Diversity and density of springtails (Collembola) in a grass-clover ley in North-west Norway

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The diversity and density of springtails (Collembola) were studied in an organically managed grass-clover ley at Tingvoll experimental farm in NW Norway during 2011–2012. In total after one sampling in 2011 and 3 samplings in 2012, 42 species were identified. Our results included a new species for the Norwegian fauna, *Onychiurus edinensis* (Bagnall, 1935) and one species very unusual to agricultural soils, *Oligaphorura ursi* (Fjellberg, 1984). The most abundant species was *Parisotoma notabilis* (Schäffer, 1896), followed by three species of *Mesaphorura* Börner, 1901, two species of *Protaphorura* Absolon, 1901 and *Isotomurus graminis* Fjellberg, 2007. A high number of *P. notabilis* has also been found in pastures in Iceland (Gudleifsson & Bjarnadottir 2008), in forest habitats in Norway (Hågvar 1982, Fjellberg *et al.* 2005) and in agricultural soil in Denmark (Axelsen & Kristensen 2000) and Sweden (Lagerlöf & Andrén 1991). The average density of springtails was 7 917 individuals m^{-2} in 2011. In 2012, the density was generally higher and varied between 16 182 and 41 515. We have proposed a grouping of the species into "epigeic" and "endogeic", dependent on the presence or absence of eye organs and colour. Such classification is relatively easy and may give useful information in cases when identification to species is not possible.

Key words: Collembola, springtails, Norway, agricultural soil, soil fauna, springtails, *Onychiurus edinensis*, *Oligaphorura ursi*.

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Introduction

Springtails (Collembola) are a highly diverse group of micro arthropods living in vegetation, litter and in soil, commonly found to a depth of 10–15 cm (Hopkin 2007, Lagerlöf & Andren 1991, Ponge 2000). Many factors including food availability, soil type, microclimate and species composition in adjacent habitats influence the total distribution of springtails within a specific site. The group comprises a high diversity of species, and springtails may be found in almost any habitat all over the world, except in water (Fjellberg 1998, Hopkin 2007). The vertical distribution in soil varies with season and between species, and springtails have been reported down to 3 m soil depth in (irrigated) agricultural land in California (Price & Benham 1977). Most individuals are found above ground and in the upper 5 cm of the soil/litter layer (Fjellberg *et al*. 2005, Bardgett & Cook 1998).

On a global level, the current number of species described is approximately 8000 (Bellinger *et al.*, 2014). In Norway, springtails have been extensively studied in natural habitats and in forests (e.g. Lie-Pettersen 1896, Hågvar 1982, 1983, Fjellberg 1998, 2007), and 334 species from 19 families have been identified (Fjellberg 2010).

Fewer studies have been conducted on springtails in agricultural soil in Norway, hence this paper represents the latest Norwegian findings.

Springtail ecology.

A close relation between springtail species and habitat was already described by Gisin in 1943 (Gisin 1943), who emphasised that the composition of the springtail fauna could be used as a zoological description of a habitat. His classification into five ecological groups ("Lebensformenklassen") was linked to humidity and soil layers. This approach was more recently revised by Petersen (2002), who found contrasting differences in size, reproduction, metabolic activity and food preferences between typical surface/litter living and soil pore living springtails. He proposed the term "epedaphic" for soil surface/litter living species, and "euedaphic" for species living in soil pores. These terms come close to terms used by Salmon *et al*. (2014) , who compared a large European dataset of springtails. They found that springtails living in epigeic (above ground) and open habitats more often had well developed locomotory organs (furca, legs), presence of hair sensitive to air (e.g. trichobotria), organ sensitive to light (e.g. ocelli, eye spot), large body size and pigmentation (UV protection and signals), and more often performed sexual reproduction. Species living in edaphic (more soil dwelling habitat) and woodland habitats were characterised by short locomotory appendages, small body size, high number of defence organs (pseudocelli), presence of post-antennal organs and parthenogenetic reproduction.

Springtails commonly feed on plant debris, or they graze on fungi, algae and bacteria (Hopkin 1997, Ponge 2000, Jørgensen *et al.* 2003, Hopkin 2007, Larsen *et al*. 2008,). Some species are predators and a few species may feed on plant roots (Ponge 2000, Hopkin 2007). Some species are selective, feeding on either organic matter, fungi or other microarthropods, while many species are omnivorous, feeding on a wide spectrum of food items in their close vicinity (Ponge 2000, Jørgensen *et al.* 2003). Some species may harm plants by grazing on young leaves, but springtails are generally not considered as a plant pest in Scandinavia. Springtails play an important role in the soil ecosystem as grazers and to some extent as decomposers of organic matter (Seatstedt 1984, Hopkin 1997). Springtails, including their eggs, are important as prey for mites, spiders, beetles and some birds (Hopkin 1997).

It might be argued that the fauna of springtails in cultivated soil, where disturbances occur regularly due to soil tillage, manure application, harvesting and pesticide applications, will be limited and low in diversity of species. Compaction by soil tillage and other mechanical operations seem to affect especially the density of springtails in cultivated land negatively, through inversion of soil layers and less diversity of pores (Heisler & Kaiser 1995, Larsen *et al.* 2004, Petersen 2000). Crop types, crop rotations and other changes in vegetation, may have negative or positive effects on mesofauna, while harvesting clearly decreased the density of springtails, as discussed in Larink (1997). The diversity of plant species, and the inclusion of grasses and legumes in the cropping systems, beneficially affected both the density and diversity of springtails in a grassland study (Sabais *et al.* 2011).

Effects of vegetation.

