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Subalpine and alpine assemblages of Lepidoptera in the surroundings of a powerful smelter on the Kola Peninsula, NW Russia

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Summary

Subalpine and alpine Lepidoptera were collected in 1993-1994 in the Monche and Tshuna Mts. (Kola Peninsula, NW Russia) in ten localities situated 4 to 32 km SSW of a powerful smelter in Monchegorsk. No differences in species composition were discovered either between subalpine and alpine habitats or among localities. Ordination analysis revealed no clear environmental gradients, but mean ambient concentration of sulphur dioxide (estimated by manganese concentration in birch leaves) explained a significant part of variation in the abundance of Lepidoptera, whereas no relationships were found between abundance and foliar concentration of the main metal pollutant (nickel). The number of specimens collected during a fixed time (30 min) peaked in localities with moderate pollution loads, while high pollution cause populations to decline. However, the rarefaction-corrected species richness on three plots closest to the smelter was 1.3 times higher than on more distant plots, while diversity (measured by Shannon entropy) did not change. In contrast to the transect counts of butterflies, the method used in the present study is good for environmental assessment programmes even in the areas with low species richness and harsh climatic conditions.

Résumé

L'auteur a récolté des Lépidoptères subalpins et alpins en 1993-1994 dans les Monts Monche et Tshuna (Péninsule de Kola, Russie du Nord-Ouest) dans dix localités situées à 4-32 km au Sud-Ouest/Sud d'une puissante usine de fonderie à Monchegorsk. Il n'a pas trouvé de différences dans le cortège des espèces, soit entre biotopes alpins et subalpins, soit entre les localités. L'analyse n'a pas révélé de gradients environnementaux nets ; mais la concentration ambiante moyenne de dioxyde de soufre (estimée d'après la concentration du manganèse dans les feuilles de bouleau) expliquait une partie significative de la variation quant à l'abondance des Lépidoptères. On n'a en revanche pas trouvé de rapports entre cette abondance et la concentration du principal métal polluant (nickel) dans les feuilles. Le nombre de spécimens récoltés durant un temps fixe (30 minutes) atteignit son maximum dans les localités modérément polluées, tandis qu'une forte pollution entraîne une diminution des populations. Cependant, la richesse en espèces, corrigée selon la raréfaction, sur trois terrains très proches de la fonderie était 1,3 fois plus élevée que sur les terrains plus éloignés, tandis que la diversité (mesurée par entropie de Shannon) n'a pas changé. Comparativement au comptage des papillons par transect, la méthode utilisée pour la présente recherche convient pour les programmes d'évaluation de l'environnement même dans les régions pauvres en espèces et/ou dont le climat est vraiment très rude.

Introduction

Subalpine and alpine habitats of the Kola Peninsula, NW Russia, form relatively small patches within the boreal forest zone. However, these mountain habitats display a distinctive fauna of moths and butterflies (Kozlov & Jalava, 1994). This fauna includes some rare and local species, which should be considered in conservation programmes in northern Europe.

In contrast to boreal forest lepidopterans, the data on habitat associations and abundance of moths and butterflies in subalpine birch woodlands and alpine tundra in Fennoscandia are quite fragmentary. The community ecology of mountain Lepidoptera was studied by Fridolin (1935, 1936), and after his pioneer work, only little attention has been paid to this subject. The importance of ecological investigations in subalpine and alpine communities of the Kola Peninsula is emphasised by the large-scale environmental deterioration caused by aerial emissions of the nickel smelter in Monchegorsk (Kozlov & Haukioja, 1995). Recently, the north-eastern parts of the Monche Mts. have become surrounded by industrial barrenlands, but the extent of polluted territory in the mountains and the environmental effects of pollutants on subalpine and alpine ecosystems are poorly documented. Therefore the main objective of this investigation was to quantify the impact of aerial emissions on the abundance and species richness of the mountain Lepidoptera.

Material and methods

Study area and emission source

The Kola Peninsula, situated in the north-west corner of Russia, belongs geographically to northern Fennoscandia. The highest peaks are in the centre of the Peninsula : Chibiny mountains (1190 m), Lovozerskie tundra (1120 m), Tshuna-tundra (1072 m) and Monche-tundra (965 m). These mountains are formed of alkaline phosphate minerals and have a very rich alpine flora (Ramenskaja, 1983).

The Severonikel smelter complex situated in Monchegorsk (68°N, 33°E) produces aerial emissions consisting mostly of SO_2 and heavy metals (Ni, Cu, Co). The total amount of pollutants emitted in 1990 was 2.64×10^8 kg, including 2.33×10^8 kg of SO_2 and 1.58×10^7 kg of dusts containing heavy metals (2.7×10^6 kg of nickel, 1.8×10^6 kg of copper) (Berlyand, 1991). This level of pollution was characteristic at least for the years 1986-1990, but during the past two years emissions of sulphur dioxide have been reduced (1.82×10^8 kg in 1992, 1.31×10^8 kg in 1993) ("Gipronikel" Institute, official data).

