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Effects of fire on scuttle flies (Diptera: Phoridae) in a pine forest in Poland

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Durska, E. 2015: Effects of fire on scuttle flies (Diptera: Phoridae) in a pine forest in Poland. — Entomol. Fenica 26: 181–193.

Ecological consequences of fire on the scuttle fly communities were investigated in a pine forest in Poland (Garwolin Forest). Data from 1,243 identifiable individuals, representing 48 species, were used. The scuttle fly communities in fire-affected plots were similar in terms of the number of species but less diverse than those in an undisturbed reference plot. The response of the flies to the fire was species-specific. Four *Megaselia* species (*M. brevicostalis*, *M. nigriceps*, *M. elongata* and *M. obscuripennis*) were most numerous in the plot most affected by fire. Approximately three years after the fire the scuttle fly communities were relatively similar to those found in a clear-cut pine plantation (Białowieża Primeval Forest) as well as to those in post-windthrow habitats (Pisz Forest) in which logs were removed or left. The *Megaselia* species are the winners in the fire affected habitats and seem to be more stress-tolerant than other genera of the scuttle flies.

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Received 8 May 2015, accepted 28 July 2015

1. Introduction

In sub-boreal forests, burned wood provides food, shelter or sites of reproduction for a large number of living organisms. The smoke and heat following fire lures pyrophilous insects, and the modified forest habitat attracts saproxylic species (Lyon *et al.* 1978, Holliday 1984, Holliday 1991, Moretti *et al.* 2006). These species are crucial to the decomposition of coarse woody debris and to nutrient cycling after disturbances (Speight 1989, Cobb *et al.* 2011, Keville *et al.* 2013, Lee *et al.* 2014). Fires have a major impact on soil, and these changes have implications for litter-dwelling organisms (Vincent *et al.* 2009 and literature therein). Burnt trees are utilized as breeding material and nutrient sources (fast-growing post-fire fungi) by saproxylic, secondary saproxylic (sensu Speight 1989) and sapro/mycophagous species, which are largely scuttle flies (Disney 1994, Toivanen & Kotiaho 2007, Disney & Pagola-Carte 2009, Durska 2013). The larvae of a great number of different Diptera are connected with the humification phase, living in wet decaying wood or in tree holes (Speight 1989).

Natural and anthropogenic disturbances in forest ecosystems, e.g. forest fires, are components of ecosystems worldwide. They provide open areas required by many species and may have both advantageous and negative impacts on habitats (Sousa 1984, Platt & Connell 2003). Disturbances contribute to biodiversity by increasing spatial heterogeneity (Fox 1979, Knisley 2011 and literature therein).

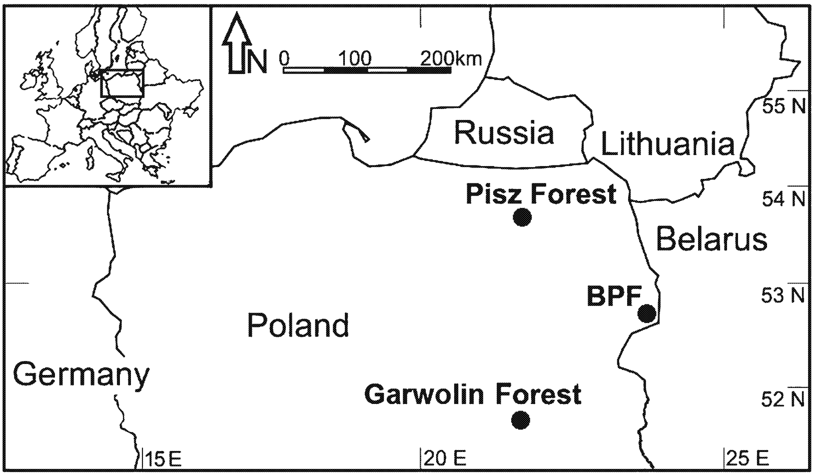


Fig. 1. Location of the study plots in Poland: Garwolin Forest, Białowieża Primeval Forest (BPF) and Pisz Forest.

New habitats in forests created after some anthropogenic disturbances are very similar to those created after natural disturbances: both are short-lived and remain suitable for pioneer species (Southwood 1962, Travis & Dytham 1999, Brändle *et al.* 2000).

Previous studies on Phoridae inhabiting areas after disturbances show that the disturbed areas created by fire are remarkably diverse and species-rich with respect to this insect group (Durska *et al.* 2010). Many of these are a major component of the pioneer fauna that recolonize habitats devastated by episodes such as clearcutting, windstorms or forest fires (Durska 2006, 2009, Durska *et al.* 2010, Żmihorski & Durska 2011, Durska 2013). Both fire intensity and environmental heterogeneity influence two components of post-fire faunal communities: animals that have survived the fire and colonizers from the surrounding habitats.