Fjellberg *et al.* (2005) investigated the effect of changing tree species on the springtail fauna in Northern Norway. The planting of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) or Norway spruce (*Picea abies* L.) on land formerly covered by birch (*Betula pubescens* Ehrh.) changed the species composition and increased the density of springtails. Initial values were not measured, but 50 years after planting of spruce, the mean density was 91 000 individuals m^{-2} in Sitka forest and 53 000 under Norwegian spruce, compared with only 32 000 in the birch forest. Springtail densities found in spring were 40–80 % above those found in autumn. For species diversity, the levels were comparable in the three vegetation types; 36 species were found in birch, 32 in Sitka and 34 in Norway spruce forest, and in total 52 species were found at the study site. *Parisotoma notabilis* (Schäffer, 1896) was the most abundant species, found in all the habitats. *Mesaphorura macrochaeta* (Rusek, 1976) was also abundant, found in highest densities in the two spruce habitats, and low densities in the birch forest. Hågvar (1982) reported 31 500–200 000 springtails m^{-2}, belonging to 15–26 species, in 8 coniferous habitats in the south of Norway.

In a semi-natural habitat in Western Norway, composed of old, probably never ploughed meadows used for grazing and hay production, mites (Acari) and springtails were recorded (Gulvik *et al.* 2008). The highest numbers of springtails were found in regularly cut or grazed old meadows, where the number of individuals comprised 26 200 m^{-2}. In fields where deciduous forest was emerging, and in restored fields where trees had been cut and grazing started again, much lower densities were found (10 900–12 500). The proportion of springtails in the total arthropod mesofauna (Acari + Collembola) was highest in the restored fields, which may indicate that springtails are more adaptive to disturbances than mites are.

Nordic studies of agricultural soil.

On arable land, regular disturbances make the studies of springtails more complicated than in more stable habitats. Several North-European studies of agricultural soil have been performed (e.g. Bardgett & Cook 1998, Filser *et al*. 2002, Sabais *et al*. 2011). In the Nordic countries springtails have been studies in arable land in Iceland (Gudleifsson & Bjarnadottir 2008), Sweden (Lagerlöf & Andren 1991) and Denmark (Axelsen & Kristensen 2000, Petersen, H. 2000). For some of these studies, an ecological description of springtail fauna on the site was not the primary purpose, but the reported species diversity and densities are still of high interest. In general, these studies show that the densities, and to some extent the diversity, of springtails may be quite high even in intensively managed fields with regular disturbance.

In perennial pastures (grazed) and hayfields on northern Iceland, 4 000–10 000 individuals m^{-2} belonging to 14 species were found in the top 0–2 cm layer of the swards (Gudleifsson & Bjarnadottir 2008). The density was nine times higher in summer than winter, but even during winter, some soil dwelling species were found. Similar to the forest study in Northern Norway (Fjellberg *et al*. 2005), *Parisotoma notabilis* was the most common species.

In a Danish study, 120 000 springtails m^{-2} were recorded in barley (*Hordeum vulgare* L.), after soil incorporation of a fodder radish (*Rapanus sativus* L.) catch crop (Axelsen & Kristensen 2000). On average for several catch crops, about 50 000 springtails m^{-2} were found, belonging to 26 species. *Mesaphorura* spp., *Parisotoma notabilis* and *Folsomia fimetaria* (Linnaeus, 1758) were the most abundant species. The study was carried out in barley with grass-clover ley as subcrop. This diversity of plants, and the incorporation of organic matter (radish) before sowing the subcrop and barley, partly explains the quite high densities found in this study.

In a Swedish study, 11 800 individuals m^{-2} were found as an average value over five years in barley, 16 500 in grass ley and 30 500 in alfalfa (*Medicago sativa* L.). Fifteen species of springtails were identified, and the species composition was comparable in all crops (Lagerlöf & Andrén, 1991). The dominant species were *Folsomia* spp., *Mesaphorura krausbaueri* Börner, 1901 and *Isotomiella minor* (Schäffer, 1896).

The project SoilEffects (Løes *et al*. 2013) offered a possibility to sample springtails over two years in the sward (incl. topsoil) of an organically managed perennial grass-clover ley. The study site was at Tingvoll farm, the research station of Bioforsk Organic Food and Farming. The present paper describes the species diversity and density of springtails at this site. The main aim of the paper is to increase the knowledge about the springtail fauna in agricultural soil in Norway, influenced by agricultural activities such as soil tillage, fertilisation and regular harvesting. Further, we discuss to what extent a simplified classification of this highly diverse group of soil animals may give meaningful ecological information. A complete classification to species is very time consuming and demands specialist knowledge. Is it possible to reveal some useful knowledge by classifying the springtails into two groups only; pigmented surface/vegetation dwellers and non-pigmented soil dwellers?