Sampling procedure

Ten pairs of 200 × 200 m size plots were established at the timberline (formed by *Betula pubescens tortuosa*) on the north-eastern and eastern slopes of the Monche and Tshuna Mts., 4 to 32 km of the smelter (Fig. 1). Within each locality, the two plots representing birch

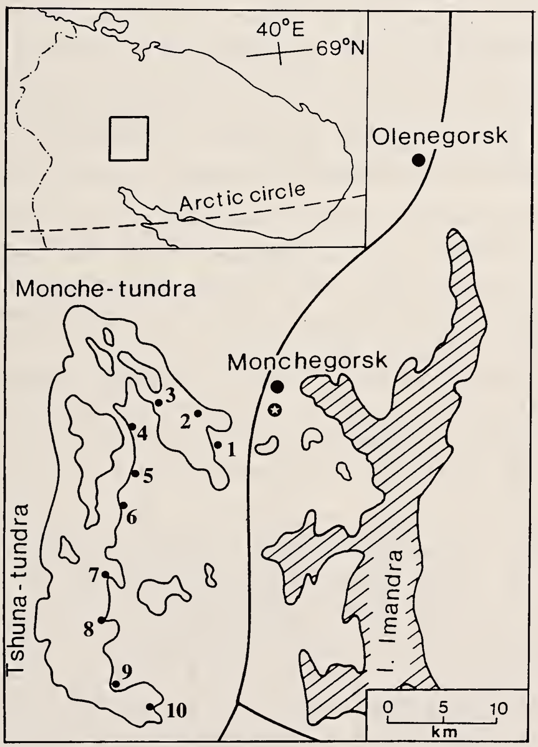


Fig. 1. Study area. Localities (dots) are numbered ; the smelter is marked by an asterisk. Mountain relief is shown by contours of 400 and 800 m. Inserted : position of the study area within the Kola Peninsula.

woodlands and mountain tundra were situated 200 to 800 m apart (altitudinal difference 20 to 100 m).

The plots were chosen with as similar vegetation as possible. In the subalpine woodlands, birch trees were sparse, 2 to 4 m tall, with an understorey formed by *Betula nana* and *Juniperus sibirica* and a surface cover dominated by dwarf shrubs (*Empetrum nigrum*, *Vaccinium myrtillus*) and lichens (*Cladina*, *Cetraria*). The tundra plots belong to *Betula nana* communities, with a predominance of *E. nigrum* in dwarf-shrub layer, below which are sparse mosses (*Pleurozium schreberi*, *Pohlia nutans*, *Orthocaulis kunzeanus*, *Barbilophozia hatcheri*) and usually a dense lichen cover (*Cetraria nivalis*, *C. islandica*, *Cladina stellaris*, *Cladonia* spp.).

Samples were taken during the periods 12-23 July 1993 and 15-22 July 1994 by collectors walking from Monchegorsk to the southernmost plot through the roadless mountains. It was planned to apply a similar sampling effort to all plots, but weather conditions and some technical problems interfered with the sampling design. Moreover, the field processing of samples taken in 1993 clearly demonstrated that the total number of specimens collected in the two localities closest to the smelter was too low for reasonable estimation of diversity characteristics. Therefore, additional sampling was arranged on these two plots.

Sampling was conducted when the temperature was above 10°C, the wind did not exceed 3 on the Beaufort scale, and not earlier than 2 hours after the last rain. The collector hunted for all moths and butterflies within the plot during 30 min. The sampled specimens were sorted according to species, and voucher specimens were preserved for determination when necessary. Time of sampling sessions was randomised among localities ; weather conditions during sessions (air temperature, wind speed, cloudiness) were recorded. In total, 1599 specimens representing 107 species were collected during 175 sessions (Table 1).

The following variables were recorded at each plot (Table 1) : habitat (HAB : subalpine woodland or alpine tundra), altitude (ALT, to the nearest 10-20 m), slope aspect (ASP, to the nearest 45°), total plant cover (COV), tree cover (TRE), dwarf-shrub cover (SHR), number of vascular plant species (VPL), total species number for vascular plants, mosses and lichens (TPL). Within each of 20 plots, 14 subplots were randomly chosen to measure characteristics of the vegetation. TRE, VPL and TPL were accounted in four plots of 10 × 10 m size, whereas COV and SHR were measured in ten plots of 1 × 1 m size ; complete results of this work will be published elsewhere (Koroleva, pers. comm.).

Table 1

Number of specimens of Lepidoptera collected at the study plots in Monche and Tshuna Mts. in 1993-1994. For locality numbers, see Fig. 1. Nomenclature follows Varis *et al.* (1987).

