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Green Roofs Support a Wide Diversity of Collembola in Urban Portland, Oregon

By

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An undergraduate honors thesis submitted in partial fulfillment of the
requirements for the degree of
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Abstract

Green roofs can help address habitat loss in urban areas by supporting plant and animal communities. To determine whether green roofs can support collembola biodiversity, we collected pitfall samples from April-June 2015 on two extensive and two intensive green roofs in urban Portland, Oregon. Twenty morphospecies were found across the roofs, indicating that green roofs support a diversity of collembola taxa. The intensive roofs were more biodiverse than the extensive, though roof type may not be the most significant factor affecting collembolan biodiversity. Each of the four green roofs were characterized by a different and unique most dominant morphospecies, and, indeed, each roof possessed a different set of top-three abundant collembola taxa. While green roofs support moderate collembola diversity, preserving natural habitat is important to maintain species richness.

1. Introduction

Green roofs are intentional, artificial constructions on the rooftops of buildings. Green roofs consist of a waterproof membrane, drainage layer, a filter membrane, growing medium, and vegetation successively layered on top of a typical building rooftop (Liu, 2004). They are usually vegetated, having originated from roof-gardens (Oberndorfer et al., 2007). There are two main roof types, which are divided by the depth of the substrate and thus the identity of the vegetation. Extensive roofs typically have a shallow substrate layer and feature succulent plants of the genus *Sedum* (and so may be called *Sedum roofs)*. Intensive roofs (which are so named as they require more intensive care, per Getter & Rowe (2006) typically have more herbaceous vegetation (and so may be called herbaceous roofs), potentially including shrubs and trees, and thus require a substrate deeper than 20 cm (Oberndorfer et al., 2007). While there are many reasons for constructing green roofs, they are typically economic in nature (including reducing building energy demands, assisting with storm water drainage, or increasing roof durability among others—see Gedge & Kadas (2005); Getter & Rowe (2006); Oberndorfer et al., (2007); Williams et al., (2014) for a review of benefits that green roofs can provide). A perhaps inadvertent by-product is that they may provide habitat for many different types of animals and plants. As green roof areas are typically small (Francis & Lorimer, 2011), they can support small organisms that disperse easily and can complete their life cycles on the roof, or that are highly mobile and use the green roofs as part of their wider range. Evidence of arthropod movement between green roofs has been found (Braaker et al., 2014), demonstrating that there may be connectivity between otherwise disjunct areas. Differences in factors such as vegetation type and cover, substrate composition, moisture, and depth, or micro-topography, can affect which species successfully colonize various green roofs. Given the potential (but perhaps not yet tenable) ability to shape the species composition on green roofs raises conservation questions, including if the green roofs are 'green enough' to support threatened or rare species (Gedge & Kadas, 2005). In many cases, extensive green roofs with commercially-bought *Sedum* vegetation do not replicate pre-development ecosystems (Gedge & Kadas, 2005).

As urbanization and the area that cities demand increases, the influence of cities expands into surrounding undeveloped landscapes (Grimm et al., 2008). While some artificial environments may function as natural analogues (Lundholm & Richardson, 2010), more often, urbanization leads to habitat fragmentation and loss of many (native) animals and plants, a serious concern (McKinney, 2002), with endangerment possibly leading to extinction. In his extensive review, McKinney (2008) noted that 79% of invertebrate and 100% of vertebrate studies analyzing the transition from developed (20-50% impervious surfaces) to highly urbanized (over 50% impervious) land saw reductions in species richness. Plants also followed a general trend of loss of species richness with high development. Interestingly, in some cases, studies looking at development of rural areas or land outside suburban areas found that it was correlated with an occasional increase in invertebrate and vertebrate richness (12%, 30%), while plants increased their richness 65% of the time. This may be explained by the intermediate disturbance hypothesis, which states that moderate human development leads to an environmental heterogeneity that can cause a more diverse species community (McKinney, 2002, 2008). Nonetheless, which variables are responsible for increases or declines in species richness are not yet known (McKinney, 2002).

Because green roofs are built on land already used by or appropriated for human use (Francis & Lorimer, 2011), green roofs are an opportunity to practice what Michael Rosenzweig (2003) coined 'Reconciliation ecology--' an ecological sub-discipline that seeks to reconcile what are already human-dominated landscapes and the biodiversity of the area on which they were built. As Rosenzweig writes, conserving or restoring enough land to promote biodiversity worldwide is not feasible, so reconciliation ecology seeks to reconcile human land-use with the needs of the organisms that were previously present. Green roofs can function as ecological systems and provide necessary habitat and resources for wildlife (Oberndorfer et al., 2007).

Whether green roofs tend to support native species or invasive ones is still unknown (Williams et al., 2014). Urban areas are often characterized by the presence and dominance of invasive, generalist species as opposed to organisms that were adapted to some previously available niche: over 50% of species at the urban core tend to be nonnative (McKinney, 2002). For example, Angold et al. (2006) found increasing dominance of ubiquitous urban generalists over woodland or woodland-associated ground beetle species. Additionally, conditions on the roof are typically more extreme than ones experienced at the ground level: high sun exposure and low substrate are typical of green roofs (Getter & Rowe, 2006). This often makes native plants unsuitable for some green roofs (Oberndorfer et al., 2007). Madre et al. (2013) and Rumble & Gange (2013)found the majority of green roof arthropod species they inventoried were adapted to dry, hot conditions (i.e. drought-tolerant, thermophilic or xero-thermophilic). Thus, green roofs may not support local taxa, unless the locally threatened ecosystems are climatically analogous. Nonetheless, some rare or endangered native species have been observed on green roofs in generally temperate climates like in London, England (Kadas, 2006), so the value of green roofs as habitat for rare and/or native species is still undetermined.

Much of the previous work on invertebrates inhabiting green roof has been on beetles and spiders in Europe or Canada (Kadas, 2006; MacIvor & Lundholm, 2011; Madre, et al., 2013; Schindleret al., 2011; Braaker et al., 2014). Relatively little work has been done on soil-dwelling invertebrates such as collembola or mites (though see Schrader & Böning (2006) and Rumble & Gange (2013).

Collembola are primarily soil-dwelling arthropods that are considered to be a sister group to insects, but are not part of Class Insecta. They are morphologically distinguished from other arthropods by the presence of a collophore (a tube-like structure that protrudes from their first abdominal segment and is likely used for gas-exchange purposes). Often, they also possess a furcula which they can use as a springing-mechanism, and this gives rise to their common name: springtails.

Like most soil-dwelling arthropods, they are more often found in moist environments as opposed to dry ones ((Verhoef & van Selm, 1983), as most collembola easily desiccate (Verhoef & van Selm, 1983; Alvarez et al., 1999), though some collembola species have adapted to dry environments (see Elnitsky et al. (2008) for a discussion of desiccation tolerance in an Antarctic collembolan). They are often found in leaf-litter.

As collembola are typically detritivores, they consume decaying vegetation but also fungi, and can contribute to soil-formation processes. They can also be found in grassy areas, in trees, or even in intertidal zones. They are often preyed upon by carnivorous arthropod organisms such as spiders, mites, centipedes, and ground beetles.