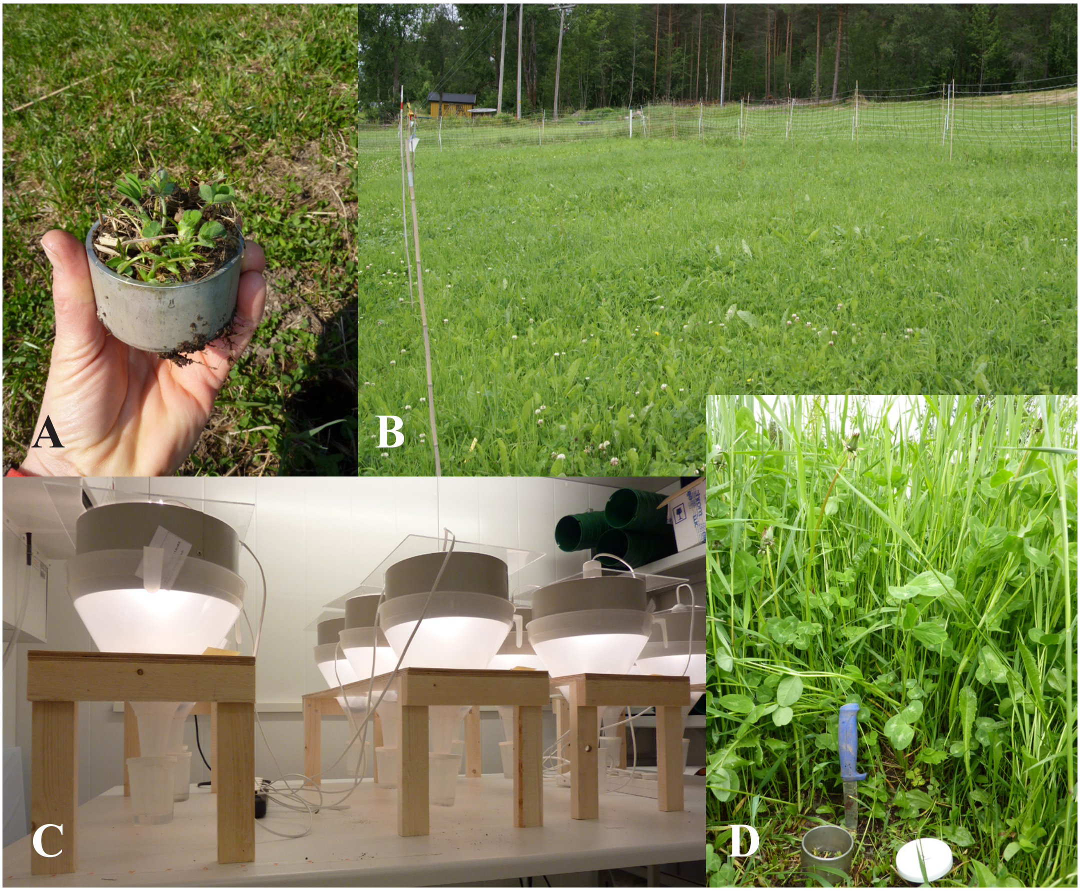

FIGURE 1. **A**. Sample of sward and soil, 100 cm^3. **B**. Overview of field site, July 2012. **C**. The funnel system for extraction of springtails from the sward samples. **D**. Sampling equipment and vegetation by sampling in June 2012. All photos by R. Pommeresche.

Methods and material

Site description

The study site was located at Tingvoll farm (62°54′N, 8°11′E) in North-west Norway. Sward samples (0–3.8 cm soil depth) for extraction of springtails were taken in spring 2011, and spring and summer 2012, from an organically managed grass-clover ley established in 2009. In total four samplings were done. The ley was part of an experiment designed to compare effects of non-digested and anaerobically digested slurry on several soil characteristics, including soil fauna (Løes *et al.* 2013). Samples were taken from plots which received either no manure (n=4), digested slurry (n=4) or undigested cattle slurry (n=4). The effects of manure application on species composition and density are discussed elsewhere. Each experimental plot measured 3 m x 8 m, with four replicate plots in a randomized block design. Each block contained four manure treatments and one control with no manure application, and measured 15 m x 8 m. The soil at the experimental site is a loamy sand, with pH (H_2O) 5.82, total C content 11.03 % and extractable P concentration = 28.7 mg kg^{-1} dry soil in April 2011. An automatic weather station located about 300 m from the field site has recorded weather data since 1995. During 1995–2013, the average annual air temperature (2 m height) was 6.5 °C, and the average precipitation during May–August was 95.1 mm. The average air temperature (2 m height) and soil temperature

(10 cm depth) one week before sampling, was 9.1 and 7.3°C in April 2011, 6.2 and 4.3 °C in April 2012, 5.6 and 6.3 °C in May 2012, 9.8 and 10.9 in June 2012.

Based on weighing and drying of soil samples (105 ºC until constant weight), the soil water content at sampling was calculated as weight % of the dry soil. The average and (min-max) water content in the soil at the sampling dates was 67 (59–95) % in April 2011, 62 (39–93) % in April 2012, 66 (44–108) % in May 2012 and 51 (31–65) % in June 2012.

Sampling and extraction

In 2011, sampling of springtails occurred only once, on April 24, before manure application that year. In 2012, sampling occurred on April 26, May 3 and June 14. Manure was applied on April 30 in 2012. On June 14, the vegetation was cut at the sward surface before sampling. At each sampling date, one sample per plot was collected (n= 12). Altogether, the springtail fauna was examined in 48 samples from this study site.

By sampling, metal cylinders (Ø = 5.8 cm, h = 3.8 cm) were used to sample sward + soil (= soil) samples of 100 cm^3. The cylinders were gently tapped with a rubber hammer into the soil. When the cylinder had reached the requested soil depth, a plastic lid was placed on top of the metal cylinder. Soil was cut with a knife to allow for placing a flat bricklayer spade and excavate the cylinder. Excess soil and roots were cut off to make the soil sample fit inside the cylinder. Thereafter a plastic lid was placed to cover the bottom of the sample.

Within one hour after sampling, the samples were placed in a slightly modified Berlese/Tullgren funnel to extract the soil fauna (Figure 1). The samples were slowly dried by means of a light bulb (40 W), which forced the fauna to move downwards. The samples were placed with the sward down on a fine meshed nylon net (mesh size 0.8 mm x 0.8 mm), which again was placed on a 5 cm x 5 cm metal sieve plate (mesh size 3 mm x 3 mm) in the lower part of the funnel. The net prevented the soil from falling into the capture bottle. The funnel had a top diameter of 25 cm and a bottom diameter of 2.6 cm. The tip of each funnel was placed over a folded paper leading to a plastic capture bottle, containing 80 % ethanol. The extraction period was 7 days with continuous light.

The springtails were extracted from the capture solution by a micro-sieve (nylon net, mesh size 45 µm x 45 µm), and thereafter stored in 80 % ethanol. To achieve a better preservation, the ethanol solution with springtails was boiled for 10–20 seconds to dissolve the external wax layer of the animals. The springtails were identified to species or genus by 40–400 x magnification. In some cases, microscope slides were prepared of transparent animals to study details required for classification. A droplet of a lactic acid-glycerol mixture (3:1) was then applied over the specimen(s) on an object glass and carefully heated until transparency was achieved. Then a cover glass was gently placed on the top, and the slide was sealed with nail polish.

