The leafhopper fauna of green roofs including the Mediterranean leafhopper *Circulifer haematoceps* new for the Netherlands (Auchenorrhyncha: Cicadellidae)

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In 2018-2019, the insect fauna of green roofs in the western and southern part of the Netherlands was sampled with pan traps and pitfall traps. Nineteen species of leaf- and planthoppers were collected. *Circulifer haematoceps* is a new species for the Netherlands and was found on green roofs in three different cities. The biology and taxonomic status of this species is discussed in detail. Ecological information is given on the more common leafhoppers.

Introduction

The construction of green roofs is a recent development in many Dutch cities. Green roofs are becoming increasingly popular among governments and municipalities because they provide many innovative solutions to our urbanisation and climate change problems. They reduce local sewage overflow during heavy rainfalls (Mentens *et al*. 2006), which reduces energy costs on alternative water retention services. They mitigate the Urban Heat Island (UHI) effect (Castleton *et al*. 2010), reducing health risks for vulnerable groups like elderly people and babies during heat waves in summer (Li & Yeung 2014). Furthermore, they improve sustainability of a city by reducing air pollution, energy costs of a building and increasing longevity of a roof (Kleerekoper *et al*. 2012). It is thus no wonder that green roofs are imposed by the government in cities like Singapore and Zurich, where they have realised that their cities would not be liveable without them.

Besides all these benefits that green roofs provide, they also have an important contribution to biodiversity (Braaker *et al*. 2014, Kadas 2006). Large parts of urban area comprise unused (flat) rooftops and by greening these, our loss in biodiversity can be counteracted to an extent. These new, unique habitats provide interesting, well-functioning ecosystems where even new and rare species of insects are found.

Methods

In 2018-2019 an inventory was made of the insect fauna of 21 (2018) and 25 (2019) green roofs in the cities of Amsterdam, Rotterdam, The Hague, Wageningen and Helmond located in the western, central and southern parts of the Netherlands.

A pilot sampling was done in 2018 on 21 green roofs in the period between August 16 and September 27, 2018, while 25 roofs, including 18 of the roofs of 2018, were sampled thrice in 2019, once between April 8 and May 15, once between May 22 and July 7 and once between July 1 and August 1.

Each roof was sampled with six pitfall traps and four pan traps, of which the latter was increased in 2019 to eight pan traps, three white, three yellow and two blue pan traps. The content of the traps was collected after 24 hours. Unfortunately, only a limited number of samples was available from the 2018 pilot.

From the samples collected, the adult Auchenorrhyncha (in this case only planthoppers Delphacidae and leafhoppers Cicadellidae) were further studied and identified to species level. In case only females were collected at a site it was not possible to identify them to species level for *Anaceratagallia* (5♀♀), *Euscelis* (4♀♀), *Macrosteles* (1♀) and *Psammotettix* (2♀♀). The first two were omitted from the data set.

The following characteristics were recorded in 2019 for each roof: roof age, roof area, roof height, the amount (percentage coverage) of green space within 300 meter of the roof in square meters. Additionally, on each roof, vegetation height, vegetation cover and microrelief were estimated, as well as the weather during trapping. The latter included average temperature, wind speed and duration of sunshine, recorded by the KNMI station nearest to the roof. Furthermore, each roof was categorized as either (1) *Sedum roofs* with a substrate layer of maximum 10 cm and a roof coverage of more than 90% by *Sedum*, (2) *Herbaceous roofs* with a substrate layer of 9 to 30 cm, and a vegetation of various herbs, possibly with *Sedum*, or (3) *Roof gardens* with a substrate layer deeper than 15 cm and a vegetation of herbs,

Table 1. Auchenorrhyncha on Dutch green roofs collected in pitfalls and pan traps. Data from 2018 and 2019 combined. The number of green roofs with a certain Auchenorryncha species collected with pan traps (A), or pitfall traps (B). The total number of green roofs with a certain Auchenorrhyncha (C). The number of males (♂ ♂) and females (♀ ♀) in the pan traps and pitfall traps are summarized. B: brachypterous, M: macropterous.
Tabel 1. Auchenorrhyncha verzameld op Nederlandse groene daken met bodem- en schotelvallen. De gegevens uit 2018 en 2019 zijn gecombineerd. Het aantal groene daken met een cicadesoort verzameld via schotelvallen (A), respectievelijk via bodemvallen (B). Het totaal aantal groene daken waarop een cicadesoort waargenomen is (C). Het aantal ♂ ♂ en ♀ ♀ verzameld per soort, bodem- en schotelvangsten tezamen. B: brachypteer, M: macropteer.

