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Effects of pollution and urbanization on diversity of frit flies (Diptera: Chloropidae)

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Abstract

Frit flies were investigated during the summer of 1989 in 30 sites situated in two polluted areas, ≈ 120 km NEE of St. Petersburg, Russia. Both urban lawns and semi-natural grasslands were sampled around Volkhov aluminum smelter and Syasskij pulp and paper mill. Fluorine- and sulphur-containing aerial emissions did not affect species richness, diversity, or composition of species assemblages of Chloropidae, whereas habitat deterioration during the course of urbanization caused changes in species composition and a decline in species richness and diversity of frit flies.

Keywords: Chloropidae, diversity, aerial pollution, urbanization, fluorine, sulphur dioxide.

Résumé

Au cours de l'été 1989, nous avons étudié des oscines sur 30 sites de deux zones polluées situées à environ 120 km à l'ENE de St.-Petersbourg en Russie. Nous avons pris des échantillons dans des pelouses urbaines et des prairies semi-naturelles situées autour de la fonderie d'aluminium de Volkhov et de l'usine de pâte à papier de Syasskij. Les émissions aériennes fluorées et sulfurées n'affectent pas la richesse et la diversité spécifiques, ni la composition des assemblages d'espèces de chloropides, alors que la détérioration de l'habitat due à l'urbanisation provoque des modifications de la composition spécifique et un déclin de la richesse et de la diversité spécifiques des oscines.

INTRODUCTION

Although aerial emissions represent one of the major factors of environmental disturbance (FREEDMAN, 1989), the effect of pollution on biodiversity is still poorly documented (ARMENTANO & BENNETT, 1992; NEWMAN *et al.*, 1992). Decreases in species richness and diversity (measured with the Shannon-Weaver index) with increases in pollution have been demonstrated for vascular plants (WINNER & BEWLEY, 1978; FREEDMAN & HUTCHINSON, 1980), aquatic invertebrates and other animals (NEWMAN *et al.*, 1992). These data, together with common sense, have lead to a general consensus that polluted habitats display a reduction in diversity (RAPPORT *et al.*, 1985; MAGURRAN, 1988). However, pollution does not always cause adverse effects on insect diversity. Moderate levels of pollution may increase species richness for particular groups (YANOVSKIJ & VSHIVKOVA, 1984; YANOVSKIJ & BUTANAEV, 1990; PISAREVA, 1992). Furthermore, species richness of Lepidoptera in industrial barrens adjacent to the Severonikel smelter was almost the same as in primary spruce forests (KOZLOV, 1994), whereas subalpine localities proximate to this smelter displayed higher diversity of moths and butterflies than unpolluted mountain habitats (KOZLOV, 1995). Thus, more data is needed before predictions can be made on how pollution will affect insect diversity.

Frit flies (Chloropidae) are small to very small dipterous insects. They are very abundant in open landscapes, especially in grasslands. Larvae of most species feed on grasses, others are unspecialized saprophages or predators (NARCHUK, 1987). These flies are known to respond to both sulphur- and fluorine-containing aerial emissions by having increases in density in moderately polluted areas (DABROWSKA-PROT, 1984; BÄHRMANN, 1985; ZVEREVA, 1993*a*, 1993*b*).

The objective of this investigation was to quantify the impact of aerial emissions on overall diversity and species composition of frit flies, and to separate effects of pollution from effects of urbanization.

MATERIALS AND METHODS

Study area, emission sources, and distribution of pollutants

The study was conducted in Volkhov region, about 120 km NEE of the city of St. Petersburg. The region belongs to the mid-taiga zone, with mixed forests dominated by Norway spruce (*Picea abies*) near Volkhov or Scots pine (*Pinus sylvestris*) near Syasstroj. Two birch species, *Betula pubescens* and *B. pendula,* were the most abundant deciduous trees in the study area.