The height of the sampling cylinders was 3.8 cm, and hence, the density of springtails (individuals m^{-2}) may be calculated as the number in the cylinder times 380 (volume of 1 m^2 soil layer with a thickness of 3.8 cm = 38 000 cm^3, divided by the cylinder volume which was 100 cm^3).

Species identification and groups

Most adult springtails were identified to species, while most juvenile and some adult individuals were identified only to genus, all by using the keys of Arne Fjellberg (Fjellberg 1998; Fjellberg 2007). For the genus *Deuterosminthurus* sp., only one individual was found, and not identified to species. Hence, this genus has been recorded as a species to calculate the total number of species observed. For other genus, e.g. *Mesaphorura*, five species were identified and in this case, the genus as such is not included in the total number of species (Table 1).

Springtails can be grouped into three groups according to habitat preferences (Larink 1997, Petersen 2002). Species living on the surface of the soil are epigeic, species living in the upper soil layers and partly on the soil surface are hemiedaphic, and those living in deeper soil layers are euedaphic. However, a direct link between this grouping and which species belongs

TABLE 1. Identified springtail species and number of individuals (ind.). Nomenclature, presence of eye organs (ocelli, + or -), pigmentation (pig., - is white), typical size and colours according to Fjellberg (1998, 2007). Abundance is indicated as xxx for > 500 ind., xx = 100 –500 ind., x = 20 – 99 and no x for < 20. Taxons marked by * are not included in the number of species, but in the density values.

				Date of sampling								
Abundance	**Species/ taxon**	**Family**	**Subclass/ section**	**April 2011**	**April 2012**	**May 2012**	**June 2012**	**Sum ind.**	**Ocelli**	**Pigment.**	**Size (mm)**	**Colour**
	"Epigeic"											
	Deutero-sminthurus sp.	Bourleti-ellidae	Symphy-pleona		1	5		6	+	+	1	yellow brown
	Brachysto-mella parvula	Brachysto-mellidae	Poduro-morpha	1				1	+	+	1	blue violet
x	*Lepidocyrtus lanuginosus*	Entomo-bryidae	Entomobryo-morpha	6	8	5	3	22	+	+	2	pale brown
	*Lepidocyrtus sp **	Entomo-bryidae	Entom.	3				3	+	+		yes
	Desoria grisea	Isotomidae	Entom.			1		1	+	+	2	grey
	Desoria intermedia	Isotomidae	Entom.		2	1		3	+	+	2.1	blue violet
	Desoria propinqua	Isotomidae	Entom.				3	3	+	+	2.1	grey
	Desoria tigrina	Isotomidae	Entom.		1			1	+	+	2.1	brown grey
	Folsomia brevicauda	Isotomidae	Entom.			1		1	+	+	0.8	brown
x	*Folsomia manolachei*	Isotomidae	Entom.		6	19	5	30	+	+	1	brown grey
x	*Folsomia quadrioculata*	Isotomidae	Entom.	10	29	15	7	61	+	+	2	brown grey
x	*Isotoma anglicana*	Isotomidae	Entom.	2		15	4	21	+	+	3.5	violet/ blue
	Isotoma caerulea	Isotomidae	Entom.		1			1	+	+	3.5	blue/ brown
xx	*Isotoma sp. juv.**	Isotomidae	Entom.	8	3		3	14	+	+		yes
	Isotoma viridis	Isotomidae	Entom.	7	7			14	+	+	4	greenish
xx	*Isotomurus graminis*	Isotomidae	Entom.	32	88	26	1	147	+	+	2.75	green
	Isotomurus italicus	Isotomidae	Entom.	1	1			2	+	+	2	green brown
	*Isotomurus sp. juv.**	Isotomidae	Entom.	7	151	22	35	215	+	+		yes
x	*Isotomurus unifasciatus*	Isotomidae	Entom.		47	14	9	70	+	+	2.7	violet pattern
xxx	*Parisotoma notabilis*	Isotomidae	Entom.	23	378	137	160	698	+	+	2	grey brown

TABLE 1. *continued*

Abundance	Species/ taxon	Family	Subclass/ section	Date of sampling: April 2011	April 2012	May 2012	June 2012	Sum ind.	Ocelli	Pigment.	Size (mm)	Colour
	Pseudisotoma sensibilis	Isotomidae	Entom.	10				10	+	+	2.7	blue/ brown
	Sminthurinus elegans	Katiannidae	Symph.	12		2		14	+	+	0.7	violet pattern
	*Sminthurinus sp. juv.**	Katiannidae	Symph.		9	1		10	+	+		yes
xx	*Friesea truncata*	Neanuridae	Podurom.	14	36	31	21	102	+	+	1	blue grey
	Micranurida pygmaea	Neanuridae	Podurom.		1		1	2	+	+	0.5	some pigment
	Sminthurus viridis	Sminthur-idae	Symph.	7	3		2	12	+	+	3	yellow green
	Sminthurides schoetti	Sminthuri-didae	Symph.			3		3	+	+	0.5	violet pattern
x	*Sphaeridia pumilis*	Sminthuri-didae	Symph.	1	4	18	15	38	+	+	0.5	grey/ reddish
	Pogonognath-llus flavescens	Tomocer-idae	Entom.		1			1	+	+	4.5	yellow brown
	Sum individuals			**144**	**777**	**316**	**269**	**1506**			**2.00**	
	Number of species			**13**	**17**	**15**	**14**	**25**				
	"Endogeic"											
	Pseudosinella immaculata	Entomo-bryidae	Entomo-bryomorpha		2	2	3	7	-	-	1.9	white
	Willemia anophthalma	Hypo-gastruridae	Poduro-morpha				3	3	-	-	0.65	white
xx	*Folsomia fimetaria*	Isotomidae	Entom.	10	31	33	28	102	-	-	1.4	white
	Folsomia stella	Isotomidae	Entom.				1	1	-	-	1.8	white
	Isotomiella minor	Isotomidae	Entom.	1	11	3	3	18	-	-	1.1	white
xx	*Megalothorax minimus*	Neelidae	Symphyp-leona		39	7	54	100	-	+	0.4	white/ reddish
x	*Mesaphorura hylophila*	Onychiur-idae	Podurom.		36	2	27	65	-	-	0.65	white
	Mesaphorura jirii	Onychiur-idae	Podurom.			1	1	2	-	-	0.65	white
xx	*Mesaphorura krausbaueri*	Onychiur-idae	Podurom.		54	42	115	211	-	-	0.65	white
xx	*Mesaphorura macrochaeta*	Onychiur-idae	Podurom.	45	75	14	59	193	-	-	0.65	white

