Chapter 6
Structure of Plant Communities

6.1 Introduction

Vegetation, i.e., the plant life of a region, not only shapes terrestrial ecosystems but also serves several crucial functions in the biosphere. Due to the importance of vegetation for mankind, deterioration of plant communities under pollution impacts attracted considerable scientific and public attention more than a century ago (Holland 1888; Haselhoff & Lindau 1903; Stoklasa 1923).

Historically, the majority of studies exploring pollution effects on plant communities were conducted in forested areas of Europe and North America. A large body of publications report decreases in forest vitality, often followed by forest decline, at different scales, from local, around point polluters (National Research Council of Canada 1939; Bunce 1979; Symeonides 1979; Sutherland & Martin 1990; Rigina & Kozlov 2000; Aznar et al. 2007), to regional (Pitelka & Raynal 1989; Kandler & Innes 1995; Bussotti & Ferretti 1998; Akselsson et al. 2004; Allen et al. 2007).

The effects of extreme pollution pressure on plant communities are relatively well documented, and forest decline near big smelters is a textbook example of the adverse impact of aerial pollution on terrestrial ecosystems (Treshow 1984; Freedman 1989). However, we still lack an understanding of patterns and processes occurring at lower levels of pollution. Although some responses are common across several community types and across several kinds of polluters, natural variation, the adaptation potential of individual species and intrinsic community differences complicate any interpretation (Armentano & Bennett 1992). Long ago, meta-analysis was suggested as useful tool to fully interpret the literature and to ascertain the likelihood of trends common to ecosystems and pollution regimes (Armentano & Bennett 1992); however, to our knowledge, no attempts were made to achieve this goal. As a result, conclusions on the overall effects of pollution on vegetation are usually made on the basis of a few case studies reporting consequences of the most severe impacts (Gordon & Gorham 1963; Wood & Nash 1976; Freedman & Hutchinson 1980b). Moreover, these conclusions are geographically biased, since almost no data exist on pollution-induced changes in plant communities other than in northern and temperate forests (Zvereva et al. 2008).

M.V. Kozlov et al. *Impacts of Point Polluters on Terrestrial Biota,*
DOI 10.1007/978-90-481-2467-1_6, © Springer Science+Business Media B.V. 2009

Last but not least, forestry-oriented studies often concentrate on losses of economically important products, primarily timber, and neglect changes in other groups of plants (Linzon 1986; Carrier & Krippl 1990; Feng et al. 2002). However, losses of ecosystem services may be much more costly than losses of timber (Costanza et al. 1997). To attempt a better understanding of the ecosystem-level effects of pollution on terrestrial biota (Chapter 9), we have chosen for this study a set of indices reflecting both the structure and function of the selected plant communities.

A primary characteristic of vegetation is its three-dimensional structure, described by the horizontal and vertical distributions of plant biomass. This structure is determined by both environmental and historical factors and species composition. Horizontal distribution, i.e., the pattern of spacing of plant stems on the ground, is not considered in the present study. Vertical distribution of biomass is explored by evaluating the cover of vegetation layers, which is a rough but commonly used approximation of biomass. Additionally, we measured stand basal area and height of the dominant tree species, which are indicative of the aboveground biomass and provide a link to several functional characteristics of the stand.

Our meta-analysis of indices reflecting plant community structure, along with basic goals (search for general patterns and identification of sources of variation), aims at verification of several assumptions concerning pollution impacts on forests, in particular:

(a) Standing biomass, as reflected by height and basal area, decreases with pollution.
(b) Conifers are more sensitive to pollution than deciduous trees, and therefore the proportion of conifers among top-canopy trees decreases with pollution.
(c) Trees are more sensitive to pollution than herbs and grasses, and therefore community destruction under pollution impacts follows a downward pattern (trees decline first, while field layer vegetation is the last to decline).
(d) Natural forest regeneration is suppressed by pollution.

These effects have been observed in only some of the polluted areas, and their generalization (Woodwell 1970; Kozlowski 1980; Smith 1981; Treshow 1984; Freedman 1989) is so far lacking proper statistical support.

Species composition and spatial distribution (reflected by diversity measured at different spatial scales) are inherent parts of plant community structure. Recent meta-analysis, based on 86 individual studies conducted in the impact zones of 60 polluters (Zvereva et al. 2008), demonstrated that plot-specific estimates of species richness of vascular plants (α diversity) generally decreased with pollution. However, the responses were not uniform across the studies. In particular, we have revealed the effects of methodology on the variation of effect sizes (ESs) as well as the publication bias (i.e., studies covered by the ISI database reported adverse effects that were on average twice as large as those reported in other studies). This gives special importance to the analysis of original data that were collected using uniform methods. Furthermore, our data allow testing of the hypothesis that the species composition changes with pollution, a problem that was impossible to resolve by meta-analysis of the published data, which are generally restricted to summary statistics, such as species richness or diversity indices (Zvereva et al. 2008).

On the other hand, limitations imposed by the structure of published data (Zvereva et al. 2008) allowed us to explore only a few potential sources of variation in responses of plant communities to industrial pollution. In particular, the majority of published studies compared species lists, without any attempt to address the effects of overall abundance of plants on species richness. Therefore, in this chapter, in addition to performing meta-analysis of vegetation cover *per se*, we explored relationships between changes in species richness and in vegetation cover that serves as a rough measure of abundance. This was done in order to test the hypothesis (Kozlov et al. 1998) that a decline in species richness (measured per area unit) with an increase in pollution is an artefact caused by an overall decrease in plant abundances.

The latter hypothesis is in line with several publications (Begg et al. 1997; Salminen & Haimi 1999; Hobbs 2003; Chalcraft et al. 2008) that stressed the importance of spatial scales in assessing pollution effects on biodiversity. The structure of our data (replicated lists of species for each study site) allows us to explore the effects of industrial pollution at three spatial scales: small (within plots), intermediate (among plots) and large (within the study site). This approach is necessary to check whether the assessment of α diversity (i.e., mean number of species per study plot) accurately predicts pollution effects on regional biodiversity.

Finally, we were interested in temporal changes in plant communities, and in mechanisms behind these changes. While vegetation damage around industrial enterprises is routinely attributed to pollution (even when pollution is only one of the factors responsible for deterioration of ecosystem health), at a regional level atmospheric pollutants are seen as one of many causal factors related to vegetation changes, primarily forest decline (Whittaker et al. 1974; Cogbill 1977; Field et al. 1992; Duchesne et al. 2002). Elucidating temporal and spatial patterns of the effects imposed by industrial polluters on structure, productivity, and regeneration of plant communities may lead to a better understanding of the role of atmospheric pollutants in regional processes and thus result in a wide array of practical applications.

6.2 Materials and Methods

6.2.1 Study Areas and Sampling Design

The structure of plant communities was assessed around 14 of 18 polluters (Tables 6.1–6.41). We have chosen not to collect information on the abundances and diversity of plants around Apatity, Harjavalta, Krompachy and Volkhov because vegetation in these areas was greatly modified by other kinds of human activities. In particular, primary forests near the power plant in Apatity were

Table 6.1 Vegetation cover (%) in the impact zone of aluminium smelter at Bratsk, Russia (data of 2002)

Site	Top-canopy	Understorey	Field layer	Mosses
1–1	46.7	10.0	60.0	23.3
1–2	76.7	5.0	22.7	23.3
1–3	36.7	18.3	61.7	21.7
1–4	36.7	13.3	60.0	46.7
1–5	56.7	6.0	73.3	33.3
2–1	53.3	16.7	28.7	60.0
2–2	60.0	30.0	23.3	50.0
2–3	66.7	6.0	43.3	30.0
2–4	76.7	11.7	55.0	25.0
2–5	53.3	5.0	63.3	46.7
ANOVA: *F/P*	7.19/0.0001	2.46/0.04	9.40/<0.0001	5.37/0.0009
Dist.: *r/P*	–0.03/0.94	–0.45/0.19	0.70/0.03	–0.09/0.80
Poll.: *r/P*	–0.10/0.79	0.22/0.54	0.46/0.18	0.48/0.16

All data were collected in 2002 from three plots 10 × 10 m size. Cover of bare ground equals to zero in all sites; epigeic lichens found at two sites only (1–5: cover 0.7%; 2–5: cover 0.3%). ANOVA: test for significance of variation between study sites. Dist.: Pearson linear correlation between site-specific means and log-transformed distance from polluter. Poll.: Pearson linear correlation between site-specific means and concentration of the selected pollutant.

Table 6.2 Vegetation cover (%) in the impact zone of the fertiliser factory at Jonava, Lithuania

Site	Top-canopy	Understorey	Field layer	Mosses
1–1	46.7	78.3	24.0	8.8
1–2	63.3	11.7	33.5	59.5
1–3	41.7	16.7	8.6	89.5
1–4	45.0	11.0	12.0	64.0
1–5	50.0	43.3	20.0	49.5
2–1	40.0	21.7	44.5	38.5
2–2	46.7	25.0	7.6	20.0
2–3	50.0	61.7	18.5	58.1
2–4	35.0	71.7	17.0	91.5
2–5	63.3	5.7	16.2	82.5
ANOVA: *F/P*	2.23/0.06	18.0/<0.0001	9.42/<0.0001	12.8/<0.0001
Dist.: *r/P*	0.15/0.69	–0.11/0.77	–0.62/0.06	0.66/0.04
Poll.: *r/P*	–0.52/0.12	0.59/0.07	–0.35/0.32	–0.23/0.52

Cover of top-canopy and understorey estimated in 2002 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Cover of epigeic lichens and bare ground equals to zero in all sites. For other explanations, consult Table 6.1.

repeatedly felled and burned, and the secondary regrowth is now under severe recreation impact. No primary forests are left near the aluminium smelter in Volkhov, and the entire area has been greatly modified by centuries of agricultural practice. In Harjavalta, Scots pine stands near the smelter were planted in the late 1950s to replace forest killed by pollution; most of the more distant stands were

Table 6.3 Vegetation cover (%) in the impact zone of the aluminium smelter at Kandalaksha, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	66.7	6.3	34.5	60.0	0.6	0
1–2	70.0	2.3	24.3	69.0	0	0
1–3	56.7	0.3	33.5	52.5	0.1	0
1–4	63.3	0.7	55.5	39.5	0	0
1–5	60.0	3.0	60.0	11.5	0	1.0
2–1	60.0	1.0	28.5	11.6	0	10.0
2–2	76.7	1.0	35.7	33.5	0	1.0
2–3	45.0	0	18.7	56.1	0.5	0
2–4	50.0	1.7	42.5	51.5	0	0
2–5	60.0	0	24.1	60.5	4.5	0
ANOVA: *F/P*	1.63/ 0.17	1.46/ 0.23	6.41/ <0.0001	7.01/ <0.0001	4.37/ <0.0001	73.0/ <0.0001
Dist.: *r/P*	−0.32/0.36	−0.33/0.35	0.34/0.33	0.16/0.65	–	–
Poll.: *r/P*	0.51/0.13	0.33/0.36	−0.30/0.40	−0.15/0.68	–	–

Cover of top-canopy and understorey estimated in 2002 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Absence of correlation coefficients indicates that the data were not used in meta-analyses. For other explanations, consult Table 6.1.

Table 6.4 Vegetation cover (%) in the impact zone of the copper smelter at Karabash, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Bare ground
1–1	16.7	0	0.2	0	13.3
1–2	23.3	0	3.0	1.7	0
1–3	46.7	2.0	51.5	0	0
1–4	46.7	0.7	53.0	0.9	0
1–5	63.3	7.7	23.4	0.1	0
2–1	10.3	0	0	0	10.0
2–2	30.0	5.0	0.2	2.5	0
2–3	53.3	4.3	19.1	0.0	0
2–4	40.0	3.3	67.5	2.7	0
2–5	60.0	3.0	25.0	15.8	0
ANOVA: *F/P*	15.5/<0.0001	2.47/0.04	35.9/<0.0001	8.24/<0.0001	6.87/0.0002
Dist.: *r/P*	0.87/0.001	0.48/0.16	0.72/0.02	0.49/0.15	–
Poll.: *r/P*	−0.83/0.003	−0.40/0.25	−0.68/0.03	−0.32/0.37	–

Cover of top-canopy and understorey estimated in 2003 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Cover of epigeic lichens equals to zero in all sites. Absence of correlation coefficients indicates that the data were not used in meta-analyses. For other explanations, consult Table 6.1.

also planted in different years and are intensively managed to maximise timber production. The mountainous landscape around Krompachy, in combination with a long history of human settlements, mining, and intensive agriculture, made selection of comparable study sites nearly impossible. For more details on these and other impact zones, consult Section 2.2.

Table 6.5 Vegetation cover (%) in the impact zone of the iron pellet plant at Kostomuksha, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens
1–1	46.7	0	76.7	70.0	0
1–2	46.7	0	57.0	95.0	0
1–3	36.7	0	43.3	95.0	0
1–4	33.3	0	74.0	95.0	0
1–5	33.3	1.0	63.3	95.0	0
2–1	30.0	3.0	71.7	68.3	0
2–2	60.0	0	51.3	95.0	0
2–3	50.0	0	45.0	95.0	0
2–4	40.0	0	50.0	94.3	9.0
2–5	40.0	0.3	73.7	95.0	0.3
ANOVA: *F/P*	2.19/0.07	4.85/0.0018	2.81/0.03	20.7/<0.0001	2.45/0.05
Dist.: *r/P*	−0.19/0.61	−0.49/0.15	−0.19/0.60	0.84/0.002	–
Poll.: *r/P*	−0.24/0.50	0.85/0.002	0.41/0.24	−0.80/0.005	–

Cover of top-canopy and understorey estimated in 2002 from three plots 10 × 10 m size, cover of other layers – in 2006 from ten plots 1 × 1 m size. Cover of bare ground equals to zero in all sites. Absence of correlation coefficients indicates that the data were not used in meta-analyses. For other explanations, consult Table 6.1.

Table 6.6 Vegetation cover (%) in the impact zone of the nickel-copper smelter at Monchegorsk, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	0.7	9.3	0.4	10.9	0	90.0
1–2	0	38.3	0	2.0	0	70.0
1–4	13.3	6.7	15.0	6.5	10.2	10.0
1–5	15.0	11.7	40.5	10.1	5.6	10.3
2–3	0	5.0	1.0	2.5	0.9	91.7
2–4	0	11.7	0.7	25.4	5.9	78.3
2–5	43.3	13.3	16.6	4.3	7.0	16.0
2–8	10.0	3.0	48.5	46.0	4.4	4.3
2–9	36.7	11.7	56.0	43.3	2.7	1.7
2–10	36.7	10.0	52.0	63.3	2.2	0
ANOVA: *F/P*	10.3/<0.0001	2.77/0.03	24.5/<0.0001	8.28/<0.0001	2.54/0.02	105.4/<0.0001
Dist.: *r/P*	0.70/0.02	−0.25/0.48	0.88/0.001	0.72/0.02	0.34/0.34	−0.88/0.001
Poll.: *r/P*	−0.53/0.11	−0.11/0.77	−0.70/0.02	−0.46/0.18	−0.33/0.35	0.83/0.003

Cover of top-canopy and understorey estimated in 2001 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. For other explanations, consult Table 6.1.

Table 6.7 Vegetation cover (%) in the impact zone of the aluminium smelter at Nadvoitsy, Russia

Site	Top-canopy	Understorey	Field layer	Mosses
1–1	40.0	0	22.5	8.0
1–2	53.3	3.3	22.9	71.0
1–3	43.3	0.3	37.8	7.0
1–4	35.0	1.3	39.7	67.0
1–5	43.3	0.4	57.5	12.5
2–1	31.7	0.7	21.0	18.2
2–2	56.7	5.0	33.5	26.0
2–3	21.7	10.0	40.0	49.0
2–4	20.0	0	32.5	59.5
2–5	31.7	2.4	45.5	4.0
ANOVA: *F/P*	6.23/0.0003	4.33/0.0031	4.21/0.0001	13.3/<0.0001
Dist.: *r/P*	–0.25/0.48	–0.05/0.89	0.89/0.0006	0.09/0.80
Poll.: *r/P*	0.46/0.18	–0.06/0.87	–0.80/0.006	–0.11/0.76

Cover of top-canopy and understorey estimated in 2004 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Cover of epigeic lichens and bare ground equals to zero in all sites. For other explanations, consult Table 6.1.

Table 6.8 Vegetation cover (%) in the impact zone of the nickel-copper at Nikel and ore-roasting plant at Zapolyarnyy, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	2.0	15.0	0	0	0	68.3
1–2	2.0	31.7	2.5	3.0	0	53.3
1–3	1.7	36.7	45.2	16.0	0	0.7
1–4	3.3	14.3	33.0	32.0	0	0.3
1–5	12.7	7.3	39.0	40.0	12.7	1.3
2–1	3.7	13.7	1.1	1.7	0	81.7
2–2	4.3	15.0	7.4	7.5	0	46.7
2–3	8.3	30.0	19.7	1.5	1.6	5.0
2–4	8.3	18.3	49.0	20.5	14.0	0.7
2–5	17.7	28.3	25.3	45.5	2.3	2.3
ANOVA: *F/P*	1.54/ 0.20	1.59/ 0.18	20.5/ <0.0001	8.26/ <0.0001	3.49/ 0.0010	14.4/ <0.0001
Dist.: *r/P*	0.66/0.04	0.07/0.84	0.79/0.006	0.85/0.002	0.51/0.13	–0.91/0.0003
Poll.: *r/P*	–0.43/0.22	–0.29/0.42	–0.71/0.02	–0.61/0.06	–0.38/0.27	0.85/0.002

Cover of top-canopy and understorey estimated in 2001 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. For other explanations, consult Table 6.1.

Table 6.9 Vegetation cover (%) in the impact zone of the nickel-copper smelters at Norilsk, Russia

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	0.7	6.0	38.3	0	0	20.0
1–2	2.0	61.7	43.3	0	26.7	2.0
1–3	2.7	63.3	48.7	1.0	78.3	0.7
1–4	16.7	50.0	33.3	1.0	56.7	3.0
1–5	6.7	35.0	51.7	6.0	40.0	1.3
2–1	0	11.7	35.0	0	18.3	6.7
2–2	1.3	25.0	31.7	0	70.0	3.7
2–3	31.7	23.3	63.3	0	15.0	1.0
2–4	13.3	38.3	60.0	1.0	93.3	0
2–5	20.0	6.7	73.3	6.7	86.7	0.3
ANOVA: *F/P*	9.17/<0.0001	5.96/0.0004	4.73/0.0018	40.9/<0.0001	7.75/<0.0001	21.8/<0.0001
Dist.: *r/P*	0.56/0.09	0.32/0.36	0.62/0.05	0.73/0.02	0.64/0.05	−0.78/0.008
Poll.: *r/P*	−0.46/0.18	−0.57/0.08	−0.49/0.15	−0.49/0.15	−0.66/0.04	0.93/<0.0001

All data were collected in 2002 from three plots 10 × 10 m size. For other explanations, consult Table 6.1.

Table 6.10 Vegetation cover (%) in the impact zone of the copper smelter at Revda, Russia

Site	Top-canopy	Understorey	Field layer	Mosses
1–1	18.3	0	0.8	41.5
1–2	56.7	5.3	15.0	18.2
1–3	45.0	18.3	39.0	32.5
1–4	56.7	3.0	54.7	1.0
1–5	46.7	43.3	45.5	24.7
2–1	50.0	1.0	7.1	0.3
2–2	50.0	1.0	27.5	3.1
2–3	53.3	11.7	21.3	1.0
2–4	53.3	1.0	54.0	19.5
2–5	38.3	30.0	66.0	67.2
ANOVA: *F/P*	2.02/0.09	5.87/0.0005	20.3/<0.0001	11.2/<0.0001
Dist.: *r/P*	0.26/0.46	0.69/0.03	0.92/0.0001	0.34/0.34
Poll.: *r/P*	−0.47/0.17	−0.56/0.09	−0.83/0.003	−0.23/0.52

Cover of top-canopy and understorey estimated in 2003 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Cover of epigeic lichens and bare ground equals to zero in all sites. For other explanations, consult Table 6.1.

Table 6.11 Vegetation cover (%) in the impact zone of the aluminium smelter at Straumsvík, Iceland

Site	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	0	3.6	29.5	13.6	0
1–2	0	42.9	64.0	0.4	0
1–3	0	31.9	64.0	0.6	8.3
1–4	0	13.8	60.0	4.3	2.3
1–5	6.0	52.0	34.0	1.9	2.0
2–1	0	26.4	46.0	2.9	0
2–2	0	14.1	71.5	1.2	1.3
2–3	0	17.5	59.5	5.6	0.5
2–4	0	20.7	76.0	0.6	2.2
2–5	0.7	23.1	76.0	0.2	0.5
ANOVA: *F/P*	4.78/0.0017	4.13/0.0002	3.75/0.0005	5.14/<0.0001	3.50/0.01
Dist.: *r/P*	–	0.42/0.22	0.24/0.50	–0.34/0.33	0.02/0.96
Poll.: *r/P*	–	–0.58/0.08	–0.62/0.06	0.84/0.002	–0.26/0.47

Cover of understorey estimated in 2002 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. Top-canopy cover equals to zero in all sites. Absence of correlation coefficients indicates that the data were not used in meta-analyses. For other explanations, consult Table 6.1.

Table 6.12 Vegetation cover (%) in the impact zone of the nickel-copper at Sudbury, Canada

Site	Top-canopy	Understorey	Field layer	Mosses	Lichens
1–1	3.0	0	13.9	9.9	10.2
1–2	18.3	0	36.2	15.7	5.6
1–3	20.0	4.3	40.5	3.5	2.3
1–4	13.3	16.7	43.8	6.4	1.8
1–5	40.0	0.3	3.5	8.6	0
2–1	3.0	0	10.0	20.7	11.5
2–2	40.0	10.3	5.1	20.1	4.2
2–3	23.3	16.7	43.5	0.8	0
2–4	20.0	10.0	49.5	0.2	0
2–5	36.7	11.0	10.6	0.9	0
ANOVA: *F/P*	8.16/<0.0001	5.02/0.0013	13.7/<0.0001	2.99/0.0037	3.94/0.0003
Dist.: *r/P*	0.66/0.04	0.46/0.18	0.18/0.62	–0.75/0.01	–0.92/0.0002
Poll.: *r/P*	–0.46/0.18	–0.48/0.16	–0.49/0.16	0.83/0.003	0.92/0.0001

Cover of top-canopy and understorey estimated in 2007 from three plots 10 × 10 m size, cover of other layers – in 2007 from ten plots 1 × 1 m size. For other explanations, consult Table 6.1.

Table 6.13 Vegetation cover (%) in the impact zone of the power plant at Vorkuta, Russia

Site	Understorey	Field layer	Mosses	Lichens	Bare ground
1–1	66.0	55.0	73.3	1.7	0
1–2	69.3	33.3	80.0	2.0	0
1–3	52.7	38.3	86.7	4.7	0
1–4	55.3	47.0	78.3	8.7	1.7
1–5	58.7	25.0	85.0	6.7	3.3
2–1	70.3	35.0	73.3	0	0
2–2	62.7	33.3	83.3	5.7	0
2–3	62.3	31.7	86.7	6.7	0
2–4	56.0	25.7	81.7	6.0	2.0
2–5	60.0	27.3	90.0	2.3	0.7
ANOVA: *F/P*	5.29/0.0009	1.42/0.24	4.57/0.0022	1.83/0.12	2.31/0.06
Dist.: *r/P*	−0.75/0.01	−0.50/0.14	0.75/0.01	0.65/0.04	–
Poll.: *r/P*	0.68/0.03	−0.13/0.72	−0.26/0.47	−0.45/0.19	–

All data were collected in 2002 from three plots 10 × 10 m size. Absence of correlation coefficients indicates that the data were not used in meta-analyses. For other explanations, consult Table 6.1.