	A. Pan traps	B. Pitfall traps	C. Roofs	♂ ♂	♀ ♀
Delphacidae					
Stenocranus major (Kirschbaum, 1868)	1		1		2 ♀ M
Conomelus sp.	1				1 ♀ B
Javesella dubia (Kirschbaum, 1868)	2		2	1 ♂ B	1 ♀ M
Cicadellidae					
Megophthalminae					
Megophthalmus scanicus (Fallén, 1806)	1		1	1	
Agalinae					
Anaceratagallia ribauti (Ossiannilsson, 1938)	8	9	13	80	14
Anaceratagallia venosa (Geoffroy, 1785)		1	1	1	
Aphrodinae					
Anoscopus serratulae (Fabricius, 1775)		2	2	2	
Aphrodes makarovi Zachvatkin, 1948	7	3	7	33	6
Typhlocybinae					
Eupteryx decemnotata Rey, 1891	2		2	2	
Empoasca decipiens Paoli, 1930	1		1	1	
Eupteryx notata Curtis, 1837	1	1	1	3	
Zyginidia scutellaris (Herrich-Schäffer, 1838)	2		2	6	1
Deltocephalinae					
Arthaldeus pascuellus (Fallén, 1826)	1		1	1	
Circulifer haematoceps (Mulsant & Rey, 1885)	3	1	3	16	2
Eupelix cuspidata (Fabricius, 1775)	1		1		1
Euscelis incisus (Kirschbaum, 1858)	12	6	12	85	10
Macrosteles sp.		1	1		1
Ophiola russeola (Fallén, 1826)	1	2	2	6	2
Psammotettix sp.	2		2		2
Total				**238**	**43**

trees and shrubs. To see if these variables affect plant-and leafhopper species richness, a generalized linear model with a poisson distribution was fitted for the 2019 data, which included the following variables: roof age, roof area, roof height, the area in m^2 of green space within 300 meter of the roof, vegetation height, vegetation cover, microrelief, temperature, wind speed and duration of sunshine. Microrelief and vegetation height were excluded from the statistical models due to collinearity with type of green roof. Using stepwise selection, multiple models were considered and non-significant variables eliminated based on the Aikake information criterion, which is an indicator of model quality, until two models of similar quality remained. These two models are presented in the results.

1. Plot of the mean species richness of plant-and leafhoppers per roof type. Based on data from 2019.
1. Grafiek van de gemiddelde soortenrijkdom van spoor- en dwergcicaden per type dak. Gebaseerd op data uit 2019.

Results

Collected specimens

Table 1 gives an overview of the collected material. In total, 281 specimens representing 19 species) were collected from 22 green roofs. Compared to the 422 species of Auchenorrhyncha known from the Netherlands, these 19 species represent only a small fraction. Details on the biology of leafhopper species will be given for species collected at more than two green roofs.

Roof types

Statistical analysis revealed that roof type and roof age had a significant effect on species richness. No other variables had a significant effect on species richness. Herbaceous roofs and roof gardens were significantly more species rich than *Sedum* roofs (mean estimate of sedum roofs compared to roof gardens -1.4395 with confidence interval -2.522 to -0.3565 and mean estimate of sedum roofs compared to herbaceous roofs -1.68 with confidence interval -2.8645 to -0.4955) (see also table 2-3, figure 1). No difference was found between herbaceous roofs and roof gardens (mean estimate 0.2405, confidence interval -0.4885 to 0.97). This clear divergence in species richness per type of roof likely reflects the greater vegetation diversity

Table 2. Numbers of plant and leafhoppers at each roof top. Data from 2018 and 2019 combined.
Tabel 2. Het aantal cicaden per daktuin. Gegevens uit 2018 en 2019 gecombineerd.