TABLE 1. *continued*

Abundance	Species/ taxon	Family	Subclass/ section	Date of sampling: April 2011	April 2012	May 2012	June 2012	Sum ind.	Ocelli	Pigment.	Size (mm)	Colour
x	*Mesaphorura sp. juv.**	Onychiuridae	Podurom.		22	9	23	54	-	-		white
xx	*Mesaphorura tenuisensillata*	Onychiuridae	Podurom.		47	19	87	153	-	-	0.65	white
	Oligaphorura ursi	Onychiuridae	Podurom.				3	3	-	-	1.3	white
	Onychiurus edinensis	Onychiuridae	Podurom.		3		2	5	-	-	1	white
xx	*Protaphorura armata*	Onychiuridae	Podurom.	43	71	20	42	176	-	-	1.8	white
xx	*Protaphorura cancellata*	Onychiuridae	Podurom.		49	34	28	111	-	-	1.7	white
xx	*Stenaphorura lubbocki*	Onychiuridae	Podurom.	7	94	9	24	134	-	-	1	white
	Stenaphorura quadrispina	Onychiuridae	Podurom.				1	1	-	-	1	white
	Sum individulas			**106**	**534**	**195**	**504**	**1339**			**1.08**	
	Number of species			**5**	**12**	**12**	**17**	**17**				
	Total											
	Sum of individuals			**250**	**1311**	**511**	**773**	**2845**				
	Individuals m^{-2}			**7917**	**41515**	**16182**	**24478**					
	Species number/sampling			**21**	**33**	**30**	**32**					
	Total number of species							**42**				

where, is not easy to find in the literature. Based on Fjellberg (1998, 2007), we sorted the dataset into two categories, with or without eye organs (ocelli/eyes). We also noted whether the species was pigmented or (close to) white. Species with eye organs and pigmentation were grouped as "epigeic" (Table 1), whereas species without eye organs and lacking or only scarce pigmentation were grouped as "endogeic". Salmon et al. (2014) also used a division into epigeic and endogeic springtails, dependent on their habitat preference.

Results

Species density and diversity

In total, 2845 individuals of springtails were found and identified to 42 species (Table 1). The number of species was lower in 2011 (21) than in 2012, where the numbers were comparable on all sampling dates (30-33). In 2011, the average density was 7 917 individuals per m^2. In 2012, the density was generally higher, and varied from 16 182 to 41 515 per m^2 (Table 1).

The most abundant species, with a total of 698 recorded individuals, was *Parisotoma notabilis*. This species was especially numerous in April

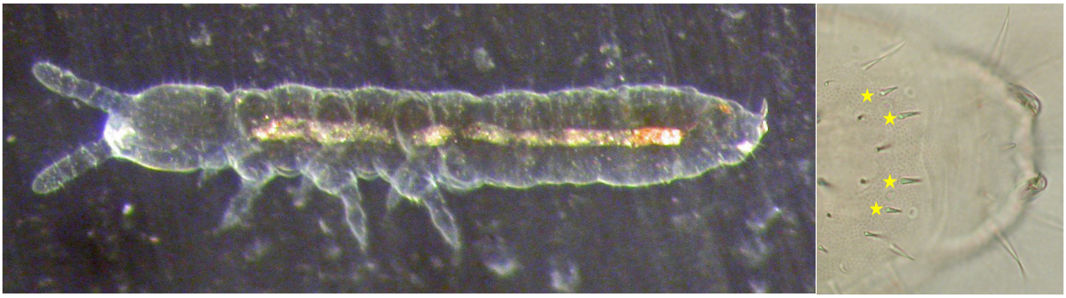

FIGURE 2. The first record in Norway of *Onychiurus edinensis* (Bagnall, 1935), found in grass-clover sward in Tingvoll, NW Norway, 2012. Right side, marked with yellow stars, the characteristic thick, spine-like setae on the fifth abdominal segment that identifies this species. Photos: Arne Fjellberg.

2012. Other common (100-500 individuals recorded) species were *Mesaphorura krausbaueri* > *Mesaphorura macrochaeta* > *Protaphorura armata* > *Mesaphorura tenuisensillata* > *Isotomurus graminis* > *Stenaphorura lubbocki* > *Protaphorura cancellata* > *Folsomia fimetaria* > *Friesea truncata* > *Megalothorax minimus*. The juveniles of *Isotomurus* were also common, and were most likely *I. graminis* or *I. unifasciatus*, since these were recorded with 147 and 70 individuals, whereas for *Isotomurus italicus,* only two individuals were recorded. 7 species were found in numbers between 20–99 and for the remaining 22 species, less than 20 individuals were found.

In addition to *P. notabilis*, six of the common species were found on all sampling dates. These species were *M. macrochaeta*, *P. armata*, *I. graminis*, *S. lubbocki*, *F. fimetaria* and *F. truncate*. *Folsomia quadrioculata, Lepidocyrtus lanuginosus* and *Isotomiella minor* were also found on all sampling dates, but in lower numbers.

