig. 4. Trap station transect extended from the Rickenbach forest edge into open country (agriculture, wetland). The size of the black dots indicates species richness per yearly catch. A maximum of 30 species was collected in the mantle structure, and 18 species in the forest canopy 50 m inside the forest. Two species of *Sialis* (Megaloptera) were restricted to the transect extension into open countryside

notata is a "mantle-species", because the two highest catches (both over 20%) are in the mantle region. Table1 defines the criteria for qualifying the species according to their spatial distributions. Only 14 species could not be qualified, because they were too rare or their distribution did not fit any of the qualifications defined in Table 1.

Table 1. Types of habitat preferences according to the species distribution patterns exemplified in Fig. 5. The right column shows the number of species attributed to the different types of habitat preferences

True forest species (catches in interior equal to or higher than edge)	3
Canopy species (2 best catches in topmost 2 traps)	3
Mantle species (2 best catches in upper edge traps)	14
Shrub belt species (2 best catches in lower edge traps)	9
Herbaceous fringe species (maximum in herbaceous fringe)	9
Contact zone species (presence in most of the peripheral traps)	7
Ubiquist species (similar presence in most structures)	4
Open land species (maximum catch outside forest)	0
Not classified (too rare or erratic distribution)	14
Total (Neuroptera, Raphidioptera, Mecoptera)	63

Type	Cult.	Herb.	Shrub	Mantle	Forest 1m	Forest 11 m	Forest 50 m	
Mantle, Canopy						2.33 29%	0.00	Canopy 30 m
Mantle					2.50 31%		0.00	Forest 22 m
Shrub, Mantle				1.14 14%			0.00	Forest 14 m
Shrub			0.33 4%				0.00	Forest 6 m
	0.83 10%	0.50 6%	0.20 2%	0.00	0.17 2%	0.00	0.00	Forest floor

Fig. 5. All information from the various transects condensed into an idealized sloped forest edge: In our example of the snakefly species *Phaeostigma notata*, the upper figures per trap station represent average numbers of individuals collected per trap per year at comparable trap locations of the different forest edge sites. Percentages are given (lower figures) to identify habitat preferences according to criteria listed in Table 1. Underlined are percentages above an arbitrary threshold of 20%. Cult.: cultivated area (meadow, field crop, etc.) with traps 10 m away from the forest edge

Table 1 shows the number of species for the different habitat qualifications and Table 2 shows the habitat preferences for the listed single species. The most striking result is that only three species, *Hypochrysa elegans*, *Hemerobius micans*,

Table 2. List of species collected, with number of specimens per species, habitat preference according to spatial distribution (Fig. 5) and preference criteria defined in Table 1. Flight phenology is shown to the right, where flight peaks are indicated proportionally for species with a total of more than 4 specimens collected. Double squares are peaks for months with more than 33% of the yearly catch, triple squares for catches of more than 66%

Order Family Species	Specimens collected	Habitat preference	Phenology
Neuroptera			
Coniopterygidae			
Coniopteryx borealis	63	mantle	
Coniopteryx drammonti	2	shrub belt	
Coniopteryx esbenpeterseni	13	herb. fringe	
Coniopteryx haematica	1	not class.	
Coniopteryx lentiae	24	herb. fringe	
Coniopteryx pygmaea	152	shrub belt	
Coniopteryx hoelzeli	91	herb. fringe	
Coniopteryx tineiformis	200	mantle	
Conwentzia pineticola	5	contact zone	
Conwentzia psociformis	15	mantle	
Helicoconis lutea	32	herb. fringe	
Parasemidalis fuscipennis	6	shrub belt	
Semidalis aleyrodiformis	7	herb. fringe	
Hemerobiidae			
Drepanepteryx algida	2	not class.	
Drepanepteryx phalaenoides	4	mantle	
Hemerobius atrifrons	2	not class.	
Hemerobius fenestratus	9	contact zone	
Hemerobius gilvus	1	not class.	
Hemerobius handschini	4	not class.	
Hemerobius humulinus	282	shrub belt	
Hemerobius lutescens	8	mantle	
Hemerobius marginatus	23	ubiquist	
Hemerobius micans	261	true forest	
Hemerobius nitidulus	18	mantle	
Hemerobius perelegans	3	shrub belt	
Hemerobius pini	163	shrub belt	
Hemerobius stigma	20	canopy	
Micromus angulatus	3	herb. fringe	
Micromus variegatus	10	herb. fringe	

The phenology columns (left to right) are: February, March, April, May, June, July, August, September, October, November.