Species	Subalpine plots										Alpine plots									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Micropterigidae																				
Micropterix aureatella (Scop.)	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nepticulidae																				
Ectoedemia weaveri (Stt.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
Incurvariidae																				
Incurvaria oehlmanniella (Hb.)	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Incurvaria vetulella (Zett.)	-	3	1	-	2	-	1	1	-	-	-	-	-	-	-	1	-	-	1	-
Incurvaria circulella (Zett.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Lampronia rupella (D. & S.)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Psychidae																				
Taleporia borealis (Wck.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Sterrhopterix standfussi (Wck.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Psyche norvegica (Schöyen)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Tineidae																				
Monopis weaverella (Scott)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-
Monopis spilotella (Tengstr.)	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Gracillariidae																				
Callisto coffeella (Zett.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Douglasiidae																				
Tinagma dryadis Stgr.	-	-	-	2	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-
Yponomeutidae																				
Paraswammerdamia conspersella (Tengstr.)	-	1	-	-	6	1	2	2	-	3	-	-	1	-	17	-	22	1	-	1
Argyresthiidae																				
Argyresthia glabratella Z.	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Argyresthia conjugella Z.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Plutellidae																				
Plutella xylostella (L.)	7	8	-	1	-	-	1	-	2	3	2	3	-	1	-	-	-	-	4	2
Oecophoridae																				
Schiffermuelleria stipella (L.)	-	10	-	2	2	34	6	24	2	2	-	1	-	2	-	12	1	5	1	1
Pleurota bicostella (Cl.)	7	-	-	-	2	3	-	-	-	-	4	-	-	1	3	6	3	-	-	-

Table 1 (cont.)

Species	Subalpine plots										Alpine plots									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Elachistidae																				
Elachista parasella Tr.-O.	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Elachista nielswolffi Svenss.	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Cosmiotes exactella (H.-S.)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coleophoridae																				
Coleophora vacciniella H.-S.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Coleophora glitzella Hofm.	-	2	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	-	1	-
Coleophora murinella Tengstr.	1	1	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-
Coleophora virgaureae Stt.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Coleophora idaeella Hofm.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Gelechiidae																				
Chionodes viduella (F.)	-	1	-	-	1	2	-	1	-	1	-	-	-	-	1	-	-	1	-	1
Chionodes continuella (Z.)	-	1	-	-	-	1	1	-	-	-	-	-	-	-	-	2	2	-	-	-
Altenia perspersella (Wck.)	1	1	-	-	-	1	1	-	-	-	-	1	1	-	3	-	1	-	2	-
Scrobipalpa murinella (Dup.)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Neofaculta infernella (H.-S.)	-	2	2	-	2	1	4	-	-	4	1	1	1	-	2	-	2	-	2	3
Aproaeremia anthylidella (Hb.)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-
Tortricidae																				
Aphelia viburnana (D. & S.)	1	1	-	-	1	-	-	-	-	-	3	-	-	-	1	1	-	-	-	2
Clepsis senecionana (Hb.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lozotaenia forsterana (F.)	-	-	-	-	-	3	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Eulia ministrana (L.)	-	3	-	-	-	2	-	1	2	-	-	-	-	-	-	-	-	-	-	-
Aethes deutschiana (Zett.)	4	15	12	2	6	5	20	3	-	-	-	5	13	2	-	21	9	6	-	-
Cochylis dubitana (Hb.)	-	2	1	-	-	2	-	-	-	-	-	-	-	-	-	3	-	1	-	-
Cochylis nana (Hw.)	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sparganothis rubicundana (H.-S.)	2	2	-	-	4	-	4	1	1	1	1	1	1	1	8	3	15	1	2	4
Olethreutes ledianus (L.)	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	5
Olethreutes obsoletanus (Zett.)	-	-	-	-	-	-	3	1	3	-	-	-	1	-	1	2	1	1	-	-
Olethreutes arbutellus (L.)	1	-	-	-	-	-	-	-	1	2	1	-	-	-	-	-	2	-	-	1
Olethreutes aquilonanus (Karvonen)	1	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-
Olethreutes noricanus (H.-S.)	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-

Table 1 (cont.)