Results of special interest were the first record in Norway of *Onychiurus edinensis* (Bagnall, 1935, photo in Figure 2). Five individuals of *O. edinensis* were found in one unfertilised plot in April and June 2012. Further it was a surprising result to find the arctic-alpine species *Oligaphorura ursi* (Fjellberg, 1984) in a lowland grass-clover ley. Three individuals of *O. ursi* were found in two fertilized plots in June 2012. The gender of the specimens was not identified. Both species belong to the Poduromorpha section and the Onychiuridae family. Microscope slides of *O. edinensis* and *O. ursi* are available upon contact with the authors. Arne Fjellberg has confirmed the identification of these species.

Grouping the species by morphology

The material comprised a relatively large variation in colors and body forms of springtails (Figure 3). We found large, colored species like *Isotomurus graminis* and *Isotoma viridis* (Bourlet, 1839) (Figure 3), but also many small species with no eyes and short extremities e.g. white *Mesaphorura* spp. (Figure 3) and *Stenaphorura lubbocki* Börner, 1901. The "epigeic" group, with eye organs and pigmentation, comprised 25 species (Table 1). The "endogeic" group, lacking eye organs and mostly white, comprised 17 species. *F. truncata* is an exception in the epigeic group with relatively short extremities. With exception of *Megalothorax minimus*, all the endogeic species lack pigmentation and are white in color.

The most abundant species were both epi- and endogeic. For instance, *P. notabilis* and *I. graminis* have eyes, furca and pigmentation whereas *M. macrochaeta*, *P. armata* and S. *lubbocki* are blind, with a much reduced furca and with no or little pigmentation (Figure 3).

The species in the epigeic group are generally larger and had a greater size range than the species in the endogeic group (Table 1). The average typical size (Fjellberg 1998, 2007) for adult species in the epigeic group was 2.0 mm, ranging from 0.5 to 4.5 mm. The average typical size for the endogeic species was 1.1 mm, ranging only from 0.65 to 1.9 mm in size.

Springtails are divided in two main sections according to morphology (Fjellberg 1998, 2007):

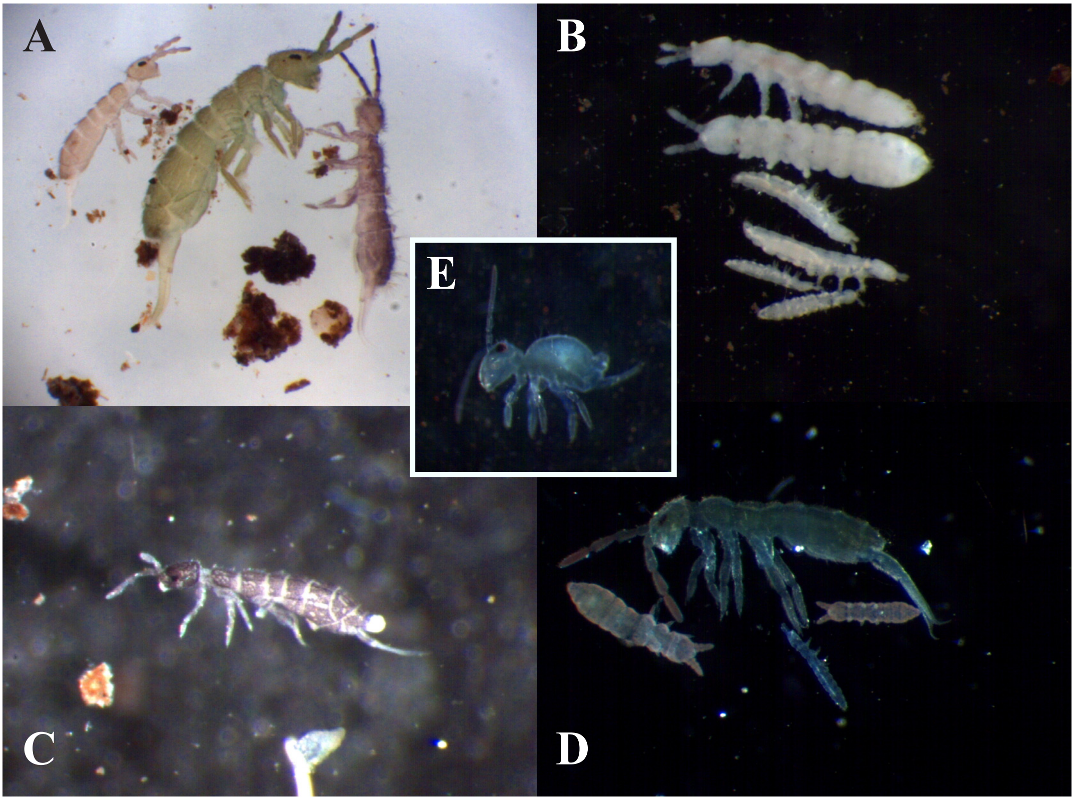

FIGURE 3. Photos of some species found in organically managed grass-clover ley at Tingvoll research farm in 2011 or 2012. **A**. From left, *Pseudisotoma sensibilis* (Tullberg, 1876), *Isotomurus graminis* (typical length 2.5–3 mm) and *Isotoma viridis*. **B**. From above two individuals of *Protaphorura armata* (Tullberg, 1869) (1.8 mm), two individuals of *Stenaphorura lubbocki* (Börner, 1901) and two individuals of *Mesaphorura macrochaeta* (Rusek, 1976), the latter with a typical length of 0.6–0.7 mm. **C**. *Parisotoma notabilis* (Schäffer, 1896 with a characteristic eyespot and diffusely brownish grey pigmentation, and a typical size of about 1.0 mm. **D**. Some specimens made transparent in a mixture of lactic acid/glycerol. The largest one is *Isotomurus graminis*, the thinnest one is *Mesaphorura macrochaeta*. The remaining two are the predatory species *Friesea truncate* Cassagnau, 1958. **E**. A transparent juvenile specimen of *Sminthurus viridis* (Linnaeus, 1758). Yellowish green as adult and up to 3 mm in body size. All photos by R. Pommeresche.

