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Diatom and microarthropod communities of three airfields in Estonia – their differences and similarities and possible linkages to airfield properties

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ABSTRACT

Even though airfields, which are often anthropologically modified natural areas, are continuously influenced by human activities, their soils are still dynamic ecosystems containing various habitats for microscopic groups of organisms which are often ignored. In this exploratory study, the microarthropod fauna, Collembola (Hexapoda) and oribatid mites (Acari: Oribatida), and diatom (Bacillariophyta) flora were identified in three Estonian airfields, both runway sides and snow-melting sites were investigated. The communities of these airfields shared approximately 10–60% of the species belonging to each studied bioindicator group. The shared species were generally characteristic of a broad habitat spectrum. Communities were also characterized based on their species richness and diversity and in relation to location and the purpose of different airfield areas (e.g. snow-melting sites vs. runway sides). Also, species indicative of a specific airfield or purpose of the area within the airfield were identified using Indicator Species Analysis. Some possible linkages between airfield properties and communities, e.g. airfield that had highest pollutant concentrations had also maintained high diversity and species richness, were noted. Despite the contamination levels the airfield soils had still maintained a functioning soil ecosystem.

KEYWORDS

airfields, soil, Oribatida, Collembola, diatoms, bioindicators

INTRODUCTION

Civil aviation is a fast-growing industry driven by globalisation. Previously the environmental impacts of aircraft emissions (Moussiopoulos et al. 1997; Rissman et al. 2013), noise (Vanker et al. 2013), de-icing chemicals (Turnbull & Bevan 1995) and polycyclic aromatic hydrocarbons (Ray et al. 2008) have been studied. Also, airfield vegetation and wildlife studies are common (Servoss et al. 2000; Blackwell et al. 2008, 2009; Belant et al. 2013; Fischer et al. 2013). However, in the context of airport soils and anthropogenic soils in general, there is less information (Pytka et al. 2003; Baran et al. 2004; Ray et al. 2008; McNeill & Cancilla 2009; Werkenthin et al. 2014). Even more scarcely studies on airfield soil biota have been conducted. Among the few exceptions is a study exploring the microarthropod communities in the area of Orio al Serio Airport in Bergamo, Italy (Migliorini et al. 2003) and another studying the development of earthworm communities on translocated grassland turf from Manchester airport, United Kingdom (Butt et al. 2003). Research on urban microarthropod communities are more common. The subjects range from roadside soils (Eitminavičiūtė 2006a,b; Magro et al. 2013) to urban soil quality assessment (Santorufo et al. 2012).

Soil mites, including Oribatida (Acari), are considered fairly resistant towards anthropogenic activities (Skubała 1997; Khalil et al. 2009; Santorufo et al. 2012), however their species specific response to various disturbances and environmental changes make them valuable bioindicators (Paoletti & Bressan 1996). Other soil microarthropods such as springtails (Hexapoda: Collembola) and other mite orders are considered less sensitive towards traffic related environmental changes, though this does not lessen their importance as potential bioindicators (Paoletti & Bressan 1996 ; Eitminavičiūtė 2006a), e.g. when and where other groups are only present in low numbers. Many microarthropod species are also known for tolerating exposure to heavy metals due to their accumulative properties, which makes them suitable for studying aviation related disturbances

(Van Straalen & Van Wensem 1986; Heikens et al. 2001). Diatoms, mostly known from their bioindication abilities in water (Dickman 1998), are so far less used for in soil ecological research, but can still be considered as potential indicators of soil habitat properties (van Kerckvoorde et al. 2000; Van de Vijver et al. 2008; Heger et al. 2012; Vacht et al. 2014).

Based on previous studies from urban areas and traffic related disturbances (Santorufo et al. 2012) the following hypotheses were set: Although, microarthropod and diatom communities vary between the airfields the communities at the studied airfields also share a substantial percentage of species which can be considered typical to areas affected by intensive traffic related disturbances such as airfields; Diatom and microarthropod (Collembola and oribatid mites) species indicative of specific airfields and the purpose of different airfield areas can be identified.

This pilot study aims (1) to describe and analyze the microarthropod fauna and diatom flora of Tallinn, Tartu and Pärnu airfields and their community parameters; (2) to identify the extent of the shared community of each bioindicator group in comparison of the three airfields and the components of the shared community; (3) to attempt to identify whether the studied airfield soils have maintained their functionality based on their biological properties. These aims were achieved.

1. MATERIAL AND METHODS

1.1. Study sites

Three Estonian airfields (Fig. 1) were selected based on their accessibility, aviation history, availability of background information and natural conditions for studying soil communities. The main characteristics of these three airfields are shown in Table 1. Based on the soil maps provided by Estonian Land Board (http://geoportaal.maaamet.ee/est/Kaardiserver/Mullakaart-p96.html), the soils of Tallinn airfield range from Rendzi Leptosols to Histosols. In Tartu the soils have been classified as Luvisols influenced by excess moisture (gleying) and in Pärnu airfield as Gleysols. Since their classification, several decades ago, they have been subject to draining in various extent.

The three airfields have experienced aviation related disturbances in various extents. For example, Tallinn airfield today acts as the primary airfield in Estonia with highest passenger and aircraft movement numbers and also receives intensive maintenance activities. Tartu airfield has low usage intensity but has been most recently (< 15 years) reconstructed, including partial removal and filling of soil. Pärnu airfield, on the other hand, is today only used for a few regional flights, but has been under extensive military use during the Soviet era (1940-1991) which may have resulted in high exposure to aviation related pollutants. Therefore, it is impossible to place the airfields on a clearly definable anthropogenic disturbance gradient.