Table 6.14 Vegetation cover (%) in the impact zone of the aluminium smelter at Žiar nad Hronom, Slovakia

Site	Top-canopy	Understorey	Field layer	Mosses	Bare ground
1–1	91.7	1.7	0	0.3	0
1–2	85.0	0.7	0.2	0.3	0.2
1–3	93.3	0	7.3	0.1	1.3
1–4	80.0	0.3	7.3	0.3	1.7
1–5	88.3	0	15.0	2.0	0.5
2–1	93.3	5.7	3.3	2.7	15.0
2–2	93.3	0	9.3	11.7	6.7
2–3	91.7	1.0	16.7	3.3	1.7
2–4	93.3	0	3.0	2.0	1.0
2–5	85.0	1.7	10.0	4.3	1.7
ANOVA: *F/P*	4.22/0.0035	2.88/0.02	3.01/0.02	9.00/<0.0001	14.4/<0.0001
Dist.: *r/P*	−0.25/0.49	−0.38/0.28	0.71/0.02	0.23/0.53	−0.19/0.60
Poll.: *r/P*	−0.01/0.99	0.09/0.80	09.66/0.04	−0.38/0.28	−0.28/0.44

All data were collected in 2002 from three plots 10 × 10 m size. Cover of epigeic lichens equals to zero in all sites. For other explanations, consult Table 6.1.

Table 6.15 Stand characteristics in the impact zone of aluminium smelter at Bratsk, Russia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of Scots pine	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	20.3	7P2B1A	23.0	245	72.1	57.8
1–2	28.0	8P1B1A	24.3	11	86.0	0
1–3	32.7	8P2B	31.7	37	83.6	8.3
1–4	32.7	8P1B1A	27.0	53	80.8	16.7
1–5	35.0	7P3B	27.7	64	69.8	46.7
2–1	8.7	4L3S3B	16.0	0	4.2	–
2–2	30.3	7P1S1B1A	17.0	43	66.6	8.3
2–3	33.3	7P2L1B	23.0	128	72.9	68.4
2–4	21.7	7P2B1A	27.7	187	70.4	42.4
2–5	26.7	8P2B	26.7	379	75.9	76.8
ANOVA (G_H): $F(\chi2)/P$	13.3/ <0.0001	189.9/ <0.0001	10.2/ <0.0001	5.30/ 0.0009	9.15/ <0.0001	3.96/ 0.0082
Dist.: r/P	0.54/0.11	–	0.71/ 0.02	0.37/ 0.30	0.41/ 0.23	0.40/ 0.28
Poll.: r/P	−0.85/ 0.0016	–	−0.67/ 0.03	−0.31/ 0.39	−0.90/ 0.0004	−0.15/ 0.71

Data collected in 2002.
[a] A, European aspen (*Populus tremula*); B, white birch (*Betula pubescens*); L, Siberian larch (*Larix sibirica*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).
G_H: test for significance of variation in stand composition between study sites. For other explanations, consult Table 6.1

Table 6.16 Stand characteristics in the impact zone of the fertiliser factory at Jonava, Lithuania

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of Scots pine among mature trees[b]
	Basal area, m^2/ha	Composition[a]	Height, m		
1–1	44.3	10P	20.3	43	96.3
1–2	41.3	9P1Q	24.7	176	91.1
1–3	41.0	10P	23.0	53	100.0
1–4	38.0	7P2B1S	29.3	133	72.3
1–5	41.0	10P	23.3	219	99.2
2–1	34.3	10P	15.3	53	100.0
2–2	37.3	5P3B1S1Q	27.0	85	54.8
2–3	45.7	10P	25.0	165	100.0
2–4	33.0	10P	17.3	523	98.0
2–5	51.0	7P3S	25.7	528	71.9
ANOVA (G_H): $F(\chi^2)/P$	2.42/0.05	901.4/<0.0001	45.41/<0.0001	6.14/0.0004	39.9/<0.0001
Dist.: r/P	0.27/0.45	–	0.44/0.20	0.62/0.06	−0.11/0.76
Poll.: r/P	−0.46/0.18	–	−0.26/0.46	0.12/0.73	−0.14/0.71

Data collected in 2005.
[a] B, common birch (*Betula pendula*); P, Scots pine (*Pinus sylvestris*); Q, English oak (*Quercus robur*); S, Norway spruce (*Picea abies*).
[b] Only one Scots pine seedling had been recorded in the course of the survey (on site 1–4).
For other explanations, consult Tables 6.1 and 6.15

Table 6.17 Stand characteristics in the impact zone of the aluminium smelter at Kandalaksha, Russia

Site	Stand characteristics[a]		Seedling density, exx/ha	Proportion (%) of Scots pine	
	Basal area, m^2/ha	Composition[b]		Among mature trees	Among seedlings
1–1	23.3	10P	544	98.5	15.1
1–2	34.0	10P	885	96.1	9.9
1–3	27.0	10P	85	100.0	21.1
1–4	28.7	9P1B	208	94.2	21.4
1–5	21.7	8P2B	763	84.2	8.8
2–1	23.7	10P	389	100.0	3.9
2–2	29.3	10P	229	100.0	36.7
2–3	13.0	9P1S	117	91.4	91.1
2–4	23.3	9P1S	400	89.9	79.6
2–5	16.0	10P	75	98.4	53.7
ANOVA (G_H): F (χ^2)/P	2.48 0.0434	30.0/0.04	5.51/0.0007	2.21/0.0674	5.44/0.0008
Dist.: r/P	−0.33/0.35	–	−0.20/0.57	−0.54/0.10	0.39/0.27
Poll.: r/P	0.53/0.11	–	0.39/0.25	0.54/0.11	−0.61/0.06

Data collected in 2002.
[a] Stand height had not been measured.
[b] B, white birch (*Betula pubescens*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).
For other explanations, consult Tables 6.1 and 6.15

Table 6.18 Stand characteristics in the impact zone of the copper smelter at Karabash, Russia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of Scots pine	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	5.7	10B	5.3	16	0	0
1–2	20.0	2P8B	18.0	917	22.8	88.8
1–3	28.0	6P4B	24.7	368	60.8	60.9
1–4	34.7	6P4B	24.0	165	57.7	48.0
1–5	30.0	5P5B	22.0	213	53.3	70.5
2–1	2.7	10B	6.7	0	0	–
2–2	19.7	5P5B	11.3	720	46.7	98.4
2–3	28.3	6P4B	24.3	560	57.6	64.4
2–4	32.0	4P6B	21.3	16	40.9	50.0
2–5	57.7	8P2B	20.3	165	84.7	39.9
ANOVA (G_H): F (χ^2)/P	23.4/ <0.0001	206.9/ <0.0001	75.9/ <0.0001	1.51/ 0.21	3.56/ 0.0086	3.22/ 0.03
Dist.: r/P	0.90/ 0.0005	–	0.79/ 0.0065	−0.19/ 0.60	0.80/ 0.0054	−0.02/ 0.96
Poll.: r/P	−0.83/ 0.0031	–	−0.91/ 0.0003	−0.17/ 0.63	−0.79/ 0.0070	−0.21/ 0.58

Data collected in 2003.
[a] B, common birch (*Betula pendula*); P, Scots pine (*Pinus sylvestris*).
For other explanations, consult Tables 6.1 and 6.15

Table 6.19 Stand characteristics in the impact zone of the iron pellet plant at Kostomuksha, Russia

	Stand characteristics[a]		Seedling	Proportion (%) of Norway spruce	
Site	Basal area, m^2/ha	Composition[b]	density, exx/ha	Among mature trees	Among seedlings
1–1	25.7	5S4P1B	91	51.5	0
1–2	34.5	9S1P	96	88.9	0
1–3	36.7	5S4P1B	299	47.5	26.3
1–4	32.3	6S3P1B	69	56.3	11.1
1–5	26.7	8P1S1B	32	14.6	16.7
2–1	29.7	5S4P1B	283	48.0	4.5
2–2	44.0	6S3P1B	91	58.3	14.1
2–3	30.5	7S2P1B	5	66.6	100.0
2–4	20.3	9P1B	240	0	0
2–5	23.3	8P1B1S	53	9.7	0
ANOVA (G_H): F (χ^2)/P	3.35/0.02	399.6/<0.0001	1.23/0.33	14.0/<0.0001	6.11/0.0007
Dist.: r/P	−0.24/0.50	–	−0.33/0.35	−0.45/0.19	0.07/0.85
Poll.: r/P	0.13/0.71	–	0.38/0.29	0.19/0.60	−0.20/0.57

Data collected in 2002.
[a] Stand height had not been measured.
[b] B, white birch (*Betula pubescens*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).
For other explanations, consult Tables 6.1 and 6.15

Table 6.20 Stand characteristics in the impact zone of the nickel-copper smelter at Monchegorsk, Russia

	Stand characteristics				Proportion (%) of Norway spruce	
Site	Basal area, m^2/ha	Composition[a]	Height, m	Seedling density, exx/ha	Among mature trees	Among seedlings
1–1	0.3	10B	2.3	5	0	0
1–2	0.3	10B	2.1	528	0	0
1–4	2.3	6P4B	2.6	528	0	0
1–5	5.3	5P5B	7.3	736	0	15.3
2–3	0	–	1.9	0	–	–
2–4	0	–	2.0	0	–	–
2–5	2.0	5B3S2P	6.9	907	27.8	5.1
2–8	12.0	9S1B	11.3	1,173	87.2	84.5
2–10	11.0	5B4S1P	11.8	320	36.3	71.6
2–12	18.7	8S2B	11.3	363	83.6	27.1
ANOVA (G_H): F (χ^2)/P	36.6/ <0.0001	94.2/ <0.0001	19.5/ <0.0001	5.85/ 0.0005	23.3/ <0.0001	49.8/ <0.0001
Dist.: r/P	0.87/0.0010	–	0.87/0.0010	0.45/0.20	0.73/0.04	0.63/0.09
Poll.: r/P	−0.62/0.05	–	−0.65/0.04	−0.59/0.07	−0.47/0.24	0.53/0.18

Data collected in 2001.
[a] B, white birch (*Betula pubescens*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).
For other explanations, consult Tables 6.1 and 6.15

Table 6.21 Stand characteristics in the impact zone of the aluminium smelter at Nadvoitsy, Russia

	Stand characteristics			Seedling density,	Proportion (%) of Scots pine	
Site	Basal area, m^2/ha	Composition[a]	Height, m	exx/ha	Among mature trees	Among seedlings
1–1	41.3	9P1B	19.7	2,021	86.9	55.1
1–2	31.0	7P2B1A	17.7	837	72.8	0.4
1–3	36.7	9P1B	24.3	272	86.5	0
1–4	35.7	6P4B	24.7	69	62.4	24.4
1–5	26.7	5B3P1S1A	17.0	341	34.2	7.8
2–1	33.7	7P3B	21.3	1,472	72.0	86.7
2–2	29.0	6P2B1A1S	24.3	192	61.2	0
2–3	27.7	9P1B	24.7	64	90.9	24.4
2–4	27.0	9P1B	17.7	53	92.7	36.7
2–5	40.3	6P3B1A	25.0	309	55.1	4.7
ANOVA (G_H): F (χ^2)/P	1.81/0.12943	260.6/<0.0001	72.3/<0.0001	3.08/0.02	4.87/0.0015	6.45/0.0003
Dist.: r/P	–0.24/0.50	–	0.00/0.99	–0.73/0.02	–0.48/0.16	–0.54/0.11
Poll.: r/P	0.12/0.72	–	–0.14/0.71	0.72/0.02	0.14/0.71	0.47/0.17

Data collected in 2004.

[a]A, European aspen (*Populus tremula*); B, white birch (*Betula pubescens*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).

For other explanations, consult Tables 6.1 and 6.15

Table 6.22 Stand characteristics in the impact zone of the nickel-copper smelter at Nikel and ore-roasting plant at Zapolyarnyy, Russia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of mountain birch	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	0	–	4.2	0	–	–
1–2	0.3	10B	3.3	0	100.0	–
1–3	2.0	10B	6.8	747	100.0	90.5
1–4	0.7	10B	3.7	0	100.0	–
1–5	0	–	3.8	64	–	100.0
2–1	1.7	10B	2.5	0	100.0	–
2–2	1.0	–	3.3	395	0	56.1
2–3	4.3	6P4B	6.7	2,000	38.9	92.6
2–4	2.0	10B	6.0	1,227	100.0	89.4
2–5	11.7	6P4B	7.2	864	38.9	95.1
ANOVA (G_H): F (χ^2)/P	8.49/<0.0001	39.2/<0.0001	11.3/<0.0001	2.59/0.04	6.02/0.0079	2.82/0.09
Dist.: r/P	0.40/0.25	–	0.45/0.19	0.31/0.38	−0.01/0.98	0.85/0.03
Poll.: r/P	−0.26/0.47	–	−0.42/0.23	−0.39/0.27	0.09/0.84	−0.94/0.0044

Data collected in 2001.

[a]B, white birch (*Betula pubescens*); P, Scots pine (*Pinus sylvestris*).

For other explanations, consult Tables 6.1 and 6.15

Table 6.23 Stand characteristics in the impact zone of the nickel-copper smelters at Norilsk, Russia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of Siberian larch	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	0	–	–	0	–	–
1–2	0.3	10L	7.0	0	100.0	
1–3	1.0	10L	6.5	0	100.0	–
1–4	4.0	10L	6.0	5	100.0	100.0
1–5	2.0	8L2A	5.5	16	75.0	100.0
2–1	0	–	–	5	–	100.0
2–2	0.3	10B	2.0	59	0	0
2–3	10.7	6L3B1S	16.0	1,093	58.3	10.2
2–4	5.0	10L	8.3	37	100.0	100.0
2–5	7.0	6L4B	19.3	37	64.3	60.0
ANOVA (G_H): F (χ^2)/P	9.75/<0.0001	41.6/0.007	57.3/<0.0001	20.7/<0.0001	4.52/0.02	5.05/0.03
Dist.: r/P	0.54/0.10	–	0.49/0.21	0.04/0.91	0.39/0.34	0.23/0.63
Poll.: r/P	−0.45/0.20	–	−0.34/0.41	−0.06/0.87	−0.78/0.02	−0.22/0.64

Data collected in 2002.
[a]A, Siberian alder (*Duschekia fruticosa*); B, white birch (*Betula pubescens*); L, Siberian larch (*Larix sibirica*); S, Norway spruce (*Picea abies* ssp. *obovata*).
For other explanations, consult Tables 6.1 and 6.15

Table 6.24 Stand characteristics in the impact zone of the copper smelter at Revda, Russia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of Scots pine	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	23.0	4S4F2B	18.7	229	3.2	0
1–2	33.0	4S4F2B	24.0	917	0	0
1–3	41.0	6F2B1S1A	26.3	885	1.7	0
1–4	28.7	5S3B2P	25.0	176	23.1	0
1–5	34.7	8F2S	25.0	336	0	0
2–1	17.0	5P2A2S1F	19.3	1,243	47.7	11.5
2–2	29.3	5S5P	18.3	576	44.1	11.5
2–3	24.7	5B3P1F1S	21.7	288	29.3	5.7
2–4	47.7	8P1S1B	24.7	165	82.6	0
2–5	52.0	6S3P1F	24.0	96	26.7	0
ANOVA (G_H): F (χ^2)/P	9.34/<0.0001	904.6/<0.0001	7.29/0.0001	5.62/0.0007	11.7/<0.0001	3.24/0.01
Dist.: r/P	0.72/0.02	–	0.80/0.0060	–0.58/0.08	–0.03/0.94	–0.59/0.07
Poll.: r/P	–0.73/0.02	–	–0.94/<0.0001	0.28/0.43	0.11/0.77	–0.63/0.05

Data collected in 2003.

[a]A, aspen (*Populus tremula*); B, white birch (*Betula pubescens*); F, Siberian fir (*Abies sibirica*); P, Scots pine (*Pinus sylvestris*); S, Siberian spruce (*Picea abies* ssp. *obovata*).

For other explanations, consult Tables 6.1 and 6.15

Table 6.25 Stand characteristics in the impact zone of the nickel-copper smelter at Sudbury, Canada

Site	Stand basal area, m^2/ha	Stand composition[a]	Proportion (%) of aspen among mature trees[b]
1–1	0	–	–
1–2	4.3	6P2M2B	0
1–3	15.7	4P4O1B1F	0
1–4	11.0	7A2P1B	72.8
1–5	30.7	5A3F1B1O	48.5
2–1	0	–	–
2–2	17.7	8B2M	0
2–3	15.7	8A2P	75.3
2–4	11.3	4A2M2P2B	21.2
2–5	24.0	7A3F	65.2
ANOVA (G_H): F (χ^2)/P	7.48/<0.0001	322.3/<0.0001	9.35/0.0001
Dist.: r/P	0.80/0.0051	–	0.63/0.10
Poll.: r/P	−0.67/0.04	–	−0.64/0.09

Data collected in 2007.

[a] A, quaking aspen (*Populus tremuloides*); B, canoe birch (*Betula papyrifera*); F, balsam fir (*Abies balsamea*); M, red maple (*Acer rubrum*); O, red oak (*Quercus rubra*); P, jack pine (*Pinus banksiana*).

[b] Seedlings were not counted.

For other explanations, consult Tables 6.1 and 6.15

Table 6.26 Stand characteristics in the impact zone of the aluminium smelter at Žiar nad Hronom, Slovakia

Site	Stand characteristics			Seedling density, exx/ha	Proportion (%) of European beech	
	Basal area, m^2/ha	Composition[a]	Height, m		Among mature trees	Among seedlings
1–1	25.0	8B2H	30.0	416	81.8	65.7
1–2	24.3	5H4P1B	23.3	629	7.3	8.3
1–3	30.7	6H4B	26.3	4,149	36.9	89.6
1–4	40.0	9B1F	33.7	2,800	94.3	77.8
1–5	33.0	9B1O	33.3	5,728	91.5	65.2
2–1	27.0	6B3H1P	30.0	6,149	62.8	63.3
2–2	27.3	10B	29.0	6,736	100.0	99.3
2–3	25.3	6B2H1M1L	32.0	5,771	55.4	29.5
2–4	44.0	9B1F	35.3	1,691	87.0	98.2
2–5	29.0	7B1A1H1F	36.3	9,989	79.3	3.3
ANOVA (G_H): F (χ^2)/P	6.90/0.0002	604.5/<0.0001	6.46/0.0003	4.72/0.0019	67.2/<0.0001	12.9/<0.0001
Dist.: r/P	0.61/0.06	–	0.78/0.0074	0.56/0.09	0.54/0.11	0.08/0.82
Poll.: r/P	–0.44/0.20	–	–0.47/0.17	–0.67/0.03	–0.29/0.41	–0.18/0.62

Data collected in 2002.

[a] A, European ash (*Fraxinus excelsior*); B, European beech (*Fagus sylvatica*); F, silver fir (*Abies alba*); H, European hornbeam (*Carpinus betulus*); M, Norway maple (*Acer platanoides*); O, durmast oak (*Quercus petraea*); L, small-leaved lime (*Tilia cordata*).

For other explanations, consult Tables 6.1 and 6.15.

Table 6.27 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the aluminium smelter at Bratsk, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Abies sibirica	w	0	0	0	0	0	0	0	0	1	0
Achillea millefolium	h	0	1	0	3	0	0	2	0	1	0
Aconitum volubile	h	0	0	0	0	0	0	0	0	0	0
Adenophora coronopifolia	h	2	2	0	0	0	0	0	0	0	0
Adoxa moschatellina	h	1	0	2	0	2	2	3	0	1	0
Agrimonia pilosa	h	0	0	2	2	0	1	0	3	0	0
Angelica sylvestris	h	0	1	2	0	2	1	0	0	2	2
Antennaria dioica	h	1	0	0	0	0	0	0	1	0	0
Artemisia latifolia	h	0	0	0	0	3	0	0	0	0	0
Betula pendula	w	0	0	3	3	0	0	0	3	0	0
Betula pubescens	w	3	3	1	2	3	3	3	0	3	3
Calamagrostis arundinacea	g	2	1	1	1	3	1	1	3	2	1
Calamagrostis purpurea	g	1	0	1	0	0	0	2	0	0	0
Carex globularis	g	1	2	1	2	2	3	1	3	1	2
Cirsium helenioides	h	1	1	0	1	0	0	0	0	0	2
Clematis alpina ssp. *sibirica*	ds	0	1	3	2	2	3	0	3	3	1
Conioselinum tataricum	h	3	2	0	2	2	2	3	0	0	1
Cotoneaster niger	w	0	0	0	0	0	1	0	1	0	0
Crepis sibirica	h	0	1	1	0	1	0	0	0	1	0
Cypripedium guttatum	h	1	1	0	1	0	0	0	0	0	1
Dendranthema zawadskii	h	0	0	0	0	0	0	0	1	0	0
Duschekia fruticosa	w	0	0	3	3	0	2	1	3	2	0
Epilobium angustifolium	h	3	1	3	3	1	3	3	0	2	1
Equisetum pratense	h	0	0	0	0	0	0	0	0	3	3
Euphorbia jenisseiensis	h	1	3	0	0	0	0	0	0	0	0
Festuca gigantea	h	0	0	3	0	0	0	0	0	0	0
Festuca ovina	g	0	0	0	0	0	0	1	0	0	0
Fragaria vesca	h	0	0	0	0	0	3	0	0	0	0
Galium boreale	h	3	2	0	1	3	3	0	1	3	2
Geranium albiflorum	h	2	3	0	2	0	3	3	0	2	0
Goodyera repens	h	0	0	0	0	1	0	0	0	0	0
Gymnocarpium dryopteris	h	0	0	1	1	2	0	0	0	3	0
Hieracium sp.	h	1	0	0	0	0	0	0	0	0	0
Hieracium umbellatum	h	0	1	1	0	0	0	0	0	1	0
Lactuca sibirica	h	1	1	3	0	1	1	0	0	1	1
Larix sibirica	w	3	0	2	2	1	2	3	3	2	3
Lathyrus sp.	h	3	3	1	3	3	1	1	3	1	2
Lathyrus vernus	h	0	0	1	3	3	0	0	0	3	3
Ledum palustre	ds	3	0	1	0	3	1	3	0	0	3
Lilium pilosiusculum	h	0	0	0	0	0	0	0	0	1	0
Linnaea borealis	h	0	1	3	3	3	0	2	2	3	2
Lonicera altaica	w	1	0	0	0	0	0	0	1	1	0
Lonicera caerulea ssp. *pallasii*	w	0	0	0	1	2	0	0	1	0	2
Luzula pilosa	g	0	0	0	0	0	0	0	0	1	0
Lycopodium annotinum	h	0	0	0	0	0	0	0	0	0	2
Maianthemum bifolium	h	2	0	2	3	2	0	3	2	2	3
Melica nutans	g	0	0	0	0	0	0	0	0	1	0
Orthilia secunda	h	1	0	0	0	1	0	0	3	0	0

(continued)

Table 6.27 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Paris quadrifolia	h	0	0	0	2	0	0	0	0	0	0
Pedicularis labradorica	h	0	0	0	0	0	0	1	0	0	0
Pedicularis resupinata	h	0	0	0	0	1	0	1	0	0	0
Peucedanum palustre	h	1	0	0	0	0	0	0	0	0	0
Picea abies ssp. *obovata*	w	1	1	0	0	0	3	1	2	2	3
Pinus sibirica	w	0	0	0	0	0	0	0	3	3	0
Pinus sylvestris	w	3	3	3	3	3	2	3	3	3	3
Pleurospermum uralense	h	0	1	0	1	1	0	1	0	0	1
Polemonium racemosum	h	0	1	0	0	0	0	0	0	0	0
Populus tremula	w	2	2	2	2	1	1	3	0	3	3
Pulmonaria mollis	h	0	1	2	1	1	0	0	0	1	0
Pulsatilla flavescens	h	2	2	1	1	2	1	0	0	0	1
Pyrola rotundifolia	h	3	0	3	1	2	0	0	2	0	3
Ranunculus acris ssp. *borealis*	h	0	1	0	0	0	0	0	0	0	0
Rosa acicularis	w	2	2	3	3	2	3	3	2	3	3
Rubus matsumuranus	w	0	0	1	2	0	1	0	0	0	0
Rubus saxatilis	h	1	3	3	3	3	2	3	3	3	3
Rumex aquaticus	h	0	0	0	0	0	1	0	0	0	0
Salix caprea	w	0	0	1	0	0	1	0	1	1	0
Salix hastata	w	0	1	0	0	1	1	0	0	0	1
Salix phylicifolia	w	0	0	0	0	1	2	0	0	0	0
Salix taraikensis	w	0	0	0	0	1	0	0	0	0	0
Sanguisorba officinalis	h	0	3	3	2	0	1	1	0	0	0
Saposhnikovia divaricata	h	0	1	0	0	0	0	0	0	0	0
Saussurea sp.	h	0	2	0	0	0	0	0	0	0	0
Saxifraga nelsoniana	h	0	0	0	1	0	0	0	0	0	0
Senecio sp. (cf. *integrifolius*)	h	0	0	0	0	0	0	0	2	1	0
Solidago daurica	h	0	0	0	1	0	0	0	0	0	0
Sorbus aucuparia	w	0	0	3	3	1	2	0	0	1	0
Spiraea media	w	3	3	0	2	2	3	2	1	3	0
Tanacetum bipinnatum	h	0	2	0	1	0	2	0	0	0	0
Tanacetum vulgare	h	0	0	0	0	0	0	1	0	0	0
Thalictrum minus	h	0	3	2	3	2	1	1	0	3	3
Trientalis europaea	h	0	0	2	2	0	0	1	0	2	3
Trifolium lupinaster	h	0	1	0	0	1	0	0	1	2	3
Trollius asiaticus	h	3	3	0	3	3	3	3	3	3	3
Vaccinium myrtillus	ds	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	ds	2	0	0	0	2	0	3	0	0	0
Vaccinium vitis-idaea	ds	3	3	3	3	3	1	3	3	3	3
Veratrum sp.	h	0	0	0	0	0	0	2	0	0	0
Vicia cracca	h	3	0	0	0	1	1	1	0	2	3
Viola canina	h	1	0	0	0	2	3	1	0	0	1
Viola epipsiloides	h	0	0	0	1	0	0	0	0	1	0
Viola uniflora	h	3	2	1	3	1	1	1	0	1	3