Entomobryomorpha, generally well pigmented, slender and mobile forms with long extremities or white forms with furca, and Poduromorpha, mostly short, thick and less mobile species with shorter extremities, often white, lacking furca. A characteristic subclass of the Entomobryomorpha is Symphypleona, with bodies more or less globular (Figure 3). Classifying species into these sections or subclass (Table 1) revealed that most of the Entomobryomorpha and Symphypleona belonged to the epigeic group, whereas most of the Poduromorpha belonged to the endogeic group.

The epigeic group consisted mainly of species from the Isotomidae family, and the endogeic group of species from the Onychiuridae family (Table 1). The genus Folsomia, from the Isotomidae family, had species both with and without eye organs, and were therefore represented in both the epigeic and endogeic group. The families with eye organs, Sminthuridae, Sminthurididae, Katiannidae and Bourletiellidae, were all in the epigeic group, whereas the Neelidae with no eyes belonged to the endogeic group.

Discussion

Species density and diversity

The average density of springtails was five times higher in April 2012 than in April 2011, and the number of species was also much higher in that year (30-33 vs. 21). This could be due to differences in weather conditions; however, the spring of 2012 was considerably colder than in 2011 and therefore the difference is opposite to that which could have been expected. Former studies found fewer springtails under winter conditions than summer conditions (Gudleifsson and Bjarnadottir 2008). The soil humidity was comparable in both years. Another explanation may be that the manure application on some plots in 2011 has increased the springtail density and diversity. The effect of slurry application on springtails is discussed in a separate paper.

The composition of species was quite different in the two years. Altogether, 25 out of a total of 42 species were only found in 2012 (Table 1); many of these with several individuals or on more than one sampling date. 16 of these 25 species were found in April 2012 and 9 in May and/or June. This shows that it was not primarily the additional samplings in May and June that caused the higher diversity in 2012. The sampling may not have been thorough enough to reveal the complete springtail fauna. In any case, the big variation in species composition with time is important to have in mind when ecological studies of springtails are carried out.

The recorded densities are comparable to other studies in agricultural fields in UK and Ireland (Bardgett & Cook 1998), Germany (Filser *et al.* 2002, Sabais *et al.* 2011) and other Nordic countries (Lagerlöf and Andren 1991, Axelsen and Kristensen 2000, Gudleifsson & Bjarnadottir 2008) However, the number of species is well above the values found in Iceland (14 species, Gudleifsson and Bjarnadottir 2008) and Sweden (14 species, Lagerlöf and Andren 1991). The number of species is comparable to the value found in Denmark (26 species, Axelsen and Kristensen 2000), after incorporation of large amounts of plant material and establishment of a protective plant canopy.

The number of species in our study in grass-clover ley was comparable to the number found in less disturbed natural habitats in Norway, such as spruce forest (32–34 species), birch forest (36 species, Fjellberg *et al.*, 2005), and different natural coniferous forests (15–26 species, Hågvar 1982). This is a somewhat surprising result, since regular disturbance in arable soil impact the soil fauna. The heterogeneous vegetation in the organically managed ley, with significant proportions of weeds and legumes in addition to different grasses, has likely contributed to the rich springtail fauna found here. The presence of legumes has been found to increase the density and diversity of springtails, most likely because of high litter quality and increased microbial biomass in the rhizosphere of legumes (Salamon *et al.* 2004).

New and rare species

This paper presents the first record of *Onychiurus edinensis* in Norway. About this species, Fjellberg (1998) mentions an unpublished Danish record from fields at Askov, S. Jutland and that the species is common in grazed meadows at Rothamsted, England. The species is white with a typical length of 1 mm. The thick, spine-like setae on the fifth abdominal segment (Figure 3) readily identifies this species (Fjellberg, 1998). Apart from these spines, *O. edinensis* is very similar to the much more common *Protaphorura armata*.

The alpine species *Oligaphorura ursi* is white, with a slender body and a typical length of 1.3 mm. Fjellberg (1998) has found this species on Arctic islands (Svalbard, Bjørnøya) and in Scandinavian mountain areas. Fjellberg (1998) reported one catalogued record from Northern Sweden, but none from Finland or Denmark of this species. This may not be surprising, since *O. ursi* is usually found close to alpine or arctic lakes and streams. The high diversity and the presence of rare species shows that agricultural land may be more interesting for ecological studies than might be expected.

Common Nordic agricultural species

The most abundant species at this site were also common in former studies in the Nordic countries. *P. notabilis* was abundant also on Iceland (Gudleifsson & Bjarnadottir 2008), in forest habitats in Norway (Hågvar 1982, Fjellberg *et al.*, 2005) and in agricultural soil in Denmark (Axelsen & Kristensen 2000) and Sweden (Lagerlöf & Andrén, 1991).

Most of the common species found in our study, were also common in the referred studies from Iceland, Denmark and Sweden. Due to identification to different taxonomic levels, different taxonomy and some differences in sampling methods, only an overall comparison is possible. The second most abundant species, *Mesaphorura krausbaueri* (Table 1), was also found in the Danish and Swedish studies, but no *Mesaphorura* spp. were reported in the Icelandic pastures. According to Fjellberg (1998) *M. krausbaueri* is recorded from all four countries, and can be mixed with the very similar *M. macrochaeta*. The latter is the third most abundant species in our material.

Protaphorura armata was the fourth most abundant species in the present study. In the Icelandic study, four species of *Protaphorura* were recorded, but no specimens of *P. armata*. In addition to *P. armata*, we found *P. cancellata* (Gisin, 1956) with 111 individuals in 2012. This genus was not reported in the Swedish or Danish study. Fjellberg (1998) reports several records from both countries. This genus may generally avoid cultivated soil habitats, and/or the appearance may be explained by the proximity of our field to forest and field margins with natural vegetation. The study in Iceland was done in permanent grassland.