Two major point sources of aerial emissions in the study area are Volkhov aluminum smelter and Syasskij pulp and paper mill, situated in the towns of Volkhov and Syasstroj, respectively. The total amount of pollutants emitted in 1989 by the aluminum smelter was 1.17×10^7 kg, including 0.34×10^7 kg of SO_2, 0.30×10^7 kg of dust, 1.99×10^5 kg of sulphuric acid and 2.52×10^5 kg of fluorine. The pulp and paper mill emitted 1.06×10^7 kg, including 0.55×10^7 kg of SO_2, 0.25×10^7 kg of dust, and 100 kg of chlorine (BERLYAND, 1990).

The distribution of fluorine-containing pollutants around aluminum smelter was assessed in 1989 by sampling 10 leaves from 5 trees of white birch, *Betula pubescens* Ehrh., in 24 study sites at the end of the growing season (mid-September). Unwashed leaves were dried at +80°C for 12 h. The samples were analyzed by colorimetric method in the laboratory of Volkhov Sanitary and Epidemiological Station. To reveal among-year variation, we sampled birch leaves in mid-September of 1994 in 12 of our 24 sites, 5 trees per plot. These samples were analyzed by the potentiometric method in the Finnish Forest Research Institute. In 1994, fluorine concentrations were only 10-40% of those recorded in 1989 (due to reduction of emissions in 1993-1994), but a correlation between plot-specific values obtained in 1989 and 1994 ($r_s = 0.95$, $n = 12$, $P < 0.0001$) indicated that the measurements of 1989 reflected well the long-term spatial patterns of pollutant distribution.

Concentrations of sulphur dioxide around the pulp and paper mill were estimated in 1989 by determining the maximum life span of spruce needles in the lower part of crowns of 10 mature trees per study site. This bioindicator, which is easy to measure, reflects well the long-term impact of sulphur dioxide (KNABE, 1981) and can be converted to SO_2 concentrations by using the regression equation of TSVETKOV (1990).

Sampling design

We sampled frit flies in mid-June and mid-August of 1989 in 24 sites situated 0.5 to 10 km from Volkhov aluminum smelter, and 10 August 1989 in 6 sites situated 0.6 to 13.5 km from the Syasskij pulp and paper mill. To provide true replicates of pollution load, study sites outside urbanized areas were chosen along two transects starting from the emission source. The most distant localities in these transects demonstrated a background concentration of pollutants and were therefore considered as reference sites. Outside the urbanized areas, flies were collected in grass patches (on meadows, forest clearings and/or along small forest roads), at least 500 m away from agricultural landscapes. To reduce effects of traffic-borne pollutants, the sites were chosen at least 50 m from the roadside. Semi-natural grasslands in all these sites were dominated by *Deschampsia* spp. and looked externally similar. We did not attempt to record species composition of plants in our study sites, because grass-feeding fruit flies are generally polyphagous (Narchuk, 1987). In both Volkhov and Syasstroj towns, we sampled frit flies on lawns (dominated by *Poa annua*) at least 50 m from streets with traffic intensity exceeding 10 cars per hour in daytime.

Flies were collected on dry sunny days between 11 a.m. and 7 p.m. by sweeping vegetation with a standard entomological net. Each replicate consisted of 100 sweeps and covered an area of ca 60 m^2; four replicates were taken from each site during the sampling session. Insects were narcotized by chloroform, sorted, and then frit flies were preserved on cotton layers. In total, 2 444 specimens of 34 species were collected.

Data analysis

Specimens of each species were counted in each replicate, and the mean number of specimens per 100 sweeps was calculated by averaging results of four replicates. Then data from the four replicates were pooled, the total number of species in sample (consisting of 400 sweeps) was counted and Shannon-Weaver diversity index was calculated. The rarefaction-corrected species richness was calculated as the number of species expected in a random sample of 50 frit flies (Krebs, 1989). Although the differences in species richness between samples collected early and late in the season approached significance level (Kruskal-Wallis test for rarefaction-corrected values: $\chi^2 = 3.18$, df = 1, $P = 0.07$), the diversity index did not change (Kruskal-Wallis test: $\chi^2 = 1.32$, df = 1, $P = 0.25$), which allowed us to combine these samples for further analysis.