Green roofs can provide habitat for at least 30 collembola species in mild and temperate Hanover, Germany (Schrader & Böning, 2006), and they can persist on a multiyear basis (that is, they can reproduce on the green roofs and are not constrained to continued colonization from other sites) (Rumble & Gange, 2013). However, both studies were conducted on extensive green roofs in Europe. It is still unknown how extensive green roofs compare in biodiversity to intensive green roofs in the United States.

This study was conducted to determine overall collembola biodiversity on four representative green roofs (two herbaceous, two *Sedum*) in the urban core of the Portland, Oregon area. The study was framed as an inquiry into three major points: 1) what is the biodiversity of collembola on the green roofs; 2) do both herbaceous and *Sedum* green roofs provide habitat for collembola; 3) if so, do they promote similar or different species. To test these principles, we analyzed total number and abundance of morphospecies on the roofs over a three-month time-period.

2. Methods

2.1 *Sampling and collection*

Pitfall traps were placed on four urban green roofs in the Portland, OR area and sampled every two weeks between 9 April 2015 and 26 June 2015 (see Appendix I for building names, locations, and sample dates). Ten traps were placed on each roof in a permanent position in an equidistant rectangular pattern. Traps were distributed at linear distances of 10m wherever possible; as not all roofs have the same dimensions or shape, some traps were spaced no closer than 5m apart (see (Ward et al. (2001)for a description of how pitfall trap distance affects specimens caught). Traps were filled to two-thirds capacity with 10% acetic acid (vinegar) to preserve the caught specimens. Vinegar was used because of its relatively low volatility, non-toxic effects for vertebrates such as birds that visit the green roofs (personal observation), and for cost considerations as well. The traps (125 ml plastic cups) were placed inside a 5cm diameter PVC pipe connector and then placed in the substrate so the lip of the cup was flush with the ground. The cups were covered with a roof of corrugated plastic and nails to prevent rainfall flooding and vinegar evaporation; later in the collecting season, after interference from birds, traps were additionally covered with a chicken-wire screen that was weighted with a brick to prevent tampering.

The contents from all ten pitfall traps on a roof were aggregated into one sample from the roof per date. We observed that the vinegar discolored some specimens (collembola and spiders) and may have deteriorated their physical structure as well, so in the lab the contents of the sample were transferred from 10% acetic acid to 80% ethanol for longer-term preservation. This was accomplished by straining the samples over a coffee filter until the acetic acid dripped away; then, the coffee filter and its contents were immersed in 80% ethanol.

2.2 *Parataxonomy and identification*

Samples were first broadly sorted into groups of beetles, spiders, and a group of all other specimens with the use of a dissecting microscope at magnifications between 6.3x-12.0x magnification. Afterwards, collembola were extracted from the ‘other’ specimen category primarily by pipette, or, in the case of the more robust individuals, carefully picked out by forceps, again under a dissecting microscope, with magnification up to 30.0x. Care was taken to ensure this separation of collembola was comprehensive, and that all visible collembola were separated out.

Collembola were grouped into distinct morphospecies, an acceptable substitute for when identifying to species is not feasible (Oliver & Beattie, 1996). We were able to classify some collembola as belonging to Order Symphypleona. Morphospecies counts of greater than 20 individuals were estimated.

Photographs of each morphospecies were taken using QCapture (QImaging, Surrey, BC, Canada) or LAS EZ (Leica Microsystems Inc, Buffalo Grove, IL, USA) software. Images were stacked where appropriate using Zerene Stacker (Zerene Systems, Richland, WA, USA). The images used for identifying distinct morphospecies are included in Appendix II. Voucher specimens of each morphospecies are preserved in 80% ethanol and stored in the Museum of Natural History at Portland State University.

2.3 *Statistical Analysis*

Species richness and the Shannon-Weiner index (H’) were calculated to quantitatively compare collembola diversity between different roof sites. The Jaccard Index of Similarity was used to determine which roofs hosted the most similar community compositions.

3. Results

In total, 5016 individuals in 20 morphospecies were observed between April 9 and June 26 (see Fig. 1). Some morphospecies were observed at each collection date, while others varied in how frequently they were observed. The most species-rich roof, CWW, supported 18 morphospecies, only 9 of them were observed on three or more collection dates.

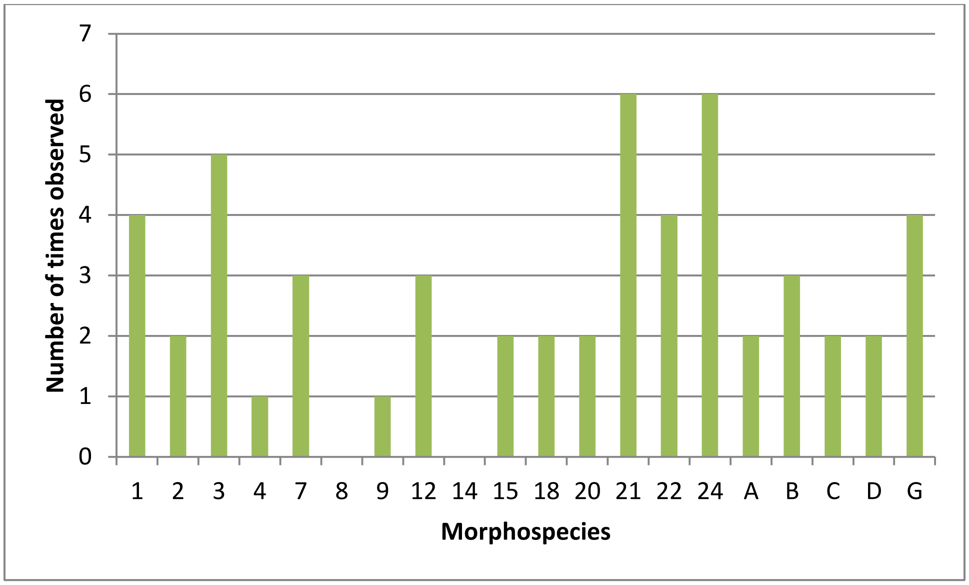

Figure 1: The number of times each collembola morphospecies was observed over the collecting season on the herbaceous roof CWW

We do not have data from May 14 on roof OC due to bird disturbances of the pitfall traps. Additionally, the April 9 data on roof HW is an outlier—only three individuals total were observed—significantly fewer than any other sample. Because we cannot accurately predict the morphospecies totals and abundances for the two dates, we have not attempted to interpolate these values.

3.1 *Morphospecies results*

Number of morphospecies had a variable trend based on whether the roofs were herbaceous (CWW and HW) or *Sedum* (ET and OC) (see Fig. 2). Herbaceous morphospecies richness decreased over the course of the season, while the *Sedum* roofs increased in diversity until mid-May, then decreased. On both sets of roofs, morphospecies number declined by the end of June.