Location	City	roof type	Number of species	*Anaceratagallia ribauti*	*Euscelis incisus*	*Aphrodes makarovi*	*Circulifer haematoceps*	Other species
Accenture	Amsterdam	roof garden	5		×			*Stenocranus major* *Arthaldeus pascuellus* *Anoscopus serratulae* *Psammotettix* ♀
Aegon	Den Haag	roof garden	1	×				
B.Amsterdam	Amsterdam	roof garden	5	×	×	×		*Conomelus sp.* *Anoscopus serratulae*
Dakakker	Rotterdam	roof garden	2	×	×			
De Boele	Amsterdam	roof garden	0					
Eneco	Rotterdam	roof garden	1		×			
Erasmus MC	Rotterdam	roof garden	5	×	×			*Javesella dubia* *Eupteryx notata* *Macrosteles sp.*
Strijp	Eindhoven	roof garden	1			×		
VU Daktuin	Amsterdam	roof garden	2	×		×		
Zalmstraat	Rotterdam	roof garden	4		×			*Eupteryx decemnotata* *Ophiola russeola* *Psammotettix* ♀
Museon	Den Haag	herbaceous	3	×			×	*Eupteryx decemnotata*
NEMO	Amsterdam	herbaceous	4	×	×	×		*Megophthalmus scanicus*
NIOO	Wageningen	herbaceous	4	×	×			*Zyginidia scutellaris* *Eupelix cuspidata*
NU VU	Amsterdam	herbaceous	2	×	×			
Smartroof 2.0	Amsterdam	herbaceous	2		×			*Javesella dubia*
Stadskantoor	Helmond	herbaceous	3	×		×	×	
CBK Rotterdam	Rotterdam	*Sedum*	0					
Dalton	Den Haag	*Sedum*	0					
Hellevoetsluis	Hellevoetssluis	*Sedum*	1	×				
Het Nieuwe instituut	Rotterdam	*Sedum*	1				×	
IVN	Amsterdam	*Sedum*	1					*Ophiola russeola*
Joost Banckertsplaats	Rotterdam	*Sedum*	0					
Kalverpassage	Amsterdam	*Sedum*	2			×		*Empoasca decipiens*
Lumen	Wageningen	*Sedum*	2	×				*Zyginidia scutellaris*
Theil	Rotterdam	*Sedum*	1	×	×			
Alexandrium	Rotterdam	*Sedum*	1	×				sampled only in 2018

Table 3. General Linear models for Delphacidae and Cicadellidae species richness. Confidence intervals outside of zero are considered significant. Based on 2019 data.
Tabel 3. Lineaire modellen voor Delphacidae en Cicadellidae-soortenrijkdom. Betrouwbaarheidsintervallen buiten nul worden als significant aangemerkt. Gebaseerd op de data van 2019.

	Model 1			**Model 2**		
	Estimate	2.50%	97.50%	Estimate	2.50%	97.50%
Herbaceous-Roof garden	0.197	-0.531	0.925	0.284	-0.446	1.015
Sedum - Roof garden	-1.475	-2.567	-0.382	-1.404	-2.477	-0.331
Sedum - Herbaceous	-1.672	-2.843	-0.501	-1.688	-2.886	-0.49
Roof age	1.477	0.109	2.828	1.456	0.052	2.835
Roof area	0.697	-0.146	1.505	Not included		
AIC	83.1			83.8		

(species number and vegetation layer) of roof gardens and herbaceous roofs with more plant species and also with more vegetation layers. Roof age was also included in both models, with a significant positive effect (mean estimate 1.4665, confidence interval 0.0805 to 2.8315. Species richness thus increases over time, indicating a colonization effect.

Species composition

Few adults of Delphacidae and Typhlocybinae were collected. The adults of these groups mainly live higher up on their host-plants. Pitfalls are more suitable to collect insects that are active at the ground level, therefore almost no Delphacid and Typhlocybinae material was collected in these traps. Two Delphacids, one female of *Conomelus* and one male of *Javesella dubia*, were

2.*Circulifer haematoceps*. Lorch am Rhein, Hessen, Germany, 6.viii.2010. Photo: Gernot Kunz
2.*Circulifer haematoceps*. Lorch am Rhein, Hessen, Duitsland, 6.viii.2010.

short winged. This indicates that at least of these species a reproducing population was present, since short winged adults have no migration capacity.

Most Megophthalminae, Agalinae and Aphrodinae species are ground-dwelling and are well represented in pitfall and pan trap samples. The most widely distributed leafhopper (13 roof tops out of 26) is *Anaceratagallia ribauti* (table 1) and this leafhopper was also the second most common species in numbers (94 specimens, 33% of all leafhoppers collected), mainly in July. This leafhopper species has one generation and adults hibernate. It is a polyphagous species living on dicotyledonous plants, mainly *Plantago* species, often at disturbed dry locations (Nickel 2003). *Anaceratagallia venosa* is sometimes found syntopically with *A. ribauti* but prefers dryer more basic and less vegetated sites (Nickel 2003). Contrary to the well represented *A. ribauti* on our green roofs only one individual of *A. venosa* was sampled, perhaps due to the fact that the vegetation cover of green roofs is often dense (Table 1).

Aphrodes makarovi was the third most common leafhopper (39 specimens) in our study, occurring at seven green roofs (Table 1). The last instar *Aphrodes* nymphs collected at several green roofs can probably also be attributed to this species. This leafhopper is polyphagous on herbs like *Taraxacum*, *Cirsium*, *Urtica dioica*, *Rumex* and others. It has one generation and the egg overwinters (Holzinger 2009, Nickel 2003).