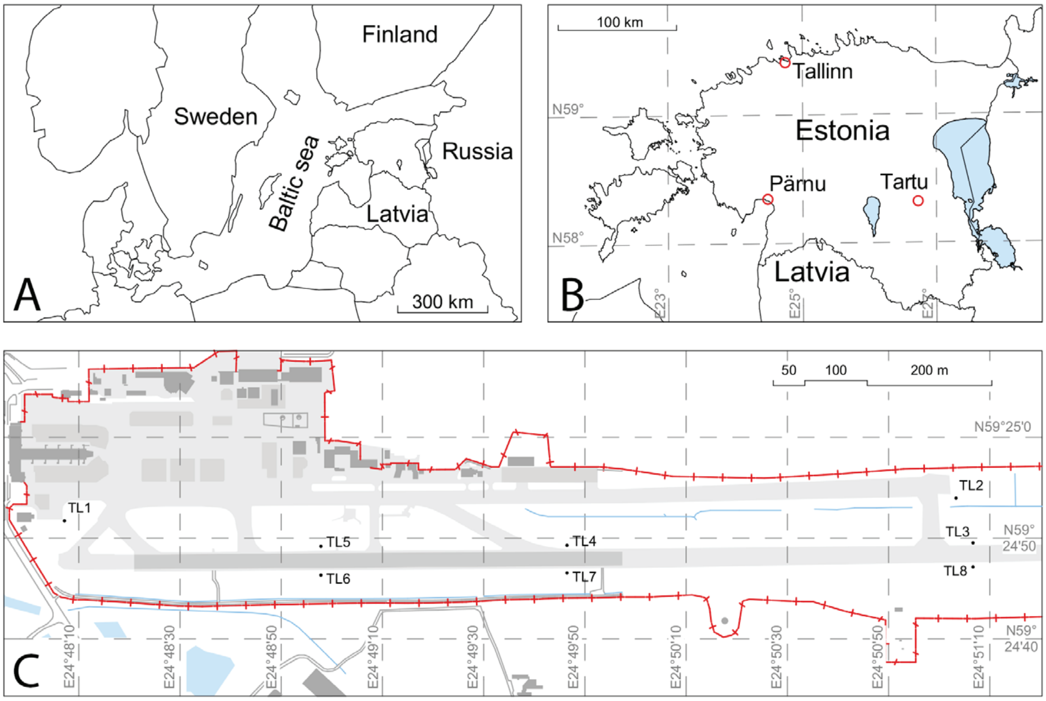
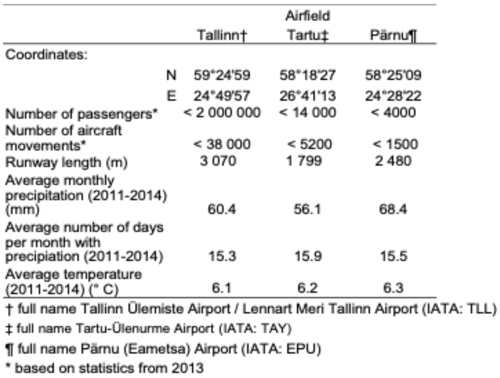


Figure 1. Location of study sites in north-eastern Europe (A) and in Estonia (B) and general sampling design within the airfields (C) where TL1 and TL2 mark the sampling sites on slow-melting sites, and TL3 through TL8 mark the runway side sampling sites.

Table 1. Characteristics of Tallinn, Tartu and Pärnu airfields



			Airfield	
		Tallinn†	Tartu‡	Pärnu¶
Coordinates:				
	N	59°24'59	58°18'27	58°25'09
	E	24°49'57	26°41'13	24°28'22
Number of passengers*		< 2 000 000	< 14 000	< 4000
Number of aircraft movements*		< 38 000	< 5200	< 1500
Runway length (m)		3 070	1 799	2 480
Average monthly precipitation (2011-2014) (mm)		60.4	56.1	68.4
Average number of days per month with precipiation (2011-2014)		15.3	15.9	15.5
Average temperature (2011-2014) (° C)		6.1	6.2	6.3

† full name Tallinn Ülemiste Airport / Lennart Meri Tallinn Airport (IATA: TLL)

‡ full name Tartu-Ülenurme Airport (IATA: TAY)

¶ full name Pärnu (Eametsa) Airport (IATA: EPU)

* based on statistics from 2013

1.2. Sampling procedure and laboratory analysis of samples

Sampling was conducted in September, 2013, and repeated in September 2014. In addition to six sampling points at runway sides also two snow-melting sites were sampled from each airfield. Fig. 1 shows the general sampling design at each airfield. Because sampling at the airfields was to some extent restricted (e.g the allowed time for sampling and the volume of soil removed from the site) eight samples were collected for this explorative study from each airfield each year (in total 48 samples of each bioindicator group). A ø 5 cm soil auger was used to collect samples from 0-10 cm of topsoil (196 cm^3) for microarthropod (oribatid mites and springtails) and diatom extraction, microbial measurements and soil chemical analysis.

Microarthropods were extracted using Berlese-Tullgren funnel until samples were fully dry (at least 72 hours) and stored in 90% ethanol. For clearing purposes 80% lactic acid was used for oribatid mites. Samples were hand sorted and identified by species. Keys by Fjellberg (1998; 2007) and Hopkin (2007) were used to identify adult Collembola. The nomenclature follows Bellinger et al (1996-2018). For the identification of adult oribatid mites keys by Weigmann (2006) and Niedbala (2008) were used. The nomenclature follows Weigmann (2006).

For diatom analysis soil samples (N = 24) were mixed and 2 cm^3 of soil was extracted, then treated with 10% HCl and 30% H_2O_2 while heating the samples to remove carbonates and organic matter. Samples were decanted and centrifuged to remove other unnecessary components. The solution (0.1 ml) was transferred to cover glass, dried and fixed with Naphrax. Samples were examined under 600–1000 × magnification (using immersion oil nd = 1.516). From each sample 300–500 valves were identified and counted along random transects. Damaged valves were counted as a separate individual when more than half of the valve was intact. Diatoms were identified to species level and when this was impossible due to damages, to genus level (Krammer & Lange-Bertalot 1988, 1991; Hamilton et al. 1992; Lange-Bertalot & Metzeltin 1996; Round & Bukhtiyarova 1996; Lange-Bertalot & Metzeltin, 1996; Lange-Bertalot, 1997; Krammer, 2000; Compère, 2001; Lange-Bertalot et al. 2011; Souffreau et al. 2013; Lowe et al., 2014). The nomenclature follows Krammer & Lange-Bertalot (1988; 1991) with additions from newer taxonomic literature (e.g Compère, 2001; Lange-Bertalot et al. 2011).