The number of specimens, numbers of species (both actual and rarefaction-corrected) and Shannon-Weaver diversity index were tested by non-parametric ANOVA (SAS NPAR1WAY procedure) with the habitat type (semi-natural grasslands vs lawns) as a class variable. Relationships between sample characteristics, including proportions of the most abundant species in total catch of Chloropidae, and estimates of pollution load were investigated by calculating correlation coefficients (SAS Institute, 1990).

Modifications in species composition, as well as relationships between the structure of assemblages and environmental variables (the type of habitat, distance to the source of emission, pollution load), were analyzed by canonical correspondence analysis after square-root transformation of species data (CANOCO statistical programme; Ter Braak, 1987).

RESULTS

Correspondence analysis of samples collected around Volkhov aluminum smelter explained only 32.6% of variation and revealed no clear pattern in plot ordination. Although the Monte Carlo permutation test showed that the first ordination axis was significant (99 random permutations, $F = 2.98$, $P < 0.01$), the forwarded selection of environmental variables demonstrated that the type of habitat (urban lawns or semi-natural grasslands) was responsible for the major part of species – environment relationships, whereas concentration of fluorine had the lowest explanatory value. Analysis of samples collected around Syasskij pulp and paper mill demonstrated that even the first ordination axis was not significant ($F = 1.48$, $P < 0.35$), and the largest part of among-sample variation was also related to the habitat type.

Consistent with these results, no effects of pollution on species richness and diversity of Chloropidae was revealed by correlation analysis (table I, fig. 1). The proportions of the 7 most abundant species (represented by more than 50 specimens in total catch around Volkhov aluminum smelter) also did not correlate with foliar fluorine concentration ($P = 0.18 - 0.97$).

TABLE I. – *Correlations between estimates of pollution loads and diversity measures of Chloropidae. r = Pearson correlation coefficient. N = sample size. P = probability level.*

Site	Diversity measure	Habitat					
		Grasslands			Lawns		
		r	*N*	*P*	*r*	*N*	*P*
Volkhov	Species per sample	−0.24	6	0.65	−0.04	18	0.87
	Species per 50 exx	0.05	6	0.93	−0.03	18	0.92
	Shannon-Weaver index	0.12	6	0.83	0.04	18	0.87
Syasstroj	Species per sample	−0.26	5	0.68		–	
	Species per 50 exx	0.00	5	0.99		–	
	Shannon-Weaver index	0.27	5	0.66		–	

Grass patches in semi-natural habitats and lawns in towns differed neither in abundance ($F_{1,28} = 2.14$, $P = 0.15$) nor in diversity ($F_{1,28} = 0.12$, $P = 0.73$) of Chloropidae. However, the actual number of species per sample was higher ($F_{1,28} = 4.60$, $P = 0.041$) in natural habitats (8.09 ± 1.00) than in towns (6.21 ± 0.34). Differences in rarefaction-corrected species richness were even more significant ($F_{1,28} = 6.94$, $P = 0.014$) suggesting that urbanization decreased suitability of habitats for some Chloropidae species. Nineteen of the 34 species considered in the present study were sampled in semi-natural habitats only (Appendix 1). However, the proportion of these 19 species in the total catch was only 5.9%, indicating that urbanization affected mostly species with low abundance.