Data collected 2–4.8.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.28 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the fertilising factory at Jonava, Lithuania

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Acer negudo	w	1	0	0	0	0	0	0	0	0	0
Acer platanoides	w	1	2	0	0	0	1	3	3	3	0
Betula pendula	w	0	1	0	2	0	0	3	0	0	1
Bilderdykia convolvulus	h	0	0	0	0	0	3	0	0	0	0
Calamagrostis arundinacea	g	0	0	0	1	0	0	0	1	3	3
Calamagrostis canescens	g	0	0	3	3	3	0	0	0	0	0
Carduus crispus	h	0	1	0	0	0	0	0	0	0	0
Carpinus betulus	w	0	0	0	0	0	0	1	0	0	0
Chelidonium majus	h	2	3	0	0	0	3	3	0	0	0
Convollaria majalis	h	0	1	0	0	1	0	0	0	0	0
Corylus avellana	w	2	3	3	3	2	0	3	1	0	3
Cystopteris fragilis	h	0	0	2	2	1	0	0	3	0	0
Dryopteris carthusiana	h	0	0	0	0	0	0	0	0	0	3
Dryopteris filix-mas	h	1	1	3	0	3	2	3	3	2	1
Epilobium angustifolium	h	0	0	0	0	0	2	0	2	1	0
Equisetum fluviatile	h	0	0	0	0	1	0	0	0	0	0
Equisetum pratense	h	1	0	0	0	0	0	0	0	0	0
Erodium cicutarium	h	0	0	1	0	0	0	0	0	0	0
Euonymus verrucosus	w	0	0	0	0	0	0	1	0	0	0
Fragaria vesca	h	1	2	2	3	3	0	0	3	3	2
Frangula alnus	w	1	3	3	3	3	0	2	3	3	3
Galeopsis tetrahit	h	2	2	0	2	1	3	0	2	2	0
Galium album	h	0	0	0	0	0	0	0	0	2	0
Galium boreale	h	0	1	0	0	0	0	0	0	0	0
Galium palustre	h	0	1	0	0	0	0	0	0	0	0
Geum urbanum	h	0	3	0	0	0	0	0	0	2	0
Hieracium laevigatum	h	0	0	0	2	0	0	0	0	0	0
Hieracium mixopolium	h	0	0	0	0	0	0	0	0	0	0
Hieracium silvularum	h	0	0	1	0	1	0	0	1	0	0
Humulus lupulus	h	3	0	0	0	0	0	0	0	0	0
Hypericum perforatum	h	0	0	0	1	1	0	0	0	2	0
Impatiens parviflora	h	0	3	2	1	3	0	3	0	0	0
Knautia arvensis	h	0	0	0	2	0	0	0	1	3	0
Lonicera xylosteum	w	1	0	0	0	0	0	0	0	0	0
Luzula pilosa	g	0	0	0	3	2	0	0	0	0	1
Lysimachia vulgaris	h	0	0	0	0	3	0	0	0	0	0
Maianthemum bifolium	h	0	1	0	0	0	0	0	0	0	1
Malus domestica	w	0	0	0	0	0	0	0	2	0	0
Malus sylvestris	w	0	1	0	0	0	0	0	0	0	0
Melampyrum pratense	h	0	0	0	0	0	0	0	0	0	0
Melica nutans	g	0	3	0	0	0	0	0	0	0	0
Moehringia trinervia	h	1	3	3	2	3	3	3	0	0	1
Mycelis muralis	h	1	2	3	0	3	3	0	3	2	3
Oxalis acetosella	h	3	3	3	1	3	0	3	0	3	3
Paris quadrifolia	h	0	0	0	0	0	0	0	0	0	1
Phragmitis australis	g	0	0	0	0	2	0	0	0	0	0
Picea abies	w	0	1	1	3	3	0	3	2	2	3
Pinus sylvestris	w	3	3	3	3	3	3	3	3	3	3

(continued)

Table 6.28 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Populus tremula	w	0	0	0	0	0	0	0	1	2	2
Prunus domestica	w	1	0	1	0	0	1	0	0	0	0
Prunus serotina	w	0	0	0	0	0	0	0	2	0	0
Pyrola rotundifolia	h	0	0	1	0	0	0	0	0	0	0
Pyrus communis	w	0	1	0	0	0	0	0	0	0	0
Quercus robur	w	3	3	3	3	3	3	2	3	3	3
Ribes uva-crispa	w	0	0	0	0	0	1	0	0	0	0
Rubus caesius	w	3	0	0	0	0	0	0	0	0	0
Rubus idaeus	w	3	3	3	3	3	3	3	3	3	3
Rumex acetosa	h	0	0	0	1	0	0	0	0	1	0
Rumex acetosella	h	0	0	0	3	0	0	0	0	0	0
Salix cinerea	w	0	1	0	0	0	0	0	0	0	0
Sambucus racemosa	w	0	1	1	0	0	0	0	0	0	0
Silene vulgaris	h	0	0	0	0	0	0	0	0	0	0
Solidago virgaurea	h	0	2	0	1	1	0	0	0	0	1
Sorbus aucuparia	w	2	2	3	3	3	1	3	3	2	3
Stellaria holostea	h	0	0	0	0	2	0	0	0	0	0
Tilia cordata	w	1	0	0	0	1	0	0	0	1	0
Urtica dioica	h	3	3	0	0	0	3	2	1	2	0
Vaccinium myrtillus	ds	0	0	0	3	0	0	0	0	0	2
Veronica chamaedrys	h	0	0	0	0	0	0	0	2	0	0
Veronica officinalis	h	0	0	0	0	0	0	0	0	2	0
Viburnum opulus	w	0	1	0	0	1	0	0	0	0	0
Vicia sepium	h	0	1	0	0	0	0	0	0	0	0
Viola riviniana	h	0	0	0	3	0	0	0	0	0	0

Data collected 3–5.9.2005. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.29 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the aluminium smelter at Kandalaksha, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Andromeda polifolia	ds	0	0	0	0	0	0	0	1	0	0
Arctostaphylos uva-ursi	ds	0	0	0	0	0	0	0	0	0	2
Betula nana	w	0	0	0	0	0	0	0	2	0	0
Betula pendula	w	1	0	0	0	0	0	1	0	0	0
Betula pubescens	w	3	3	3	3	3	2	3	3	1	2
Calluna vulgaris	ds	0	0	0	0	1	0	0	3	2	2
Carex globularis	g	0	0	1	0	0	0	0	2	0	0
Deschampsia cespitosa	g	0	0	0	0	0	1	0	0	0	0
Deschampsia flexuosa	g	3	1	3	3	3	2	3	1	2	0
Diphasium complanatum	h	0	0	0	0	2	0	0	0	0	0
Empetrum nigrum	ds	2	3	3	3	3	3	3	3	3	3
Epilobium angustifolium	h	1	2	1	2	3	3	3	0	1	1
Gymnocarpium dryopteris	h	0	0	0	1	0	0	0	0	0	0
Hieracium sp.	h	0	0	0	0	1	1	0	0	0	0
Juniperus communis ssp. *nana*	w	1	1	3	3	2	1	1	0	1	1
Ledum palustre	ds	3	3	2	2	3	1	3	3	3	0
Linnaea borealis	h	3	3	2	3	3	3	3	0	3	0
Luzula pilosa	g	2	0	0	3	2	2	2	0	2	0
Lycopodium annotinum	h	0	1	0	1	0	0	0	0	0	0
Lycopodium clavatum	h	0	1	0	0	0	0	0	0	0	0
Melampyrum sylvaticum	h	0	1	3	3	3	0	2	0	3	0
Moneses uniflora	h	1	0	0	0	0	3	1	0	0	0
Picea abies ssp. *obovata*	w	2	3	2	3	3	1	1	3	3	3
Pinus sylvestris	w	3	3	3	3	3	3	3	3	3	3
Poa pratensis	g	0	0	0	0	0	1	1	0	0	0
Populus tremula	w	3	3	0	0	3	2	0	0	0	0
Salix caprea	w	3	1	3	1	2	3	3	0	0	1
Salix phylicifolia	w	2	0	0	0	1	0	0	0	0	0
Solidago virgaurea	h	2	3	2	3	3	3	2	0	0	0
Sorbus aucuparia	w	3	3	1	3	1	3	3	0	1	0
Trientalis europaea	h	3	0	0	2	0	2	3	0	1	0
Vaccinium myrtillus	ds	3	3	3	3	3	3	3	3	3	3
Vaccinium uliginosum	ds	3	1	2	2	3	0	3	3	2	2
Vaccinium vitis-idaea	ds	3	3	3	3	3	3	3	3	3	3

Data collected 26.6.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.30 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the copper smelter at Karabash, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Abies sibirica	w	0	1	0	0	0	0	0	1	0	1
Achillea millefolium	h	0	0	0	0	3	0	1	0	2	1
Aconitum septentrionale	h	0	0	1	0	2	0	0	0	0	0
Adenophora lilifolia	h	0	0	1	1	0	0	0	3	0	2
Aegopodium podagraria	h	0	0	0	3	3	0	0	0	3	1
Agrimonia pilosa	h	0	0	0	1	2	0	0	0	1	1
Agrostis capillaris	g	0	2	0	0	2	0	0	0	3	0
Agrostis gigantea	g	0	0	0	0	0	0	1	0	0	0
Ajuga reptans	h	0	0	3	2	3	0	0	2	3	0
Alchemilla sp.	h	0	0	0	0	0	0	0	0	3	0
Alnus incana	w	0	0	0	0	0	0	2	0	0	0
Angelica sylvestris	h	0	0	0	2	0	0	0	2	0	1
Antennaria dioica	h	0	0	0	0	0	0	0	0	0	2
Asarum europaeum	h	0	0	1	0	0	0	0	0	2	0
Athyrium filix-femina	h	0	0	0	1	1	0	0	0	1	0
Betula pendula	w	3	2	1	3	3	3	3	1	3	0
Betula pubescens	w	0	3	0	0	0	0	0	3	1	3
Brachypodium pinnatum	g	0	1	0	0	1	0	0	1	1	0
Bupleurum longifolium ssp. *aureum*	h	0	0	0	0	0	0	0	0	0	1
Calamagrostis arundinacea	g	0	3	3	0	0	0	2	3	1	0
Calamagrostis obtusata	g	0	1	3	3	0	0	0	3	0	0
Calamagrostis purpurea ssp. *langsdorfii*	g	0	0	0	0	0	0	0	0	0	3
Campanula glomerata	h	0	0	1	1	2	0	0	0	1	0
Campanula sp.	h	0	0	0	0	0	0	0	1	0	1
Campanula stevenii ssp. *wolgensis*	h	0	0	2	0	0	0	0		0	0
Carduus nutans	h	0	0	0	0	2	0	0	0	0	0
Carex montana	g	0	0	0	0	0	0	0	0	1	0
Carex sp.	g	0	0	0	0	0	0	0	0	0	1
Cerastium fontanum ssp. *triviale*	h	0	0	0	0	0	0	0	0	1	0
Cerastium pauciflorum	h	0	0	0	2	0	0	0	0	0	0
Chamaecytisus ruthenicus	w	0	2	3	3	1	0	0	3	2	3
Conioselinum tataricum	h	0	0	0	0	2	0	1	1	3	0
Cotoneaster niger	w	0	0	0	0	0	0	0	0	1	0
Crataegus sanguinea	w	0	0	0	1	1	0	0	0	0	0
Dactylis glomerata	g	0	0	0	0	2	0	0	0	1	0
Deschampsia cespitosa	g	0	2	0	3	3	0	0	0	3	0
Digitalis grandiflora	h	0	0	2	1	0	0	0	0	0	1
Elymus repens	g	0	1	0	0	0	0	0	0	0	0
Epilobium angustifolium	h	0	0	0	0	0	0	0	0	0	2
Epipactis atrorubens	h	0	0	1	0	1	0	0	0	0	0
Epipactis helleiborine	h	0	0	1	0	0	0	0	0	0	0
Equisetum pratense	h	0	2	0	0	0	0	0	0	0	0
Euphorbia sp.	h	0	0	0	0	0	0	0	1	0	0
Festuca rubra	g	0	2	0	0	0	0	1	2	1	0
Festuca valesiaca	g	0	0	0	0	0	0	0	1	0	0

(continued)

Table 6.30 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Filipendula ulmaria	h	0	0	0	0	1	0	0	0	1	0
Filipendula vulgaris	h	0	0	2	2	2	0	0	0	1	1
Fragaria vesca	h	0	0	3	3	3	0	0	3	3	3
Galeopsis bifida	h	0	0	0	0	0	0	0	0	0	1
Galium boreale	h	0	0	3	2	3	0	1	3	2	3
Galium odoratum	h	0	0	0	0	0	0	0	0	1	0
Galium ruthenicum	h	0	0	0	0	0	0	2	0	0	0
Geranium sylvaticum ssp. *pseudosibiricum*	h	0	0	0	0	2	0	0	0	0	0
Geranium sylvaticum ssp. *sylvaticum*	h	0	0	3	3	3	0	0	3	3	1
Geum rivale	h	0	0	0	0	3	0	0	0	0	0
Geum urbanum	h	0	0	0	2	0	0	0	0	3	0
Glehoma hederacea	h	0	0	0	0	0	0	0	0	2	0
Hieracium caespitosum ssp. *brevipilum*	h	0	0	0	0	2	0	0	0	1	0
Hieracium pilosella	h	0	0	0	0	0	0	0	0	1	0
Hieracium umbellatum	h	0	0	1	0	0	0	0	2	0	0
Hypericum maculatum	h	0	0	0	0	2	0	0	0	0	0
Hypochoeris maculata	h	0	0	0	0	0	0	1	2	0	0
Inula salicina	h	0	0	2	0	0	0	0	0	0	0
Larix sibirica	w	0	0	0	0	0	0	0	3	0	0
Lathyrus gmelinii	h	0	0	0	0	0	0	0	0	1	2
Lathyrus pisiformis	h	0	0	2	1	1	0	0	0	0	0
Lathyrus pratensis	h	0	0	0	1	1	0	0	0	0	0
Lathyrus vernus	h	0	0	3	3	2	0	0	2	2	3
Leucanthemum vulgare	h	0	0	0	0	1	0	0	0	3	0
Lilium martagon	h	0	0	2	2	0	0	0	2	2	1
Lonicera sp.	w	0	0	0	0	3	0	1	0	0	0
Luzula pilosa	g	0	0	0	1	0	0	0	0	0	0
Maianthemum bifolium	h	0	1	1	3	0	0	0	3	3	2
Melampyrum pratense	h	0	0	2	1	1	0	0	3	0	1
Melica nutans	g	0	0	0	0	1	0	0	0	3	0
Moneses uniflora	h	0	0	0	1	0	0	0	0	0	2
Neottia nudus-avis	h	0	0	0	0	0	0	0	0	0	1
Neottianthe cucullata	h	0	0	0	1	0	0	0	0	0	0
Origanum vulgare	h	0	0	1	1	0	0	0	0	0	0
Orthilia secunda	h	0	0	2	3	1	0	1	3	1	3
Phleum phleoides	g	0	0	0	0	1	0	0	0	0	0
Picea abies ssp. *obovata*	w	0	0	0	0	0	0	0	1	0	1
Pimpinella saxifraga	h	0	0	3	2	0	0	2	2	0	2
Pinus sylvestris	w	0	3	3	3	3	0	3	3	3	3
Plantago major	h	0	0	0	0	0	0	0	0	3	0
Plantago media	h	0	0	0	1	0	0	0	0	0	0
Pleurospermum uralense	h	0	0	0	0	0	0	0	2	0	1
Polygonatum officinale	h	0	0	2	1	0	0	0	3	1	3
Polygonum bistorta	h	0	0	0	0	0	0	0	0	2	0
Populus tremula	w	0	3	3	3	1	0	0	1	0	0
Potentilla erecta	h	0	0	1	0	0	0	0	2	0	0

(continued)

Table 6.30 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Primula veris ssp. *macrocalix*	h	0	0	1	0	3	0	0	0	1	0
Prunella vulgaris	h	0	0	0	2	1	0	0	0	3	0
Prunus padus	w	0	0	0	2	1	0	0	0	2	2
Pteridium aquilinum	h	0	1	2	0	3	0	0	2	0	0
Pulmonaria mollis	h	0	0	0	0	1	0	0	0	0	0
Pulmonaria obscura	h	0	0	2	3	2	0	0	0	2	2
Pyrola media	h	0	0	0	2	0	0	0	1	0	1
Pyrola rotundifolia	h	0	0	0	3	0	0	0	1	3	1
Ranunculus acris	h	0	0	0	0	0	0	0	0	1	0
Ranunculus auricomus	h	0	0	0	0	0	0	0	0	1	0
Ranunculus cassubicus	h	0	0	0	2	2	0	0	0	3	0
Ranunculus monophyllus	h	0	0	0	0	0	0	0	0	2	0
Ranunculus polyanthemos	h	0	0	0	0	1	0	0	0	2	0
Ranunculus repens	h	0	0	0	0	0	0	0	0	0	1
Ranunculus sp.	h	0	0	0	0	2	0	0	0	1	0
Rosa canina	w	0	0	1	3	3	0	0	2	3	0
Rubus idaeus	w	0	0	0	0	1	0	0	0	2	0
Rubus saxatilis	h	0	0	3	3	3	0	0	3	3	3
Salix caprea	w	0	0	0	0	1	0	0	0	0	0
Sanguisorba officinalis	h	0	0	2	2	2	0	3	3	1	3
Saussurea controversa	h	0	0	0	0	1	0	0	0	0	3
Silene nutans	h	0	0	0	1	0	0	0	1	0	2
Silene repens	h	0	0	1	0	0	0	0	0	0	0
Silene wolgensis	h	0	0	0	0	0	0	2	0	0	0
Solidago virgaurea	h	0	0	1	1	2	0	0	2	0	1
Sorbus aucuparia	w	0	0	1	3	3	0	1	2	0	3
Stellaria graminea	h	0	0	0	2	0	0	0	0	1	0
Succisa pratensis	h	0	0	1	0	0	0	0	1	0	1
Taraxacum sp.	h	0	0	0	0	1	0	0	0	3	1
Thalictrum minus	h	0	0	0	0	1	0	0	0	1	1
Tilia cordata	w	0	0	0	0	0	0	0	0	0	1
Trientalis europaea	h	0	0	0	1	0	0	0	2	1	2
Trifolium lupinaster	h	0	0	2	3	3	0	3	2	2	3
Trifolium medium	h	0	0	3	3	3	0	0	1	1	2
Trifolium pratense	h	0	0	0	0	0	0	0	0	3	0
Trifolium repens	h	0	0	0	3	2	0	0	0	3	0
Trollius europaeus	h	0	0	0	0	0	0	0	0	2	3
Tussilago farfara	h	0	0	0	1	3	0	0	0	0	1
Urtica dioica	h	0	0	0	0	2	0	0	0	2	0
Vaccinium myrtillus	ds	0	1	1	1	0	0	0	3	0	0
Vaccinium vitis-idaea	ds	0	2	3	3	1	0	0	3	2	3
Veronica chamaedrys	h	0	0	3	3	3	0	0	1	3	3
Vicia cracca	h	0	0	3	0	2	0	0	0	0	0
Vicia sepium	h	0	0	0	3	1	0	0	0	2	0
Vicia sylvatica	h	0	0	0	0	0	0	0	0	1	3
Viola canina	h	0	1	1	1	0	0	0	2	1	1
Viola hirta	h	0	0	1	1	0	0	0	1	3	2
Viola mirabilis	h	0	0	0	2	0	0	0	0	0	0

Data collected 23–25.7.2003. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.31 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the iron pellet plant at Kostomuksha, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Andromeda polifolia	ds	0	0	0	1	0	0	0	0	0	0
Betula pendula	w	1	0	0	0	0	0	0	0	0	1
Betula pubescens	w	3	2	3	3	2	3	2	3	3	3
Calamagrostis arundinacea	g	2	1	0	3	0	3	1	0	0	1
Calamagrostis purpurea ssp. *phragmitoides*	g	1	0	0	0	0	0	0	0	0	0
Calluna vulgaris	ds	0	0	0	0	0	0	0	0	0	1
Carex globularis	g	0	1	1	1	0	0	0	0	0	0
Deschampsia flexuosa	g	3	3	3	3	1	3	3	3	0	2
Empetrum nigrum	ds	0	0	0	2	0	0	0	0	3	3
Epilobium angustifolium	h	3	0	1	0	0	3	1	1	1	0
Equisetum sylvaticum	h	0	1	0	1	0	0	0	0	0	0
Geranium sylvaticum ssp. *sylvaticum*	h	0	0	0	0	0	3	0	0	0	0
Goodyera repens	h	0	0	1	1	0	1	0	1	0	0
Gymnadenia conopsea	h	0	0	0	0	0	1	0	0	0	0
Gymnocarpium dryopteris	h	0	1	1	0	0	2	0	0	0	0
Hieracium caespitosum	h	0	0	0	0	0	1	0	0	0	0
Hieracium murorum	h	0	0	0	0	0	1	0	0	0	0
Juniperus communis ssp. *nana*	w	0	0	3	0	1	2	1	0	0	3
Ledum palustre	ds	0	0	0	2	3	0	0	0	3	3
Linnaea borealis	h	3	3	3	0	0	3	3	0	0	0
Listera cordata	h	0	2	0	0	0	0	0	0	0	0
Luzula pilosa	g	3	0	3	0	0	1	2	3	0	1
Lycopodium annotinum	h	0	1	0	0	0	2	2	0	0	0
Maianthemum bifolium	h	0	1	2	0	0	2	0	0	0	0
Melampyrum pratense	h	0	0	0	0	0	1	0	0	0	0
Melampyrum sylvaticum	h	2	2	3	2	3	3	2	3	1	3
Orthilia secunda	h	2	1	3	0	0	0	1	0	0	0
Picea abies ssp. *obovata*	w	3	3	3	3	2	3	3	3	1	3
Pinus sylvestris	w	3	0	3	2	3	0	3	2	3	3
Populus tremula	w	1	0	0	1	2	3	2	0	2	0
Rubus chamaemorus	h	0	0	0	2	0	0	0	0	0	0
Salix caprea	w	2	0	0	0	0	0	1	1	0	1
Salix phylicifolia	w	0	0	0	0	0	0	0	1	0	0
Solidago virgaurea	h	3	1	3	0	0	3	2	2	0	0
Sorbus aucuparia	w	3	3	3	2	1	3	3	1	0	2
Trientalis europaea	h	3	1	1	0	0	3	0	1	0	0
Vaccinium myrtillus	ds	3	3	3	3	3	3	3	3	3	3
Vaccinium uliginosum	ds	0	0	0	1	3	0	0	1	3	3
Vaccinium vitis-idaea	ds	3	3	3	3	3	3	3	3	3	3