Soil parameters were measured to characterize the airfields in general, not to link them directly to soil communities, therefore, the soil samples from each airfields were pooled. These samples were analyzed at the Estonian Environmental Research Center with ICP-AES for Cu, Pb, Zn and Cd because these metals are considered most indicative of traffic related pollution (Davis et al. 2001). Samples were also analysed for total-N, P and K, Ca, Mg and pH_{KCl} at the Estonian Agricultural Research Centre. Soil organic matter and carbonate content was measured using loss-on-ignition method (prepASH®, Precisa). Soil microbial respiration rates (basal respiration) and Substrate Induced Respiration (SIR) were determined using manometric respirometers (Oxitop®, WTW).

1.3. Data analysis

Species data from two years of sampling were pooled for numerical analyses. Communities were described by observed Collembola and oribatid mite abundance per sample, presence-absence data was noted for diatoms. Because all microarthropod communities from the same volume of soil were identified and counted, only their observed species richness were calculated. Diatom communities were described based on rarefied species richness (Heck et al. 1975; Oksanen 2012). All bioindicator groups were characterized based on community diversity (Shannon's H). Also the Oribatida Collembola ratio (O/C) was calculated for each airfield. The number of repetitions for soil chemical and microbial analysis was limited due to fieldwork restrictions and therefore this data was only analyzed using descriptive statistical methods to give an overview on general soil characteristics.

Kruskal-Wallis test, ANOVA, and average linkage cluster analysis based on Bray-Curtis dissimilarity were used to compare the communities of Tallinn, Tartu and Pärnu airfields and the different land uses within airfields (runway sides and snow-melting fields). Indicator Species Analysis (ISA) (Dufrene & Legendre 1997; De Cáceres & Legendre 2009) together with Monte Carlo randomization technique for testing the statistical significance ($P < 0.05$) of Indicator Values (IV) was used to identify potential indicator species. Community parameter calculations, descriptive and generalising analyzes were conducted using R programming environment (R Development Core Team 2014) with the 'indicspecies' (De Cáceres & Legendre 2009), 'MASS' (Venables & Ripley 2002) and 'vegan' (Oksanen 2013) package, and IBM SPSS Statistics 20.0.

2. RESULTS

2.1. Soil properties

Although the soil maps provided by Estonian Land Board show some differences between the three airfield soils and all of them have maintained some characteristics of the original soils (e.g. higher carbonate content in Tallinn) they have all been affected by aviation, airfield maintenance, and aviation related construction activities e.g. draining, tilling, removal and filling. An overwhelming area of these soils can today be classified as Technosols (IUSS Working Group WRB 2015), characterized by a dense and tightly rooted mull type humus horizon that contains various artifacts such as pieces of glass, aluminium, plastic, paint and runway construction materials. Table 2 lists the results from soil chemical analyses, including results from a previous study on Tallinn airfield soil (Keskküla 2011), and soil microbial parameter measurements.

2.2. Community properties

The results from community properties are shown in Table 3 separating between the runway sides and snow-melting sites. On Pärnu airfield the oribatid mites outnumbered the Collembola (O/C ratio 3.0). In Tallinn the O/C ratio was 0.8 and in Tartu 0.5.

2.3. Collembola community composition

In total 31 springtail species were identified, belonging to 22 genera. The most abundant species, forming 31% of the total abundance, was *Protaphorura armata* Tullberg, 1869. The snow-melting sites of the three airfields shared five springtail species: *Anurida granaria* Nicolet, 1847, *Metaphorura affinis* Börner, 1902, *P. armata*, *Parisotoma notabilis* Schaeffer, 1896 and *Ceratophysella* sp. Runway sides shared 11 species, including almost all of those also found from snow-melting sites (except *Ceratophysella* sp). In addition, the airfield runway sides also shared *Folsomia candida* Willem 1902, *Folsomia sexoculata* Tullberg, 1871, *Isotoma minor* Schaeffer, 1896, *Isotoma viridis* Bourlet, 1839, *Isotomurus* sp., *Tomocerus vulgaris* Tullberg, 1871 and *Lepidocyrtus lanuginosus* Gmelin, 1788.

An explorative average linkage cluster analysis revealed that based on the springtail communities the three airfields cannot be distinguished from each-other. The part of the community not shared by all studied airfields can be considered site specific, possibly depending on the natural conditions (e.g. hydrological regime, soil development prior to aviation related activities) and anthropogenic history (e.g. history and placement of the filling soil on site, type and quantity of de-icing chemicals) of each site. These site specific species included e.g. *Bourletiella arvalis* Fitch, 1863 (characteristic of Tartu airfield), *Micranurida pygmaea* Börner, 1902 (characteristic of Pärnu airfield) and *Folsomia quadrioculata* Tullberg, 1871 (characteristic of Tallinn airfield).

Table 2. Results from soil chemical and microbial analysis. Heavy metal and oil product (C10-C40) concentration result ranges for Tallinn (*) are based on previous research (Keskküla 2011), others are based on a single result from repreated measurements (N=10) or expressed as Mean ± SE as provided by the laboratory

	Airfield		
	Tallinn	Tartu	Pärnu
Oil products C10-C40 (mg/kg)	55 – 109*	45	170
Pb (mg/kg)	9.26 – 23.70*	7.7	7.9
Zn (mg/kg)	23.60 – 54.50*	42.3	134
Cu (mg/kg)	12.50 – 14.80*	15.9	16.3
Cd (mg/kg)	< 0.001	< 0.001	< 0.001
pH_{KCl}	7.2	6.5	7.3
P (mg/kg)	34.0 ± 0.0	37.3 ± 3.8	31.8 ± 0.2
K (mg/kg)	567.3 ± 1.8	93.8 ± 1.1	158.5 ± 25.9
Total N (%)	0.27 ± 0.03	0.31 ± 0.01	0.52 ± 0.01
Organic matter content (%)	19	27	24
Carbonate content (%)	2.93	1.87	7.37
Basal respiration (mg O_2/kg DM × h)	3.83	3.73	6.10
Substrate Induced Respiration (SIR) (mg biomass C/g DM)	1.27	0.95	1.10

The list of all encountered species together with their abundance (per sample) at each airfield, separating between the runway sides and snow-melting sites is given in Appendix (Table A.1.). No significant differences were detected in the species abundance in comparison of the three airfields. In three-way ISA (Tallinn, Tartu and Pärnu airfield), springtails were not significantly strong indicators of any of the airfields singularly, but as a combination *M. affinis* (IV = 0.87, *P* = 0.02) and *T. vulgaris* (IV = 0.81, *P* = 0.011) were indicative of Pärnu and Tallinn airfields.