Species	Subalpine plots										Alpine plots									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Olethreutes bipunctanus (F.)	-	-	-	-	4	-	-	-	-	-	-	-	-	-	6	4	-	-	-	5
Olethreutes hyperboreanus (Karvonen)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Olethreutes metallicanus (Hb.)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Olethreutes schulzianus (F.)	11	7	6	2	4	6	4	1	1	6	12	4	1	3	10	6	9	6	-	10
Olethreutes schaefferanus (H.-S.)	-	2	1	-	3	-	2	-	1	-	-	4	2	2	1	-	4	2	4	-
Olethreutes turfosanus (H.-S.)	4	4	2	1	2	1	5	2	6	1	8	-	1	2	-	3	6	4	5	3
Olethreutes concretanus (Wck.)	2	1	-	-	-	-	-	-	2	-	-	-	-	-	-	2	-	1	-	-
Orthotaenia undulana (D. & S.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Apotomis boreana Krogerus	3	7	-	-	-	1	2	-	-	-	1	1	-	-	1	-	-	-	-	-
Apotomis lemniscatana (Kenn.)	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Apotomis algidana Krogerus	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Apotomis sauciana (Fröl.)	4	3	1	1	-	-	-	5	25	1	-	1	1	-	-	-	-	10	1	-
Ancylis unguicella (L.)	-	-	-	-	-	-	2	-	-	-	2	-	-	1	4	-	1	-	-	-
Ancylis myrtillana (Tr.)	11	6	15	8	36	14	8	11	4	23	3	4	3	3	20	31	17	6	5	6
Epinotia tetraquetrana (Hw.)	2	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epinotia nemorivaga (Tengstr.)	1	2	-	-	-	-	-	-	-	3	-	1	-	-	-	-	1	1	-	4
Epinotia nanana (Tr.)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Gypsonoma nitidulana (Lien. et Zell.)	-	-	-	-	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	3
Epiblema simploniana (Dup.)	1	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Eriopsela quadrana (Hb.)	-	1	-	1	-	-	-	3	-	-	-	-	-	-	-	1	1	3	-	-
Cydia aureolana (Tengstr.)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Pterophoridae																				
Platyptilia calodactyla (D. & S.)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyralidae																				
Polopeustis altensis (Wck.)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Pyla fusca (Hw.)	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Myelopsis tetricella (D. & S.)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Crambus lathoniellus (Zinck.)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Catoptria furcatella (Zett.)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-
Catoptria maculalis (Zett.)	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eudonia murana (Curt.)	-	-	-	-	-	1	-	-	-	3	-	-	-	-	-	-	-	-	-	17

Table I (cont.)

Species	Subalpine plots										Alpine plots									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Pyrausta porphyralis (D. & S.)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Anania funebris (Ström)	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Udea inquinatalis (Lien. & Zell.)	1	-	-	-	2	4	1	3	1	-	1	1	-	1	1	1	1	-	1	2
Udea decrepitalis (H.-S.)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Zygaenidae																				
Zygaena exulans (Hochenw.)	2	-	-	-	-	-	-	2	4	-	-	-	-	-	-	-	4	-	31	-
Lycaenidae																				
Vacciniina optilete (Knoch)	-	2	-	-	2	1	-	-	-	-	-	-	-	-	-	1	-	3	-	-
Nymphalidae																				
Clossiana freija (Thnbg.)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	1	-
Clossiana euphrosyne (L.)	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Satyridae																				
Erebia ligea (L.)	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Erebia disa (Thnbg.)	-	-	-	-	-	-	-	-	-	-	3	6	-	-	-	-	-	-	-	-
Erebia pandrose (Bkh.)	-	-	-	-	-	-	1	-	2	-	2	4	1	-	-	2	8	-	3	-
Oeneis bore (Schn.)	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	1	-	-	-	-
Geometridae																				
Scopula ternata (Schrank)	1	-	-	1	2	-	1	-	1	6	-	-	-	-	2	-	1	-	-	4
Xanthorhoe spadicearia (D. & S.)	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xanthorhoe montanata (D. & S.)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xanthorhoe annotinata (Zett.)	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Entephria polata (Dup.)	1	2	-	-	-	-	-	-	-	-	4	3	-	1	-	1	6	-	-	3
Entephria caesiata (D. & S.)	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Rheumaptera subhastata (Nolcken)	2	8	12	2	2	5	4	11	20	-	-	2	1	1	-	3	-	5	1	-
Psychophora sabini frigidaria (Guenée)	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-
Eupithecia satyrata (Hb.)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eupithecia gelidata Möschl.	9	2	1	4	4	12	10	-	2	2	1	2	-	1	3	3	9	1	-	-
Pygmaena fusca (Thnbg.)	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	7	-	2	-
Ematurga atomaria (L.)	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parietaria vittaria (Thnbg.)	-	-	-	-	-	-	2	5	-	-	-	-	-	-	2	-	2	-	-	-
Glacies coracina (Esp.)	5	-	-	-	-	-	-	-	-	-	10	3	5	1	4	-	-	2	4	-

Table 1 (cont.)

Species	Subalpine plots										Alpine plots									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Noctuidae																				
Sympistis heliophila (Payk.)	-	3	1	-	1	1	-	-	2	-	-	2	1	-	-	-	-	3	1	-
Sympistis lapponica (Thnbg.)	5	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Sympistis zetterstedtii (Stgr)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Anarta melanopa (Thnbg.)	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Lasionycta staudingeri (Auriv.)	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polia conspicua sabmeana Mikkola	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-

Table 2

Values of environmental variables and total sampling effort at the study plots.
Abbreviations of variables : HAB — habitat (s = subalpine woodland, a = alpine tundra), DIS — distance to the smelter ; ALT — altitude ; ASP — slope aspect ; COV — total plant cover ; TRE — tree cover ; SHR — dwarf-shrub cover ; VPL — number of vascular plant species ; TPL — total species number of vascular plants, mosses and lichens ; NIC and MAN — concentrations of nickel and manganese in foliage of mountain birch.