Data collected 18.7.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.32 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the nickel-copper smelter at Monchegorsk, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–4	1–5	2–3	2–5	2–7	2–8	2–9	2–12
Andromeda polifolia	ds	0	0	1	0	0	2	0	0	0	0
Arctostaphylos alpinus	h	0	0	0	0	0	1	0	0	0	0
Betula nana	w	1	1	2	3	0	3	1	2	1	1
Betula pubescens	w	0	2	2	3	3	2	2	3	2	3
Calamagrostis lapponica	g	0	2	0	1	0	0	0	0	0	0
Calluna vulgaris	ds	0	0	2	2	0	0	0	0	1	0
Carex brunnescens	g	0	0	0	1	0	0	0	0	0	0
Carex cespitosa	g	0	0	0	0	0	0	0	1	0	0
Carex dioica	g	0	0	1	0	0	1	0	1	0	0
Carex flava	g	0	0	0	0	0	0	0	1	0	0
Carex globularis	g	0	0	0	1	0	0	0	0	0	0
Carex juncella	g	0	0	0	0	0	0	0	1	0	0
Carex nigra	g	0	0	0	0	0	1	0	0	0	0
Carex rostrata	g	0	0	0	0	0	1	0	0	0	0
Carex vaginata	g	0	0	1	0	0	0	0	1	0	0
Cirsium helenioides	h	0	0	0	0	0	0	0	1	0	0
Comarum palustre	h	0	0	0	0	0	0	0	0	0	1
Cornus suecica	h	0	0	0	0	0	0	0	1	0	0
Crepis paludosa	h	0	0	1	0	0	0	0	0	0	1
Dactylorhiza maculata	h	0	0	0	0	0	0	0	0	1	0
Deschampsia cespitosa	g	0	0	0	1	0	0	0	0	0	0
Deschampsia flexuosa	g	0	1	1	1	0	0	3	2	2	2
Drosera rotundifolia	h	0	0	0	0	0	0	0	1	0	0
Eleocharis quinqueflora	g	0	0	0	0	0	0	0	1	0	0
Empetrum nigrum	ds	1	1	3	2	1	1	3	3	3	2
Epilobium angustifolium	h	0	0	1	2	1	0	2	1	1	1
Equisetum fluviatile	h	0	0	0	0	0	0	0	0	0	1
Equisetum palustre	h	0	0	1	1	0	2	0	1	0	0
Equisetum sylvaticum	h	0	1	1	1	0	0	0	1	0	0
Eriophorum angustifolium	g	0	0	1	0	0	2	0	1	0	0
Eriophorum scheuchzeri	g	0	0	1	0	0	0	0	0	0	0
Eriophorum vaginatum	g	0	1	0	1	0	1	0	1	0	0
Festuca ovina	g	0	0	0	0	0	0	0	1	0	0
Geranium sylvaticum ssp. *sylvaticum*	h	0	0	0	0	0	0	0	0	1	0
Juniperus communis ssp. *nana*	w	0	0	0	1	0	0	1	2	0	2
Ledum palustre	ds	0	1	3	3	0	3	2	1	3	0
Linnaea borealis	h	0	0	0	0	0	0	2	1	2	0

(continued)

Table 6.32 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–4	1–5	2–3	2–5	2–7	2–8	2–9	2–12
Luzula pilosa	g	0	0	0	0	0	0	0	0	1	1
Lycopodium annotinum	h	0	0	0	0	0	0	1	0	0	0
Melampyrum sylvaticum	h	0	0	0	0	0	0	0	1	1	2
Menyanthes trifoliata	h	0	0	0	0	0	1	0	0	0	0
Molinia caerulea	g	0	0	0	0	0	0	0	1	0	0
Orthilia secunda	ds	0	0	1	0	0	0	0	0	1	0
Parnassia palustris	h	0	0	0	0	0	0	0	1	0	0
Picea abies ssp. *obovata*	w	0	1	2	1	0	2	2	3	3	3
Pinguicula vulgaris	h	0	0	0	0	0	0	0	1	0	0
Pinus sylvestris	w	0	1	3	3	0	2	1	0	1	0
Poa pratensis	g	0	1	0	0	0	0	0	0	0	0
Populus tremula	w	0	0	0	0	0	0	0	0	1	0
Potentilla erecta	h	0	0	0	0	0	0	0	2	0	0
Rubus chamaemorus	h	0	1	0	2	0	2	0	2	0	0
Salix borealis	w	1	1	3	2	0	0	0	2	1	2
Salix caprea	w	0	1	3	1	2	0	1	1	0	1
Salix glauca	w	0	0	1	0	0	0	0	0	1	0
Salix myrsinites	w	0	0	0	1	0	0	0	0	0	0
Salix phylicifolia	w	0	1	1	1	1	0	0	0	1	2
Saussurea alpina	h	0	0	0	0	0	0	0	1	0	0
Scirpus hudsonianus	g	0	0	0	0	0	0	0	1	0	0
Solidago virgaurea	h	0	0	0	0	0	0	0	1	0	2
Sorbus aucuparia	w	0	0	0	0	0	0	0	0	1	0
Tofieldia pusilla	h	0	0	0	0	0	0	0	1	0	0
Trientalis europaea	h	0	0	0	0	0	0	0	2	0	2
Vaccinium microcarpum	ds	0	0	1	0	0	1	0	1	0	0
Vaccinium myrtillus	ds	0	0	2	0	1	0	3	3	3	2
Vaccinium uliginosum	ds	0	1	3	3	0	2	0	2	2	3
Vaccinium vitis-idaea	ds	0	0	2	3	2	1	3	2	3	3
Viola epipsila	h	0	0	0	0	0	0	0	1	0	0

Data collected 17.6–6.7.1997. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.33 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the aluminium smelter at Nadvoitsy, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Achillea millefolium	h	0	0	0	0	0	1	0	0	0	0
Alnus incana	w	0	2	2	0	0	0	2	0	2	3
Antennaria dioica	h	1	0	0	0	0	0	0	0	0	0
Betula nana	w	0	1	0	0	1	0	0	0	0	0
Betula pendula	w	3	0	2	2	0	3	1	1	2	2
Betula pubescens	w	3	3	1	3	3	3	3	3	0	3
Calamagrostis arundinacea	g	0	0	1	0	0	0	0	0	0	0
Calamagrostis canescens	g	0	1	0	0	0	0	0	0	0	0
Calluna vulgaris	ds	3	0	2	1	0	3	0	3	2	1
Carex brunnescens	g	0	0	0	0	0	0	1	0	0	0
Carex curta	g	0	1	0	0	0	0	0	0	0	0
Carex globularis	g	0	0	0	0	1	0	0	0	0	1
Carex magellanica	g	0	1	0	0	0	0	0	0	0	0
Deschampsia cespitosa	g	0	1	0	1	0	0	2	0	0	0
Deschampsia flexuosa	g	0	1	3	3	0	3	1	3	0	3
Dryopteris carthusiana	h	0	1	0	0	0	0	1	0	0	0
Empetrum nigrum	ds	3	1	1	1	2	3	0	3	3	0
Epilobium angustifolium	h	0	1	3	2	0	3	2	0	0	0
Equisetum arvense	h	0	3	0	0	0	0	0	0	0	0
Equisetum sylvaticum	h	0	0	0	2	0	0	1	0	0	0
Festuca ovina	g	0	0	0	0	0	1	0	0	0	0
Fragaria vesca	h	0	0	0	0	0	0	1	0	0	0
Geranium sylvaticum ssp. *sylvaticum*	h	0	0	0	0	0	0	1	0	0	0
Geum rivale	h	0	1	0	0	0	0	0	0	0	0
Hieracium laevigatum	h	0	0	2	0	0	3	0	0	0	0
Hieracium murorum	h	0	0	3	1	0	2	2	0	0	2
Juncus filiformis	g	0	0	0	0	1	0	0	0	0	0
Juniperus communis ssp. *nana*	w	0	0	0	3	0	1	0	3	0	3
Ledum palustre	ds	1	2	1	3	3	0	0	2	3	2
Linnaea borealis	h	0	0	1	1	0	0	2	0	0	0
Luzula pilosa	g	0	0	3	1	0	0	2	0	0	3
Lycopodium annotinum	h	0	0	1	1	0	0	0	0	0	0
Maianthemum bifolium	h	1	1	0	0	0	0	3	1	0	1
Melampyrum pratense	h	1	0	3	2	2	0	1	2	2	3
Menyanthes trifoliata	h	0	3	0	0	0	0	0	0	0	0
Moneses uniflora	h	1	1	0	0	0	0	0	0	0	0
Orthilia secunda	h	0	2	0	0	0	0	0	0	0	0
Oxalis acetosella	h	0	0	0	0	0	0	3	0	0	0
Picea abies ssp. *obovata*	w	3	3	0	2	2	3	3	0	0	2
Pinus sylvestris	w	3	3	3	3	3	3	3	3	3	3
Platanthera bifolia	h	0	1	0	0	0	0	0	0	0	0

(continued)

Table 6.33 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Populus tremula	w	2	0	1	0	3	3	0	2	2	3
Pyrola minor	h	0	2	0	0	0	1	2	0	0	0
Ranunculus repens	h	0	1	0	0	0	0	2	0	0	0
Rubus chamaemorus	h	0	2	0	0	0	0	0	0	0	1
Rubus idaeus	w	0	0	0	0	0	0	3	0	0	0
Rubus saxatilis	h	0	0	0	0	0	0	1	0	0	0
Salix aurita	w	0	0	0	0	1	0	0	0	0	0
Salix caprea	w	1	0	3	0	1	3	3	0	2	1
Salix myrsinifolia	w	0	1	0	1	0	0	0	0	0	0
Salix phylicifolia	w	0	0	0	0	0	0	0	0	0	1
Solidago virgaurea	h	0	0	0	0	0	1	0	0	0	0
Sorbus aucuparia	w	1	2	3	2	0	3	3	0	3	3
Taraxacum sp.	h	0	0	0	0	0	1	0	0	0	0
Trientalis europaea	h	0	1	0	0	0	0	3	0	0	0
Tussilago farfara	h	0	0	0	0	0	0	1	0	0	0
Urtica dioica	h	0	0	0	0	0	0	1	0	0	0
Vaccinium microcarpum	ds	0	2	0	0	0	0	0	0	0	0
Vaccinium myrtillus	ds	2	3	3	3	3	3	3	3	3	3
Vaccinium uliginosum	ds	0	1	0	1	2	0	0	3	3	2
Vaccinium vitis-idaea	ds	3	3	3	3	3	3	3	3	3	3
Veronica chamaedrys	h	0	0	0	0	0	0	2	0	0	0
Vicia sepium	h	0	0	0	0	0	0	1	0	0	0
Viola riviniana	h	0	1	0	0	0	0	0	0	0	0

Data collected 25–27.7.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.34 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the nickel-copper smelter at Nikel and ore-roasting plant at Zapolyarnyy, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Alnus incana	w	0	0	0	0	0	1	0	0	0	0
Andromeda polifolia	ds	0	0	3	3	1	1	2	1	1	1
Arctostaphylos alpinus	h	0	0	3	3	0	0	0	0	2	0
Arctostaphylos uva-ursi	ds	0	0	0	0	0	0	1	0	0	0
Bartsia alpina	h	0	0	0	1	0	0	0	0	1	0
Betula nana	w	0	3	3	3	3	0	0	3	3	3
Betula pubescens	w	2	1	3	2	2	2	3	3	3	3
Calamagrostis lapponica	g	0	0	0	0	0	0	0	2	0	0
Calamagrostis purpurea	g	1	0	0	0	0	0	0	0	0	0
Calamagrostis stricta	g	0	0	0	0	0	0	0	0	1	0
Calluna vulgaris	ds	0	0	0	0	0	0	2	1	0	0
Caltha palustris	h	0	0	0	0	0	0	0	0	1	0
Campanula rotundifolia	h	0	0	0	0	0	0	1	0	0	0
Carex aquatilis	g	1	0	0	0	0	0	0	0	0	0
Carex bigelowii	g	0	0	0	0	1	0	0	0	0	0
Carex brunnescens	g	0	0	0	0	0	0	0	0	0	1
Carex curta	g	0	0	1	0	0	0	0	0	0	0
Carex dioica	g	0	0	1	0	0	0	0	0	0	0
Carex nigra	g	0	0	1	3	2	0	0	0	0	0
Carex rostrata	g	1	0	1	0	0	0	0	0	0	0
Carex rotundata	g	0	0	0	0	0	0	0	0	0	1
Carex vaginata	g	0	0	0	3	1	0	2	0	2	0
Cirsium helenioides	h	0	0	0	0	0	0	1	0	1	0
Cornus suecica	h	0	0	3	3	1	0	0	0	3	0
Dactylorhiza traunsteineri	h	0	0	0	1	0	0	2	0	1	0
Deschampsia cespitosa	g	2	0	0	0	0	1	0	1	0	0
Deschampsia flexuosa	g	0	3	3	3	3	2	3	3	3	3
Empetrum nigrum ssp. *hermaphroditum*	ds	2	3	3	3	3	1	3	3	3	3
Epilobium angustifolium	h	0	0	0	0	0	0	2	0	0	0
Equisetum arvense	h	0	1	0	0	0	2	2	0	2	0
Equisetum fluviatile	h	1	0	1	0	0	0	0	0	0	0
Equisetum palustre	h	0	0	1	0	0	0	0	0	0	0
Equisetum sylvaticum	h	0	0	3	0	1	0	1	3	0	2
Eriophorum angustifolium	g	1	0	0	0	1	0	0	0	0	0
Eriophorum russeolum	g	1	0	0	0	0	0	0	0	0	0
Eriophorum scheuchzeri	g	1	0	0	0	0	0	0	0	0	0
Eriophorum vaginatum	g	0	0	2	0	1	0	1	0	1	2

(continued)

Table 6.34 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Geranium sylvaticum ssp. *sylvaticum*	h	0	0	0	1	0	0	1	0	2	0
Geum rivale	h	0	0	0	0	0	0	0	0	1	0
Gymnadenia conopsea	h	0	0	0	0	0	0	1	0	0	0
Hieracium alpinum	h	0	0	0	0	1	0	0	0	0	0
Hieracium vulgatum	h	0	0	0	0	0	0	0	0	1	0
Juncus trifidus	g	0	0	0	2	2	0	0	0	0	0
Juniperus communis ssp. *nana*	w	0	1	1	1	0	0	1	0	1	1
Ledum palustre	ds	0	2	3	1	0	2	3	3	3	2
Linnaea borealis	h	0	0	0	0	0	0	0	0	2	1
Lychnis alpina	h	0	0	0	0	0	1	0	0	0	0
Lycopodium dubium	h	0	0	0	1	0	0	0	0	0	0
Melampyrum pratense	h	0	0	1	2	1	0	0	0	0	0
Melica nutans	g	0	0	0	0	0	0	1	0	0	0
Molinica caerulea	g	0	0	0	1	1	0	0	0	0	0
Pedicularis lapponica	h	0	0	0	2	0	0	0	0	0	0
Phyllodoce caerulea	ds	0	0	0	3	1	0	0	0	0	0
Pinguicula vulgaris	h	0	0	0	1	1	0	0	0	0	0
Pinus sylvestris	w	0	1	0	0	0	1	2	3	1	2
Poa angustifolia	g	1	0	0	0	0	0	0	0	0	0
Poa pratensis	g	1	0	0	0	0	1	0	0	0	0
Potentilla erecta	h	0	0	0	1	0	0	1	0	1	0
Pyrola minor	h	0	0	0	0	0	0	1	0	1	0
Rubus chamaemorus	h	0	1	3	3	1	0	2	3	2	2
Rubus saxatilis	h	0	0	0	0	0	0	1	0	0	0
Rumex acetosa	h	0	0	0	0	0	0	1	0	1	0
Salix borealis	w	1	0	1	1	0	2	2	1	1	0
Salix caprea	w	0	0	1	0	0	0	0	0	0	0
Salix glauca	w	2	1	2	3	1	2	0	1	0	1
Salix lapponum	w	0	0	1	1	1	0	0	0	0	0
Salix myrsinites	w	0	0	0	0	0	2	2	0	2	0
Salix phylicifolia	w	2	3	3	0	0	0	0	2	0	1
Saussurea alpina	h	0	0	0	1	0	0	0	0	1	0
Solidago virgaurea	h	0	0	2	3	1	0	1	0	3	0
Sorbus aucuparia	w	0	0	0	0	0	0	0	0	3	0
Taraxacum sp.	h	0	0	1	1	0	0	0	0	0	0
Tofieldia pusilla	h	0	0	0	1	0	0	1	0	0	0
Trientalis europaea	h	0	0	0	1	0	0	0	0	1	1
Vaccinium myrtillus	ds	0	3	3	3	3	1	3	3	3	3
Vaccinium uliginosum	ds	1	2	3	3	0	1	3	3	2	3
Vaccinium vitis-idaea	ds	0	3	3	3	3	1	3	3	3	3

Data collected 17–18.7.2001. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.35 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the nickel-copper smelters at Norilsk, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Achillea impatiens	h	0	0	1	0	0	0	0	2	0	0
Aconitum septentrionale	h	0	0	1	0	0	0	0	0	0	0
Aconitum volubile	h	0	0	1	0	0	0	0	0	0	0
Allium schoenoprasum	h	1	0	0	0	0	0	0	0	0	0
Andromeda polifolia	ds	3	1	0	1	0	3	0	0	3	0
Anthoxanthum alpinum	g	0	0	0	0	1	0	0	3	0	0
Arctagrostis latifolia	g	0	1	0	0	2	1	0	0	0	0
Arctostaphylos alpinus	ds	0	0	1	3	3	0	0	0	0	0
Betula nana	w	1	3	3	3	3	3	3	3	3	1
Betula pubescens	w	0	0	0	0	0	0	1	3	0	3
Calamagrostis purpurea ssp. *purpurea*	g	0	0	0	0	0	0	2	2	0	0
Calamagrostis stricta	g	0	0	0	0	0	1	2	0	0	0
Cardamine macrophylla	h	0	0	2	0	0	0	0	0	3	0
Cardaminopsis petraea	h	0	0	1	0	0	0	0	0	0	0
Carex globularis	g	0	0	0	0	0	0	0	0	0	3
Carex parallela ssp. *redowskiana*	g	0	1	0	0	0	0	0	0	0	0
Carex pediformis	g	0	1	0	0	0	0	0	0	2	0
Carex rotundata	g	0	2	0	1	0	1	0	0	1	0
Carex vaginata	g	0	2	3	1	0	0	0	0	2	0
Cassiope tetragona	ds	1	0	0	0	0	0	0	0	0	0
Cirsium helenioides	h	0	0	0	0	0	0	0	1	0	0
Clematis alpina ssp. *sibirica*	ds	0	0	0	0	0	0	0	2	0	0
Conioselinum tataricum	h	0	0	0	0	0	0	0	1	0	0
Dryas octopetala	h	3	3	1	2	2	0	0	0	1	0
Duschekia fruticosa	w	3	3	1	3	3	3	0	3	3	2
Empetrum nigrum	ds	3	3	1	3	3	3	3	3	3	2
Epilobium angustifolium	h	0	2	0	0	0	0	0	0	0	0
Epilobium davuricum	h	0	1	0	0	0	0	0	0	0	0
Equisetum arvense	h	0	1	1	0	1	1	1	0	0	0
Equisetum sp.	h	3	3	3	3	3	2	3	3	3	3
Eriophorum scheuchzeri	g	1	0	0	0	0	1	1	0	0	0
Festuca ovina	g	1	0	3	3	2	0	0	0	0	0
Festuca rubra	g	0	0	2	1	0	0	0	0	3	0
Festuca vivipara	g	0	2	0	0	0	0	0	0	0	0
Galium boreale	h	0	0	1	0	0	0	0	2	0	0
Geranium sylvaticum ssp. *pseudosibiricum*	h	0	0	1	0	0	0	0	2	0	0
Hedysarum hedysaroides ssp. *arcticum*	h	2	1	0	0	0	0	0	0	2	0
Hierochloe alpina	g	0	0	1	0	1	0	0	0	0	0
Juniperus communis ssp. *nana*	w	2	0	0	0	0	0	0	3	1	0
Lagotis minor	h	0	0	0	0	0	0	0	0	2	0
Larix sibirica	w	2	2	2	3	3	2	0	3	3	3
Ledum decumbens	ds	0	2	2	3	3	3	3	0	3	3
Linnaea borealis	h	0	0	0	0	0	0	0	3	0	1
Luzula arctica	g	0	0	0	0	1	0	0	0	0	0
Luzula confusa	g	0	0	0	1	0	0	0	0	0	0

(continued)

Table 6.35 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Luzula tundricola	g	0	0	0	0	1	0	0	0	0	0
Lychnis sibirica ssp. *samojedorum*	h	0	1	0	0	0	0	0	0	0	0
Lycopodium annotinum	h	0	0	0	0	0	0	0	1	0	0
Minuartia stricta	h	0	1	0	0	0	0	0	0	0	0
Oxytropis campestris ssp. *sordida*	h	2	0	0	0	0	0	0	0	0	0
Parnassia palustris	h	0	0	0	0	0	0	0	0	2	0
Pedicularis labradorica	h	0	0	1	3	2	1	0	2	1	0
Pedicularis oederi	h	0	1	0	0	0	0	0	0	0	0
Pedicularis sudetica	h	0	0	0	1	0	1	0	0	0	0
Petasites frigidus	h	0	1	1	3	2	0	0	0	0	0
Petasites sibiricus	h	0	0	0	0	0	0	0	0	1	0
Picea abies ssp. *obovata*	w	0	0	0	0	0	0	3	3	1	3
Poa arctica	g	2	3	2	3	1	2	0	2	0	0
Poa pratensis	g	3	2	0	2	3	1	3	1	0	0
Polygonum bistorta	h	3	3	2	0	0	0	0	1	2	0
Polygonum viviparum	h	1	3	2	3	2	0	1	2	3	0
Potentilla sp.	h	0	0	0	0	1	0	0	0	0	0
Pyrola minor	h	0	1	1	1	0	0	0	2	3	0
Pyrola rotundifolia	h	1	1	2	1	0	0	0	3	0	0
Rubus arcticus	ds	0	0	0	0	0	0	0	2	0	0
Rubus chamaemorus	h	0	0	0	0	0	2	3	0	0	3
Rumex thyrsiflorus	h	0	0	0	0	0	0	1	0	0	0
Salix arctica	w	3	3	2	0	0	1	0	3	3	0
Salix bebbiana	w	1	2	2	3	3	3	3	2	3	0
Salix cinerea	w	0	0	0	0	0	1	0	0	0	0
Salix hastata	w	0	3	1	2	2	0	0	0	0	0
Salix lanata	w	1	3	2	1	3	2	3	0	3	0
Salix phylicifolia	w	0	0	0	1	0	0	0	0	0	0
Salix recurvigemmis	w	2	1	2	0	0	3	0	0	0	0
Saussurea alpina	h	1	3	2	0	0	0	1	3	3	0
Saxifraga nelsoniana	h	0	0	0	1	0	0	0	0	2	0
Saxifraga serpyllifolia	h	2	0	0	0	0	0	0	0	0	0
Schoenus ferrugineus	g	0	1	0	0	0	0	0	0	0	0
Senecio integrifolius	h	0	2	0	0	1	0	0	0	1	0
Seseli condensatum	h	0	0	1	0	0	0	0	1	1	0
Silene wahlbergella	h	0	1	0	0	0	0	0	0	0	0
Solidago virgaurea	h	0	0	1	0	0	0	0	3	0	0
Sorbus aucuparia	w	0	0	0	0	0	0	0	1	0	0
Stellaria palustris	h	0	1	3	2	3	0	2	0	2	0
Thalictrum alpinum	h	0	1	2	0	0	0	0	0	1	0
Thalictrum minus	h	0	0	1	0	0	0	0	1	0	0
Tofieldia pusilla	h	0	0	0	0	0	0	0	0	1	0
Trollius asiaticus	h	3	0	1	0	0	0	0	2	1	0
Vaccinium microcarpum	ds	0	0	0	0	0	0	0	0	1	0
Vaccinium myrtillus	ds	0	0	0	0	0	0	0	3	0	0
Vaccinium uliginosum	ds	3	3	3	3	3	3	3	3	3	2
Vaccinium vitis-idaea	ds	0	3	3	3	3	2	1	3	3	3
Valeriana capitata	h	0	0	1	0	0	0	0	0	2	0
Veratrum sp.	h	0	0	0	0	0	0	0	3	0	0
Vicia sp.	h	0	1	0	0	0	0	0	0	0	0