On Family level, *Neanuridae* were significantly more abundant at snow-melting sites compared to runway sides (χ^2 = 5.715, df = 1, *P* = 0.017). The trend was opposite for *Tomoceridae* (χ^2 = 6.611, df = 1, *P* = 0.01). Significant differences in species abundance depending on the purpose of the airfield area (runway side or snow-melting sites) were rare, only a few species showed significant difference – e.g. *T. vulgaris* (χ^2 = 6.611, df = 1, *P* = 0.01) and *L. lanuginosus* (χ^2 = 7.689, df = 1, *P* = 0.006) that were both only found on runway sides. Two-way ISA supported the assumption that these two species can be considered significantly indicative of airfield runway sides (IV = 0.85, *P* = 0.011 and IV = 0.82, *P* = 0.017 respectively). The results from ISA, where the sites were divided into six groups (separating between airfields, their runway sides and snow-melting sites) showed that *T. vulgaris* (IV = 0.93, *P* = 0.01) and *L. lanuginosus* (IV = 0.93, *P* = 0.003) are more specifically strongly and significantly associated with the combination of Tallinn and Tartu runway sides. These species, however, can not be considered ideal indicators of these runway sides because they can also be found on other sites in addition to the two runway sides (A = 0.9459 and B = 0.9429 respectively) and they cannot be found

Table 3. Collembola, oribatid mites and diatom community parameters (observed species richness for Collembola and oribatid mites, rarefied species richness for diatoms and diversity expressed by Shannon's H on the runway sides and snow-melting sites of Tallinn, Tartu and Pärnu airfields

		Airfield					
		Tallinn		Tartu		Pärnu	
		Runway sides	Snow-melting sites	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites
Collembola	Species richness	19	9	20	18	22	14
	Shannon's H	2.56	1.72	2.60	1.96	2.35	2.47
Oribatid mites	Species richness	24	10	9	6	16	10
	Shannon's H	2.77	2.06	1.27	1.10	1.98	2.06
Diatoms	Rarefied species richness	23	10	17	8	21	32
	Shannon's H	2.27	1.58	1.93	1.40	2.57	2.81

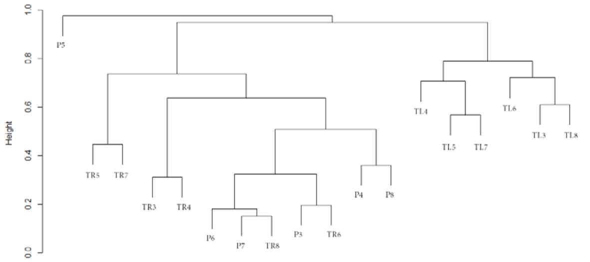


Figure 2. Average linkage cluster analysis of the oribatid mite samples collected from runways sides, abbreviation beginning with TL refer to Tallinn airfield, TR to Tartu airfield and P to Pärnu airfield, numbers stand for sampling sites within the airfield as shown on Fig.1.

from all the sampled sites on Tallinn and Tartu runway sides (B = 0.9167 for both).

2.4. Oribatida community composition

In total 34 oribatid mite species were identified, belonging to 22 genera. The majority of species found on airfield soils belong to suborder Brachypylina. The most abundant species were *Scheloribates laevigatus* Koch, 1836 and *Tectocepheus velatus velatus* Michael, 1880. These two species made up 37% of the total abundance, 19% and 18% respectively. While the snow-melting sites of the three airfields shared only one oribatid mite species, *T. velatus velatus*, the runway sides had five species incommon: *Liebstadia pannonica* Willmann, 1951, *Platynothrus peltifer* Koch, 1839, *S. laevigatus*, *Trichoribates incisellus* Kramer, 1897 and *T. velatus velatus*. The list of all encountered species together with their abundance (per sample) at each airfield, separating between the runway sides and snow-melting sites at each airfield is given in Appendix (Table A.2.).

No significant differences in oribatid mite species abundance depending on the purpose of the airfield area (runway side or snow-melting sites) or airfield were detected ($P > 0.05$). The explorative average linkage cluster analysis showed that at the snow-melting sites the oribatid mite communities were not differentiable based on the specific airfield. The communities belonging to the runway sides, however, formed a distinct group together with the communities on the Tallinn airfield, and separated them from the communities of Tartu and Pärnu (Fig. 2). No significant differences were observed in the abundance of oribatid mite species in comparison on runway sides and snow-melting sites nor in comparison of the three airfields.

Some site specific species such as *Eupelops acromios* Hermann, 1804 and *Nothrus silvestris* Nicolet, 1855, characteristic only of Tallinn airfield, and *Punctoribates punctum* Berlese, 1908, characteristic of Pärnu airfield, were encountered. When grouping the sites into six groups (separating between airfields, their runway sides and snow-melting sites) the ISA did not reveal any oribatid mite species that were significantly indicative. In three-way ISA *E. acromios* was significantly indicative of Tallinn airfield (IV = 0.79, $P = 0.01$). *S. laevigatus*, *T. velatus velatus* and *Eupelops hygrophilus* Knülle, 1954 were significantly ($P < 0.04$) linked to various combinations of two airfields. Even though *L. pannonica* inhabited only runway side soils, no significant indicators were found that could identify different land use within airfields.

2.5. Diatom community composition

In total 49 diatom species were identified belonging to 30 genera. The most abundant diatoms were *Hantzschia amphioxys* (Ehrenberg) Grunow, 1880 (26.1%), *Aulacoseira granulata* (Ehrenberg) Ehrenberg, 1843 (12.9%) and *Luticola mutica* (Kützing) Mann, 1990 (9.7%). The snow-melting sites shared five species, which in addition to the three most abundant species were *Fragilaria nitzschioides* (Grunow) Lange-Bertalot, 2011 and *Navicula cari* (Ehrenberg) Ehrenberg, 1836. The runway sides of the three airfields shared eight species. These included the most abundant diatom species mentioned previously and also *Pinnularia obscura* (Krasske) Patrik & Reimer, 1966, *N. cari*, *Humidophila contenta* (Grunow) Lowe et al., 2014 and *F. nitzschioides.* An explorative cluster analysis did not reveal notable similarities between the diatom communities of the three airfields, in comparison of the snow-melting sites and runway sides.