The present study complements previous research on the response of scuttle fly communities to disturbances in pine forests of the Polish Lowland (see Durska 2013). Specifically, the aim of this study was to compare scuttle fly communities colonizing fire-affected forest habitats with communities colonizing forest habitats after anthropogenic (clearcutting, logging-windthrow) and natural (left-windstorm) disturbances. Scuttle flies, due to their highly diversified life cycles and environmental requirements, as well as relatively high number of species, could be useful to assess the stage of the community succession in disturbed habitat (Disney 1983a, 1994, Disney & Durska 1998, 2008, Mikulski *et al.* 2009, Disney & Durska 2011, Durska 2013, Ng'endo *et al.* 2013, Malewski *et al.* 2015).

2. Materials and methods

2.1. Study sites

The Garwolin Forest (GF) (51°58'7" N, 21°39' 40" E) is located in Central Poland (Fig. 1). The forest, mostly on sandy soil, comprises nutrient-poor to semi-rich habitats, with understorey vegetation dominated by mosses (*Polytrichum* spp.), grasses (*Calamagrostis* spp., *Deschampsia flexuosa*) and shrubs (*Rubus* spp., *Vaccinium* spp.). Moist pine forest found in the GF is represented by *Peucedano–Pinetum* in its subboreal variety (Matuszkiewicz *et al.* 1993). The tree stands are composed mainly of Scots pine (*Pinus sylvestris*), with a lower proportion of Norway spruce (*Picea abies*), oaks (*Quercus* spp.), birches (*Betula* spp.) and occasional other species (Matuszkiewicz *et al.* 1993). On 6 July 2010 an anthropogenic fire destroyed approximately 1.5 ha of the GF. A small open-area habitat, in which weak fire had destroyed the under storey, was left for natural regeneration. Three plots were selected: plot G I in the center of the fire zone; plot G II, adjoining plot G I and approximately 10 m from the border of plot G I; and plot G III, a control plot, 10 m from the border of plot G II. Plots G II and G III were placed further away from the burnt area (in a straight line).

2.2. Site with forest fire

Scuttle flies in the GF were collected in the second and third year after the fire episode (2012 and 2013). The stand age was 50 years old.

The material was collected using yellow plastic pans, 18 cm in diameter, containing water, 75% ethylene glycol and some detergent (Bańkowska & Garbarczyk 1982). Three traps were placed in each of the sampling plots at ground level in a straight line (altogether nine traps every 10 m). The trapping lasted from May through October and traps were emptied fortnightly.

Identification was conducted under a dissecting microscope with the material transferred to glycerol. Analyses based on the *Megaselia* Rondani species used only male individuals, as most females of *Megaselia* spp. are not identifiable at species level. For determination, the keys of Disney (1983b, 1989), Schmitz (1938–1958) and Schmitz *et al.* (1974–1981) were used. The material from this study is deposited at the Museum and Institute of Zoology (PAS), Warsaw, Poland and the University of Cambridge, Museum of Zoology, UK.

2.3. Sites used for comparison

The data obtained from the plot in the center of the fire zone (G I) were compared to the data obtained for scuttle fly communities inhabiting pine forests (Białowieża Primeval Forest and Pisz Forest) after anthropogenic (clearcutting, logging-windthrow) and natural (left-windthrow) disturbances, as well as with scuttle fly communities from an intact forest habitat (old-growth) (for details see Durska 2013).

Scuttle flies in Białowieża Primeval Forest (BPF) were collected in 1986 and 1987. In BPF, the plots were randomly selected within even-aged pine plantations as well as within old-growth stands. In Pisz Forest (PF), scuttle flies were collected in 2005, three years after a windstorm, from six stations in the natural windthrow (i.e. left-windthrow as habitat type) and from five stations in the managed windthrow (i.e. logged-windthrow as habitat type) (for details see Żmihorski & Durska 2011, Durska 2013).

It is worth stressing that the vegetation type and period of time after disturbance (ca. 3 years) of these compared forest habitats (pine forest BPF and PF) are similar to the habitat and time after disturbance of the habitats in the Garwolin Forest (GF).

2.4. Statistical analysis

Species diversity of scuttle fly communities recorded in the three plots of GF (G I, G II, G III), in the compared habitats (clear-cut of BPF and left- and logged-windthrow plots of PF) as well as in the old-growth stands of BPF were assessed with the help of rarefaction curves implemented in EstimateS 800 software. Coleman rarefaction curves were used in order to estimate the expected cumulative number of species for a given number of sampled individuals. In addition, the total species richness, corrected for unseen species in the samples, was also assessed. For this purpose an Abundance-based coverage estimator (ACE) and Chao1 estimator (Colwell 2005, Chao *et al.* 2006) were applied. This method uses the abundance of rare species ($n \leq 10$ individuals) in samples to estimate the number of unseen species and is commonly used in faunistic research (Chao *et al.* 2006).