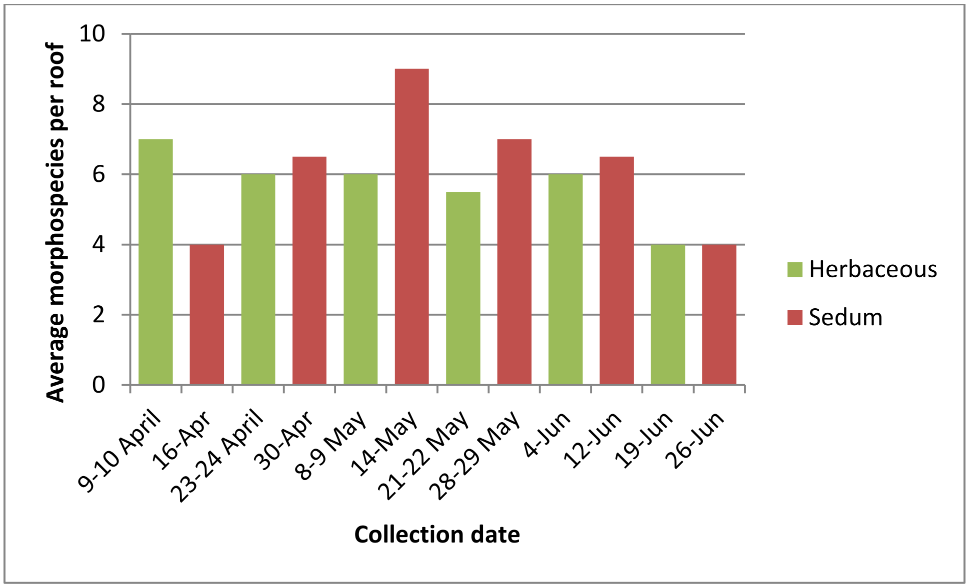

Figure 2: Average number of unique morphospecies observed at each collecting date on herbaceous (CWW and HW) or *Sedum* (OC and ET) roofs

CWWR had the greatest number of morphospecies observed across the six collection dates (18 morphospecies) and HWR had the fewest (11). See Table 1 for complete classification. Appendix III contains the full raw data.

Table 1: Total morphospecies richness observed over the season on each roof

Roof	CWWR	HWR	ETR	OCR	Herbaceous	*Sedum*
Morphospecies richness	18	11	13	14	18	19

The two herbaceous roofs (CWWR and HWR) hosted a combined 18 morphospecies (missing morphospecies 8 and 14), while the two *Sedum* roofs (ETR and OCR) hosted a combined 19 (missing morphospecies 7). Notably, one morphospecies, morphospecies 14, was only observed on OCR, where it was observed on three different collection dates. All other morphospecies were observed at least once on two or more roofs. As Fig. 3 shows, when morphospecies were observed on both types of green roofs, they were observed with similar frequency.

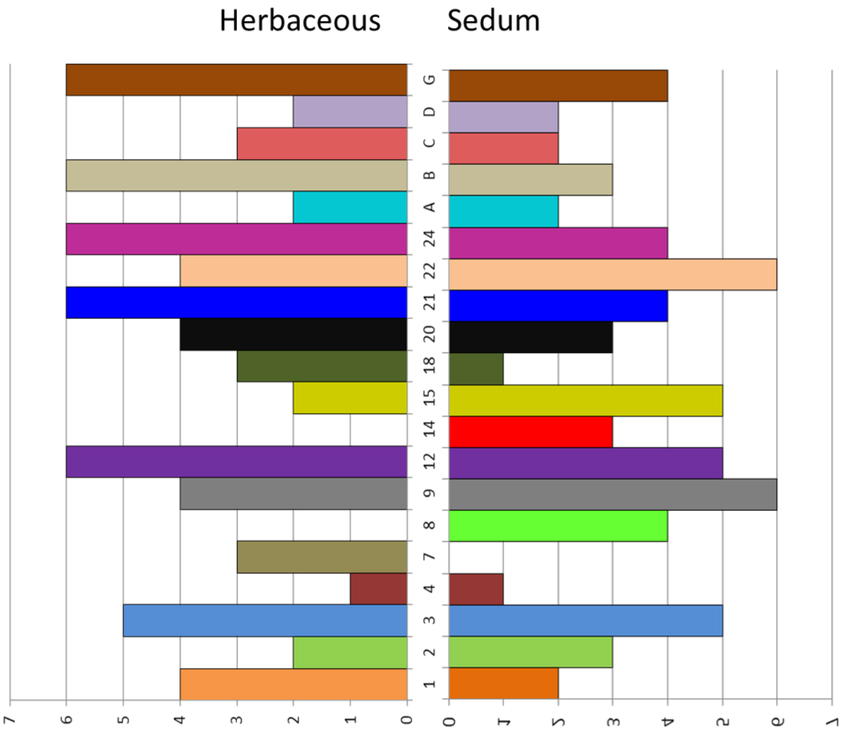

Figure 3: Number of collection dates where a morphospecies were observed on at least one roof, split into herbaceous (CWW and HW) and *Sedum* (ET and OC)

Each roof was dominated by a different morphospecies that accounted for between 36% (morphospecies 21, CWW) and 67% (morphospecies 12, OCR) of the total individuals counted (Fig. 4). For both *Sedum* roofs, one morphospecies accounted for over half of the total individuals (morphospecies 12, OCR; morphospecies 9, ETR), while this was not observed in herbaceous roofs. In all cases, individuals of one or two morphospecies constituted over half the observed total.

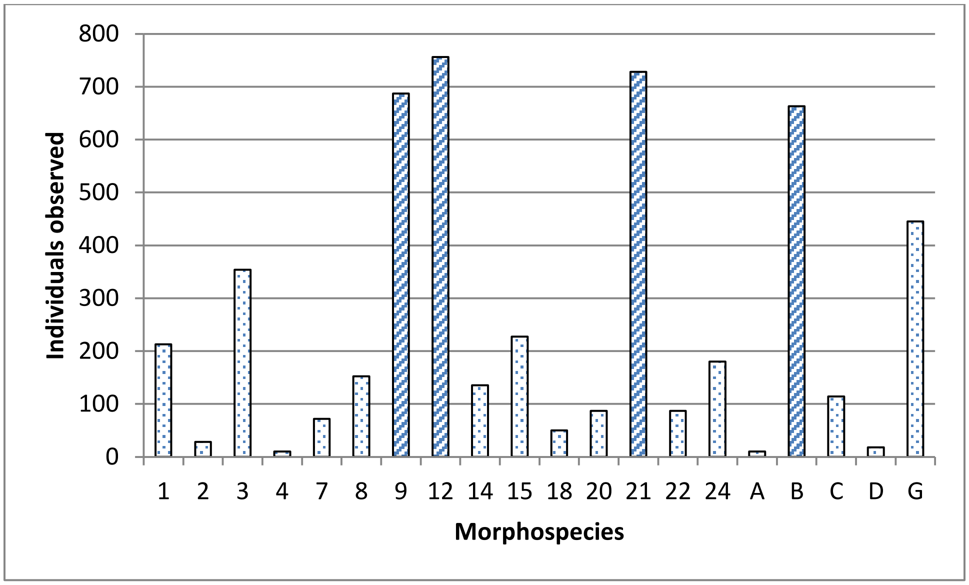

Figure 4: Morphospecies abundance distribution summed across all roofs and dates. The four darkest columns show the one most abundant morphospecies per roof (9: ET, 12: OC, 21: CWW, B: HW)

Each green roof had a different set of three most abundant morphospecies (Fig. 5). The two *Sedum* roofs support two different communities with very little overlap of morphospecies: none of the seven most abundant morphospecies on each roof (covering 96% of the population, OCR; 97%, ETR) are shared. This reveals that the broad-scale, overall community composition on each roof is very different.