Site #	HAB	DIS (km)	ALT (m)	ASP	COV (%)	TRE (%)	SHR (%)	VPL	TPL	NIC µg/mg	MAN µg/mg	No of sessions	Species recorded	Specimens collected
1	s	4.5	300	NNE	75	1	75	10	17	58	322	14	34	99
2	s	4.8	400	NE	95	1	45	7	17	35	405	13	32	106
3	s	10.2	400	SW	95	5	50	14	26	16	398	6	15	58
4	s	11.2	380	ENE	100	15	75	13	20	19	120	7	22	38
5	s	11.7	450	E	100	50	75	10	22	22	550	7	23	91
6	s	14.8	450	E	100	25	95	19	30	20	716	7	27	112
7	s	20.5	480	E	50	15	75	9	13	23	810	7	24	88
8	s	23.6	480	ESE	80	50	75	9	18	26	828	7	22	82
9	s	28.4	500	N	100	25	100	12	20	34	848	7	23	86
10	s	30.0	450	ENE	100	10	95	21	30	34	578	6	22	70
1	a	5.0	320	NNE	60	0	60	7	17	58	322	16	25	72
2	a	5.2	450	NE	75	0	50	10	17	35	405	14	30	62
3	a	10.0	500	SW	95	0	25	12	26	16	398	6	15	34
4	a	11.5	400	ENE	85	0	80	7	20	19	120	7	17	25
5	a	11.9	480	E	100	0	50	12	22	22	550	9	22	93
6	a	15.3	480	E	100	0	50	11	30	20	716	9	33	122
7	a	20.8	520	E	75	0	50	4	13	23	810	12	32	145
8	a	23.8	500	ESE	95	0	50	9	18	26	828	7	20	63
9	a	28.6	520	N	100	0	50	8	20	34	848	8	21	74
10	a	30.2	480	ENE	75	0	55	9	30	34	578	6	23	82

To assess pollution load, at each site we sampled about 50 leaves from each of five trees of mountain birch, *Betula pubescens tortuosa* (diameter 40-80 mm, height 3-5 m). The trees were randomly chosen at the upper tree limit, approximately between the subalpine and alpine plots. Leaves were taken both in 1993 and 1994 at a height of 1.2-1.4 m and stored in paper bags. Unwashed leaf samples were dried for 12 h at 80°C, then ground with a mill and analysed separately. Concentrations of nickel and manganese were determined by X-ray fluorescence (Spectrace 5000 spectrometer, Tracor X-ray, Holland). Nickel is the main metal pollutant of the smelter, whereas foliar concentration of manganese decreases with an increase of SO_2 concentration in the ambient air (Kozlov *et al.*, 1995). The locality-specific means based on two years of data are used in the analyses (variables NIC and MAN).

The quality of the analytical data was checked by replicate analyses of the same samples, representing different contamination levels, both by blind tests with the same analytical procedure in the original laboratory, and by inductively-coupled plasma atomic emission spectroscopy after wet digestion (HNO_3-H_2O_2). The latter analyses were conducted in the Finnish Forest Research Institute, a laboratory belonging to the intercalibration network organised by the International Union of Forest Research Organisations and the European Community. In both cases, the results of the independent analyses showed a very high correlation ($r = 0.935$-0.994, $n = 30$, $p < 0.0001$). The mean ratios (based on 30 samples) between concentrations of metals estimated by X-ray fluorescence and by the atomic emission spectroscopy were : 1.07 for Ni and 1.21 for Mn. Since we were interested in intra-plot differences more than in absolute values, the X-ray fluorescence was accurate enough to meet the goals of our study.

Statistical analysis

The number of specimens, number of species and Shannon diversity index (H) were analysed in respect to sampling conditions by the SAS GLM procedure ; Type III Sum of Squares was used to assess the significance of effects. Distributions of the numbers of specimens and species, as well as of their log-transformed values, significantly deviated from the normal distribution ; therefore these characteristics were square-root transformed before analyses. Since sampling design was unbalanced in respect of time, collector, and weather conditions, least-squares means (LSMs) were computed for each locality. LSMs are simply estimators of the plot marginal means that would be expected if the design had been balanced (SAS Institute, 1990).

The relationships between lepidopteran assemblages and the environmental variables listed above were analysed by canonical correspondence analysis (CCA ; CANOCO statistical program) (Ter Braak, 1987). The pooled list of species recorded at each study plot (Appendix) was used to estimate rarefaction corrected values for species richness (Krebs, 1989) and to calculate the plot-specific values of the Shannon diversity index (H). Comparisons between plots or plot groups were conducted by analysis of variance (SAS ANOVA procedure). Correlation coefficients were calculated by SAS CORR procedure (SAS Institute, 1990).

Results

Subalpine and alpine lepidopteran assemblages differ in respect of their sensitivity to sampling conditions. The numbers of both specimens and species in alpine samples were mostly influenced by air temperature ; sampling time, wind speed and cloudiness also showed significant effect on abundance. In contrast, numbers of specimens in subalpine samples depended mostly on the collector (Table 3).