Data collected 23–28.7.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.36 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the copper smelter at Revda, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Abies sibirica	w	3	3	3	1	3	3	3	3	3	3
Achillea millefolium	h	0	0	0	0	0	0	0	0	1	0
Aconitum septentrionale	h	0	0	1	3	3	0	0	2	0	0
Actaea spicata	h	0	0	1	0	2	0	0	0	0	0
Aegopodium podagraria	h	0	1	1	3	3	3	1	3	3	3
Agrostis capillaris	g	0	0	0	0	0	0	3	0	1	0
Ajuga reptans	h	0	0	0	3	3	0	0	3	1	1
Alchemilla acutiloba	h	0	0	0	0	0	0	0	1	0	1
Alchemilla murbeckiana	h	0	0	0	0	0	0	0	0	1	0
Alchemilla sarmatica	h	0	0	0	2	0	0	0	0	0	0
Alhemilla wichurae	h	0	0	0	0	0	0	0	0	1	0
Alnus incana	w	0	0	0	0	0	3	0	2	0	0
Angelica sylvestris	h	0	0	0	0	0	0	0	0	1	0
Asarum europaeum	h	0	0	3	0	2	0	0	1	1	3
Athyrium filix-femina	h	0	1	3	0	3	0	0	0	0	2
Betula pendula	w	3	0	0	1	0	3	2	1	3	0
Betula pubescens	w	3	3	0	3	2	3	1	2	3	1
Brachypodium pinnatum	g	0	0	0	2	1	0	0	0	0	0
Cacalia hastata	h	0	0	2	0	2	0	0	0	1	0
Calamagrostis obtusata	g	3	3	2	2	2	3	1	3	3	1
Calamagrostis purpurea ssp. *langsdorfii*	g	1	1	2	0	0	0	0	0	0	0
Campanula glomerata	h	0	0	0	0	0	0	0	1	0	0
Carex digitata	g	0	0	0	0	0	0	0	0	1	0
Carex montana	g	0	0	2	1	0	0	0	0	0	0
Carex sp.	g	1	0	0	0	0	0	0	0	0	0
Centaurea sp.	h	0	0	0	0	0	0	0	1	0	0
Cerastium fontanum ssp. *triviale*	h	0	0	0	0	2	0	0	0	0	0
Cerastium pauciflorum	h	0	2	3	2	0	0	1	0	1	3
Chamaecytisus ruthenicus	h	0	0	0	0	0	1	2	0	3	0
Chrysosplenium alternifolium	h	0	0	0	1	1	0	0	0	0	0
Circaea alpina	h	0	0	1	0	3	0	0	0	0	3
Cirsium helenioides	h	0	1	0	0	0	0	0	1	0	0
Cirsium oleraceum	h	0	0	0	0	0	0	0	1	0	0
Cirsium sp.	h	0	0	0	1	0	0	0	0	1	0
Clematis alpina ssp. *sibirica*	h	1	0	0	0	0	0	0	0	1	0
Corydalis solida	h	0	0	0	0	1	0	0	0	0	0
Crepis paludosa	h	0	1	1	0	1	0	0	0	0	0
Crepis sibirica	h	0	0	1	0	0	0	0	0	0	0
Daphne mezereum	w	0	0	0	1	1	0	0	0	1	0
Deschampsia cespitosa	g	0	2	0	2	0	2	0	2	1	3
Digitalis grandiflora	h	0	0	0	0	0	0	0	1	0	0
Dryopteris assimilis	h	0	0	0	0	1	0	0	0	0	0
Dryopteris carthusiana	h	0	1	0	1	2	0	0	0	0	1
Dryopteris filix-mas	h	0	1	3	0	0	0	0	2	0	0
Elymus repens	g	0	0	0	0	0	0	1	0	0	0
Epilobium angustifolium	h	1	0	1	0	0	1	3	1	0	0
Epilobium palustre	h	0	0	0	0	1	0	0	0	0	0

(continued)

Table 6.36 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Equisetum pratense	h	0	0	0	0	0	1	0	0	0	0
Equisetum sylvaticum	h	0	3	1	3	3	2	0	0	0	3
Euphorbia sp.	h	0	0	0	0	0	0	0	0	0	3
Filipendula ulmaria ssp. *denudata*	h	0	0	0	2	0	0	0	1	0	0
Fragaria vesca	h	0	0	0	3	3	0	0	1	3	3
Galium boreale	h	0	0	0	3	0	3	0	2	3	0
Galium odoratum	h	0	0	0	0	3	0	0	0	0	3
Geranium sylvaticum ssp. *sylvaticum*	h	0	1	2	3	0	0	0	3	3	3
Geum rivale	h	0	1	0	0	3	0	0	2	0	2
Glechoma hederacea	h	0	0	0	0	1	0	0	1	0	0
Gymnocarpium dryopteris	h	0	2	1	0	1	0	0	0	0	0
Heracleum sibiricum	h	0	0	2	0	1	0	0	1	0	0
Hieracium sp.	h	0	0	1	0	0	0	0	0	0	0
Hieracium umbellatum	h	0	0	0	0	0	0	0	0	1	0
Hypericum maculatum	h	0	0	0	1	0	0	0	0	0	0
Impatiens noli-tangere	h	0	0	0	0	3	0	0	0	0	3
Juniperus communis	w	0	0	0	0	0	1	0	0	2	0
Lathyrus gmelinii	h	0	3	1	1	2	0	0	3	0	0
Lathyrus vernus	h	0	1	1	3	3	0	0	0	3	1
Lilium martagon	h	0	0	0	0	0	0	0	0	2	0
Lonicera tatarica	w	0	0	1	0	2	0	0	0	3	0
Luzula pilosa	g	0	0	1	3	1	0	0	0	3	0
Lysimachia vulgaris	h	0	0	0	0	0	0	0	2	0	0
Maianthemum bifolium	h	0	3	3	3	2	0	0	3	3	0
Melampyrum pratense	h	0	0	1	3	0	0	0	1	2	0
Melica nutans	g	1	1	1	0	1	0	0	1	1	0
Milium effusum	g	0	0	0	0	2	0	0	0	0	1
Moneses uniflora	h	0	0	2	0	0	0	0	0	0	0
Myosotis sylvatica	h	0	0	1	1	3	0	0	0	0	2
Orthilia secunda	h	0	0	1	3	0	0	0	0	2	0
Oxalis acetosella	h	0	2	3	2	3	0	0	1	1	3
Padus racemosa	w	0	1	0	1	0	0	0	3	1	0
Paris quadrifolia	h	0	0	2	0	3	0	0	0	0	0
Picea abies ssp. *obovata*	w	3	3	3	3	3	3	3	3	3	3
Pinus sylvestris	w	2	0	0	3	0	3	3	3	3	1
Plantago major	h	0	0	0	0	0	0	0	0	1	0
Platanthera bifolia	h	0	0	0	0	0	0	0	0	1	0
Poa palustris	g	0	0	0	0	0	0	0	0	0	1
Populus tremula	w	0	0	1	2	0	2	3	2	0	0
Potentilla erecta	h	0	0	0	0	0	0	0	1	0	0
Prunella vulgaris	h	0	0	0	3	1	0	0	0	1	1
Pteridium aquilinum	h	0	0	0	0	0	0	0	1	0	0
Pulmonaria mollis	h	0	0	1	1	3	0	0	0	1	0
Pulmonaria obscura	h	0	0	0	1	0	0	0	0	0	0
Pyrola media	h	0	2	2	1	0	0	0	0	1	1
Pyrola minor	h	0	0	0	0	0	0	0	1	0	0

(continued)

Table 6.36 (continued)

Species	Life form	Occurrences of species on sampling plots 1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Pyrola rotundifolia	h	0	0	0	1	0	0	0	2	2	0
Ranunculus acris ssp. *borelais*	h	0	0	0	0	0	0	0	0	1	0
Ranunculus cassubicus	h	0	0	0	0	0	0	0	1	1	0
Ranunculus polyanthemos	h	0	0	0	0	0	0	0	0	1	0
Ranunculus repens	h	0	0	0	3	0	0	0	0	1	3
Ribes nigrum	w	0	1	2	0	0	1	0	0	2	0
Rosa acicularis	w	0	0	0	0	0	1	0	0	0	0
Rosa canina	w	0	3	0	3	3	0	1	3	3	0
Rubus idaeus	w	0	2	3	1	3	1	2	3	1	3
Rubus saxatilis	h	0	0	2	3	2	0	0	3	3	2
Rumex acetosa	h	0	0	0	0	0	1	0	0	0	0
Salix caprea	w	2	1	0	0	0	2	2	2	1	1
Sambucus racemosa	w	0	0	1	0	2	0	0	0	0	0
Sanquisorba officinalis	h	1	0	0	0	0	3	1	3	2	0
Senecio nemorensis	h	0	0	1	0	1	0	0	0	0	0
Solidago virgaurea	h	0	0	1	2	3	0	0	0	2	0
Sorbus aucuparia	w	2	3	3	3	3	0	1	2	2	3
Stachys officinalis	h	0	0	0	1	0	0	0	0	0	0
Stellaria bungeana	h	0	0	0	0	1	0	0	0	0	0
Stellaria graminea	h	0	0	0	0	0	0	1	0	0	0
Stellaria holostea	h	0	0	0	2	3	0	0	0	0	0
Stellaria longifolia	h	0	0	0	0	0	0	0	0	1	0
Stellaria media	h	0	0	0	0	0	0	1	0	0	0
Succisa pratensis	h	0	0	0	0	0	0	0	1	0	0
Taraxacum officinale	h	0	0	0	1	0	0	1	0	0	0
Thalictrum flavum	h	0	0	0	0	3	0	0	0	0	0
Thalictrum minus	h	0	0	1	1	0	0	0	3	1	1
Tilia cordata	w	0	0	3	0	0	0	0	0	0	0
Trientalis europaea	h	0	0	2	3	1	0	0	0	3	0
Trifolium lupinaster	h	0	0	0	0	0	0	0	0	2	0
Trifolium medium	h	0	0	0	0	0	1	1	0	0	0
Trifolium pratense	h	0	0	0	0	0	0	0	0	1	0
Trifolium repens	h	0	0	0	0	0	0	0	0	1	0
Trollius europaeus	h	0	0	0	2	0	0	0	2	1	3
Tussilago farfara	h	0	0	0	1	0	0	3	2	0	0
Urtica dioica	h	0	0	0	0	1	1	2	0	0	3
Vaccinium myrtillus	df	3	0	0	2	0	0	1	0	3	0
Vaccinium vitis-idaea	df	3	0	0	0	0	1	1	1	3	0
Valeriana wolgensis	h	0	0	0	0	1	0	0	0	0	0
Veratrum lobelianum	h	0	2	0	1	0	0	0	3	0	0
Veronica chamaedrys	h	0	0	0	3	0	0	1	0	2	1
Viburnum opulus	w	0	1	0	0	1	0	0	3	0	0
Vicia sepium	h	0	0	0	2	0	0	0	0	3	0
Vicia silvatica	h	0	0	0	0	1	0	1	0	0	1
Viola canina	h	0	0	0	2	0	0	1	0	2	0
Viola mirabilis	h	0	0	0	0	2	0	0	0	0	0
Viola selkirkii	h	0	0	1	0	1	0	0	0	0	0

Data collected 17–21.7.2003. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.37 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the aluminium smelter at Straumsvík, Iceland

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Agrostis capillaris	g	0	0	0	0	0	0	0	1	0	0
Agrostis vinealis	g	0	3	1	2	1	2	2	2	3	1
Alchemilla acutiloba	h	0	0	0	0	1	0	0	0	0	0
Alchemilla alpina	h	0	3	2	2	3	3	3	3	3	0
Anthoxanthum alpinum	g	0	0	0	0	0	0	0	0	0	1
Anthoxanthum odoratum	g	0	0	1	0	0	0	0	0	0	0
Arctostaphylos uva-ursi	ds	0	0	0	0	3	0	0	2	0	2
Armeria maritima	h	0	0	3	1	1	0	1	0	1	0
Athyrium filix-femina	h	0	0	0	0	0	2	0	0	0	0
Betula pubescens	w	0	0	0	0	3	0	0	0	0	1
Calluna vulgaris	ds	0	0	2	1	3	3	3	3	1	3
Cardaminopsis petraea	h	0	2	2	3	0	2	3	3	1	1
Carex bigelowii	g	0	1	1	1	1	0	1	0	0	2
Carex sp.	g	0	0	0	1	1	0	0	0	1	0
Cerastium alpinum	h	0	0	0	1	1	0	0	1	1	0
Cerastium arcticum	h	0	0	1	1	0	1	0	0	0	0
Cystopteris fragilis	h	3	1	0	0	0	2	1	1	1	0
Dactylorhiza maculata	h	0	0	0	1	1	1	0	1	0	0
Deschampsia flexuosa	g	0	0	0	1	1	0	1	1	0	1
Draba incana	h	0	1	0	1	0	0	0	0	0	0
Dryas octopetala	h	0	3	2	1	1	2	3	3	2	0
Empetrum nigrum	ds	3	3	3	3	3	3	3	3	3	3
Erigeron borealis	h	0	1	1	0	0	2	2	1	2	2
Eriophorum scheuchzeri	g	0	0	0	0	0	0	0	1	0	0
Erysimum hieracifolium	h	1	0	0	0	0	0	0	0	0	0
Festuca richardsonii	g	0	2	2	3	1	1	1	2	2	0
Festuca vivipara	g	3	3	3	1	3	3	3	3	3	1
Galium boreale	h	3	3	3	3	3	3	3	3	3	2
Galium normanii	h	0	0	0	0	0	0	0	1	0	0
Galium uliginosum	h	2	1	0	0	1	0	0	0	0	0
Galium verum	h	0	3	3	3	3	3	3	3	3	2
Geranium sylvaticum	h	0	0	0	0	1	0	0	1	0	2
Geum rivale	h	0	0	0	0	0	0	0	1	0	0
Gypsophila fastigiata	h	0	2	1	0	0	0	0	0	0	0
Hieracium atratum s.l.	h	0	0	0	0	0	0	0	0	1	0
Hieracium pilosella s.l.	h	0	0	0	0	0	0	0	1	0	0
Hieracium praealtum	h	0	0	0	0	0	0	0	1	0	0
Hieracium sp.	h	2	0	1	0	3	0	0	0	0	0
Hieracium × floribundum	h	0	0	0	0	0	1	0	0	0	0
Juncus trifidus	g	3	2	3	3	3	3	3	3	3	3
Kobresia myosuroides	g	0	0	0	0	0	1	0	1	0	0
Luzula spicata	g	3	1	2	3	2	2	2	2	3	3
Luzula sudetica	g	0	3	1	1	2	2	3	2	3	1
Lychnis viscaria	h	0	0	0	0	0	0	1	0	0	0
Oxyria digyna	h	3	0	0	0	0	0	0	0	0	1
Pinguicula vulgaris	h	0	0	0	1	0	1	0	0	0	0
Plantago maritima	h	0	1	0	0	1	2	1	0	0	0
Poa glauca	g	1	0	0	0	0	1	1	0	0	1

(continued)

Table 6.37 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Poa pratensis	g	1	1	0	0	0	0	0	0	1	0
Polygonum viviparum	h	0	2	2	0	3	3	2	3	1	2
Potentilla crantzii	h	0	2	2	2	1	1	1	3	2	1
Ranunculus acris	h	0	2	0	0	1	2	1	1	0	1
Rhinantus minor	h	0	0	0	0	0	0	1	0	0	0
Rubus saxatilis	h	0	0	0	0	2	1	2	1	1	2
Rumex acetosa	h	2	1	0	0	2	3	0	0	0	1
Salix herbacea	w	2	3	3	3	1	3	3	3	3	0
Salix lanata	w	0	0	0	0	0	1	0	0	0	0
Salix phylicifolia	w	0	0	0	0	0	0	0	0	0	3
Saxifraga aizoides	h	0	0	0	0	1	0	0	1	0	0
Saxifraga cespitosa	h	1	1	0	0	0	0	0	0	0	1
Saxifraga hirculus	h	0	0	0	1	0	0	1	0	0	0
Sedum villosum	h	0	0	0	0	0	0	1	0	0	0
Sesleria albicans	g	0	0	0	0	0	0	0	1	0	0
Silene acaulis	h	0	2	3	3	2	0	2	3	1	1
Taraxacum officinale s.l.	h	0	0	0	1	0	0	0	0	0	0
Taraxacum sp.	h	0	1	0	0	1	2	2	2	2	2
Thalictrum alpinum	h	0	3	2	2	2	2	3	3	3	1
Thelypteris phegopteris	h	0	0	0	0	0	0	0	1	0	0
Thymus praecox ssp. *arcticus*	h	2	3	3	3	3	3	3	3	3	2
Trisetum spicatum	g	0	0	0	0	0	0	1	0	0	0
Vaccinium uliginosum	ds	2	1	3	1	3	3	3	3	3	3
Veronica officinalis	h	0	0	0	0	0	0	1	0	0	0

Data collected 11–13.7.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.38 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the nickel-copper smelter at Sudbury, Canada

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Abies balsamea	w	0	0	2	0	3	0	0	1	0	3
Acer rubrum	w	0	2	2	3	2	0	3	1	3	3
Acer spicatum	w	0	0	0	0	0	0	1	0	0	3
Achillea millefolium	w	0	0	0	3	0	0	0	0	0	0
Actaea sp.	h	0	0	0	0	0	0	0	0	0	1
Agrostis gigantea	h	2	0	0	0	0	2	1	0	0	0
Agrostis hyemalis var. *scabra*	g	2	3	3	2	0	3	2	0	1	0
Alnus incana	w	0	0	0	1	0	0	0	0	0	0
Alnus viridis	w	0	0	0	0	0	0	0	0	0	0
Amelanchier sp.	w	0	0	1	0	0	0	0	0	0	1
Anaphalis margaritacea	h	1	0	0	1	0	0	1	0	0	0
Anemone quinquefolia	h	0	0	0	0	0	0	0	0	0	1
Antennaria neglecta	h	0	0	0	1	0	0	0	0	0	0
Aster macrophyllus	h	0	0	0	3	0	0	0	3	3	1
Betula alleghaniensis	w	0	0	0	0	0	0	0	0	0	0
Betula papyrifera	w	3	3	3	2	3	3	3	1	3	1
Calamagrostis sp.	g	0	2	0	3	0	0	0	1	0	2
Carex scoparia	g	3	0	0	0	0	2	2	0	0	0
Carex sp.	g	0	0	0	3	1	0	0	3	1	3
Cirsium sp.	h	1	0	0	1	0	0	0	0	0	0
Clintonia borealis	h	0	0	2	1	0	0	0	2	0	3
Comptonia peregrina	w	0	3	0	2	0	0	0	0	1	0
Coptis trifolia	h	0	0	0	1	0	0	0	3	3	0
Cornus canadensis	h	0	0	3	2	1	0	0	1	1	0
Cornus sericea	w	0	0	0	0	0	0	0	0	0	1
Corylus cornuta	w	0	0	0	0	3	0	0	2	0	0
Crataegus sp.	w	0	0	0	0	0	0	0	0	0	1
Danthonia spicata	g	0	0	0	2	0	0	0	0	0	0
Deschampsia cespitosa	g	3	3	0	0	0	3	0	0	0	0
Diervilla lonicera	w	0	0	0	3	1	0	0	3	3	2
Dryopteris carthusiana	h	0	0	0	0	1	0	0	0	1	3
Epigaea repens	w	0	0	2	0	0	0	0	0	0	0
Epilobium angustifolium	h	0	0	0	1	0	0	0	1	0	0
Erigeron strigosus	h	2	0	0	0	0	0	0	0	0	0
Fragaria virginiana	h	0	0	0	2	0	0	0	0	0	0
Gallium triflorum	h	0	0	0	1	0	0	0	2	0	2
Gaultheria procumbens	ds	0	0	1	2	0	0	0	0	3	0
Heiracium aurantiacum	h	2	0	0	1	0	0	0	0	0	0
Heiracium caespitosum	h	2	0	0	2	0	0	2	0	1	0
Kalmia angustifolia	w	0	0	0	0	0	0	0	0	0	0
Ledum groenlandicum	df	0	0	0	0	0	0	0	0	0	0
Lotus corniculatus	h	2	0	0	0	0	0	0	0	0	0
Maianthemum canadense	h	0	0	2	0	0	0	0	0	2	1
Matteuccia struthiopteris	h	0	0	0	0	0	0	0	0	0	1
Monotropa hypopithys	h	0	0	1	0	0	0	0	0	0	0
Nemopanthus mucronatus	w	0	0	0	0	1	0	0	0	0	0
Osmunda claytoniana	h	0	0	0	0	0	0	2	0	0	0
Phleum pratense	g	0	0	0	0	0	0	0	0	0	0

(continued)

Table 6.38 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Picea glauca	w	0	0	2	0	0	0	0	2	1	0
Picea mariana	w	0	0	0	0	0	0	0	0	0	0
Pinus banksiana	w	0	2	2	1	0	0	0	1	1	0
Pinus resinosa	w	1	0	0	2	0	0	0	0	0	0
Pinus strobus	w	0	3	0	0	0	0	0	0	1	0
Polygala paucifolia	h	0	0	0	0	0	0	0	1	1	3
Populus balsamifera	w	2	0	0	1	0	0	0	0	0	0
Populus grandidentata	w	2	0	0	0	0	0	0	0	0	0
Populus tremuloides	w	3	1	0	3	3	1	1	3	1	3
Prunus pensylvanica	w	0	0	0	0	0	0	1	0	0	0
Pteridium aquilinum	h	0	3	3	3	0	0	1	3	3	1
Quercus rubra	w	0	0	3	0	0	0	3	0	3	3
Ribes glandulosum	w	0	0	0	0	1	0	0	0	0	0
Ribes sp.	w	0	0	0	0	0	0	0	1	0	1
Rosa acicularis	w	0	0	0	3	0	0	1	2	0	0
Rubus idaeus	w	0	0	0	1	0	0	0	2	0	1
Rubus pubescens	ds	0	0	0	0	0	0	0	0	0	1
Rumex acetosella	h	3	0	0	0	0	2	2	0	0	0
Salix sp.	w	3	2	1	2	0	0	2	2	1	0
Smilacina racemosa	h	0	0	0	0	0	0	0	0	1	0
Solidago canadensis	h	0	0	0	0	0	0	0	0	0	0
Solidago rugosa	h	2	0	0	1	0	0	0	0	0	0
Solidago uliginosa	h	0	0	0	1	0	0	0	0	0	0
Taraxacum officinale	h	0	0	0	0	0	0	0	0	0	0
Thuja occidentalis	w	0	0	0	0	0	0	0	0	0	0
Trientalis borealis	h	0	0	0	0	1	0	0	0	0	2
Trifolium sp.	h	1	0	0	0	0	0	0	0	0	0
Ulmus americana	w	0	0	0	0	0	0	0	0	0	2
Vaccinium angustifolium	df	0	3	3	3	1	0	2	0	2	0
Vaccinium myrtilloides	df	0	2	3	2	0	0	1	2	2	0
Verbascum thapsus	h	1	0	0	0	0	0	0	0	0	0
Vicia cracca	h	0	0	0	2	0	0	0	0	0	0
Viola sp.	h	0	0	0	1	0	0	0	0	0	1