The subfamily Deltocephalinae is the largest leafhopper subfamily in Europe, its species show a variety in life styles. The most common leafhopper (95 specimens) on the green roofs was *Euscelis incisus* occupying twelve green roofs. This leafhopper is very common in the Netherlands occurring in a range of habitats often at sunny and disturbed locations. It has one to two generations and the nymphs hibernate. In our samples, this leafhopper was found during the whole sampling period from April till August. *Euscelis incisus* is a polyphagous species found on various Fabaceae species like *Trifolium* and grasses (Holzinger 2009, Nickel 2003).

One of the striking results is the biased sex ratio. In all seven Cicadellidae species represented with more than two specimens in the samples more males were found, on average 87% (table 1). This strong deviation from the normal 50% ratio is found in pitfall as well as in pan trap samples. Males are often more active in finding females singing and walking on their hostplant. This higher activity level might result in more encounters with the traps.

Circulifer haematoceps, new for the Netherlands

Material Province of Noord-Brabant: Helmond, stadskantoor (AC 173.7-387.5), 27.vi.2019, 1♂ (pitfall), 12♂2♀ (pan trap); same location, 29.vii.2019, 2♂ (pan trap). Province of Zuid-Holland: Den Haag, Museon (AC 79.2-456.3), 8.vii.2019, 1♂ (pan trap); Rotterdam, het Nieuwe Instituut (AC 92.0-436.6), 1.vii.2019, 1♂ (pan trap) (NMR996000167454), all leg. M. Tanis, col. C.F.M. den Bieman. 1 ♂ col. Natuurhistorisch Museum Rotterdam (NMR).

The *Circulifer/Neoaliturus* group is one of the most critical groups among the Deltocephalinae, which is in need for a revision using also molecular methods. The species of this group mainly live in warmer and dry regions of the Old and New World (Nickel 2003). *Circulifer haematoceps* may consist of more than one species. For France, Della Giustina (1989) described two narrowly related species. The larger *C. haematoceps* (Mulsant

3. Greenroof Helmond Stadskantoor with a blue coloured pan trap, 29.vii.2019. Photo: Marco Tanis
3. Groen dak Helmond, Stadskantoor met een blauwe schotelval, 29.vii.2019.

4. Sand and gravel patches at the Museon green roof, The Hague (province of Zuid-Holland), 9.vii.2019. Photo: Marco Tanis
4. Zand and grind gedeeltes op het groene dak van het Museon, Den Haag (Zuid-Holland), 9.vii.2019.

& Ray, 1855) living on *Cistus*, and *C. opacipennis* (Lethierry, 1876) living on different hostplants in xerophilic vegetation. *Circulifer haematoceps* and *C. opacipennis* have the same distribution in Europe and especially in France. Della Giustina indicates the variability within each species and mentions that *C. opacipennis* may be an ecomorph of *C. haematoceps*. The first author collected in many places in the south of France and found that specimens collected from *Cistus* are larger and more colourful, while specimens from *Sedum* vegetations are smaller and pale in colour. Differences in male genitalia have not been observed. Our Dutch specimens are pale in colour without black spots or markings on wings and thorax.

Our material has been stored in ethanol and is therefore not ideal for measurements. The total body length of males was 2.73 mm (2.60-2.85 mm, N=7) and of the single female 3.05 mm. According to Della Giustina (1989), this makes them too small to be *C. haematoceps*. Due to the lack of a recent revision and following the opinion of the majority of the experts from the Czech Republic (I. Malenovsky personal communication), Germany (Biedermann & Niedringhaus 2004, Nickel 2003) and Austria (Holzinger 2009, Kunz *et al.* 2011 and personal communication) the specimens we collected have been provisionally attributed to *C. haematoceps*.

Circulifer haematoceps occurs in the whole Mediterranean area and its area extends to Eastern Europe: Cyprus, Czech Republic, East Palaearctic, France, Germany, Greece, Hungary, Italy, Near East, North Africa, Romania, Slovakia, South European Russia, Spain, Switzerland, Ukraine and, former Yugoslavia. Its occurrence in Poland needs confirmation (Holzinger 2009, Jach & Hoch 2013, Kunz *et al.* 2011). Recently, it was discovered on green roofs in London (Telfer & Wilson 2019). The specimens of *C. haematoceps* reported from Finland are considered as long-range migrants (Söderman *et al.* 2009)

The ecology of *C. haematoceps* is not well known, also due to the mentioned taxonomic confusion. For Austria, it is reported as an univoltine species with overwintering adults, and that adults could be collected all year round (Holzinger 2009). Kunz *et al.* (2011) mentioned that in Germany adults were collected in August and September. EFSA (2015) focused on the potential pest status of *C. haematoceps* and the congeneric *C. tenellus* (Baker, 1896). This report is based on literature research and states that most information is available on *C. tenellus* and that the biology of *C. haematoceps* probably resembles that of *C. tenellus*. There are reports that *C. haematoceps* is a polyphagous species (EFSA 2015, Holzinger 2009, Nickel 2003), but Kunz *et al.* (2011) suggest that it lives on *Sedum album* at sandy and stony substrates.