CCA of samples from 10 alpine and 10 subalpine plots explained only 30.2% of variation and revealed no clear pattern in plot ordination. The Monte Carlo permutation test showed that even the first axis was not significant (99 random permutations, $F = 1.12$, $P < 0.22$). Thus, CCA analysis revealed no differences in species composition between

Table 3

Effects of sampling conditions on basic characteristics of individual 30-min samples.

Habitat	Source of variation	df	F values for dependent variables ([a]) Specimens	Species	Diversity
Subalpine	Plot	9	2.21*	2.21*	1.57
	Time	1	0.60	0.16	0.65
	Temperature	1	0.00	0.11	0.02
	Wind speed	1	3.89	1.44	0.17
	Cloudiness	1	3.88	3.28	3.14
	Collector	1	12.22***	2.27	0.25
Alpine	Plot	9	3.97***	2.30*	1.87
	Time	1	14.10***	3.30	1.83
	Temperature	1	20.81***	12.61***	9.24**
	Wind speed	1	7.32***	3.98*	0.98
	Cloudiness	1	8.01***	1.69	0.36
	Collector	1	0.00	0.08	0.14

([a]) Numbers of species and specimens were square-root transformed. Significance levels : *** — P = 0.001, ** — P=0.01, * — P=0.05.

subalpine and alpine lepidopteran assemblages, and therefore the data collected from subalpine and alpine plots in the same locality were pooled for further analysis.

Abundance of Lepidoptera did not depend on foliar nickel concentrations (Fig. 2), but demonstrated a clear dome-shaped pattern in relation to foliar manganese (Fig. 3). Three groups of plots were distinguished on the basis of both Mn concentration in birch leaves and the abundance of Lepidoptera : slightly polluted plots with low abundance (localities 7, 8 and 9), moderately polluted plots with high abundance (localities 5, 6 and 10), and heavily polluted plots with low abundance (localities 1-4). Within each group, intra-plot variation in abundance was low ($F_{(2, 45)} = 0.51$, $P < 0.6058$; $F_{(2, 41)} = 1.11$, $P < 0.3403$; and $F_{(3, 79)} = 1.67$, $P < 0.1811$, respectively), whereas intra-group variation was highly significant $F_{(2, 172)} = 31.03$, $P < 0.0001$). The decrease in density close to the smelter was more pronounced in tundra (37% of the abundance in moderately polluted plots) than in woodlands (51%).

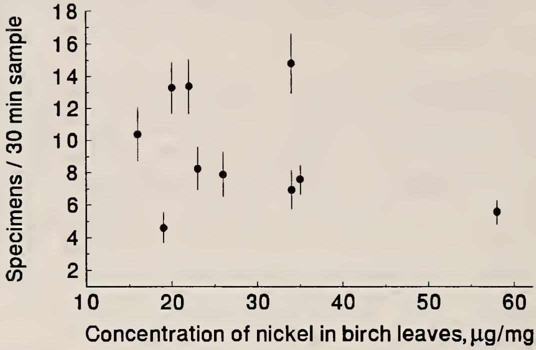
Among other environmental variables, abundance correlated only with the total number of plant species recorded in study plots (Fig. 4). Since numbers of specimens per 30-min sample were low, both the numbers of species and the diversity index (H) calculated for individual samples simply follow changes in abundance ($r = 0.96$, $n = 175$, $P < 0.0001$, and $r = 0.92$, $n = 175$, $P < 0.0001$).

The rarefaction-corrected locality-specific values of species richness as well as the diversity index (H) calculated for the pooled samples correlated neither with foliar manganese nor nickel concentrations. However, rarefaction-corrected species richness on the three plots closest to the smelter was 1.3 times higher than on more distant plots (Fig. 5), while the diversity index did not change with the pollution load (Fig. 6). Correlation between diversity and the number of plant species (TPL) was not significant.

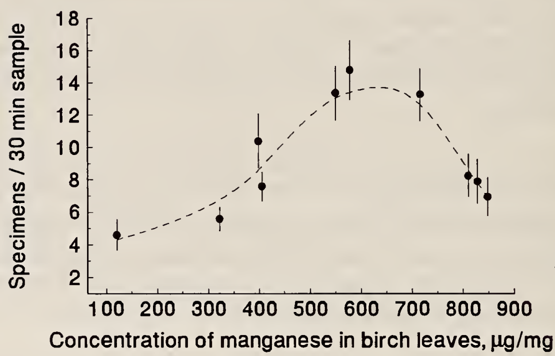
Discussion

Suitability of the sampling procedure

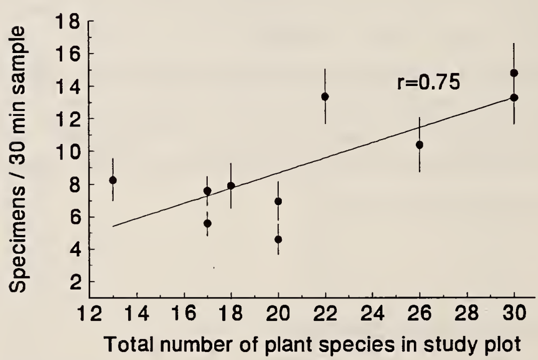
In past years, transect counts have been used for collecting quantitative information on day-active Lepidoptera. This method, originally developed for butterflies (Pollard, 1977), was later applied to all macrolepidopterans which can be distinguished in the field by the experienced observer (Väisänen, 1992). The drawbacks of transect counts are :