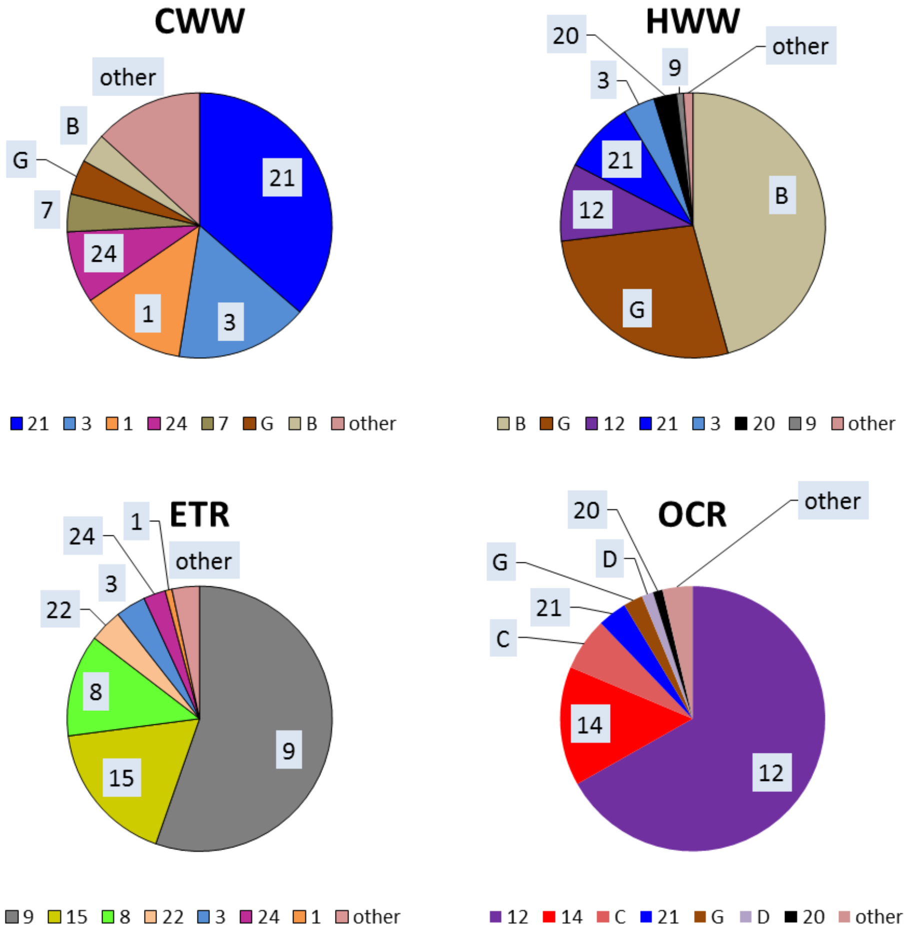

Figure 5: Relative morphospecies proportions when morphospecies abundance on each roof was summed. The top two roofs are herbaceous roofs; the bottom two are *Sedum* roofs.

The most abundant morphospecies across all roofs was morphospecies 12, with 756 individuals; the OC roof accounted for 620 of these (82%). The least abundant were morphospecies 4 and morphospecies A, each with 10 individuals, though there does not seem to be a clear trend in abundance or presence/absence per roof. An interesting result emerged, however, when collembola morphospecies of order Symphypleona were grouped. Table 2 demonstrates that collembola of the order Symphypleona were present in a significantly larger proportion on the *Sedum* roof OCR than the other three green roofs. Watering data available from the roofs as an explanatory variable is listed as well.

Table 2: Proportion of individuals belonging to the order Symphypleona across the season

Roof	% Symphypleona	Is the roof watered?
CWW	6.57	No
HWR	12.9	Yes
ETR	1.23	Yes
OCR	90.9	Occasionally by hand

3.2 *Abundance results*

The roofs with herbaceous vegetation supported a higher number of collembola than the *Sedum*, both individually and when pooled (Table 3).

Table 3: Total number of collembola over the season on each roof

Roof	CWWR	HWR	ETR	OCR	Herbaceous	*Sedum*
Count	1568	1301	1219	928	2869	2147

Collembola abundance over the season showed an interesting trend when comparing the two herbaceous roofs to each other, as well as the two *Sedum* roofs. Patterns over time mirrored each other separately on herbaceous and *Sedum* roofs, as demonstrated in Fig. 6. See Appendix IV for how weather processes may affect collembola abundance.

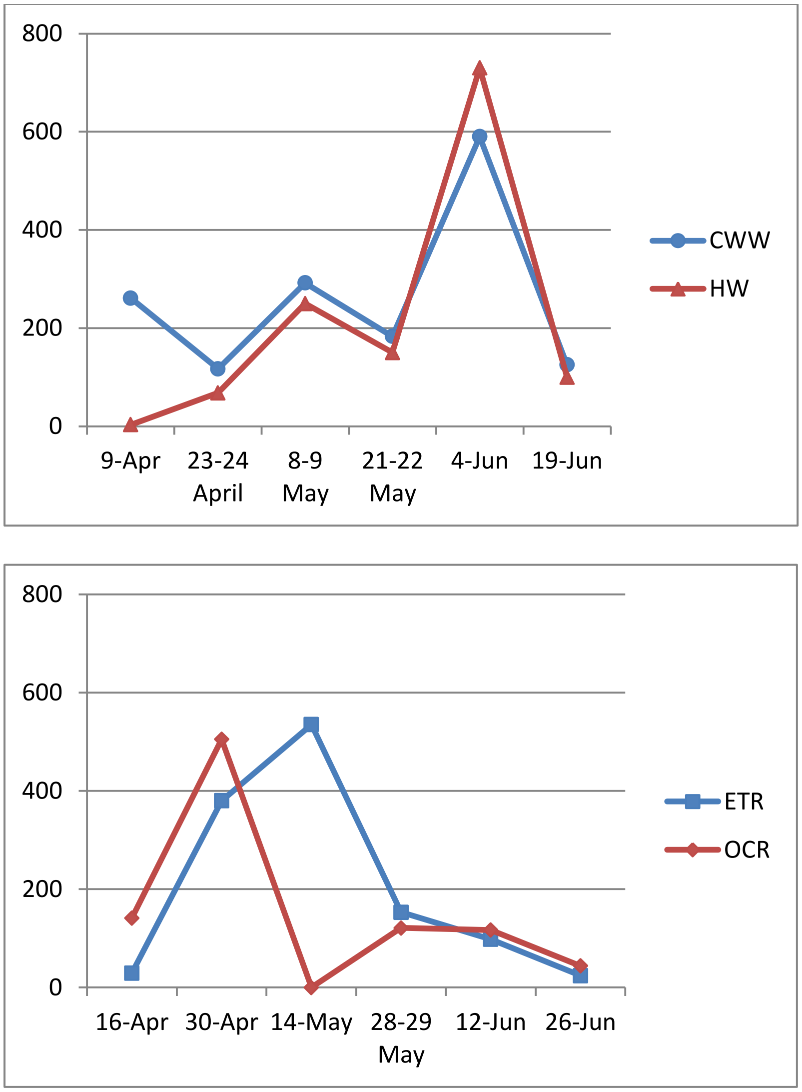

Figure 6: Collembola abundances on Herbaceous (top) and *Sedum* roofs (bottom). April 9 (HW) and May 14 (OCR) samples, as previously noted, are missing.