Data collected 19–21.10.2007. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.39 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the power plant at Vorkuta, Russia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Achillea millefolium	h	1	3	3	2	0	3	0	2	0	3
Adoxa moschatellina	h	0	0	0	0	0	0	0	0	0	2
Angelica decurrens	h	0	1	0	0	0	0	0	0	0	1
Arctostaphylos alpinus	h	2	0	0	0	1	0	0	1	0	1
Artemisia vulgaris	h	0	0	0	2	0	1	0	1	0	0
Barbarea vulgaris	h	0	2	0	3	0	0	0	1	0	0
Betula nana	w	3	3	3	3	3	3	3	3	3	3
Calamagrostis langsdorfii ssp. *langsdorfii*	g	0	0	0	1	0	0	0	0	0	1
Cardamine pratensis	h	0	0	0	0	0	3	0	0	0	1
Carex nigra	g	0	0	1	0	1	3	0	3	0	3
Carum carvi	h	0	0	0	0	0	0	0	0	0	3
Cerastium cerastoides	h	0	0	0	0	0	1	0	0	0	0
Cerastium jenisejense	h	2	1	3	2	1	1	3	3	0	3
Chrysosplenium alternifolium	h	1	0	0	0	0	0	0	0	0	0
Empetrum nigrum	ds	0	0	0	0	3	0	1	0	1	1
Epilobium angustifolium	h	1	0	0	0	0	2	1	1	0	0
Equisetum arvense	h	2	0	0	1	0	2	0	0	0	1
Equisetum palustre	h	1	0	0	0	0	0	0	0	0	0
Eriophorum scheuchzeri	g	0	0	1	0	0	0	0	0	0	0
Erysimum cheiranthoides	h	0	0	0	0	0	0	2	1	0	0
Festuca ovina	g	3	3	3	3	3	3	3	3	3	3
Geranium albiflorum	h	3	0	0	1	0	0	0	0	0	0
Geum rivale	h	1	0	0	0	0	0	0	0	0	0
Hedysarum hedysaroides ssp. *arcticum*	h	0	0	0	0	0	2	0	0	0	0
Hieracium sp.	h	0	0	0	0	0	1	0	1	0	0
Ledum decumbens	ds	0	0	0	0	2	0	0	0	0	0
Luzula campestris ssp. *frigida*	g	0	0	0	1	0	0	0	1	0	0
Myosotis laxa ssp. *caespitosa*	h	1	0	0	0	0	0	0	0	0	0
Parnassia palustris	h	0	1	0	0	0	1	0	0	0	0
Pedicularis lapponica	h	2	2	2	2	0	2	3	1	2	1
Petasites frigidus	h	0	0	3	3	2	2	2	1	0	0
Pleurospermum uralense	h	0	1	0	0	0	0	0	0	0	0
Poa alpigena	g	0	0	0	0	0	0	0	1	0	1
Poa pratensis	g	3	3	3	3	3	3	3	3	3	3
Polemonium acutiflorum	h	1	1	1	2	0	0	0	0	0	2
Polygonum bistorta	h	3	3	0	1	1	1	3	1	0	0
Polygonum viviparum	h	1	0	1	0	1	3	0	1	0	0
Pyrola minor	h	3	0	2	3	0	3	1	1	1	1
Ranunculus acris ssp. *borealis*	h	0	0	0	0	0	1	0	0	0	0

(continued)

Table 6.39 (continued)

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Ranunculus acris ssp. *glabriusculus*	h	1	0	0	1	0	1	0	0	0	2
Rubus arcticus	h	2	3	3	3	2	3	1	1	3	3
Rubus chamaemorus	h	0	0	2	0	1	0	0	1	2	0
Salix glauca	w	3	3	3	3	3	3	3	3	3	3
Salix hastata	w	0	0	0	0	0	2	0	0	0	0
Salix lanata	w	3	3	3	3	3	3	3	1	2	3
Salix lapponum	w	0	1	0	0	1	3	0	2	0	2
Salix phylicifolia	w	3	2	1	3	1	3	3	2	0	3
Salix reticulata	w	0	0	0	0	0	1	1	0	0	0
Salix × dasyclados	w	3	3	3	3	0	3	3	2	2	3
Sanguisorba officinalis	h	0	0	0	0	0	1	0	0	0	0
Saussurea alpina	h	1	0	2	0	0	0	0	0	0	0
Senecio integrifolius	h	0	0	0	0	1	0	0	0	0	1
Solidago virgaurea	h	0	2	1	2	2	0	0	1	0	0
Stellaria fennica	h	0	0	0	0	1	0	0	0	0	1
Stellaria palustris	h	0	0	0	0	0	0	2	0	0	0
Tanacetum bipinnatum	h	0	1	0	0	0	0	0	0	0	0
Taraxacum croceum	h	0	0	0	1	0	1	0	1	0	0
Taraxacum perfiljevii	h	0	0	0	0	0	1	0	0	0	0
Trientalis europaea	h	0	0	0	0	0	0	0	0	0	0
Vaccinium myrtillus	ds	0	0	0	0	3	0	0	0	0	0
Vaccinium uliginosum	ds	3	3	3	2	3	3	3	3	3	3
Vaccinium vitis-idaea	ds	3	3	3	3	3	3	3	3	3	3
Valeriana capitata	h	1	0	0	0	0	0	0	0	0	1
Veratrum lobelianum	h	0	3	0	1	0	0	0	0	0	0
Veronica longifolia	h	1	1	2	0	0	2	0	2	0	0

Data collected 8–10.7.2001. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs.

Table 6.40 Occurrences of vascular plants (numbers of sampling plots, out of three, on which the species was recorded) in the impact zone of the of the aluminium smelter at Žiar nad Hronom, Slovakia

Species	Life form	Occurrences of species on sampling plots									
		1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Abies alba	w	0	0	0	2	2	0	0	1	2	1
Acer campestre	w	0	0	3	0	3	0	1	3	0	0
Acer platanoides	w	0	0	0	0	3	0	0	3	0	2
Actaea spicata	w	0	0	1	0	0	0	0	1	0	0
Ajuga reptans	h	0	1	1	0	2	0	0	0	0	3
Asarum europaeum	h	0	0	0	0	0	0	0	3	1	3
Athyrium filix-femina	h	1	0	0	1	0	0	0	0	3	2
Ballota nigra	h	0	0	0	0	1	0	0	0	0	0
Bilderdykia dumetorum	h	0	0	0	0	0	0	0	0	0	1
Cardamine impatiens	h	0	0	0	0	0	0	0	0	0	1
Carex muricata	g	0	0	0	0	0	1	0	0	0	0
Carex pilosa	g	0	0	2	0	1	0	3	1	3	0
Carex rhizina	g	0	1	0	0	0	0	0	0	0	0
Carex sylvatica	g	0	0	0	0	1	0	0	0	0	0
Carpinus betulus	w	2	3	3	0	1	3	1	3	0	1
Corylus avellana	w	0	0	0	0	0	0	0	0	2	0
Crataegus monogyna	w	2	3	0	0	0	0	0	0	0	0
Cystopteris fragilis	h	0	0	0	0	0	0	1	3	0	1
Deschampsia flexuosa	g	0	0	0	0	0	2	3	0	0	0
Dryopteris filix-mas	h	0	0	0	0	1	1	1	3	3	0
Elymus caninus	g	0	1	0	0	0	0	0	1	0	0
Epilobium collinum	h	0	0	0	0	0	0	3	0	0	0
Epilobium montanum	h	0	0	0	0	0	2	0	2	1	0
Euphorbia amygdaloides	h	0	0	1	0	0	0	0	0	0	0
Fagus sylvatica	w	2	3	3	3	3	3	3	3	3	3
Fragaria vesca	h	0	0	0	0	0	1	1	0	0	0
Fraxinus excelsior	w	0	0	0	0	0	0	0	1	0	3
Galeobdolon luteum	h	0	0	0	0	1	0	0	1	0	1
Galeopsis ladanum	h	0	0	0	0	0	0	0	0	0	1
Galium aparine	h	0	0	0	0	0	3	2	0	0	0
Galium boreale	h	0	0	0	0	0	0	0	0	0	0
Galium odoratum	h	0	0	3	0	3	0	3	3	1	3
Geranium robertianum	h	0	0	0	0	1	0	0	0	0	1
Glechoma hederacea	h	1	0	0	0	2	0	0	2	0	2
Gymnocarpium dryopteris	h	0	0	0	0	0	0	0	0	1	0
Hieracium murorum	h	1	0	0	0	0	0	0	0	0	0
Impatiens glandulifera	h	0	0	0	0	0	0	0	2	0	0
Lamium album	h	0	0	1	0	0	0	0	0	0	0
Lathyrus vernus	h	0	0	0	0	0	0	1	0	0	0
Ligustrum vulgare	w	0	0	0	0	0	3	0	0	0	0
Luzula luzuloides	g	0	0	0	3	0	3	3	0	3	2
Maianthemum bifolium	h	1	0	0	0	0	0	0	0	0	0

(continued)

Table 6.40 (continued)

Species	Life form	Occurrences of species on sampling plots 1–1	1–2	1–3	1–4	1–5	2–1	2–2	2–3	2–4	2–5
Mycelis muralis	h	0	0	0	0	0	0	1	0	1	0
Oxalis acetosella	h	0	0	0	0	2	0	3	2	1	2
Picea abies	w	0	0	0	0	0	1	**0**	0	0	0
Pinus sylvestris	w	0	3	0	0	0	0	0	0	0	0
Polygonatum latifolium	h	0	0	1	0	0	0	0	0	0	0
Populus tremula	w	0	0	0	0	0	0	0	0	0	0
Primula elatior	h	0	0	1	0	0	0	0	0	0	0
Pulmonaria obscura	h	0	0	0	0	0	0	0	3	0	0
Quercus petraea	w	1	3	1	0	1	3	2	0	0	0
Quercus rubra	w	0	0	0	0	0	2	0	0	0	0
Ribes uva-crispa	w	0	0	0	0	0	0	0	1	0	0
Rosa sp.	w	0	1	0	0	0	0	0	0	0	0
Rubus caesius	w	1	0	0	2	0	0	0	0	0	1
Rubus idaeus	w	0	0	0	0	0	0	0	1	0	0
Sorbus aucuparia	w	2	1	0	1	0	0	0	0	0	0
Stellaria media	h	0	0	0	0	0	0	0	0	1	2
Tilia cordata	w	0	0	0	0	0	0	0	3	0	0
Urtica dioica	h	0	0	0	0	0	0	0	0	0	2
Veronica chamaedrys	h	0	0	0	0	0	2	0	0	0	0
Viola reichenbachiana	h	0	2	3	0	3	2	0	3	1	0

Data collected 29.8–1.9.2002. Life forms: ds - dwarf shrubs, g - grasses, h - herbs, w - trees and shrubs

Table 6.41 Results of statistical analyses of the data on diversity of vascular plants: between-site variation and correlations with distances and pollution loads

Polluter	Statistics[a]	All vascular plants	Trees and shrubs	Grasses	Herbs	Field layer
Bratsk	ANOVA: *F/P*	2.72/0.03	3.47/0.01	0.61/0.78	3.03/0.02	3.74/0.007
	Dist.: *r/P*	0.63/0.05	0.23/0.52	0.02/0.96	0.48/0.16	0.53/0.12
	Poll.: *r/P*	−0.34/0.34	0.22/0.53	−0.10/0.77	−0.37/0.29	−0.47/0.17
Jonava	ANOVA: *F/P*	5.19/0.0011	5.22/0.001	17.7/<0.0001	2.92/0.02	4.60/0.002
	Dist.: *r/P*	0.56/0.09	0.36/0.30	0.78/0.007	0.14/0.70	0.47/0.17
	Poll.: *r/P*	−0.12/0.75	0.12/0.75	−0.28/0.43	−0.05/0.89	−0.21/0.55
Kandalaksha	ANOVA: *F/P*	7.32/0.0001	3.63/0.008	3.17/0.02	13.0/<0.0001	8.81/<0.0001
	Dist.: *r/P*	−0.36/0.31	−0.42/0.22	−0.43/0.21	−0.38/0.28	−0.28/0.44
	Poll.: *r/P*	0.42/0.22	0.56/0.09	0.29/0.41	0.50/0.14	0.28/0.43
Karabash	ANOVA: *F/P*	55.5/<0.0001	21.3/<0.0001	9.63/<0.0001	55.4/<0.0001	56.3/<0.0001
	Dist.: *r/P*	0.92/0.0002	0.80/0.005	0.55/0.10	0.92/0.0001	0.75/0.01
	Poll.: *r/P*	−0.87/0.0010	−0.88/0.001	−0.74/0.01	−0.82/0.0035	−0.69/0.03
Kostomuksha	ANOVA: *F/P*	5.55/0.0007	1.61/0.18	5.55/0.0007	20.1/<0.0001	7.11/0.0001
	Dist.: *r/P*	−0.64/0.05	−0.40/0.25	−0.63/0.05	−0.73/0.02	−0.63/0.05
	Poll.: *r/P*	0.48/0.16	0.52/0.12	0.52/0.12	0.39/0.27	0.39/0.27
Monchegorsk	ANOVA: *F/P*	8.01/<0.0001	3.33/0.01	2.42/0.05	5.73/0.0006	8.19/<0.0001
	Dist.: *r/P*	0.48/0.16	0.36/0.31	0.16/0.67	0.58/0.08	0.50/0.14
	Poll.: *r/P*	−0.68/0.03	−0.67/0.04	−0.51/0.14	−0.49/0.15	−0.64/0.04
Nadvoitsy	ANOVA: *F/P*	5.29/0.0009	6.71/0.0002	4.18/0.004	8.84/<0.0001	4.27/0.003
	Dist.: *r/P*	−0.44/0.21	−0.21/0.55	0.14/0.71	−0.43/0.21	−0.44/0.21
	Poll.: *r/P*	0.58/0.08	0.35/0.32	−0.01/0.97	0.59/0.07	0.55/0.10
Nikel	ANOVA: *F/P*	2.97/0.0204	1.47/0.23	1.35/0.28	2.54/0.04	3.28/0.01
	Dist.: *r/P*	0.54/0.10	0.37/0.30	0.36/0.31	0.42/0.22	0.54/0.11
	Poll.: *r/P*	−0.66/0.04	−0.54/0.11	−0.15/0.68	−0.51/0.14	−0.63/0.05
Norilsk	ANOVA: *F/P*	14.4/<0.0001	3.09/0.02	5.55/0.0007	13.5/<0.0001	33.7/<0.0001
	Dist.: *r/P*	0.56/0.12	0.33/0.39	0.56/0.11	0.38/0.31	0.58/0.10
	Poll.: *r/P*	−0.61/0.08	−0.37/0.33	−0.63/0.07	−0.42/0.26	−0.61/0.08

Revda	ANOVA: *F/P*	15.2/<0.0001	6.90/0.0002	0.90/0.54	17.6/<0.0001	15.0/<0.0001
	Dist.: *r/P*	0.75/0.01	−0.07/0.84	0.54/0.11	0.91/0.0003	0.89/0.0005
	Poll.: *r/P*	−0.77/0.01	0.07/0.85	−0.65/0.04	−0.83/0.003	−0.82/0.004
Straumsvík	ANOVA: *F/P*	3.07/0.02	1.00/0.47	1/32/0.29	3.13/0.02	3.12/0.02
	Dist.: *r/P*	0.04/0.91	0.53/0.12	0.14/0.70	−0.20/0.58	0.00/0.99
	Poll.: *r/P*	−0.64/0.05	−0.62/0.06	−0.66/0.04	−0.51/0.14	−0.60/0.07
Sudbury	ANOVA: *F/P*	10.4/<0.0001	8.32/<0.0001	5.82/0.0005	7.71/<0.0001	8.21/<0.0001
	Dist.: *r/P*	0.45/0.19	0.80/0.005	−0.64/0.05	0.40/0.25	0.19/0.59
	Poll.: *r/P*	−0.50/0.14	−0.82/0.04	−0.40/0.25	0.63/0.05	−0.25/0.48
Vorkuta	ANOVA: *F/P*	8.10/<0.0001	5.27/0.001	4.94/0.0014	6.30/0.0003	6.11/0.0004
	Dist.: *r/P*	−0.50/0.14	−0.63/0.05	0.19/0.59	−0.58/0.08	−0.43/0.22
	Poll.: *r/P*	0.41/0.24	0.55/0.10	0.15/0.58	0.39/0.27	0.33/0.35
Žiar nad Hronom	ANOVA: *F/P*	3.46/0.01	5.06/0.001	4.31/0.003	4.43/0.0027	3.96/0.005
	Dist.: *r/P*	0.34/0.34	−0.26/0.48	0.06/0.88	0.56/0.09	0.55/0.10
	Poll.: *r/P*	−0.50/0.14	0.10/0.79	−0.43/0.21	−0.57/0.08	−0.66/0.004

Distance was log-transformed prior the correlation analysis. Pollution load was measured as foliar concentrations of fluorine (Bratsk, Kandalaksha, Nadvoitsy, Straumsvík, Žiar nad Hronom), strontium (Jonava), iron (Kostomuksha, Vorkuta), nickel (Monchegorsk, Nikel/Zapolyarnyy, Sudbury, Norilsk), and copper (Karabash, Revda) (for actual concentrations, consult Tables 2.27–2.43). In Norilsk, plot 2–5 was excluded from the analysis

The majority of information on the structure of plant communities was collected from three plots, 10 × 10 m in size, selected for each study site. These plots were not marked, and they were surveyed only once. However, after processing of the first data sets, we have recognised that this spatial scale is only marginally suitable to measure the cover of field layer vegetation, mosses and epigeic lichens. Therefore, for ten of 14 surveyed polluters, we have additionally assessed the cover of these plant groups, as well as of bare ground and surface stones (the latter index is reported in Chapter 3) in ten plots, 1 × 1 m in size, selected at 10 m intervals along a line crossing at least two of three larger plots.

6.2.2 Vegetation Cover

Vegetation cover was estimated visually by the same observer (M.V.K.). Repeated measurements indicated sufficient accuracy of these estimates: the differences between two measurements were below 5% for absolute values of vegetation cover not exceeding 50%, and below 10% for larger cover values.

We separately estimated and analysed cover of the following layers: (a) the top-canopy layer formed by mature woody plants (this layer is absent in tundra sites around Straunsvík and Vorkuta); (b) the understorey, i.e., the intermediate layer between the top-canopy and the field layer in forested habitats (the understorey is formed by woody plants, including both mature low-stature species and juvenile individuals of the top-canopy species); (c) the field layer, consisting of herbs, grasses and sedges, and dwarf shrubs; (d) mosses; and (e) epigeic lichens. Simultaneously, we estimated the proportion of bare ground and surface stone cover; the latter data are reported and discussed in Chapter 3 (Tables 3.2–3.15).

To test the hypothesis that trees are more sensitive to pollution than herbs and grasses, we introduced an additional response variable, the ratio between site-specific cover estimates of top-canopy and field layers. A decrease of this variable with pollution will support the hypothesis mentioned above.

6.2.3 Stand Characteristics

Stand characteristics are averaged from three point samplings, conducted from centres of the same plots (10 × 10 m size) that were used for assessment of tree cover (see above, Section 6.2.2). Stand basal area was measured by a relascope, as described by West (2003). Stand composition, expressed as relative abundances of forest-forming species (rounded to the nearest 10% in Tables 6.15–6.26), was calculated from the same records as stand basal area. The average height of the stand is based on three plot-specific values, each obtained by measuring heights of five trees forming the top-canopy layer by the angle of elevation method.

Response variables used in the analyses were (a) stand basal area, (b) stand height, (c) the proportion of the main forest-forming tree species (determined by the type of forest in which the study plots were selected), and (d) the proportion of conifers.

6.2.4 Regeneration of Dominant Woody Plants

Seedlings of woody plants, saplings and young trees (defined as trees that have not yet reached 5% of the average height of mature trees at this study site; generally less than 120 cm tall) were counted in each 10 × 10 m plot. To account for small seedlings (less than 5 cm tall) that are not easy to recognise in dense field layer vegetation, we (whenever necessary) carefully checked five to ten 1 × 1 m subplots within each plot and multiplied the average number of small seedlings by 100 to obtain a plot-specific estimate.

Response variables used in the analyses were (a) total number of seedlings, saplings and young trees, (b) the proportion of the dominant tree species, and (c) the proportion of conifers among seedlings, saplings and young trees.

6.2.5 Diversity of Vascular Plants

Every effort was made to record all species of vascular plants within each 10 × 10 m plot. Easily recognisable species were recorded *in situ* by using pre-printed forms. Vouchers of other species were determined with the assistance of professional botanists (listed in the Acknowledgements section); these vouchers are now deposited in the herbarium of the University fo Turku. In total, we were able to provide species names for about 99% of the collected specimens; the abbreviation 'sp.' in Tables 6.27–6.40 refers to non-flowering individuals whose identity cannot be revealed with certainty.

The nomenclature of plants generally follows Tutin (1964, 1968, 1972, 1976, 1980). Siberian species absent from Europe are given according to Baikov (2005), and North American species are given according to Gleason and Cronquist (1993).

To allow direct comparison of our conclusions with the meta-analysis of the published data (Zvereva et al. 2008), we considered the following partially subordinated groups: grasses and sedges (grasses hereafter), herbs, field layer vegetation (grasses and sedges, herbs and dwarf shrubs), shrubs and trees (woody plants hereafter), and all vascular plants pooled. In our analysis, we included dwarf shrubs, which are woody plants, in the field layer vegetation. This combination seemed more relevant in terms of vegetation structure because for many life-history traits, dwarf shrubs are more similar to perennial herbs than to top-canopy species.

Our data allowed calculating α, β, and γ diversity of vascular plants. For each study site, α diversity was measured as the mean number of plant species within each of three replicate 10 × 10 m plots. These values were calculated for (a) the overall species richness of vascular plants, (b) trees and shrubs, (c) herbs, (d) grasses, and (e) field layer vegetation. Analyses reported below are based on effect sizes, calculated from correlations of site-specific means with log-transformed distances from polluters (Table 6.41).

Since three methods of ES calculations (described in Section 2.5.2.2) for α diversity yielded the same conclusions, and overall effects on different groups of plants were uniform (see below, Section 6.3.4), we explored pollution effects on β and γ diversity of all vascular plants by only one method, i.e., by contrasting species richness in the two most and two least polluted study sites around each of the polluters.

Following the protocol described by Chalcraft et al. (2008), we measured site-specific β diversity as the average pairwise Jaccard distance in plant species composition among three replicate plots within the site. The two aspects of spatial variation combined in Jaccard distance (Koleff et al. 2003) can be separated by calculating β_{gl}, which measures variation in species composition attributable to spatial variation in diversity (i.e., some localities contain more species than other localities) and β_{sim}, which measures spatial variation in species composition after adjusting for differences in α diversity (i.e., some localities contain species that are absent in other localities) (Lennon et al. 2001; Koleff et al. 2003). For a given pair of plots, these indices were estimated by:

$$\beta_{gl} = 2 \times \mathrm{abs}(b - c) / [2a + b + c] \tag{6.1}$$

$$\beta_{sim} = \min(b, c) / [\min(b, c) + a] \tag{6.2}$$

where:

a = the number of species that both plots have in common
b = the number of species that are found in the first plot only and
c = the number of species that are found in the second plot but not in the first one

Since we surveyed three 10 × 10 m plots, our site-specific estimates of both β_{gl} and β_{sim} were each based on three pairwise values. We estimated γ diversity as the total number of plant species found in all three replicate plots within the site.

6.2.6 Species Composition of Vascular Plants

As has been pointed out earlier, problems in comparative analysis of data sets from different floristic regions complicate exploration of pollution-induced changes in species composition by meta-analysis (Zvereva et al. 2008). However, using original data (Tables 6.27–6.40), we can test the hypotheses that pollution affects species composition of vascular plants, either by selective species removal or colonisation by tolerant species, or both, against the null hypothesis that between-site variation in species composition is random (Table 6.42). This can be done by combining data on species richness with estimates of between-site similarities, calculated as the Jaccard index (i.e., the number of common species divided by the total number of species recorded at both sites). We assumed that any non-random (e.g., pollution-induced) change in plant species composition will result in a smaller similarity between polluted and unpolluted sites within the same pollution gradient, compared to the similarity between two unpolluted sites (Table 6.42).

Table 6.42 Relationships between characteristics of plant communities in polluted and unpolluted sites expected under different assumptions concerning pollution effects on species composition of vascular plants

Assumptions	Species richness[a]	Between-site similarity[b]	Uncommon species[c]
Variation in species composition is random, i.e., probabilities of both extinction and colonization are equal for all species	NP = NC	SPC = SC	UP = UC
Pollution causes only selective removal of sensitive species	NP < NC	SPC < SC	UP < UC
Pollution causes only colonization by tolerant species	NP > NC	SPC < SC	UP > UC
Pollution causes species replacement, i.e. selective species removal followed by colonization by tolerant species	NP = NC	SPC < SC	UP = UC

[a] NP, mean number of species in polluted sites; NC, mean number of species in clean sites.
[b] SPC, average similarity (Jaccard index) between polluted and clean sites around the same polluter; SC, similarity between two clean sites around the same polluter.
[c] UP, proportion of species present in polluted site but absent in clean site of the same gradient (relative to species number in polluted site); UC, proportion of species present in clean site but absent in polluted site of the same gradient (relative to species number in clean site).