Order Family Species	Specimens collected	Habitat preference	Phenology (February, March, April, May, June	July, August, September, October, November)
Neuroptera				
Hemerobiidae continued				
Sympherobius elegans	11	not class.	■	■ ■ ■
Sympherobius fuscescens	4	not class.	■	■
Sympherobius klapaleki	1	not class.		■
Sympherobius pellucidus	67	ubiquist	■ ■	■ ■ ■
Sympherobius pygmaeus	4	mantle	■	■
Wesmaelius concinnus	18	mantle	■	■ ■ ■
Wesmaelius fassnidgei	1	not class.		■
Wesmaelius nervosus	7	canopy	■ ■	■ ■
Wesmaelius quadrifasciatus	21	shrub belt	■	■ ■
Wesmaelius subnebulosus	15	contact zone	■ ■	■ ■ ■ ■
Chrysopidae				
Chrysopa dorsalis	1	not class.		■
Chrysopa pallens	1	not class.		■
Chrysopa perla	1	not class.		■
Chrysoperla pallida	602	mantle	■ ■ ■ ■ ■	■ ■ ■ ■ ■
Chrysoperla carnea	250	ubiquist	■ ■ ■ ■	■ ■ ■ ■ ■
Chrysoperla lucasina	98	ubiquist	■	■ ■ ■ ■ ■
Chrysopidia ciliata	57	shrub belt	■	■ ■
Cunctochrysa albolineata	62	contact zone	■ ■	■ ■ ■ ■
Dichochrysa abdominalis	63	mantle	■	■ ■ ■
Dichochrysa flavifrons	167	contact zone	■	■ ■ ■
Dichochrysa prasina	111	contact zone	■	■ ■ ■ ■
Dichochrysa ventralis	54	shrub belt	■	■ ■ ■
Hypochrysa elegans	124	true forest	■ ■ ■	■
Nineta flava	39	canopy	■	■ ■ ■
Nineta pallida	94	contact zone	■	■ ■ ■
Nineta vittata	1	not class.	■	
Nothochrysa fulviceps	155	true forest	■	■ ■ ■
Peyerimhoffina gracilis	32	mantle	■ ■	■ ■ ■ ■
Myrmeleontidae				
Euroleon nostras	1	not class.		■
Mecoptera				
Panorpidae				
Panorpa communis	910	herb. fringe	■ ■	■ ■ ■ ■
Panorpa germanica	987	herb. fringe	■ ■	■ ■ ■ ■
Raphidioptera				
Raphidiidae				
Phaeostigma notata	44	mantle	■ ■	■
Puncha ratzeburgi	11	mantle	■	■ ■
Venustoraphidia nigricollis	23	mantle	■ ■	■

and to a lesser degree *Nothochrysa fulviceps*, are truly species of the forest interior. On the other hand, no species was found preferentially outside the forest, and even the four species considered being "ubiquists" have a stronghold in the forest edge.

The species charts shown in Figs 2–4 can also be displayed at weekly or monthly intervals. Species distributions in both space and time cannot be shown here, but some indication on adult flight phenologies is given in Table 2.

For the newly (re-) detected sibling species of the *Chrysoperla carnea* group, the spatial distributions in winter and summer are of particular interest. *Chrysoperla lucasina* (HENRY *et al*. 1996) and *C. carnea* (HENRY *et al*. 2002; Cc4 sensu DUELLI *et al*. 1996, "*C. kolthoffi*" sensu LERAUT 1991) were both most frequent outside the forest in spring and summer, while in autumn and late winter they were mainly collected in the uppermost traps of the forest edges. In autumn, *C. carnea* was also trapped in large numbers in the canopy layer of the forest interior. *C. pallida* (Cc2 sensu DUELLI *et al*. 1996, "*C. carnea*" sensu LERAUT) seems to be strictly arboreal, with a preference for the forest edges all year round. Only few specimens were collected outside the forest. In autumn and late winter, equal numbers of *C. pallida* were collected in the interior forest and in the edges.

DISCUSSION

Neuroptera and Raphidioptera are generally considered to be mainly arboreal (ASPÖCK *et al*. 1980), while the Mecoptera are far less associated with forested areas. So the question "what is a real forest species?" is particularly pertinent for the Neuroptera and Raphidioptera. A species here is considered to be arboreal if it depends to a large degree (e.g. for some period during its lifetime) on the presence of trees. But that does not necessarily mean that it is a forest species. We can distinguish "true forest species", which depend to some degree on the presence of forests. Without closed stands of trees covering a certain area, that species would not be there at all. Additionally, there are "facultative forest species", which can live in forests, but also in areas with scattered single trees, or groups of trees. They do not depend on closed forest stands, and therefore the size of a forest area is not of crucial importance to their existence. Furthermore, of course, there are species, which do not even depend on the presence of trees.