Sedum roof abundances peaked three to four weeks before herbaceous roofs, but again the missing May 14 sample for OCR confounds this issue.

3.3 *Diversity and similarity between green roofs*

CWW was the most diverse single roof observed in the study, with a Shannon index of 2.07, while OC had the least diversity, with an index of 1.24. The full listing of Shannon indices is given in Table 4. The data suggests a trend that herbaceous roofs are more diverse than *Sedum* roofs, but we lack the statistical power to determine significance.

Table 4: Shannon-Weiner Diversity Index calculated for each roof

Roof	CWWR	HWR	ETR	OCR	Herbaceous (avg.)	*Sedum* (avg.)
Shannon Index	2.07	1.48	1.453	1.237	1.775	1.345

The two most similar (classified by the Jaccard index of similarity) green roofs were an herbaceous and *Sedum* roof (CWW and ETR), while the two least similar roofs were the two *Sedum* roofs, ETR and OCR (see Table 5). The two herbaceous roofs had moderate similarity.

Table 5: Jaccard similarity index correlation matrix

Roof	CWW	HWR	ETR	OCR
CWW				
HWR	0.275			
ETR	0.2791	0.25		
OCR	0.2889	0.2647	0.23	

4. Discussion

Our study is the first to examine collembola biodiversity on both intensive and extensive green roofs in the same geographic area: Schrader & Böning (2006) looked at extensive roofs, as did Rumble & Gange (2013); MacIvor & Lundholm (2011) looked at intensive roofs compared to adjacent ground-level sites. What we sought to answer was first the total morphospecies diversity on the intensive and extensive roofs, and then to compare the two in order to determine whether one roof type provided a better habitat than the other. The 20 observed morphospecies is higher than that found by both MacIvor & Lundholm (2011) who found one collembola morphospecies on five roofs, and Rumble & Gange (2013) who identified six collembola species on two roofs. Schrader & Böning (2006) found 30 collembola species on ten roofs.

All four roofs support collembola biodiversity, but not equally so. The herbaceous roof CWW supported both the most morphospecies and number of individuals. Interestingly, roof type does not seem to play the hypothesized critical role in grouping which morphospecies are observed: the two *Sedum* roofs have the least similar species composition (see the Jaccard index), and the most similar compositions belong to an herbaceous and *Sedum* roof. Indeed, CWW was more similar to the two *Sedum* roofs than it was to the other herbaceous roof, HWR. This suggests that the binary system of characterizing green roofs by vegetation may be too simplistic when explaining roof biodiversity.

The average diversity of intensive roofs was 1.775 and that of extensive roofs was 1.345. This is much higher than the value of 0.5 that Rumble & Gange (2013) found, and is higher than the results of Schrader & Böning (2006), who found a diversity of 0.88 on young roofs, and 1.04 on old roofs. Substrate moisture is likely a key reason for the substantially higher diversity we found on our roofs. Three of our roofs were nominally watered, while this was not the case for

Rumble & Gange (2013), and it is not known whether roof watering occurred at the roofs studied by Schrader & Böning (2006). Rumble & Gange (2013) found a logarithmic trend of collembolan abundance on extensive green roofs compared to substrate water content, with a threshold level of 5%, below which abundance quickly decreased, and roof watering likely contributes to keeping moisture above the threshold value, allowing higher collembola diversity.

Species-specific differences in substrate water content are likely to manifest themselves with a closer analysis of substrate moisture: Alvarez et al. (1999) found that, in arable fields, *Sminthurinus* species were successful in emerging after they re-watered soils that had undergone an experimental four-month drought. More broadly, they found various Symphypleona but no individuals from either Entomobryomorpha or Poduromorpha. Summing the given frequencies of collembola in Rumble & Gange (2013) suggests that over 97% of their observed collembola belong to Symphypleona. However, none of the ten most frequent collembola species in Schrader & Böning (2006) were Symphypleona. Our study found low proportions of Symphypleona on every roof but OCR, where they comprised 91% of the population. Roof watering is not likely to be the sole explanatory variable for our observed dramatic difference in Symphypleona proportion, but substrate moisture may be.

The total collembola abundances follow an interesting seasonal pattern. The herbaceous roofs share a similar pattern of increasing and decreasing abundances (especially see dates 2 and 3 on the *Sedum* roofs and date 5 on the herbaceous roofs for interesting paralleled spikes in abundance). Why the roofs follow such a similar trend is still unexplained, though it likely relates to soil moisture and perhaps temperature as well. While we did not have temperature or substrate moisture data, *Sedum* roofs may warm faster than herbaceous roofs do, ending dormancy in the over-wintered egg population and thus starting the collembola life cycle, resulting in more observed individuals sooner in the season. Further analysis would elucidate whether this pattern of morphospecies decline continues into July, which is expected with increased temperature and decreased water availability.

All four roofs supported a different dominant morphospecies, and, indeed, a different top-three profile (though *Sedum* roofs were even more distinct, where 96% to 97% of their communities were different. In their paper, Schrader & Böning (2006) noticed distinct patterns relating dominant collembola species based on the age of the roof and suggested that succession may play a role in which species are dominant, present, or absent. Should succession be occuring, the Jaccard index of the two oldest roofs (HWR and CWWR) should be the highest, but this is not the case. Additionally, the two youngest roofs (OCR and ETR) have the least similarity between them. This suggests that stochastic events during initial green roof colonisation play a more significant role in determining which species will become dominant on each roof. This observation, coupled with the differential morphopsecies dominance per roof, suggests that multiple green roofs of both intensive and extensive types are necessary for securing collembola biodiversity in urban areas.

The idea of green roofs as model ecosystems has been previously suggested (Oberndorfer et al., 2007). Our results suggest that when green roofs are constructed with sterilized soil so no collembola or other microarthropods are present, they may prove suitable as small-scale, easily monitorable models for island colonization, where small initial population sizes and limited dispersal area means that random fluctuations are important drivers for selection of which species can become dominant. As artificial (Oberndorfer et al., 2007), novel, locally homogenous and accessible habitats, they may prove to be ecologically relevant model systems.

5. Conclusion

Different green roofs support different collembola assemblages. Each roof had a unique most dominant set of morphospecies, and while herbaceous roofs support a higher biodiversity of collembola, *Sedum* roofs host more morphospecies. Thus, the binary system of classifying roofs as *Sedum* or herbaceous may be inadequate for accurately determining the biodiversity of animals on these roofs. Further, our data suggests that green roof collembola do not follow a succession pattern, and that instead, early conditions and random chance provide the makeup of what species are observed. If roofs are established with sterilized soil and vegetation, they may prove useful as models for mainland-island colonization processes.