2

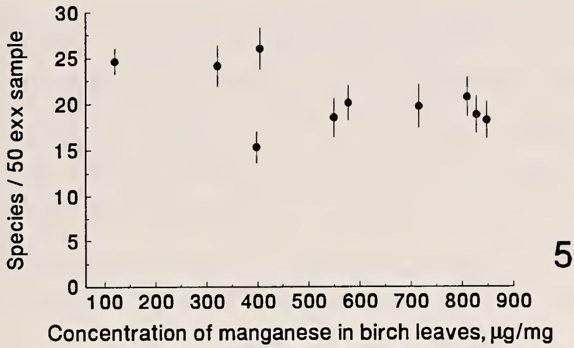


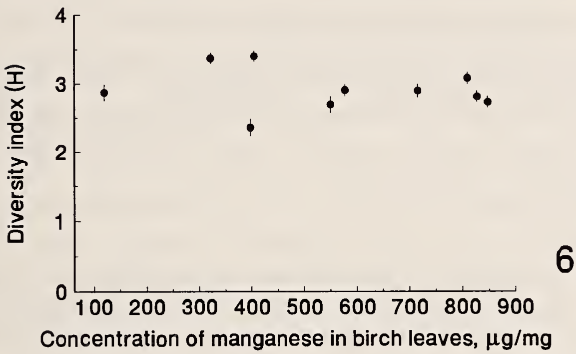
3



4

Figs 2-4. Locality-specific corrected means (LSMs) and standard errors of total abundance of Lepidoptera (specimens collected during 30 min) in relation to environmental variables : 2 — foliar nickel concentration ; 3 — foliar manganese concentration (weighted lowest approximation shown) ; 4 — total number of plants in study plots (regression is significant at $p = 0.01$).





Figs 5-6. Locality-specific diversity (means and standard errors) calculated for the pooled samples plotted against foliar manganese concentration : 5 — rarefaction-corrected species richness (number of species expected in the sample of 50 individuals) ; 6 — Shannon diversity index (H).

(1) impossibility of counting 'microlepidoptera', (2) the importance of an observer's experience in species recognition, (3) the possible over-estimation of population densities by repeated counts of the same individuals and (4) the impossibility of confirming the species observed. The sampling method used in the present study lacked these short-comings. However, the numbers of several moths may be underestimated due to their fast long-distant flight and camouflage ; this conclusion especially relates to the noctuids of the genus *Sympistis*.

Both the number of species and diversity index (H) calculated for the individual samples did not depend on the collector (Table 3) indicating that personal experience was not of critical importance for obtaining a representative sample. However, the number of collected specimens depended on the collector, but only in subalpine habitats (Table 3). This conclusion coincides with the general impression from collecting in the mountains : in alpine tundra, the number of sampled Lepidoptera almost completely depends on the frequency of their spontaneous appearance, while in more protected habitats of birch woodlands one can increase the catch by active searching and by disturbing moths from the vegetation. But since the samples were not selective in respect to the lepidopteran species, and the same collectors sampled in all plots, problems were not encountered when analysing the pooled data.

Density pattern along pollution gradient

Herbivorous insects usually respond to moderate pollution loads by an increase in population density, while high concentrations of pollutants have an adverse effect (Riemer & Whittaker, 1989 ; Kozlov, 1990). Numerous insect groups such as Eriocraniidae (Kozlov & Haukioja, 1993), Tortricidae (Kozlov, unpubl. data), Noctuidae (Kozlov, Jalava *et al.*, in press), chloropid flies (Zvereva, 1993) and the leaf beetle, *Melasoma lapponica* L. (Zvereva *et al.*, 1995) show the dome-shaped density patterns around the Severonikel smelter, when the lowland habitats are considered. These changes in densities are mostly related to sulphur dioxide, not heavy metals (Riemer & Whittaker, 1989 ; Zvereva *et al.*, 1995), although correlations with metal pollutants may also exist.

Background concentration of nickel in birch leaves in the Monchegorsk region is 16 ± 1 µg/mg, whereas the maximum site-specific value observed in the industrial barrenland near the Severonikel smelter was 586 µg/mg. In the lowlands, foliar Ni concentrations of 20 to 60 µg/mg were recorded in plots situated 20 to 50 km from the smelter (Kozlov *et al.*, 1995), where abundance of Lepidoptera was slightly higher than in the unpolluted locality (Kozlov, unpubl. data). Thus, the decrease in total abundance of Lepidoptera in the four montane plots proximate to the smelter is hardly related to metal pollutants.