Nature conservation often deplores the fragmentation of managed forests, because fragmentation is seen as a major cause for the loss of biodiversity.

Our aim was to search for exactly the kind of species that are threatened by extinction when forest areas are diminished or fragmented. Island biogeography theory (MACARTHUR & WILSON 1967) predicts, that with diminishing area of a

habitat island, the species number of habitat specialists will diminish too (MADER 1983). Many Neuroptera and Raphidioptera are undoubtedly habitat specialists in forested areas. Are they threatened by fragmentation of forests?

To answer that question, we had to find out their habitat preferences in forested areas. Are they forest specialists, i.e. more common in forests than outside? To be threatened by fragmentation of forest areas, a species has to be a "true forest species", which prefers the forest interior to the forest edges. Ecotone species, which are habitat specialists for forest-edge structures, such as the forest mantle, the shrub belt or even the herbaceous fringe (which is considered here to be an important ecotone structure of forests), may depend on the presence of forests, but do not vitally depend on the forest interior, and thereby will not make use of a larger forest area.

Table 1 and 2 clearly show that only a small minority of three species (5%) were collected inside the forest at equal or higher numbers than at the forest edges. For all other species (95%) we can assume that the size of the forest interior does not really matter much, as long as their preferred habitat within the forest edge is intact. Since we also collected very early and late in the season, we can exclude that some of these ecotone species depend on the forest interior for hibernating. The observed movement of the *Chrysoperla* species (which hibernate as adults) from the edge to the interior in late autumn hardly reached the tower site at a distance of 50 m to the forest edge.

These findings for two insect orders, notorious for depending on forests, open up the question on how generally applicable our hypotheses is, that most forest species in managed forests in fact are forest edge species. In Danish beech forests, species diversity of vascular plants was negatively correlated with forest area (LAWESSON *et al.* 1998). But the authors identified some habitat specialists for the forest interior, which they interpret as specialists for ancient forests. Continuity of forest cover seems to be more important than forest size. In our neuropteran sample of only three true forest specialists, none of them is known to be dependent on ancient forests.

Several published records show that within the interior of managed forests the number of arthropod species and individuals collected is higher in the canopy than on the ground or in between (STORK *et al.* 1997) . That is consistent with our findings for the Neuroptera, but neglects the fact that there are even more species, and individuals of these species, in the ecotone structures at the forest edge, than in the canopy.

Only few publications deal with the spatial distribution of Neuroptera, Raphidioptera, or Mecoptera in forests, and particularly in forest edges. Canopy Neuroptera were collected in various forests in Poland by (CZECHOWSKA 1994), but

there was no comparison with other forest structures. SAURE and KIELHORN (1993) collected Neuroptera on oaks and Scots pine in urban forests of Berlin. After correcting their figures for collecting effort, two-thirds of the species on oaks were collected in higher numbers at 15 m height than at 5 m. In our samples in beech forest, all species collected in the forest interior increased with height. But at the forest edges, most Coniopterygidae were preferentially in the herbaceous and shrub layer, most Hemerobiidae at intermediate heights in the shrub or mantle layer, and the Chrysopidae had their maxima in the upper mantle layer.

SAURE and KIELHORN (1993) identified *Sympherobius klapaleki* as a canopy species on oak. We only collected one specimen, and it also was found in the canopy layer of a mixed beech forest with scattered oaks. The flight phenologies given by SAURE and KIELHORN (1993) largely coincide with ours, but in general the species in Switzerland started out three weeks later, which is likely to be due to an elevation of 460–620 m in Switzerland, instead of less than 100 m at Berlin.

Of particular interest was the distribution of the three sibling *Chrysoperla* species in space and time. THIERRY *et al.* (1995) investigated the hibernation sites of all three species in central France. The evergreen *C. lucasina* was only found in ivy tufts, *C. carnea* (called "*C. kolthoffi*"), with colour change, mostly in buildings, but in late winter together with *C. pallida* (called "*C. carnea*") in dry leaves and ivy tufts. The results of our trap catches show that both *C. lucasina* and *C. carnea* enter the forest ecotone structures in autumn and stay there until next spring. While hibernating *C. lucasina* were only collected in traps in the forest edge, *C. carnea* also was found in large numbers in the canopy of the forest interior. We suspect that these individuals were caught in transit over the forest. *C. pallida* was by far the most abundant neuropteran insect in the forest edges all year round. In autumn and late winter, relatively more specimens were collected in the forest interior than in spring and summer, indicating a slight population movement in that species also – from the edges towards the interior.

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