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Appendix I

Detailed information on each green roof

Green roof name	**Abbreviation**	**GPS Coordinates (DD)**	**Most recent resurface date**	**Collection date 1**	**Collection date 2**	**Collection date 3**	**Collection date 4**	**Collection date 5**	**Collection date 6**
Central Wine Warehouse	CWW-R	45.520897 N 122.662407 W	2008	9 April 2015	23 April 2015	9 May 2015	21 May 2015	4 June 2015	18 June 2015
Ecotrust	ET-R	45.528333 N 122.680568 W	2010	16 April 2015	30 April 2015	15 May 2015	29 May 2015	11 June 2015	25 June 2015
Hamilton-West	HW-R	45.515147 N 122.687563 W	1999	10 April 2015	24 April 2015	8 May 2015	22 May 2015	4 June 2015	19 June 2015
Oregon College of Oriental Medicine	OC-R	45.524054 N 122.671152 W	2012	16 April 2015	30 April 2015	No sample collected	28 May 2015	12 June 2015	26 June 2015

Appendix II

Morphospecies images

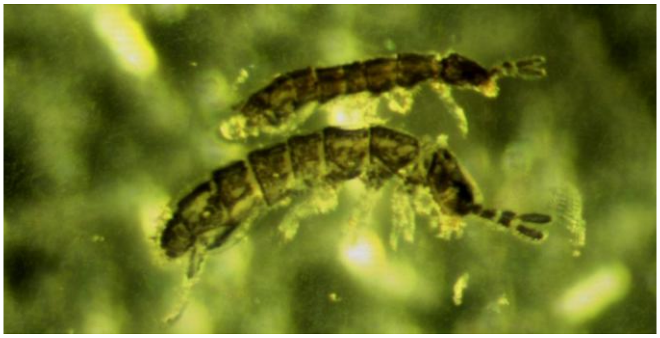
Morphospecies 1

Morphospecies 2

Morphospecies 3

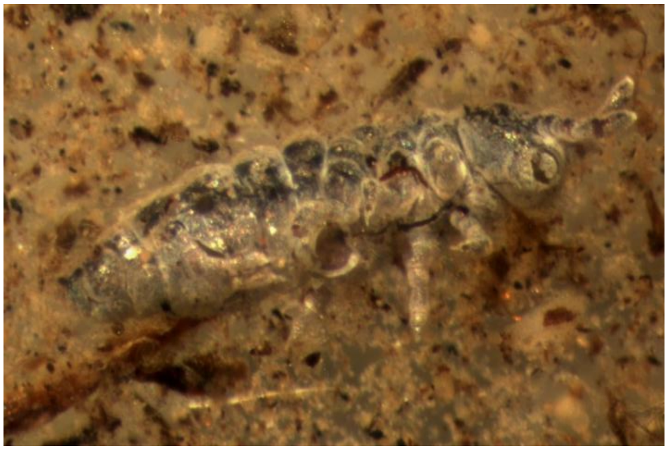
Morphospecies 4

Morphospecies 7

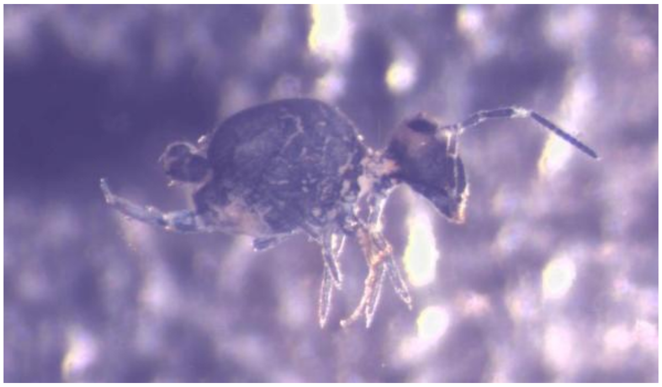


Morphospecies 8

Morphospecies 9

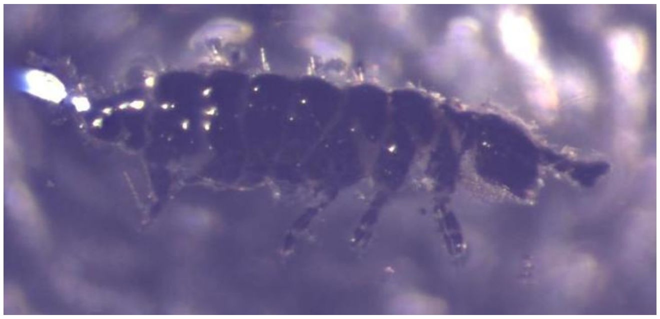


Morphospecies 12

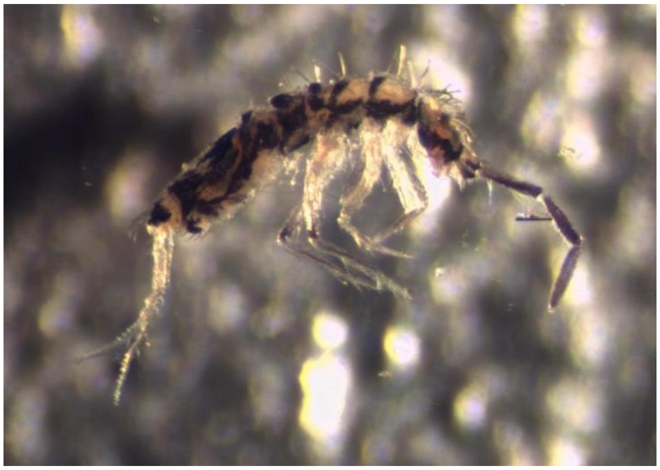


Morphospecies 14

Morphospecies 15

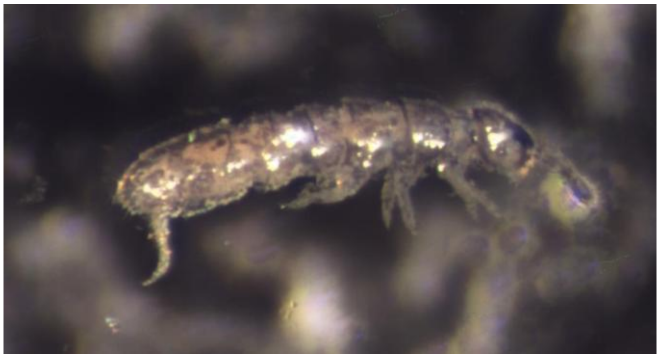


Morphospecies 18



Morpshospecies 20

Morphospecies 21



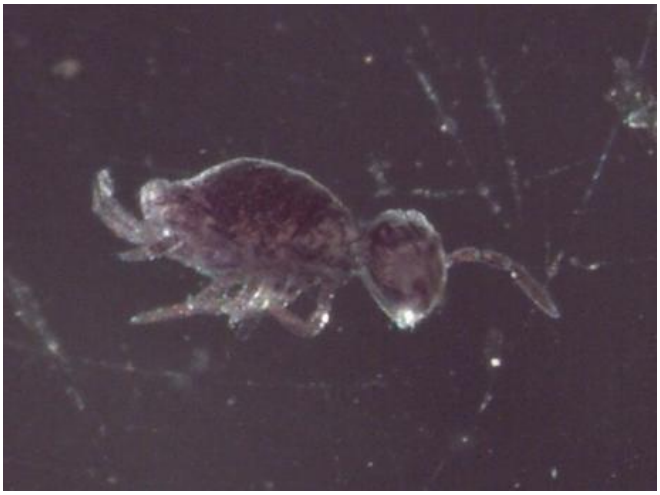
Morphospecies 22

Morphospecies 24

Morphospecies A

Morphospecies B

Morphospecies C



Morphospecies D

Morphospecies G

Appendix III

Raw data from each collection date

	CWWR							
Morph	**Date 1**	**Date 2**	**3**	**4**	**5**	**6**	**Total Observed**	**Times Observed**
1	28		100	25	50		203	4
2				4	15		19	2
3	13		75	10	125	30	253	5
4		5					5	1
7	35	7			30		72	3
8							0	0
9	1						1	1
12	1	5	1				7	3
14							0	0
15		10	1				11	2
18	6				35		41	2
20	35	2					37	2
21	75	75	50	100	250	20	570	6
22			10	3	10	10	33	4
24	3	5	25	30	25	50	138	6
A	1	1					2	2
B	12		30			15	57	3
C	45	2					47	2
D	4			1			5	2
G	2	5		10	50		67	4
Total Observed	261	117	292	183	590	125	1568	Average
Tot Morpho	14	10	8	8	9	5	18	2.7

	HWR							
Morph	**Date 1**	**Date 2**	**3**	**4**	**5**	**6**	**Total Observed**	**Times Observed**
1							0	0
2							0	0
3					50		50	1
4							0	0
7							0	0
8							0	0
9		1	5			5	11	3
12		8	50	25	20	20	123	5
14							0	0
15							0	0
18				5			5	1
20	1	20	5		10		36	4
21		15	100				115	2
22							0	0
24	1						1	1
A		2					2	1
B		15	50	80	400	50	595	5
C		2	5				7	2
D							0	0
G	1	5	35	40	250	25	356	6