There were 12 diatom species that were specific to Pärnu airfield, including e.g. *Fragilariforma virescens* (Ralfs) Williams & Round, 1988 and several species belonging to the *Stauroneis* genus. The list of all encountered species at each airfield, separating between the runway sides and snow-melting sites is given in Appendix (Table A.3.)

The results from six-way ISA (separating between airfields, their runway sides and snow-melting sites) indicated that *Pinnularia lata* (Brébisson) Rabehorst, 1853 (IV = 0.985 $P = 0.016$), *Pinnularia borealis* (Ehrenberg) Ehrenberg, 1843 (IV = 0.957 $P = 0.041$) and *Diploneis finnica* (Ehrenberg) Cleve, 1891 (IV = 0.913 $P = 0.027$) are strongly and significantly associated with the snow-melting sites of Pärnu airfield. These three species can be used to indicate the snow-melting sites of Pärnu airfield because they appear on all sampled sites (B = 1.0000) and they are largely (but not completely) restricted to them (A=0.9706, A=0.9158 and A=0.8333 respectively). Also three other diatom species – *F. nitzschioides*, *L. mutica* and *D. finnica*) were significantly ($P > 0.05$) linked to snow-melting sites of all the studied airfields.

3. DISCUSSION

The concentrations of Pb and Zn were mildly elevated (Petersell et al. 1997) in Tallinn airfield. Pärnu airfield had elevated Zn content compared to normal levels in the region. Levels of Cd were high on all airfields (Petersell et al. 1997). Nevertheless, the concentration of measured heavy metals and oil products (C10–C40) remained lower than the limits set by Estonian Environmental Ministry (Riigiteataja 2010; Pinedo et al. 2014). While most soil parameters varied only moderately between the three airfields, elevated level of K was noted in Tallinn and higher organic matter content in Tartu compared to the other airfields. Overall, both K and organic matter content in the humus horizon can be considered high (Kask & Niine 1997;

Petersell et al. 1997). While in Tallinn the elevated K content is likely linked to historic soil conditions, the high organic matter content in Tartu airfield soil is more of a mystery, possibly tied to characteristics of the filling soil used in some parts of the airfield. Soil pH values, varying from slightly acidic to neutral, reflected the historic soil conditions, indicating also that the addition of construction and other aviation related substances has not raised the soil pH as often occurs in soils under anthropogenic influence (Maechling et al. 1974).

The SIR results showed similar results as measured from Estonian road-side grasslands (Vacht 2012), but exceeded the levels measured from e.g. semi-coke heap habitats (Kalda et al. 2015). Basal respiration rate was higher than measured from road-side soils (Vacht 2012). Soil basal respiration has been shown to indicate toxicity effects (e.g. Pb, Zn, Cu) in soils (Romero-Freire et al. 2016), but not in soils with high organic matter and carbonate content such as the soils encountered in this study. Also the indicativeness of substrate induced respiration has been known to depend greatly on soil pH (Cheng & Coleman 1989). The elevated respiration rate in Pärnu may be related to the increased levels of oil products in the airfield soil (Hund & Schenk 1994).

Diatom and oribatid mite species richness (rarefied species richness for diatoms) and diversity showed similar trends in comparison of the three airfields. Collembolan diversity varied greatly, showing no strong signs on indicativeness to airfield nor airfield area purpose. The oribatid mite and diatom community diversity were similar showing high diversity in the snow-melting sites of Tallinn airfield and lowest diversity in the runways sides of Tartu airfield. In Tallinn this difference could be caused by the nature of de-icing agents used, and in Tartu the decreased diversity could potentially be linked to recent runway construction work.

Springtail communities were dominated by *P. armata* and *P. notabilisi*, which are known to inhabit highly disturbed areas (Migliorini et al. 2003; Eitminavičiūtė 2006a,b). Collembolans are considered as a relatively resistant group to anthropogenic disturbances (Bengtsson & Rundgren 1988; Haimi & Siira-Pietikäinen 1996), however, their community composition is known to respond to human-induced disturbances, especially by decreasing numbers of *Isotomidae* and *Onychiuridae* and increasing abundance of less demanding *Entomobryidae* and *Neanuridae* (Sousa et al. 2003; Magro et al. 2013). This study, however, did not encounter a strong shift in most of these groups in comparison of the three airfields nor in comparison of the snow-melting sites and runway sides. Only *Neanuridae* (e.g. *A. granaria* and *M. pygmaea*) were more abundant at the snow-melting sites, which may indicate that these areas present a suitable niche for these species. For *Entomobryidae* (e.g. *L. lanuginosus* and *L. cyaneus*) the change in abundance was opposite, making it difficult to interpret either the runway sides nor snow-melting sites as the more demanding habitat. Some studies also point out that epedaphic (Pernin et al. 2006) *L. lanuginosus* may be indifferent to soil contamination levels (Austruy et al. 2016). The comparison the Collembolan families of the three airfields did not reveal any significant differences in abundances, indicating that solely based on these parameters, the airfields cannot be ranked according to their disturbance level.

The community similarity of different airfields and airfield area purposes together with the number and percentage of shared species suggest fairly homogeneous Collembolan communities. The typical airfield springtail community consists of *A.granaria*, *M. affinis*, *P. armata*, *P. notabilis*, and likely also species belonging to *Folsomia* and *Isotoma* genera.