Our Dutch collections of adults were found in samples taken in June and July on three different roofs in three different cities (table 2). In the samples of these three locations from April-May, *C. haematoceps* was missing, suggesting that no adults of this species occur in these months. At all three locations *Sedum* species are growing and cover at least 50% of the roof, with *S. album* and *S. sexangulare* present on all three roofs. These species might be the hostplant of *C. haematoceps*. Moreover, at Museon, parts of the green roof were covered in sand gravel patches, similar to habitat descriptions in Kunz *et al.* (2011). More study is needed to get a clear picture of the hostplant relations and the phenology of this leafhopper species.

According to two major suppliers, *Sedum* mats are grown in the Netherlands from seed and not imported as *Sedum* plants from southern Europe. This suggests that *C. haematoceps* is not imported with *Sedum* plants from abroad. Probably, it is a spontaneous establishment, as was also found in London (Telfer & Wilson 2019).

The occurrence of *C. haematoceps* could not be related to the age of the roofs as roof ages differed for all three roofs.

Conclusion

Leafhoppers are commonly found on green roofs. In a study that compared green roofs to adjacent ground-level habitats, it was found that twice as many leafhoppers were present on green roofs than at ground-level (MacIvor & Lundholm 2011). This was the only group of insects that was found to be more abundant on green roofs compared to ground-level habitats. Consequently, green roofs could be a valuable habitat for plant- and leafhoppers. However, not all green roofs are of equal value. In our study, *Sedum* roofs appeared to be a less suitable habitat for plant- and leafhoppers. This could be due to their uniform vegetation and lack of vegetation layers. Herbaceous roofs and roof gardens seem to be more suitable for plant- and leafhoppers.

Sampling leaf- and planthopper fauna with pan traps and pitfalls is not the most appropriate method for this group of insects because many species live higher up on their hostplant. It is therefore better to also use sweep net sampling. In our samples, the ground dwelling leafhoppers were indeed over-represented. The strong male bias is also likely correlated with the passive character of pan trap and pitfall sampling because active moving males are more often intercepted than the more passive females. The ground dwelling leafhoppers *Euscelis*, *Aphrodes* and *Anoscopus* (same subfamilie as *Aphrodes*) in pitfall samples from lime grasslands in the southern part of the Netherlands (Cobben & Rozeboom 1983) showed also a male biased distribution with 79% males (total 214 specimens). However, the sexratio of the total number of the leaf- and planthoppers collected in this study was almost normal with 49% males (1.817 specimens collected). The discovery of *Circulifer haematoceps* as a new species for the Netherlands shows that green roofs create a new habitat for the Netherlands. In the future, more new species might be discovered on green roofs.

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Samenvatting

De cicadenfauna van daktuinen met de mediterrane dwergcicade *Circulifer haematoceps* nieuw voor Nederland (Auchenorrhyncha: Cicadellidae)

In 2018-2019 is de insectenfauna van daktuinen in West- en Zuid-Nederland geïnventariseerd met behulp van bodem- en schotelvallen. Adulte cicaden komen vaak vooral voor op de hogere plantendelen en daarom wordt slechts een beperkt deel van de fauna bemonsterd met deze bodemgebonden vallen. In totaal werden 19 cicadensoorten gevangen waarvan er één, *Circulifer haematoceps*, nieuw is voor Nederland. Deze cicade heeft mogelijk *Sedum*, een soort die typerend op groene daken voorkomt, als waardplant. Van deze soort wordt de biologie en de taxonomische status uitgebreid besproken. Van de meer talrijke cicadensoorten worden ecologische details gegeven. In de monsters komen veel cicaden voor die laag in de vegetatie of op de bodem leven wat door de gebruikte vangstmethoden verklaard kan worden. Het percentage mannetjes in de monsters is erg hoog, dit komt mogelijk omdat mannetjes actiever zijn dan vrouwtjes en zich meer verplaatsen om een partner te vinden. Meer verplaatsingen leidt tot een grotere kans om in de vallen terecht te komen.

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