DISCUSSION

The exposure of our study sites to pollution extended over 45 years, which is sufficient to cause structural changes in the affected communities (ARMENTANO & BENNETT, 1992). Abundance of Chloropidae significantly increased near both the Volkhov aluminum smelter and Syasskij pulp and paper mill (KOZLOV & ZVEREVA, 1992; ZVEREVA, 1993*a*; ZVEREVA & KOZLOV, 1993). However, we revealed no effects of fluorine- and sulphur-containing emissions on species richness, diversity or species composition of frit flies. Thus, pollution seems to affect dominant species of frit flies in a similar way, and the increase in abundance in polluted areas is

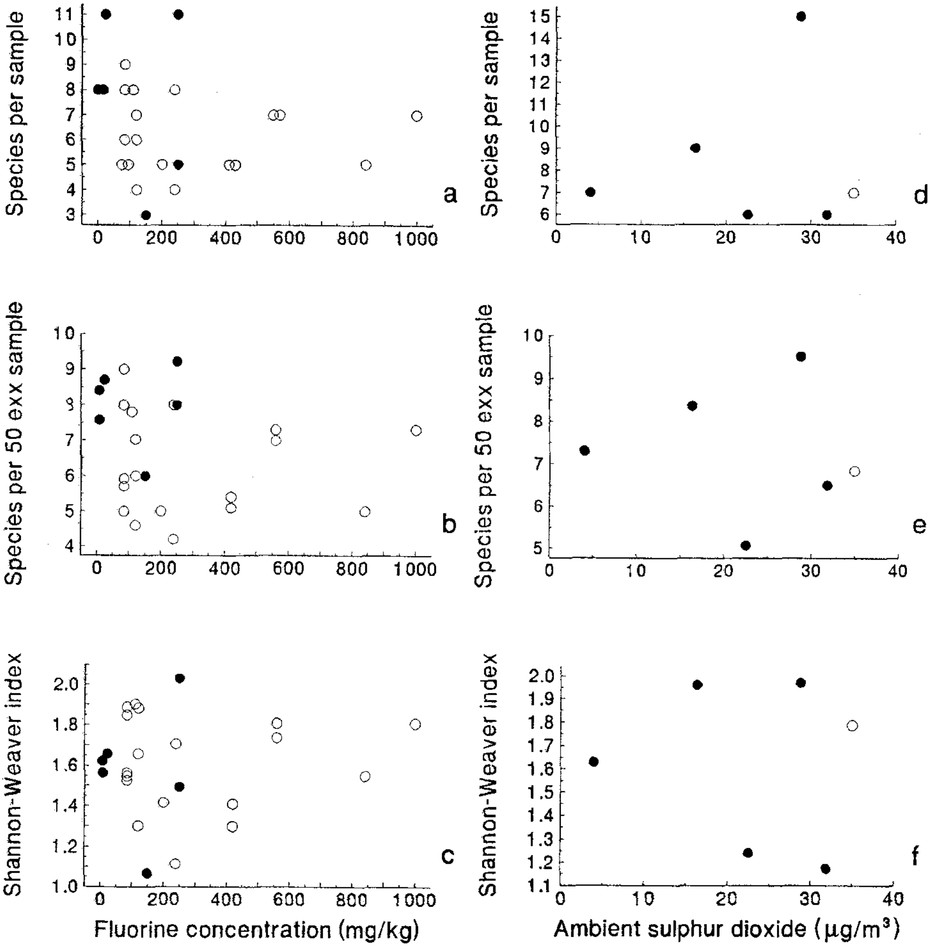

FIG. 1. – Species richness and diversity of Chloropidae along two pollution gradients. a-c, Volkhov aluminum smelter, data plotted against fluorine concentration in birch leaves in 1989; d-f, Syasskij pulp and paper mill, data plotted against the ambient SO_2 concentrations (estimated in 1989). a, d, actual number of species per sample; b, e, rarefaction-corrected number of species, as expected in the sample consisting of 50 specimens; c, f, Shannon-Weaver diversity index. Empty circles – urban lawns, filled circles – semi-natural grasslands. For correlation coefficients, *see* table 1.

based on similar increases in density of several species such as *Oscinella pusilla, O. frit, O. phlei* and *O. nigerrima*. This conclusion is in good agreement with results of DABROWSKA-PROT (1984), who attributed the increase in total abundance of Chloropidae in the polluted areas to increases in the densities of dominant *Oscinella* species.