Most of the oribatid mites found in this study (e.g. *P. punctum, S. laevigatus*) are widespread eurytopic species, usually forming the main body of edaphic communities in most disturbed landscapes in Europe (Caruso et al. 2009). The species composition of Oribatid mites resembled those of Lithuanian urban soils (Eitminavičiūtė 2006a,b) containing dominant *T. velatus velatus* and *S. laevigatus*. The latter has also been found from the area of Orio al Serio Airport in Northern Italy (Migliorini et al. 2003). The low abundance of *Oppiella nova* Oudemans, 1902 could be due to high soil pH as noted by previous studies (Eitminavičiūtė 2006a,b). Also typically moss-dwelling (Smrž 1994) *Scutovertex minutus* Koch, 1835 was found from all sites, however, only abundantly from one of the snow-melting sites in Tartu (site TR1). Previously this species has been found from the immediate proximity to the roads (Eitminavičiūtė 2006a,b) possibly showing its high tolerance towards de-icing agents and preference for hydric conditions. Some research suggest the species has a high tolerance for fluctuating abiotic soil parameters (e.g. moisture) (Smrž 1994). Also *T. incisellus, L. pannonica* and *Peloptulus phaenotus* Koch, 1844 have been previously encountered in heavy metal contaminated soils (Caruso et al. 2009; Skubała & Zaleski 2012). Therefore, the community that can be considered typical to airfields contains the following species: *T. velatus velatus*, *L. pannonica, P. peltifer*, *S. laevigatus* and *T. incisellus.* Compared to springtails the oribatid mite communities show more variability, especially in comparison of different airfield area purposes. This is why in the future, especially the effects of airfield de-icing agents on oribatid mite communities should be studied in more detail.

The dominant diatom species were the cosmopolitan *H. amphioxys, A. granulata and L. mutica*. All the studied airfields contained the same base soil community, that has also previously been found from many soil habitats both in Estonia (Vacht et al. 2014) and elsewhere (Soare & Dobrescu 2010; Heger et al. 2012) that represent a tolerant algal community which has little bioindication value that is particular to airfields. Nevertheless, the shared species of the three airfields (e.g. *F. nitzschioides*, *H. amphioxys*, *N. cari*, *L. mutica*) can be expected to be found on also other similar airfields. Also it is possible that some species (e.g. *D. finnica*) may indicate snow-melting sites mostly due to increased moisture, which are less suitable habitats for microarthropod communities. This is one of the reasons why microarthropods and diatoms should be considered as complementary bioindicator groups in soil ecological research. The ISA revealed that in comparison of the three bioindicator groups, diatoms and springtails were the most indicative on specific airfield or land use. Based on this, oribatid mites can be considered fairly robust towards airfield related disturbances.

Soil functionality is closely related to the concept of soil quality which in turn has the capability to sustain among other things biotic communities (Gardi et al. 2002). All the airfield soils are functional soils, containing a well adapted and comparatively diverse community of diatoms, springtails and oribatid mites. It has been noted on several occasions that using bioindicators should be incorporated into evaluation of soil functionality and quality of anthropogenic soils (Hartley et al. 2008). The community composition found on these airfields indicates that all main functional groups of microarthropods are present, though fungal feeders were prominent (e.g. *T. velatus velatus*, *S.* laevigatus). This means that the habitat must contain also sufficient food sources for all groups present.. Also high ratio in Acarina/Collembola may suggest high soil quality because there are known to be less mites than springtails in degraded soils (Parisi et al. 2005). The results of the O/C ratio indicates well that in an anthropogenic grassland such as airfields it is vital to include both oribatid mite and springtail identification due to the variation of the dominant group, to receive a full overview of the microarthropod communities before combining the data with diatom community data. The ratio reflects also the dominant soil process – humification over mineralization in Pärnu and mineralization over humification in Tallinn and Tartu. The elevated O/C ratio (>1) can be also considered a measure of environmental stability (Bachelier 1986) which means Pärnu airfield can be considered as the most environmentally stable out of the three airfields studied.

4. CONCLUSION

While an overwhelming area of the three airfields show characteristics of Technosols, they also show properties of the natural soils which despite the moderately elevated levels of pollutants have maintained fully functional soil biological communities. Microarthropod and diatom community parameters show more similar variation than springtail communities depending on the airfield and the purpose of the particular airfield area. All three bioindicator groups had a substantial percentage of species that can be considered typical to areas affected by disturbances, in this case airfields. These species include springtails e.g. *M. affinis* and *P. notabilis*, oribatid mites *T. velatus velatus*, *L. pannonica* and *T. incisellus,* and diatoms *F. nitzschioides*, *H. amphioxys* and *L. mutica.*

Collembola species *L. lanuginosus* and *T. vulgaris* were significantly indicative of airfield runway sides but no strong indicators of specific airfield were discovered. Oribatid mites were not indicative of different airfield purposes, only *E. acromios* was noted as indicative of Tallinn airfield.

Three diatom species, *F. nitzschioides*, *Luticola mutica* and *D. finnica,* were significantly linked to airfield snow-melting sites. Also, many diatom species were specific to Pärnu airfield.

In conclusion, it is clear that despite aviation related disturbances these three airfields have maintained a functional soil biological community that has adapted well to these conditions. Also, the shifts in O/C ratio and variation in the community parameters of the three groups indicates the potential of these three groups as complementary bioindicators of anthropogenic disturbances. Further studies are needed to confirm the connections between these bioindicators and specific soil parameters.