Total Observed	3	68	250	150	730	100	1301	Average
Tot Morpho	3	8	7	4	5	4	11	1.55

	ETR							
Morph	**Date 1**	**Date 2**	**3**	**4**	**5**	**6**	**Total Observed**	**Times Observed**
1		5		5			10	2
2		2		2	5		9	3
3	14	4	4	8	15		45	5
4							0	0
7							0	0
8	1		100	50		1	152	4
9	9	300	300	10	50	6	675	6
12	1				5		6	2
14							0	0
15		50	100	50	8	6	214	5
18							0	0
20			3				3	1
21			10				10	1
22	3	5	5	10	15	11	49	6
24		10	8	15			33	3
A	1		5				6	2
B		4		3			7	2
C							0	0
D							0	0
G							0	0
Total Observed	29	380	535	153	98	24	1219	Average
Tot Morhpo	6	8	9	9	6	4	13	2.1

	OCR							
Morph	**Date 1**	**Date 2**	**3**	**4**	**5**	**6**	**Total Observed**	**Times Observed**
1							0	0
2							0	0
3	1	5					6	3
4					5		5	2
7							0	0
8							0	0
9							0	0
12	100	350		100	50	20	620	6
14	30	100				5	135	4
15						2	2	2
18					4		4	2
20		10		1			11	3
21		25		5	3		33	4
22						5	5	2
24		4		2	2		8	4
A							0	0
B		3			1		4	3
C	10				50		60	3
D				3		10	13	3
G		8		10	2	2	22	5
Total Observed	141	505	0	121	117	44	928	Average
Tot Morpho	4	8	0	6	8	6	14	2.3

Appendix IV

Climatic factors affecting collembola number

Which weather processes affect collembola abundance is difficult to determine, but abundance is likely a function of at minimum temperature (Fig. 1), maximum temperature (Fig. 2) and roof moisture, determined by precipitation (Fig. 3), roof drainage, and whether the roof is watered. Other factors may contribute as well. It is especially confounded by collembola lifecycle dynamics, where climatic events may be visible but after a lag period.

Since abundances were so similar between roofs of the same vegetation type, CWW (herbaceous) and ET (*Sedum)* roofs were chosen as representative for the figures. No clear trend emerges from the graphics listed below, as one explanatory variable is not enough to determine abundances. The precipitation events presented in Fig. 3 sometimes occur before and sometimes after large collection dates, so rainfall total is not satisfactory to predict collembola abundance. Additionally, as mentioned above, roof substrate moisture is not determined solely by precipitation. Future studies would do well to include moisture and temperature sensors on the roofs.

All climatic data was obtained for the PDX International Airport weather station from the National Climatic Data Center at the NOAA.

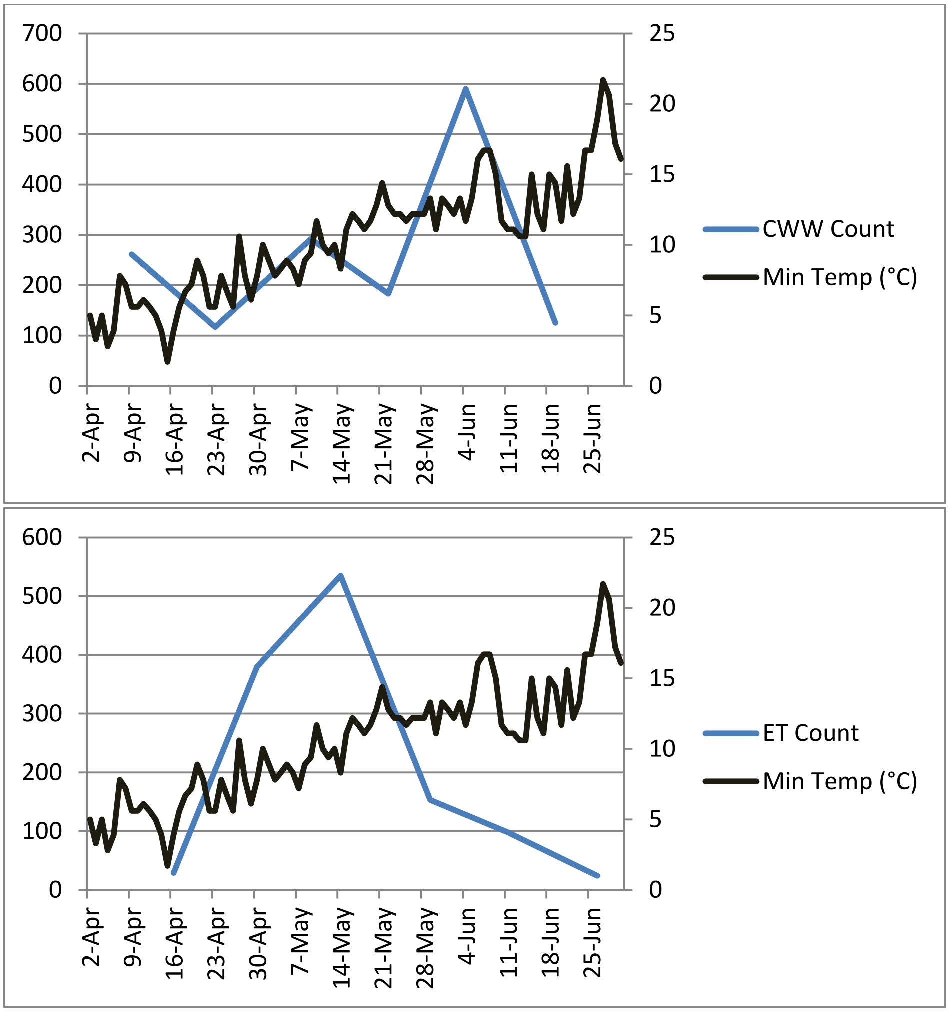


Figure 1: Green roof collembola abundance (blue) with minimum daily temperatures (°C) in black overlaid on a secondary axis