Our data indicate that decreases in diversity with an increase in fluorine concentration, reported for some xylophagous (ANISIMOVA, 1989) and soil-dwelling insects (VOROBEICHIK, 1991) cannot be generalized to other insects. We suppose that frit flies maintain populations in heavily polluted habitats because of a relatively high resistance of their host plants (Gramineae) to pollution, and larval feeding within stems of host plants, which may protect larvae from the direct impact of toxicants.

In contrast to pollution, urbanization negatively affected species richness of frit flies. Although abundance of Chloropidae on urban lawns and in patches of semi-natural grassland (subjected to similar pollution loads) was similar, several species were not recorded in towns. This species decline was revealed by both correspondence analysis and comparisons of rarefaction-corrected species richness, but not in the Shannon-Weaver diversity index, which is less sensitive to changes in species with low abundance. Since no pesticides have been applied in the towns of Volkhov and Syasstroj during at least three years preceding our study (Volkhov Sanitary and Epidemiological Station, official data), we concluded that habitat modification caused by soil amelioration, regular cutting of grass, and recreation (trampling the grass) was responsible for the decrease in species richness of frit flies in urban lawns. This observation is in good agreement with numerous reports of decreases of insect diversity with increases in urbanisation (DAVIS, 1978; KLAUSNITZER, 1987).

To conclude, the long-lasting impact of moderate levels of fluorine- and sulphur-containing aerial emissions caused no detectable changes in species assemblages of Chloropidae, whereas habitat deterioration during the course of urbanization adversely affected species richness and diversity of frit flies.

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APPENDIX 1

Abundance (total numbers of specimens) of frit flies around Volkhov aluminum smelter and Syasskij pulp and paper mill in urban (lawns) and semi-natural (grasslands) habitats. Generic sequence according to NARCHUK *(1987); within the genus, species are placed in an alphabetic order. N=number of plots.*

	Volkhov		Syasstroj	
	lawns	grasslands	lawns	grasslands
Species	($N = 10$)	($N = 14$)	($N = 1$)	($N = 5$)
Elachiptera cornuta	2	8	0	6
Polyodaspis sulcicollis	0	2	0	11
Polyodaspis ruficornis	0	0	0	2
Siphonella oscinina	0	0	0	6
Tricimba crucis	0	2	0	0
Incertella albipalpis	58	41	18	3
Oscinella alopecuri	0	0	0	20
Oscinella frit	204	95	24	144
Oscinella hortensis	0	1	0	27
Oscinella phlei	20	31	20	219
Oscinella pusilla	261	115	25	277
Oscinella nigerrima	143	40	10	81
Oscinella nitidissima	79	47	0	103
Oscinella vastator	0	0	0	6
Oscinella ventricosi	0	0	0	12
Oscinimorpha arcuata	1	0	0	0
Oscinimorpha minutissima	122	34	0	0
Meromyza laeta	10	7	3	0
Meromyza saltatrix	8	11	7	0
Meromyza smirnovi	0	0	0	1
Meromyza triangulina	0	2	0	0
Cetema cereris	0	0	0	2
Thaumatomyia glabra	0	1	0	17
Cryptonevra diadema	0	1	0	0
Cryptonevra flavitarsis	0	1	0	0
Cryptonevra obscuripennis	1	2	0	0
Cryptonevra tarsata	0	1	0	0
Chlorops laeta	0	0	0	4
Chlorops meigeni	0	1	0	0
Chlorops planifrons	0	0	0	16
Chlorops pumilionis	5	4	0	2
Chlorops ringens	1	1	0	0
Chlorops varsoviensis	0	0	0	8
Lasiosina sp.	2	0	0	0
TOTAL: specimens	828	548	107	961
species	15	22	7	21