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APPENDIX

Table A1 Collembola

	Tallinn		Tartu		Pärnu	
	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites
Collembola						
Anurida granaria (Nicolet, 1847)	0.3 ± 0.2	1.0 ± 1.0	0.2 ± 0.2	3.0 ± 3.0	0.2 ± 0.2	0.5 ± 0.5
Bourletiella arvalis (Fitch, 1863)	-	-	0.2 ± 0.2	0.5 ± 0.5	-	-
Ceratophysella bengtssoni (Ågren, 1904)	4.7 ± 2.1	-	-	3.0 ± 3.0	0.2 ± 0.2	1.5 ± 0.5
Ceratophysella sp.	2.3 ± 2.1	0.5 ± 0.5	3.0 ± 2.2	21.0 ± 20.0	0.3 ± 0.3	2.5 ± 2.5
Dicyrtomina sp.	-	0.5 ± 0.5	-	0.5 ± 0.5	1.5 ± 1.5	-
Folsomia candida (Willem, 1902)	3.5 ± 1.5	-	2.2 ± 1.8	8.5 ± 8.5	0.2 ± 0.2	0.5 ± 0.5
Folsomia fimetaria (Linnaeus, 1758)	-	-	0.5 ± 0.2	-	0.2 ± 0.2	0.5 ± 0.5
Folsomia quadrioculata (Tullberg, 1871)	0.2 ± 0.2	0.5 ± 0.5	-	-	-	-
Folsomia sexoculata (Tullberg, 1871)	3.8 ± 2.3	7.5 ± 5.5	0.7 ± 0.3	0.5 ± 0.5	3.3 ± 2.6	-
Friesea sp.	-	-	-	1.5 ± 1.5	-	-
Heteromurus nitidus (Templeton, 1835)	0.3 ± 0.2	-	-	-	-	-
Hypogastrura sp.	2.7 ± 1.8	0.5 ± 0.5	0.5 ± 0.3	11.0 ± 11.0	-	-
Isotoma minor (Schaeffer, 1896)	5.2 ± 1.7	-	1.0 ± 0.7	31.5 ± 31.5	1.2 ± 0.5	2.0 ± 0.0
Isotoma viridis (Bourlet, 1839)	1.5 ± 0.9	-	1.2 ± 0.3	0.5 ± 0.5	0.7 ± 0.4	1.0 ± 1.0
Isotomurus palustris (Müller, 1776)	1.7 ± 0.6	-	-	-	0.2 ± 0.2	1.0 ± 0.0
Isotomurus sp.	1.8 ± 1.1	-	0.8 ± 0.5	-	0.3 ± 0.2	-
Tomocerus vulgaris (Tullberg, 1871)	0.3 ± 0.2	-	1.5 ± 0.8	-	-	-
Lepidocyrtus lanuginosus (Gmelin, 1788)	3.0 ± 1.5	-	2.5 ± 1.1	-	0.3 ± 0.2	-
Metaphorura affinis (Börner, 1902)	2.3 ± 1.0	2.5 ± 2.5	7.5 ± 2.9	2.5 ± 2.5	0.5 ± 0.5	1.5 ± 1.5
Micranurida pygmaea (Börner, 1901)	-	-	-	-	0.2 ± 0.2	1.0 ± 1.0
Parisotoma notabilis (Schaeffer, 1896)	17.2 ± 7.5	2,5 ± 0.5	3.0 ± 1.9	1.5 ± 0.5	3.3 ± 1.7	1.0 ± 1.0
Proisotoma minuta (Tullberg, 1871)	0.3 ± 0.2	-	0.7 ± 0.5	35.0 ± 35.0	-	0.5 ± 0.5
Protaphorura armata (Tullberg, 1869)	1.7 ± 1.1	1.5 ± 1.5	4.7 ± 1.9	70.0 ± 70.0	0.2 ± 0.2	0.5 ± 0.5
Pseudisotoma sensibilis (Tullberg, 1876)	-	-	1.2 ± 1.2	-	-	2.5 ± 2.5
Pseudosinella sexoculata (Schött, 1902)	-	-	-	6.0 ± 6.0	-	-
Sminthurides schoetti (Axelson, 1903)	-	-	-	-	0.3 ± 0.3	-
Sminthurides sp.	-	-	-	-	0.7 ± 0.4	-
Sminthurinus aureus (Lubbock, 1862)	0.2 ± 0.2	-	-	0.5 ± 0.5	-	-
Tomocerus vulgaris (Tullberg, 1871)	2.7 ± 0.9	-	3.2 ± 0.7	-	0.3 ± 0.3	-
Willowsia buski (Lubbock, 1870)	1.2 ± 0.8	-	1.2 ± 1.0	-	-	-
Xenylla sp.	2.2 ± 1.3	-	0.5 ± 0.3	1.0 ± 1.0	-	-

Table A2 Oribatid

	Tallinn		Tartu		Pärnu	
	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites
Oribatida						
Liochthonius brevis (Michael, 1888)	-	-	-	4.0 ± 4.0	0.3 ± 0.3	1.0 ± 1.0
Liochthonius sellnicki (Thor, 1930)	-	-	-	-	0.5 ± 0.5	-
Steganacarus (Atropacarus) sticulus (Koch, 1836)	-	-	-	-	0.5 ± 0.5	-
Steganacarus (Tropacarus) carinatus (Koch, 1841)	0.2 ± 0.2	-	-	-	0.2 ± 0.2	-
Rhysotrita ardua (Koch, 1841)	-	-	-	-	0.2 ± 0.2	-
Platynothrus peltifer (Koch, 1839)	0.2 ± 0.2	-	0.7 ± 0.7	-	4.2 ± 2.1	1.0 ± 1.0
Nothrus silvestris (Nicolet, 1855)	0.2 ± 0.2	0.5 ± 0.5	-	-	-	-
Conchogneta traegardhi (Forsslund, 1947)	0.2 ± 0.2	-	-	-	-	-
Oppiella nova (Oudemans, 1902)	-	-	0.8 ± 0.8	-	0.3 ± 0.2	-
Oppiella translamellata (Willmann, 1923)	0.2 ± 0.2	-	0.8 ± 0.5	-	-	-
Tectocepheus velatus velatus (Michael, 1880)	3.2 ± 1.5	2.0 ± 2.0	10.3 ± 5.3	18.0 ± 13.0	0.2 ± 0.2	-
Scutovertex minutus (Koch, 1835)	-	1.0 ± 1.0	-	23.5 ± 23.5	0.2 ± 0.2	-
Eupelops tardus (Koch, 1835)	0.8 ± 0.5	-	-	-	-	-
Eupelops acromios (Hermann, 1804)	1.7 ± 0.8	0.5 ± 0.5	-	-	-	-
Eupelops hygrophilus (Knülle, 1954)	3.3 ± 2.2	-	-	-	1.2 ± 0.6	4.0 ± 4.0
Eupelops occultus (Koch, 1835)	-	-	0.3 ± 0.3	-	-	-
Peloptulus phaenotus (Koch, 1844)	0.3 ± 0.3	-	-	-	3.7 ± 2.1	1.0 ± 1.0
Liebstadia pannonica (Willmann, 1951)	0.2 ± 0.2	-	0.3 ± 0.3	-	0.3 ± 0.2	-
Scheloribates laevigatus (Koch, 1836)	1.7 ± 1.7	-	14.8 ± 9.9	0.5 ± 0.5	4.7 ± 1.8	4.5 ± 3.5
Scheloribates latipes (Koch, 1844)	0.7 ± 0.7	-	-	-	0.5 ± 0.3	0.5 ± 0.5
Chamobates voigtsi (Oudemans, 1902)	0.2 ± 0.2	-	-	-	-	-
Ceratozetes mediocris (Berlese, 1908)	0.2 ± 0.2	-	-	-	-	-
Ceratozetes parvulus (Sellnick, 1922)	0.7 ± 0.5	-	-	-	-	-
Ceratozetes gracilis (Michael, 1884)	0.2 ± 0.2	-	-	-	-	-
Trichoribates incisellus (Kramer, 1897)	0.8 ± 0.5	-	0.7 ± 0.5	1.0 ± 1.0	0.2 ± 0.2	-
Mycobates sarekensis (Trägårdh, 1910)	-	-	0.7 ± 0.7	0.5 ± 0.5	0.2 ± 0.2	-
Mycobates tridactylus (Willmann, 1929)	0.2 ± 0.2	-	-	-	-	-
Punctoribates punctum (Berlese, 1908)	-	-	-	-	0.2 ± 0.2	1.5 ± 1.5
Haplozetes vindobonesis (Willmann, 1935)	0.7 ± 0.7	-	-	-	-	-
Peloribates longipilosus (Csiszár, 1962)	1.7 ± 1.7	-	-	-	-	-
Galumna sp.	0.8 ± 0.3	-	-	-	-	-
Galumna lanceata (Oudemans, 1900)	0.5 ± 0.5	-	-	-	-	-
Galumna obvia (Berlese, 1914)	0.3 ± 0.3	-	-	-	-	-
Pergalumna nervosa (Berlese, 1914)	0.7 ± 0.7	-	-	-	-	-