In unpolluted regions of the Kola Peninsula, the mean concentration of manganese in birch leaves is 1032 ± 62 µg/mg (Kozlov *et al.*, 1995). Decrease of foliar manganese resulting from both the direct impact of sulphur dioxide on plant cells and the decreased availability of Mn due to increased pH of soils has repeatedly been observed (Hutchinson & Whitby, 1974 ; Løbersli & Steinnes, 1988), and therefore the Mn concentration in birch leaves can satisfactorily describe the impact of sulphur dioxide (Fig. 7).

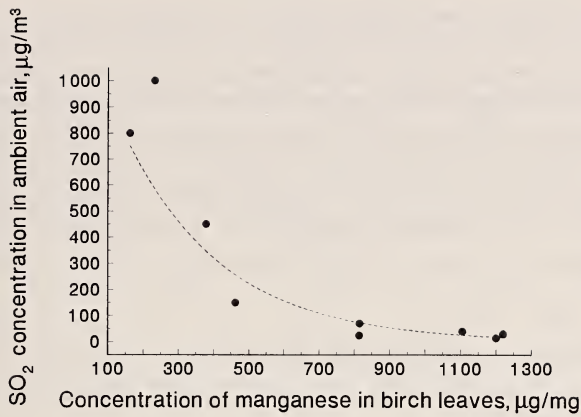


Fig. 7. Locality-specific ambient concentrations of sulphur dioxide in forest plots around Severonikel smelter (after Baklanov & Rodjushkina, 1993 ; Barkan, 1993 ; Kryuchkov, 1993) plotted against the corresponding concentrations of manganese in birch leaves (after Kozlov *et al.*, 1995).

The minimum site-specific Mn concentration observed in mountains (locality 4 : 120 µg/mg) was the same as recorded in industrial barrenlands near the Severonikel smelter (130 µg/mg ; Kozlov *et al.*, 1995) ; the maximum observed in mountains (848 µg/mg) was still lower than the background value estimated in the lowlands. However, the direct comparison of foliar manganese concentrations measured in forests and in subalpine woodlands might well be inappropriate, just because different soil properties affect the mobility of Mn^{2+} (Løbersli & Steinnes, 1988). However, the changes in abundance of Lepidoptera both in lowland forests (Kozlov, 1994 and unpubl. data) and in subalpine habitats follow a similar dome-shaped pattern, with maximum density attained at plots with estimated mean ambient SO_2 concentrations around 100 µg/m^3.

The important difference between forest and mountain habitats concerns the effects of the smelter on vegetation, which has resulted in forest decline within distances of 5 to 15 km (Kozlov & Haukioja, 1995) but has caused almost no structural changes in subalpine and alpine plant communities (Koroleva, unpubl. data). Therefore the changes in lepidopteran assemblages in subalpine and alpine habitats can be more closely related to the pollution impact on insects and/or their host plants, rather than to pollution-induced habitat deterioration.

Environmental assessment using data on Lepidoptera

Among Lepidoptera, only butterflies and skippers were generally considered as ecological indicators (Gilbert, 1984 ; Murphy *et al.*, 1990). Monitored over large areas during decades (Pollard, 1991), they contribute much to conservation biology in both a population and community context (Ehrlich & Murphy, 1987). Butterfly assemblages were found to be excellent indicators of heterogeneity due to topographic/moisture gradients, limited indicators of heterogeneity due to anthropogenic disturbance, and poor indicators of plant diversity (Kremen, 1992). However, in some areas such as northern boreal forests, subalpine woodlands and alpine tundra, both the diversity and abundance of butterflies are too low to use them in environmental assessment programs.

The present study has demonstrated that assemblages of Lepidoptera can be used for environmental assessment even in the areas with low species richness and relatively harsh climatic conditions. Consistent with the results of Kremen (1992), our data show that the pollution-induced disturbances make a low although significant contribution to the total variation in abundance of Lepidoptera. The number of vascular plant species on the plot (variable VPL) have no explanatory value, but the addition of moss and lichen species (variable TPL) improves the model suggesting that the richness of mosses and lichens correlates with some of the environmental variables not accounted in the present study (moisture conditions for example).

Although there is a general consensus that polluted habitats display a reduction of diversity (Magurran, 1988), the Shannon diversity index based on samples of Lepidoptera showed no decrease even in the two localities closest to a powerful smelter. The increase of rarefaction-corrected species richness on plots closest to the smelter is probably explained by an increase of vegetation heterogeneity caused by pollution. The typical arcto-alpine species (*Olethreutes aquilonanus*, *O. noricanus*, *Oeneis bore*) as well as species endangered in Finland (*Clossiana freija*, *Sympistis zetterstedtii*) are recorded even in the two plots closest to the smelter, confirming that the existing levels of pollution had caused only a decrease in density, not decline in species.

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