Since estimates of species richness may be affected by plant abundances (see below, Section 6.4.3) for both heavily polluted and control plots, we estimated the proportion of uncommon species, i.e., species that were absent in a site on the opposite end of the same pollution gradient. These proportions were averaged for two gradients around the same polluter and then compared across all polluters using the Kruskal-Wallis test. If pollution only removes sensitive species, then flora of the most polluted site should represent a subset of flora of an unpolluted site, with all species shared with the unpolluted site. And *vice versa* if pollution only facilitates colonization by tolerant species, then flora of the unpolluted site should represent a subset of flora of the most polluted site (Table 6.42).

6.3 Results

6.3.1 Vegetation Cover

Variation in the cover of different plant groups between study sites was significant in 53 of 63 data sets. This variation was always significant in mosses (14 data sets), while canopy cover showed the lowest variation (significant in seven of 12 data sets). However, only 44 of 118 individual correlation coefficients (with both distance and pollution) were significant (Tables 6.1–6.14).

Vegetation layers responded to pollution impacts in an uncoordinated manner; an average pairwise correlation between the cover of different layers (site-specific values standardised by polluter) did not differ from zero (z_r = 0.01, CI = –0.06 … 0.08, N = 10 pairwise correlations). This result indicates that separate analyses of changes in the cover of different layers were not redundant. Since the proportion of bare ground negatively correlated with vegetation cover (z_r = –0.30, CI = –0.49 … –0.11, N = 5 pairwise correlations), it was excluded from the meta-analysis.

Pollution effects on canopy cover (Fig. 6.1), understorey vegetation, including shrubby vegetation in treeless areas (Fig. 6.2), and ground lichens (z_r = –0.08, CI = –0.66 … 0.63, N = 6) did not differ from zero; adverse effects were detected for field layer vegetation (Fig. 6.3) and mosses (Fig. 6.4). These conclusions did not depend on the method used to calculate ES (canopy cover: Q_B = 0.37, df = 2, P = 0.83; field layer cover: Q_B = 0.26, df = 2, P = 0.88).

The absence of overall effects of pollution on canopy and understorey covers is due to contrasting responses to impacts of different polluters: a decline around non-ferrous smelters and an increase around aluminium smelters (Figs. 6.1 and 6.2). Consistently, we detected significant negative effects of acidifying polluters and significant positive effects of alkalysing polluters on both the top-canopy and the understorey plants. Pollution effects were similar around both southern and northern polluters (Figs. 6.1 and 6.2).

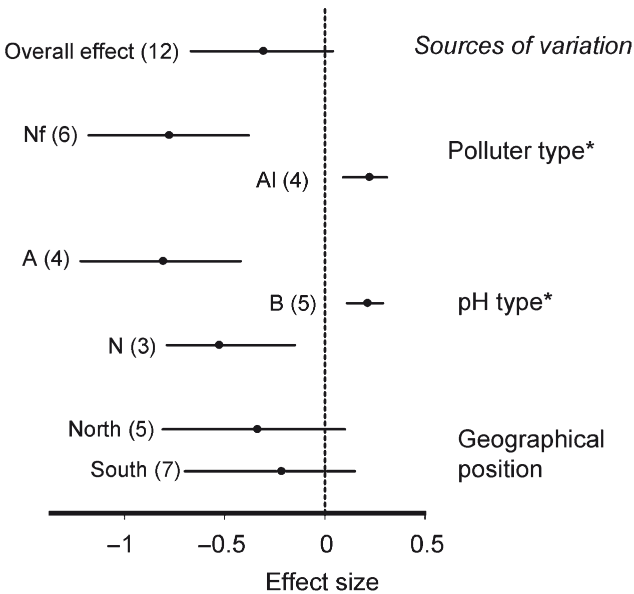

Fig. 6.1 Overall effect and sources of variation in responses of canopy cover. Horizontal lines denote 95% confidence intervals; sample sizes are shown in brackets; an asterisk denotes significant (P < 0.05) between-class heterogeneity. For classifications of polluters consult Table 2.1

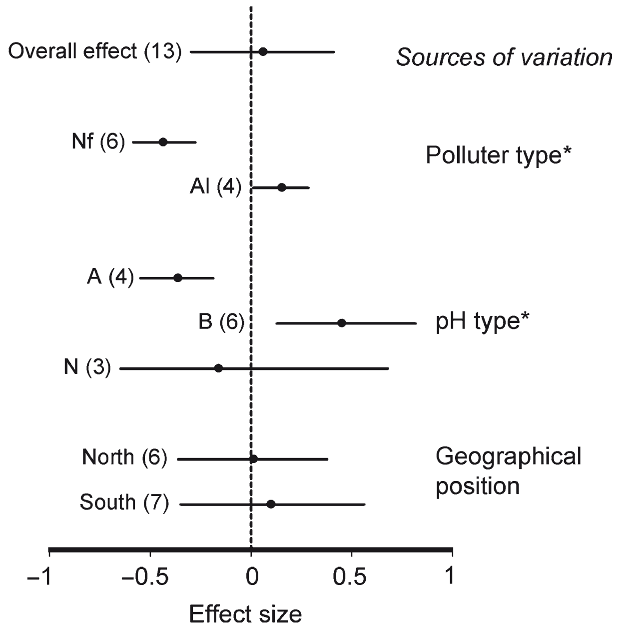

Fig. 6.2 Overall effect and sources of variation in responses of understorey vegetation cover (including shrubby vegetation in treeless areas). For explanations, consult Fig. 6.1

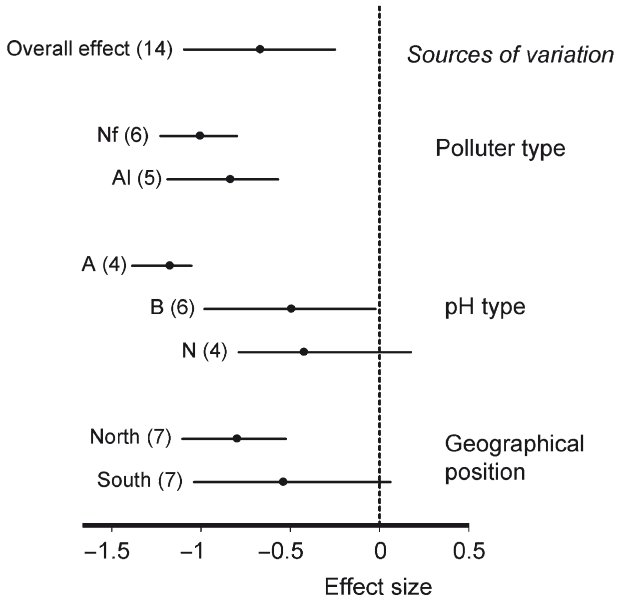

Fig. 6.3 Overall effect and sources of variation in responses of field layer vegetation cover. For explanations, consult Fig. 6.1

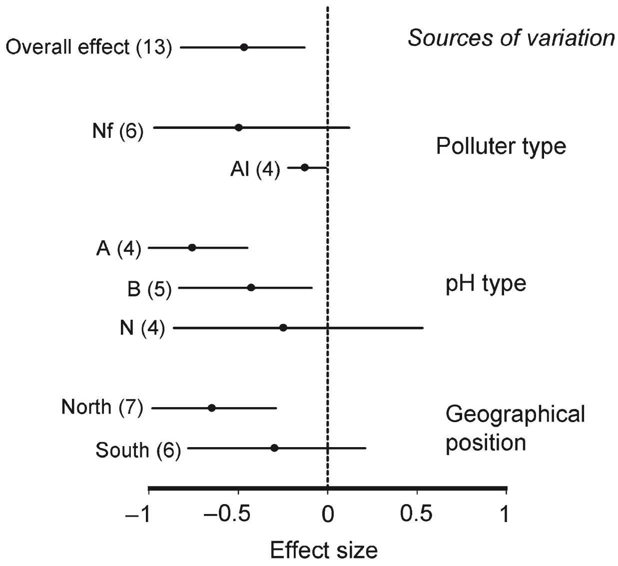

Fig. 6.4 Overall effect and sources of variation in responses of moss cover. For explanations, consult Fig. 6.1

The adverse effects of pollution on the cover of either field layer vegetation or mosses did not vary with polluter type; both acidification and alkalinisation resulted in a significant reduction of both these groups (Figs. 6.3 and 6.4). Adverse effects were significant only around the northern polluters (Figs. 6.3 and 6.4). Changes in the cover of epigeic lichens showed no variation in respect to explored categorical variables (data not shown).

Top-canopy and understorey plants generally demonstrated a weaker decline in cover than field layer vegetation; the ratio between site-specific cover estimates of these plant layers increased with pollution (z_r = 0.42, CI = 0.05 … 0.78, N = 13). This effect was independent of either the type or geographical position of the polluter (Q_B = 0.31, df = 1, P = 0.56 and Q_B = 0.12, df = 1, P = 0.72, respectively), but it changed with the pollution impact on soil pH (Q_B = 20.9, df = 2, P = 0.01). A decline in the field layer relative to top-canopy plants around acidifying polluters (z_r = 0.96, CI = 0.78 … 1.15, N = 4) was stronger than around alkalysing polluters (z_r = 0.44, CI = 0.07 … 0.78, N = 6). Around polluters that did not change soil pH, the effect was the opposite: trees and the understorey declined faster than field layer vegetation (z_r = −0.35, CI = −0.40 … −0.29, N = 2).

We have detected significant non-linear responses in 11 of 59 data sets (three dome-shaped and eight U-shaped).

6.3.2 *Stand Characteristics*

Stand characteristics generally showed pronounced between-site variation. This variation was significant in 11 of 12 data sets on basal area, nine of nine data sets on tree height, 12 of 12 data sets on species composition, and 11 of 12 data sets on the proportion of dominant tree species in the stand. However, only a few individual correlation coefficients (with both distance and pollution; nine of 24 for basal area, nine of 18 for tree height, and five of 24 for proportion of dominant tree species in the stand) were significant (Tables 6.15–6.26).

Stand height and basal area (values standardised by impact zone) significantly correlated to each other ($r = 0.63$, $N = 88$ sites, $P < 0.0001$) and showed a uniform response to pollution (correlation between ESs: $r = 0.91$, $N = 9$ impact zones, $P = 0.0008$); both these indices significantly decreased near point polluters (Figs. 6.5 and 6.6). These conclusions did not depend on the method used to calculate ES (basal area: $Q_B = 0.56$, df = 2, $P = 0.76$; tree height: $Q_B = 1.61$, df = 2, $P = 0.45$).

The general negative effect of pollution on stand basal area was mostly due to the significant effects of non-ferrous smelters, whereas the effects of aluminium plants did not differ from zero. A decrease in basal area was pronounced only in the

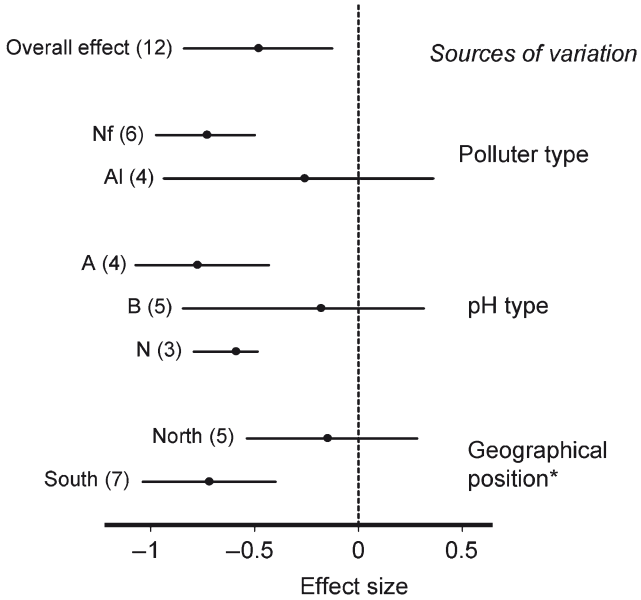

Fig. 6.5 Overall effect and sources of variation in responses of stand basal area. For explanations, consult Fig. 6.1

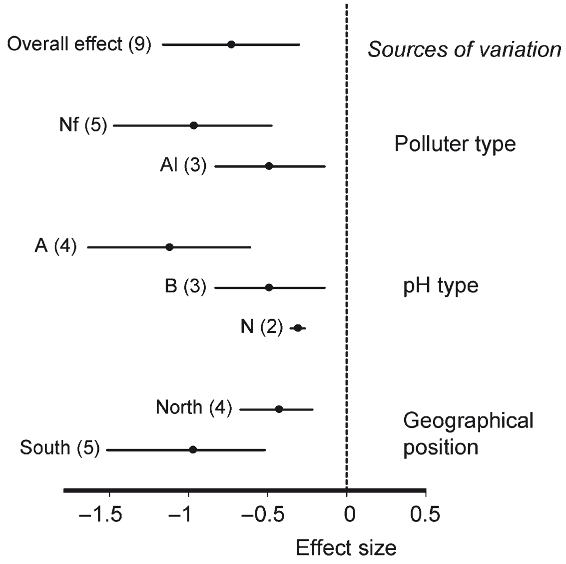

Fig. 6.6 Overall effect and sources of variation in responses of stand height. For explanations, consult Fig. 6.1

impact zones of southern polluters (Fig. 6.5). At the same time, we identified no sources of variation in stand height responses to pollution; within each group of categorical variables, all effects were significantly negative (Fig. 6.6).

Although pollution effects on stand basal area and canopy cover closely correlated to each other ($r = 0.79$, $N = 12$ impact zones, $P = 0.002$), an overall adverse effect was detected for basal area only (Fig. 6.5). This discrepancy is primarily due to contrasting impacts of aluminium smelters on these two variables: canopy cover tended to increase (Fig. 6.1), while basal area tended to decrease near these polluters (Fig. 6.5).

Neither proportion of dominant tree species ($z_r = -0.34$, CI = –0.75…0.07, $N = 12$) nor proportion of conifers (Fig. 6.7) changed under pollution impacts. However, the absence of overall effects on the latter index was due to counterbalancing impacts of non-ferrous smelters and aluminium plants (Fig. 6.7).

We have detected significant non-linear responses in two of 21 data sets (one dome-shaped and one U-shaped).

6.3.3 Regeneration of Dominant Woody Plants

Between-site variation in the total number of seedlings, saplings, and young trees was significant in nine of 11 data sets, and in the proportion of dominant tree species

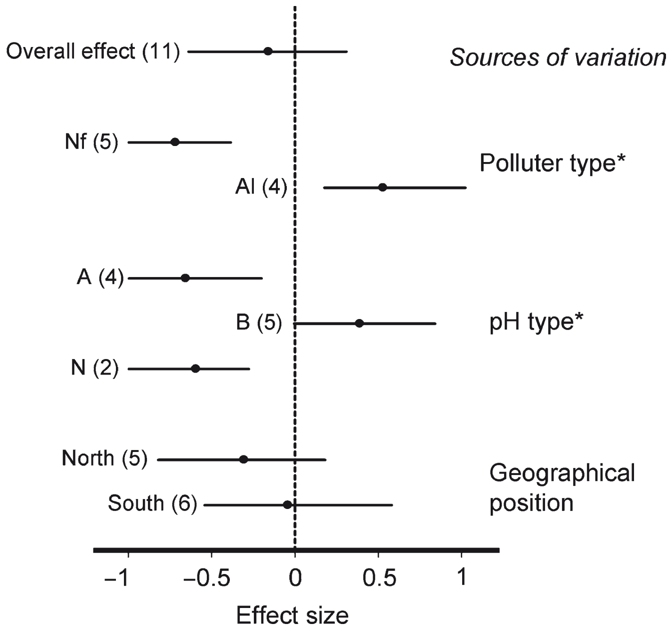

Fig. 6.7 Overall effect and sources of variation in responses of stand composition, measured by proportion of conifers in stand basal area. For explanations, consult Fig. 6.1

in another nine of 11 data sets. However, only three of 22 individual correlation coefficients (with both distance and pollution) were significant for each of these two variables (Tables 6.15–6.26); there was no concordance between data sets in which individual effects were significant.

Pollution did not affect forest regeneration, as can be concluded from the absence of effects on the number of tree seedlings (Fig. 6.8), the proportion of dominant tree species among seedlings ($z_r = -0.22$, CI = −0.66…0.22, $N = 10$), or the proportion of conifers ($z_r = -0.21$, CI = −0.59 … 0.17, $N = 11$). The conclusion on the absence of an overall effect on the number of seedlings did not depend on the method used to calculate ES ($Q_B = 0.22$, df = 2, $P = 0.90$).

The effects of pollution on the composition of mature (top-canopy) and young trees (i.e., seedlings and saplings) did not differ from each other (proportion of dominant tree species: $Q_B = 0.17$, df = 1, $P = 0.68$; proportion of conifers: $Q_B = 0.02$, df = 1, $P = 0.88$). None of the characteristics describing abundance and diversity of seedlings, saplings and young trees varied with either type or geographical position of polluters, or their impact on soil pH. Pollution effects on the abundance of regrowth were generally independent from effects on stand basal area (correlation between ESs: $r = 0.44$, $N = 11$, $P = 0.18$).

We have detected significant non-linear responses in two of 11 data sets (one dome-shaped and one U-shaped).

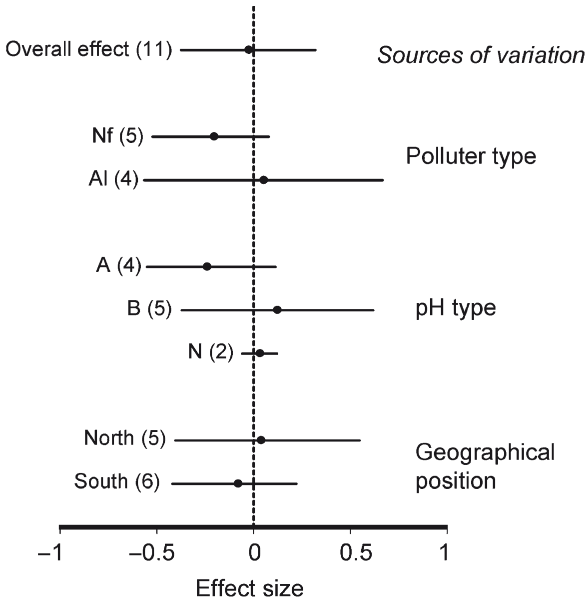

Fig. 6.8 Sources of variation in responses of stand natural regeneration, measured by number of seedlings, saplings, and young trees. For explanations, consult Fig. 6.1

6.3.4 *Diversity of Vascular Plants*

6.3.4.1 Local (Plot-Specific) Species Richness (α Diversity)

Between-site variation in species richness of different plant groups was significant in 63 of 70 data sets. However, only 35 of 140 individual correlation coefficients (with both distance and pollution) were significant (Tables 6.27–6.40).

The overall effect of pollution on the species richness of vascular plants did not differ from zero (Fig. 6.9). This conclusion did not depend on the method used to calculate ES ($Q_B = 1.63$, df = 2, $P = 0.44$).

Changes in α diversity were generally consistent among all groups of plants (Fig. 6.10). Responses of trees and shrubs did not differ from responses of field layer vegetation ($Q_B = 0.36$, df = 1, $P = 0.55$); grasses and herbs also showed uniform responses to pollution ($Q_B = 0.24$, df = 1, $P = 0.62$).

The absence of an overall effect is due to significant differences between effects caused by different types of polluters; species richness of all explored plant groups, as well as total species richness of vascular plants, decreased around non-ferrous smelters but did not change around aluminium smelters (Figs. 6.9 and 6.10). Accordingly, a decrease in species richness was recorded only near acidifying

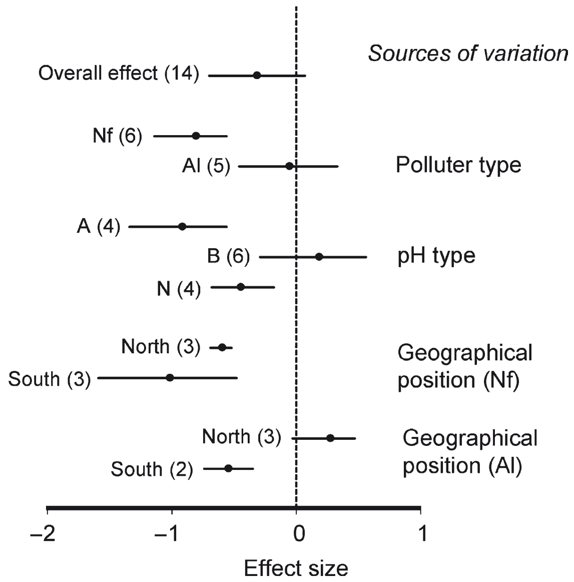

Fig. 6.9 Overall effect and sources of variation in responses of species richness of vascular plants. For explanations, consult Fig. 6.1

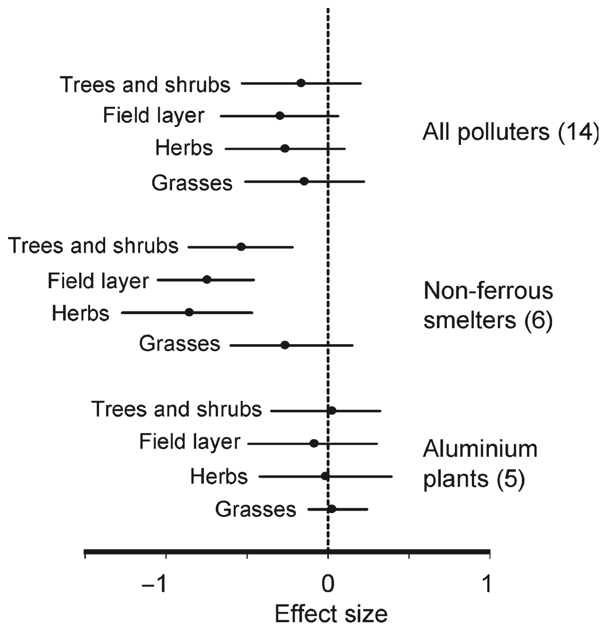

Fig. 6.10 Overall effect and sources of variation in responses of species richness of different, partially subordinated, groups of vascular plants. For explanations, consult Fig. 6.1

and neutral polluters (Fig. 6.9). Non-ferrous smelters adversely affected all plant groups except for grasses, while the effects of aluminium smelters on grasses did not differ from effects on other plant groups (Fig. 6.10). Changes in α diversity were only weakly related to changes in cover (field layer vegetation: $r = 0.50$, $N = 14$ impact zones, $P = 0.07$).

The pollution effects on the species richness of vascular plants were stronger in southern regions (Fig. 6.9). The geographical difference was significant between aluminium smelters ($Q_B = 4.76$, df = 1, $P = 0.03$) but did not reach the significance level between non-ferrous smelters ($Q_B = 2.61$, df = 1, $P = 0.11$).

We have detected significant non-linear responses in nine of 70 data sets (eight dome-shaped and one U-shaped).

6.3.4.2 Spatial Variation in Diversity (β_{gl} Diversity)

Pollution did not cause changes in spatial variation in species numbers, measured by β_{gl} ($d = 0.07$, CI = –0.75 … 0.88, $N = 14$). This effect was consistent among all groups of categorical variables and uniform across all impact zones ($Q_T = 16.2$, df = 13, $P = 0.24$). The effects of pollution on β_{gl} were independent of the effects on other measures of diversity (correlations between ESs: $r_S = -0.02 \ldots -0.32$, $N = 14$ impact zones, $P = 0.27 \ldots 0.95$).

6.3.4.3 Spatial Variation in Species Composition (β_{sim} Diversity)

Pollution did not cause changes in spatial variation in species composition, measured by β_{sim} ($d = -0.25$, CI = –0.96 … 0.47, $N = 14$). This effect was consistent among all groups of categorical variables and uniform across all impact zones ($Q_T = 14.9$, df = 13, $P = 0.31$). The effects of pollution on β_{sim} were independent of the effects on other measures of diversity (correlations between ESs: $r_S = -0.02 \ldots 0.25$, $N = 14$ impact zones, $P = 0.39 \ldots 0.95$).