Table A3 Diatom

	Tallinn		Tartu		Pärnu	
	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites	Runway sides	Snow-melting sites
Diatoms						
Achnanthes delicatula (Kützing) Grunow, 1880	-	-	-	-	-	+
Achnanthes hungarica (Grunow) Grunow, 1880	-	-	-	-	+	-
Actinella sp. (Lewis) Lewis, 1864	+	-	-	-	-	-
Amphipleura sp. (Kützing) Kützing, 1844	-	-	-	-	-	+
Aulacoseira granulata (Ehrenberg) Ehrenberg, 1843	+	+	+	-	+	+
Aulacoseira karelica (Mölder) Simonsen, 1979	+	-	-	-	-	-
Aulacoseira sp. (Ehrenberg) Thwaites, 1848	+	-	-	+	-	-
Caloneis sp. (Cleve) Cleve, 1894	-	-	-	+	-	-
Cocconeis fluviatilis (Wallace) Wallace, 1960	-	-	-	-	+	-
Cymbella affinis (Kützing) Kützing, 1844	-	-	+	+	-	+
Cymbella radiosa (Héribaud-Joseph) Héribaud-Joseph, 1903	+	-	-	-	-	-
Diploneis finnica (Ehrenberg) Cleve, 1891	-	+	-	-	-	+
Epithemia sp. Kützing, 1844	+	-	-	-	-	+
Epithemia turgida (Ehrenberg) Kützing, 1844	-	-	-	+	-	+
Eunotia paludosa Grunow 1862	-	-	+	-	-	-
Fragilaria nitzschioides (Grunow) Van Heurck 1881	+	+	+	+	+	+
Fragilaria sp. (Müller) Lyngbye, 1819	+	-	-	-	+	-
Fragilariforma virescens (Ralfs) Williams and Round, 1988	-	-	-	-	+	-
Gomphonema parvulus (Kützing) Kützing, 1849	+	-	-	+	-	+
Hantzschia amphioxys (Ehrenberg) Grunow, 1880	+	+	+	+	+	+
Humidophila contenta (Grunow) Lowe et al., 2014	+	-	+	-	+	+
Luticola mutica (Kützing) Mann, 1990	+	+	+	+	+	+
Luticola nivalis (Ehrenberg) Mann, 1990	-	+	-	-	-	-
Luticola venticosa (Kützing) Mann, 1990	+	-	-	+	-	+
Mastogloia sp. (Thwaites) Smith, 1856	-	-	-	-	-	+
Mayamaea sp. (Kützing) Lange-Bertalot, 1997	+	+	-	-	+	+
Navicula cari (Ehrenberg) Ehrenberg, 1836	+	+	+	+	+	+
Navicula cincta (Ehrenberg) Ralfs, 1861	-	-	-	+	+	-
Navicula subhamulata (Grunow) Grunow, 1880	+	-	-	-	+	+
Nitzschia alpina (Hustedt) Hustedt, 1943	+	-	-	-	+	+
Nitzschia amphibia (Grunow) Grunow, 1862	-	-	-	+	+	+
Nitzschia sp. Hassall, 1845	-	-	-	+	-	-
Pinnularia borealis (Ehrenberg) Ehrenberg, 1843	+	+	-	-	+	+
Pinnularia lata (Brébisson) Rabehorst, 1853	+	-	-	-	-	+
Pinnularia obscura (Krasske) Patrick and Reimer, 1966	+	-	-	+	+	+
Pinnularia rabenhorsti (Grunow) Krammer, 2000	-	-	-	-	+	+
Pinnularia sp. Ehrenberg, 1843	+	-	+	-	+	-
Pinnularia subcapitata Gregory, 1856	-	-	-	-	+	-
Pseudostaurosira sp. Williams and Round, 1988	-	-	-	-	-	+

continued Table A3 Diatom

Sellaphora alastos (Hohn and Hellerman) Lange-Bertalot and Metzeltin, 1996	-	-	-	-	-	+
Stauroforma exiguformis Flower, Jones and Round, 1996	-	-	-	-	-	+
Stauroneis kriegeri (Patrick) Patrick, 1945	-	-	-	-	+	-
Stauroneis sp. Ehrenberg, 1842	-	-	-	-	-	+
Staurosira construens var. venter (Ehrenberg) Hamilton, 1992	-	-	-	-	-	+
Staurosirella leptostauron (Ehrenberg) Williams and Round, 1987	+	+	-	-	-	+
Stephanodiscus sp. (Ehrenberg) Eherenberg, 1845	+	-	-	-	-	+
Suriella ovata Kützing, 1844	-	-	-	-	+	-
Tabellaria fenestrata (Lyngbye) Kützing, 1844	+	-	+	-	-	+
Ulnaria ulna (Kützing) Compère, 2001	-	-	-	-	-	+