The fifth most common species, *Isotomurus graminis* (Figure 3), was not recorded in any of the referred studies from Nordic countries. However, this species is easily mixed up with other species (Fjellberg 2007, Hopkin 2007). In the Danish study 11 specimens of *I. palustris* were found, which according to Fjellberg (2007) has an unclear taxonomic status. Fjellberg (2007) describes *I. graminis* as common in humid, disturbed grasslands, which fits well with the present study site.

Being a predatory species, *Friesea truncata* has a special interest. It was not found in the Danish or Icelandic study. In the Swedish study, the quite similar species *F. mirabilis* was common.

Feeding preferences

Studies of springtails' feeding preferences are highly dependent on the conditions posed in each study (Petersen 2002), and hence should be carefully interpreted. Analysis of gut contents may lead to the conclusion that springtails are non-selective feeders, while using food choice experiments may lead to the conclusion that they may have very specific food preferences. For instance, Jørgensen *et al.* (2003) showed a variation in the preference for eight species of fungi offered in the experiment. Some springtail species seem to be highly selective when foraging on fungi in soils, e.g. *Protaphorura armata* (Jørgensen *et al*. 2005). These authors found a 33 times higher diversity of fungi in the soil as compared to that in the guts of the springtails. However, Ponge (2000) found almost the opposite result, and claims that many springtails have become adapted to a wider spectrum of food items, often found in the immediate vicinity of the animal. Especially members in the Onychiuridae family (e.g. *Mesaphorura* spp.) were found to ingest a wide array of food materials, like plant debris and fungal and root material (Ponge, 2000). Perhaps the smaller size is forcing the *Mesaphorura* spp. (0.6–0.7 mm) to a more local and diverse feeding strategy as compared with the larger *Protaphorura* spp. (1.8 mm). We found five species of the genus *Mesaphorura* and two of the genus *Protaphorura*. We also found one typical pollen eater (*Deuterosminthurus* sp.), and quite many predatory *Friesea truncate*. Hence, the soil hosted several ecological groups of springtails with differences in feeding preference and vertical distribution.

"Epigeic" and "endogeic" species

Inspired by the approach of Salmon *et al*. (2014), we divided our results into two main groups called "epigeic" and "endogeic", but only based on pigmentation and presence or absence of eye organs. This simple grouping compared quite well with the classification of species in the sections Entomobryomorpha (including the subclass of

Symphypleona) and Poduromorpha (Fjellberg 1998, 2007), as shown in Table 1. Species like *P. notabilis* and *Isotomurus* spp*., Isotoma* spp. and *Desoria* spp. are common on the soil surface and in vegetation (Fjellberg, 2007). Belonging to the Poduromorpha, *Friesea truncate, Brachystomella parvula* and *Micranurida pygmaea* were exceptions in the epigeic group. In the endogeic group, there were five exceptions. The family Isotomidae was dominant among the epigeic species and the family Onychiuridae dominated among the endogeic species. All recorded species in the Onychiuridae family were relatively small, white, and blind, with short extremities and reduced furca, indicating a soil dwelling strategy. In Isotomidae, only some species were white and blind (*Folsomia fimetaria, F. stella* and *Isotomiella minor*, Table 1).

We found a reasonably good accordance between easily detectable morphological characteristics and established taxonomical classification (Fjellberg 1998, 2007). Hence, we believe that grouping springtail species into "epigeic" and "endogeic" according to pigmentation and presence of eyes may be useful in cases where identification to species is not possible. By this grouping, all white species will be "endogeic". For pigmented species, presence of eye organs must be examined. A few cases will be individuals with scarce pigmentation but no eyes and should go into the endogeic group. This simple grouping could be useful for scientists who may be reluctant to include springtails in their field studies due to lack of taxonomical skills.

Petersen (2002) described a more risky and venturous life-strategy among the epigeic (epedaphic) species, whereas endogeic (euedaphic) species, living in a more protected and stable environment, were more conservative with a more secure life strategy. With a higher mobility, surface living species may seek food of higher quality and with a larger dispersal, as shown by a higher metabolic activity. Even if he also emphasised the important role of a third, intermediate group of species, with a hemiedaphic life form, his contrasting approach in two groups fits well into the simple classification proposed here by using pigmentation and presence of eyes.

DNA analysis offers also an interesting opportunity to study the distribution of species that are not easily identified by eye. Porco *et al.* (2012) studied the distribution of the generally common species *P. notabilis*. Its wide distribution was linked to its nearly obligate parthenogenetic reproduction, which facilitates a rapid spreading to new localities. In spite of a homogenous morphology across Europe and North America, four distinct genetic lineages were found. This result also challenges the traditional species approach, but underlies the importance of knowledge on habitat preferences and ecological functions of the species, in addition to morphology and taxonomy.

Conclusions

The five most abundant species of springtails in organically managed grass-clover ley were *Parisotoma notabilis* > *Mesaphorura krausbaueri* > *Mesaphorura macrochaeta* > *Protaphorura armata* > *Mesaphorura tenuisensillata*. The density and diversity of springtails varied considerably between years. In general, the diversity was higher than expected, since altogether 42 species were identified. *Parisotoma notabilis* seems to be common or dominant in different habitats across the Nordic countries. The high diversity of species found here, and the identification of one new and one unexpected species, shows that agricultural soil may be of interest as a habitat for future studies of the Norwegian springtail fauna.

Springtails (Collembola) comprise a very high number of species, and the identification to the taxonomic level of species is very time consuming and requires specialist knowledge. A simple classification into "epigeic" and "endogeic" species based on pigmentation and presence/absence of eye organs seems to be useful in studies studies whose primary purpose is not the species but, for example, the effect of agronomic operations on soil biology.

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