6.3.4.4 Regional (Site-Specific) Species Richness (γ Diversity)

Pollution tended to reduce the species richness at a site-specific level, although the effect remained non-significant ($d = -0.55$, CI = –1.27 … 0.19, $N = 14$). This effect was consistent among all groups of categorical variables and uniform across all impact zones ($Q_T = 14.6$, df = 13, $P = 0.33$). The effects of pollution on γ diversity were consistent with effects on α diversity (correlations between ESs: $r_S = 0.75$, $N = 14$ impact zones, $P = 0.002$) but independent of the effects on either β_{gl} ($r_S = -0.32$, $N = 14$, $P = 0.27$) or β_{sim} ($r_S = 0.25$, $N = 14$, $P = 0.39$).

6.3.5 Species Composition of Vascular Plants

An average similarity (Jaccard index) between polluted and control sites (mean ± S.E.: 0.297 ± 0.045) did not differ ($\chi^2 = 2.74$, df = 1, $P = 0.10$) from the similarity between two control sites (0.419 ± 0.033) for the entire sample of 14 polluters. However, when polluter types were analysed separately, the difference did not appear significant for aluminium smelters ($\chi^2 = 0.01$, df = 1, $P = 0.92$), while for non-ferrous smelters, the average similarity between polluted and control sites (0.169 ± 0.048) was smaller ($\chi^2 = 5.79$, df = 1, $P = 0.02$) than the similarity between two control sites (0.309 ± 0.028). The overall pollution effects on the similarity between polluted and control sites were not significant for northern polluters, but they were marginally significant for southern polluters ($\chi^2 = 0.20$, df = 1, $P = 0.65$ and $\chi^2 = 2.98$, df = 1, $P = 0.08$, respectively).

Heavily polluted sites, on average, contained about the same ($\chi^2 = 1.19$, df = 1, $P = 0.28$) proportion of species that were absent on the opposite end of the pollution gradient (mean ± S.E.: 0.501 ± 0.055) as control sites (0.589 ± 0.064). This conclusion remained valid for both non-ferrous and aluminium smelters analysed separately ($\chi^2 = 2.56$, df = 1, $P = 0.11$ and $\chi^2 = 0.27$, df = 1, $P = 0.60$, respectively). The results did not differ between northern and southern polluters ($\chi^2 = 0.69$, df = 1, $P = 0.41$ and $\chi^2 = 1.47$, df = 1, $P = 0.22$, respectively).

6.4 Discussion

6.4.1 Vegetation Structure and Productivity

Pollution impacts on vegetation are far from being simply detrimental. One of the most interesting findings of our study is the diversity of the responses of plant communities to the impacts of point polluters. Both direction and magnitude of responses depend on many factors, including characteristics of both the polluter and plant communities, and presumably also pollution history. Moreover, different indices of plant community structure responded to pollution impacts in an uncoordinated manner.

First and most importantly, vegetation responses depend on the polluter type. In particular, decreases in the cover of top-canopy plants (Fig. 6.1) and the understorey (Fig. 6.2), in the proportion of conifers among top-canopy plants (Fig. 6.7), and in stand basal area (Fig. 6.5) were detected only near non-ferrous smelters. In contrast, near aluminium smelters we observed increases in the cover of top-canopy plants (Fig. 6.1) and the understorey (Fig. 6.2), and in the proportion of conifers among top-canopy plants (Fig. 6.7), while stand basal area did not change (Fig. 6.5). Reports on forest damage around alkalysing polluters, such as aluminium smelters and magnesite plants, are rare; acute damages were generally observed in the past, prior to implementation of strict control for emissions of gaseous fluorine and HF (Bohne 1971; Gilbert 1975). Recently, forest deterioration around aluminium smelters has mostly been associated with giant industrial enterprises in Siberia (Lyubashevsky et al. 1996; Mikhailova & Berezhnaya 2000; Mikhailova 2003). Our data support conclusion by Freedman (1989) that the adverse effects of aluminium industries on stands are less acute than the effects of non-ferrous smelters.

An absence of overall effects of pollution on the cover of top-canopy and understorey plants seems to contradict the general belief that forests decline with pollution, both around point polluters (Gordon & Gorham 1963; Freedman & Hutchinson 1980b; Innes & Oleksyn 2000) and on a regional scale (Pitelka & Raynal 1989; Bussotti & Ferretti 1998; Akselsson et al. 2004). However, our results indicate that it does not make any sense to discuss an overall ES calculated by meta-analysis because the sign and magnitude of this overall effect will mostly depend on the relative numbers of different polluters included in the sample. In particular, a zero effect on the covers of top-canopy (Fig. 6.1) and understorey plants (Fig. 6.2), as well as on the proportion of conifers (Fig. 6.7), resulted from averaging significant negative effects observed around non-ferrous smelters with significant positive effects observed around aluminium industries.

The only stand characteristics that decreased around all types of polluters were basal area (Fig. 6.5) and height (Fig. 6.6). This conclusion is consistent with the large body of forestry literature (Kozlowski 1980; Smith 1981), as well as with the results of meta-analyses of plant growth in polluted areas (Chapter 4, Roitto & Kozlov 2007, Roitto et al. 2009). More generally, our data confirm the historically accepted opinion (Woodwell 1970; Kozlowski 1980; Smith 1981; Treshow 1984; Freedman 1989) that standing biomass, as reflected by height and basal area, decreases with pollution. Since plant biomass is often used as a proxy for productivity (Clements & Newman 2002), and trees form the larger part of vegetation biomass in forest ecosystems, we (in line with Odum 1985) conclude that aboveground productivity generally decreases with pollution.

At the same time, both field layer vegetation and mosses showed similar negative responses to pollution by different industries (Figs. 6.3 and 6.4). Although a decline in field layer vegetation near point polluters is widespread (Freedman & Hutchinson 1980b; Salemaa et al. 2001; Taylor & Fox 2001), mechanisms behind this effect remain unclear. An absence of regeneration on heavily toxic soils explains the steady decline of field layer vegetation in industrial barrens (Zverev et al. 2008), but we still lack an understanding of processes occurring at lower levels of pollution load. In particular, repeated attempts to experimentally reproduce the reduction of field layer vegetation generally failed; its cover did not change or even increased following applications of acid rain and heavy metals (Nygaard & Abrahamsen 1991; Shevtsova & Neuvonen 1997; Zobel et al. 1999). Of course, these experiments could be too short to mimic effects that became evident following decades of pollution impacts. Moreover, in our opinion, these small-scale experiments were initially condemned to failure due to the impossibility of reproducing landscape-level effects, such as modifications of microclimate (discussed in Section 9.1.1).

Another important finding of our analysis is geographical variation in vegetation responses to pollution. In particular, the cover of both field layer and mosses declines only around the northern polluters (Fig. 6.3), while stand basal area declines only around the southern polluters (Fig. 6.5). We suggest several explanations for this phenomenon. First, dense canopies of more productive southern forests intercept the larger part of pollutant deposition (Nieminen et al. 1999; Neal 2002), thus providing better shelter to field layer vegetation than sparse subarctic stands. Second, even slight effects on stand density in southern forests enhance light availability to forest floor vegetation, favouring growth of grasses and herbs (McClenahen 1978; Vacek et al. 1999) and thus alleviating direct negative effects of pollution. Responses to pollution may also depend on initial diversity and productivity of affected communities, as well as on climatic effects on mobility and toxicity of pollutants (Odum 1985; Chalcraft et al. 2008; Zvereva et al. 2008).

In our opinion, the inability to create a phenomenological model explaining the detected variability of plant community responses results, in particular, from a shortage of information about the pollution impacts on plant–plant interactions. Long ago it became apparent that the responses of trees to pollution may be quite different under competitive conditions in a forest stand from what would be expected from experiments conducted with single individuals or single species (West et al. 1980; Auerbach 1981). However, almost no research on this problem has been done since then; only 14% of presentations delivered at the fifteenth to twenty-first biennial International IUFRO Meetings for Specialists in Air Pollution Effects on Forest Ecosystems (Tesche & Feiler 1992; Cox et al. 1996; Bussotti et al. 1996; Anonymous 1998, 2000, 2004; Maňkovská 2002) reported the effects of pollution on biotic interactions, and of those, most described insect–plant and plant–mycorrhyza relationships. Thus, single-species studies still dominate in pollution ecology research.

The general theory predicts that in harsh abiotic environments, plant–plant interactions will be mostly facilitative, in contrast to the dominance of competition in optimal abiotic environments (Brooker & Callaghan 1998), and this pattern was recently observed in some studies conducted around the nickel-copper smelter in Monchegorsk (Zvereva & Kozlov 2004, 2007; Eränen & Kozlov 2007). The existence of positive interactions can partially explain why the effects of pollution on vegetation are expressed to a lesser extent than expected; adverse effects may be ameliorated by positive interactions between plants as well as between plants and mycorrhizal fungi (Zvereva & Kozlov 2004, 2007; Eränen & Kozlov 2007; Ruotsalainen et al. 2007, 2008).

To conclude, responses of plant communities to pollution are diverse, and the outcome of pollution impacts on vegetation strongly depends on both the polluter and the structure of the affected community. The effects of pollution on vegetation have frequently been overestimated due to generalization of patterns that were observed around non-ferrous smelters, which impose the most acute impacts on forests.

6.4.2 *Stand Regeneration*

Regeneration (or its absence) depends on (a) regeneration sources, i.e., seed production by extant plants and their accumulation in soil seedbanks, (b) seed germinability and seedling survival, and (c) growing space for regrowth. Although pollution has adverse overall effects on plant reproduction (Roitto & Kozlov 2007; Roitto et al. 2009), several studies revealed the presence of germinable seeds even in the most contaminated study sites (Komulainen et al. 1994; Huopalainen et al. 2000; Winterhalder 2000; Salemaa & Uotila 2001). And, at least in some situations, the number of germinable seeds did not change with the distance from the polluter (Salemaa & Uotila 2001). While revegetation from seed banks is often hampered by soil toxicity (Kozlov 2005b; Salemaa & Uotila 2001), an overall decrease in stand basal area and field layer cover with pollution (Figs. 6.3 and 6.5) may favour recruitment of some tree species in less toxic soils (Eränen & Kozlov 2009; Zverev 2009). Another important issue for forest regeneration is the effect of air pollution on seedling competitive ability (Merino et al. 2008), but we are not aware of studies explicitly addressing this problem (except for Eränen & Kozlov 2009).

Data on the density and diversity of seedlings and young trees were only rarely monitored along pollution gradients (Lehvavirta & Rita 2002; Zverev 2009). In our data set, the overall effect of pollution on forest regeneration did not differ from zero and was consistent among all groups of categorical variables (Fig. 6.8). This result contradicts observations conducted in industrial barrens, where natural regeneration is suppressed (Kozlov & Zvereva 2007a); however, industrial barrens are extremes that were only observed in some of our pollution gradients. On the other hand, the relative contribution of stochastic factors to regeneration processes may be rather high (up to 83% in a study by Kubota & Hara 1996), and therefore extreme spatial variation in both density and diversity of regrowth may have prevented us from detecting pollution effects, should they exist.

To conclude, our results disagree with conclusions that natural forest regeneration is always suppressed by pollution (Kozlowski 1980; Smith 1981; Treshow 1984; Freedman 1989). An absence of regeneration occurs only in industrial barrens that have developed around non-ferrous smelters.

6.4.3 *Diversity of Vascular Plants*

As mentioned in Chapter 1, ecologists still have no unequivocal answer to an eternal question: Does industrial pollution always result in lower biodiversity? It has long been accepted that undisturbed communities have the highest species richness (Margalef 1968; Odum 1985). An alternative hypothesis suggests that species richness is maximised at intermediate levels of disturbance (Grime 1973; Connell 1978) because superior competitors and disturbance-tolerant species may coexist only at these conditions. It was also suggested that disturbance may increase diversity in communities, the initial diversity of which is low (Odum 1985).

There is no doubt that pollution is one of the factors contributing to destruction of natural habitats (Barbault 2001). On the other hand, habitats deteriorated by pollution may serve as refugia of rare and endangered species (reviewed by Kozlov & Zvereva 2007a). The absence of correlation between pollution load and diversity has been reported for different groups of insects from impact zones of several polluters (Kozlov 1997; Kozlov & Zvereva 1997; Butovsky & Gongalsky 1999; Brandle et al. 2001; Kozlov & Whitworth 2002; Ermakov 2004; Kozlov et al. 2005b), and a meta-analysis of published data yielded zero overall effect of pollution on diversity of terrestrial arthropods (Zvereva & Kozlov 2009). Thus, the validity of the widespread opinion that polluted habitats generally display a reduction in diversity (Magurran 1988) can be questioned.

The overall effect on species richness (α diversity) of vascular plants in our sample of 14 point polluters did not differ from zero (Fig. 6.9). This result contradicts the robust adverse effect of pollution on floristic diversity detected by a meta-analysis of published data (Zvereva et al. 2008) that yielded an effect two times stronger ($z_r = -0.78$; Zvereva et al. 2008) than meta-analysis of the original data ($z_r = -0.31$; Fig. 6.9).

The difference in outcomes of these two meta-analyses may indicate that the choice of polluters by authors of the published papers was biased; the polluters with evident changes in plant communities were preferentially selected to study effects on plant diversity (object selection bias). Combined with the previously discovered publication bias (journals tended to publish studies that agree with the general paradigm, i.e., adverse effects of pollution on biodiversity; Zvereva et al. 2008), our results indicate that a negative effect of pollution on plant diversity is overestimated. This gives special importance to an exploration of factors contributing to high variation in response patterns around different polluters; observed effects (Table 6.41) varied from strongly negative (e.g., around Karabash and Revda) to neutral or even positive (e.g., around Kostomuksha and Vorkuta).

A positive correlation between changes in cover and in species richness confirms the hypothesis (Kozlov et al. 1998) that the magnitude of decline in species richness with an increase in pollution is overestimated due to a confounding decrease in plant abundances. Similar overestimation of adverse effects on species richness was recently discovered for terrestrial arthropods (Zvereva & Kozlov 2009). Thus, methodologies need to be developed and additional data collected to clearly separate effects on plant diversity from effects on plant abundance.

Furthermore, a pronounced discrepancy in mean effects of aluminium smelters between published studies ($z_r = -1.45$; $N = 4$ polluters; Zvereva et al. 2008) and original data ($z_r = -0.06$; $N = 5$ polluters; Fig. 6.9) can be seen as an indication of research bias acting via selection of 'representative' study sites in such a way that presumed adverse effects are most evident. On the other hand, the discrepancy in conclusions on the effects of aluminium smelters may have resulted from changes in environmental regulations. Data used in an earlier meta-analysis were collected between 1962 and 1989, when emissions of pollutants were generally higher (see Sections 1.2 and 2.2.2) than in the 2000s, when the original data were collected.

In agreement with earlier conclusions, the strongest negative effects were detected around non-ferrous smelters. All six smelters included in our analysis caused dramatic changes in plant communities, including development of industrial barrens that represent an extreme state of pollution-induced ecosystem deterioration (Kozlov & Zvereva 2007a). A strong effect of these smelters on vegetation may be explained by a combination of soil acidification, accumulation of heavy metals, and landscape-level changes leading to loss of topsoil (Chapter 3) and unfavourable changes in microclimate (see Section 9.1.1 for discussion).

Although the geographic distribution of surveyed polluters (Fig. 2.1) is not as extensive as in the meta-analysis of published data (Fig. 1 in Zvereva et al. 2008), conclusions on geographic variation in the magnitude of plant community responses to pollution are consistent between the published and original data sets. Our data confirmed a stronger negative impacts of polluters located in warmer climates for both non-ferrous smelters and aluminium plants (Fig. 6.9).

The existence of geographical variation in responses of plant communities to pollution is one of the most interesting findings of our meta-analyses. This result is especially intriguing because it is in contrast to the general opinion on the higher sensitivity (fragility) of northern ecosystems to different kinds of human-induced disturbances. A lower sensitivity of high-latitude plant communities to pollution impacts may result from several factors, including both community structure and behaviour of pollutants.

In a meta-analysis of published data, we linked stronger responses of southern plant communities with their higher diversity, because the magnitude of species loss under pollution impacts increased with the species richness of undisturbed communities (Zvereva et al. 2008). This result is consistent with theoretical predictions by Odum (1985), who expected lower or even positive effects of disturbances on communities with lower initial diversity. Although causal relationships cannot be inferred from our data, we suggest two possible explanations for the observed pattern. First, species living in more predictable southern environments (where species richness is higher) are less able to tolerate stress than species living in less predictable northern environments (Clements & Newman 2002), which may have evolved preadaptations (Rapport et al. 1985). Second, longer vegetation periods at lower latitudes increase the exposure of plants to pollutants, while higher temperatures and increased precipitation enhance mobility and increase the toxicity of pollutants (Cairns et al. 1975; Klein 1989; Tipping et al. 1999).

Data on the pollution effects on β and γ diversity are scarce; we are only aware of publications reporting the effects of experimental applications of acid rain, heavy metals and nitrogen deposition on plant diversity on different spatial scales (Zobel et al. 1999; Chalcraft et al. 2008). These publications demonstrated increases in between-plot variation in the floristic composition of experimental plots, i.e., increases in β diversity. However, this experimental result contradicts observations of decreases in the spatial variability of structural and functional characteristics of forest litter with pollution (Bringmark & Bringmark 1995; Vorobeichik 1997). Although we did not detect pollution effects on β and γ diversity, an absence of correlations between patterns observed on different spatial scales suggests that extrapolation of the results obtained at the lowest hierarchical level may substantially bias our conclusions on the impact of pollution on biodiversity on larger spatial scales.

Finally, comparison of our results with *a priori* predictions (Table 6.42) demonstrated, that only non-ferrous smelters changed the composition of affected communities, acting via selective removal of some (presumably the most sensitive) species; both species richness and the similarity between polluted and clean sites decreased with pollution. Polluted sites around large non-ferrous smelters, such as Karabash (Table 6.30) and Monchegorsk (Table 6.32), did not contain any species that were absent in controls, suggesting an absence of colonisation. In contrast to non-ferrous industries, effects of aluminium smelters were minor relative to random variation.

To conclude, our data suggest that adverse effects of pollution on plant diversity are generally overestimated. We observed decreases in α diversity and changes in species composition only around non-ferrous smelters; moreover, the magnitude of these effects may appear smaller when a decline in plant abundances is accounted for. Adverse effects were better expressed in southern regions with higher initial diversity.

6.4.4 Temporal Changes in Plant Community Structure

What is the fate of polluted ecosystems? This question is vital for forestry worldwide, as the proportion of forested areas affected by relatively high levels of pollutant deposition is predicted to substantially increase by 2050 (Fowler et al. 1999). Maintenance of forests in polluted areas requires more intensive management than in unpolluted areas, involving 'soft' techniques and highly skilled manual labour. Regular curative measures, forming the basis for silviculture in polluted areas, should be preventive, improving the ecological stability of stands in such a way that they will better resist unavoidable pollution impacts (Kozlov 2004). Therefore, understanding pollution effects on the development of plant communities is badly needed to develop management practices for sustainable development of polluted regions.

Our understanding of changes in vegetation structure and productivity under pollution impacts is hampered by a shortage of long-term observations, documenting both the decline and recovery of vegetation following increases or decreases in pollution loads. This gives special importance to studies conducted in the Sudbury area (Anand et al. 2005) and in other areas recovering after closure of polluters (Wagner 2004) or substantial emission declines (Zverev 2009). However, temporal changes in plant communities can be inferred from static succession analysis, i.e., by comparing simultaneously collected data from study sites that presumably are at different succession stages.

Gordon and Gorham (1963) described pollution-induced changes of vegetation as peeling off the layers of forest structure: first the trees, followed by tall shrubs, and finally, under the severest conditions, the short shrubs and herbs. The similarity of this process with vegetation changes caused by chronic irradiation allowed Woodwell (1970) to suggest the generality of this 'downward' pattern of ecosystem destruction, later called 'the syndrome of spatial decline of the vertical strata of the terrestrial vegetation' (Freedman 1989). However, our meta-analysis demonstrated that this sequence, although recorded in some case studies, cannot be seen as a rule. Moreover, we have found the general pattern to be exactly opposite: field layer vegetation declines with pollution more strongly than top-canopy and understorey plants (Figs. 6.1–6.3). Also, the appearance of heavily polluted sites indicates that on many occasions, the field layer suffers first, disappearing while trees continue to grow on bare or nearly bare ground (please see color plates 22, 36 and 54 in Appendix II).

Both the severity and duration of pollution impacts may have contributed to variable outcomes of studies addressing temporal changes in polluted communities. Extreme levels of environmental contamination, existing near large point polluters, acted as selection factors eliminating not only sensitive species but also sensitive genotypes of more tolerant species; progenies of survivors showed increased tolerance to pollution (Bradshaw & McNeilly 1981; Macnair 1997; Kozlov 2005b; Eränen 2008; Eränen et al. 2009). On the other hand, inertia existing in plant communities (Milchunas & Lauenroth 1995; Zverev 2009) decreases the rate of pollution-induced changes in the abundance of long-lived plants, explaining their prevalence in severely stressed communities of industrial barrens (Kozlov & Zvereva 2007a). This pattern contradicts the hypothesis by Odum (1985) that the proportion of opportunistic species should increase with stress.

Woodwell (1967) suggested that the changes that occur in forest communities with severe disturbances (more specifically, under chronic radiation) tend to be just the reverse of those occurring during a normal (e.g., post-fire) succession. Later on (Woodwell 1970), he found many similarities between plant community deterioration under chronic radiation (Woodwell 1967) and chronic pollution (Gorham & Gordon 1963). Odum (1985) listed a reversal of succession among the general ecosystem responses to abiotic stress. This conclusion, accepted by a number of ecologists (Sigal & Suter 1987; Treshow & Anderson 1989), seems to be based on the following effects observed in stressed communities: (a) lower diversity, (b) poor stratification due to the elimination of woody plants, and (c) selection for rapid growth forms (partially due to the elimination of woody plants). However, our analyses cast doubts on the generality of all these phenomena, and plant communities affected by chronic pollution (please see color plates 9–11, 20–23, 29, 32–39, 45–47, 49, 53, 54 and 59 in Appendix II) differ substantially from communities representing early stages of post-fire succession. A decrease in productivity with pollution (Section 6.4.1) also contradicts an assumption on succession reversal, since productivity generally decreases in the course of succession (Odum 1969b). Moreover, Liu et al. (2007) concluded that sulphur dioxide, by damaging more sensitive pioneer species, can accelerate succession rather than reverse it.

Our data also demonstrated that pollution did not change the species composition of seedlings of top-canopy species. This result is interesting in view of the paradigm of decreasing similarity between seed banks and vegetation as succession proceeds (Thompson 2000). Although this paradigm has repeatedly been questioned, and temporal patterns of similarity between seed banks and vegetation differed widely among studies (Wagner et al. 2006), our data can still be seen as an indication of the relatively stable state of polluted forest ecosystems.

To conclude, we have not found any indication of succession reversal under pollution impacts. Moreover, we did not detect any dynamic process that may lead to further shifts in vegetation structure, e.g., by selective species removal or by species replacement due to altered composition of regrowth. All explored polluters have been functioning for decades, and therefore transition of plant communities from an unpolluted to a polluted state seems to be already completed. An absence of a transitional zone is most likely the result of relatively stable or decreasing amounts of emissions.

6.5 Summary

Although point polluters may drastically change both the structure and diversity of surrounding vegetation, pollution effects are not uniform and therefore cannot be generalized. Responses of plant communities demonstrated significant variation in respect to both type and geographical position of the affected community. Effects of non-ferrous smelters/acidifying polluters on most community characteristics (vegetation cover, stand basal area, proportion of conifers among top-canopy plants, diversity of vascular plants) were significantly negative, while the effects of aluminium smelters/alkalysing polluters were generally neutral or even positive. Geographical variation was inconsistent among explored community characteristics; stand basal area and plant diversity decreased around southern polluters, while the cover of field layer vegetation decreased around the northern polluters. We conclude that the adverse effects of point polluters on vegetation have been overestimated due to research and publication biases, as well as due to the tendency of both narrative reviews and textbooks to use the most striking examples of community deterioration around non-ferrous smelters to illustrate pollution impacts on terrestrial biota.