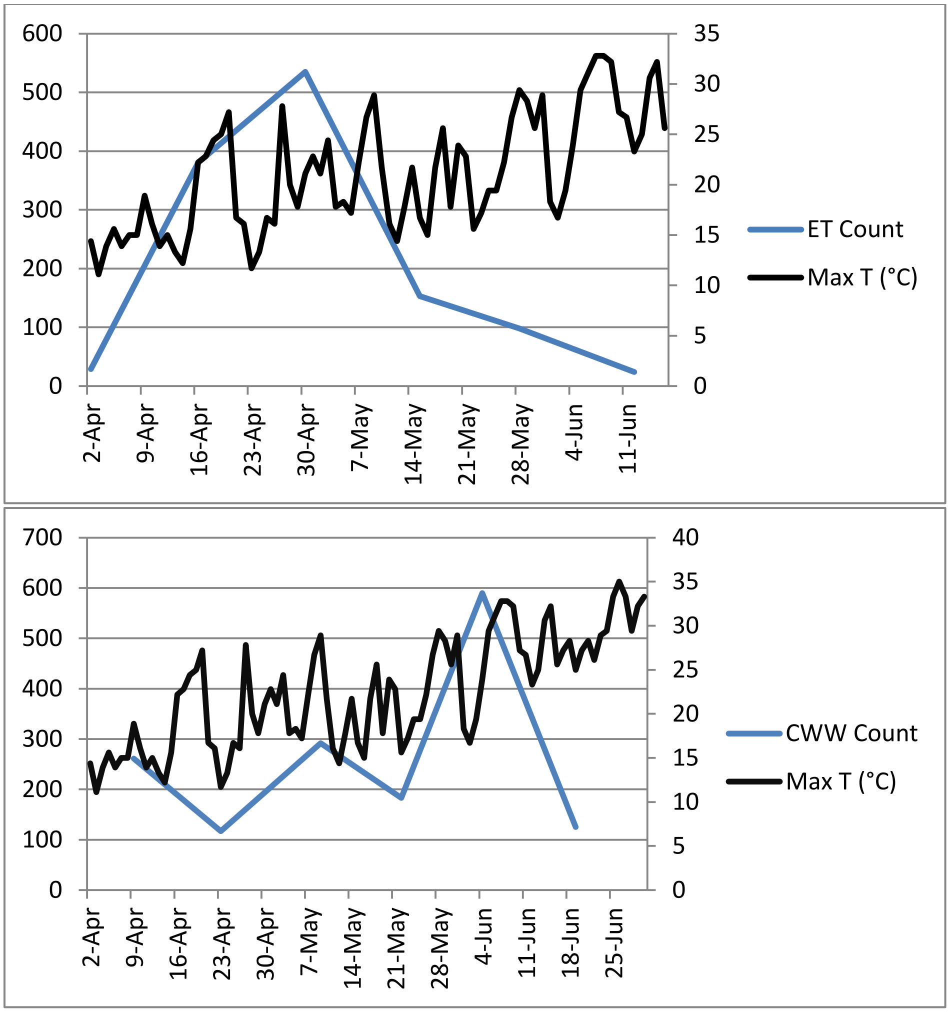
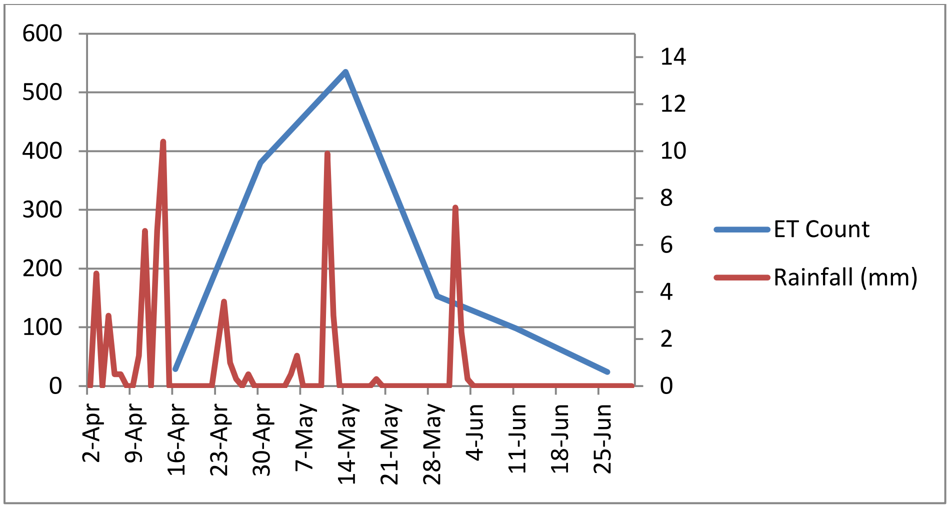


Figure 2: Green roof collembola abundance (blue) with maximum daily temperatures (°C) in black overlaid on a secondary axis



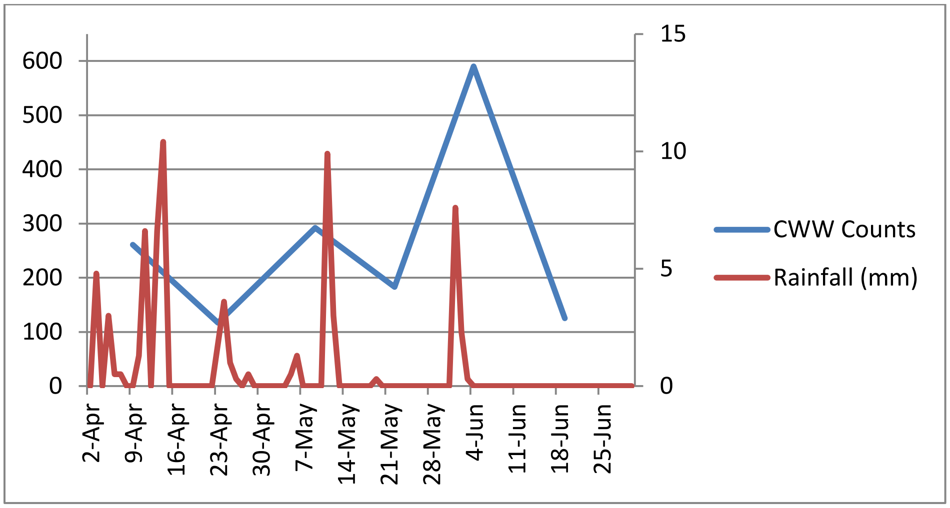


Figure 3: Green roof collembola abundance (blue) with the rainfall total (red) overlaid on a secondary axis.