To assess the similarity of the scuttle fly communities in the forest habitats studied, three indices were calculated: Sørensen (operating only with the number of common and separated species), Baroni-Urbani (operating only with the number of common, separated and absent species), and Morisita-Horn (operating with the number of individuals of each species) (Wolda 1981).

Cluster analysis was performed by using these indices as similarity functions and an agglomeration method: group of k samples with $n_{i,j}$ individuals of i species in j samples was treated as one sample with $n_{i,j_1} + n_{i,j_2} + ... + n_{i,j_k}$ individuals of i species. Finally, the three similarity dendrograms were created.

3. Results

3.1. Characteristics of scuttle fly communities after fire

Among 8,702 specimens of scuttle flies collected on the three plots in the GF (Table 1), particular attention was paid to the data concerning 1,243 specimens (all identifiable males of *Megaselia* spp., plus males and females of Phoridae from other genera) belonging to 48 species, including one unidentified species each of the *Megaselia giraudii*–complex and *M. pulicaria*–complex (Table 2). Situated at a short distance, the number of species (*S*) and individuals (*n*) were almost the same on the three plots (Table 2).

In the three plots of GF (G I, G II, G III) eleven species of the genus *Megaselia*, and *Anevrina unispinosa* (Zetterstedt), *Borophaga subsultans* (Linné), *Conicera similis* (Haliday) and *Triphleba luteifemorata* (Wood) were found in relatively high numbers ($n > 10$ male specimens in at least one sampling plot). Among these *Megaselia* dominants of the open-area habitats, three species (polysaprophagous *M. brevicostalis* (Wood), saprophagous *M. nigriceps* (Loew 1866), and zoophagous *M. elongata* (Wood)) were found in the highest numbers in the plot most affected by fire (G I). However, *Megaselia verralli* (Wood), a known pyrophilous species (Prescher *et al.* 2002) dominant in pine forest habitats after disturbances in Poland (Durska 2013), was found in very low abundance in the GF habitats (G I: $n = 3$; G II: $n = 1$; G III: $n = 1$) (Table 2).

Scuttle fly species with known biologies, accounted for 70.8% ($S = 34$) of the compared species (Table 2). The majority of the species in the three habitats were the species with sapro/mycophages larvae ($S = 27$) and a multivoltine life cycle. These species are most active during spring and autumn (for details see Durska 2013). Among the species with zoophagous larvae, e.g. *Aenigmatias lubbockii* (host: ants), *Megaselia aequalis* (host: slug eggs), *M. elongata* (host: millipedes), *M. flavicoxa* (host: sciarid larvae), *M. obscuripennis* (host: sciarid larvae), *Phalacrotophora berolinensis* (host: coccinellid pupae), and *Triphleba lugubris* (host: wasp brood) *Megaselia elongata* was the most abundant on the plot in the center of the fire zone (G I) compared to the two other plots (G I: $n = 36$; G II: $n = 22$; G III: $n = 19$) (Table 2). Some species of polysaprophagous *M. pulicaria*-complex are specialized predators of spider eggs (Table 2) (Disney 1994).

Table 1. Abundances and diversity of Phoridae in Garwolin Forest, years 2012 and 2013. Plot G I – post-fire, plot G II – not affected by fire, plot G III – control plot, not affected by fire.

	G I	G II	G III
No. of individuals	2,569	3,110	3,023
No. of *Megaselia* males	351	311	255
No. of determined males	295	251	220
No. of *Megaselia* females	2,117	2,625	2,563
No. of determined species	37	36	42
Shannon – Weaver index	4.2688	4.1689	4.2699

3.2. Diversity of scuttle fly communities

The scuttle fly communities found in the two plots most affected by fire (G I and G II) were similar in terms of the number of species for a given number of sampled individuals and less diverse than the habitat not affected by fire (G III). Estimation of total species richness corrected for unseen species in samples (ACE and Chao1 corrected) confirms this result (Table 2).

Compared to the scuttle fly communities occurring in the post-disturbance habitats (clear-cut, left- and logged windthrow), the GF plot most affected by fire (center of fire, plot G I) appeared to be the most similar to the habitat of the clear-cut stand (BPF) with regard to the number of species for a given number of sampled individuals, followed by the left- and logged windthrow habitats (PF). Estimations of total species richness corrected for unseen species in samples (ACE and Chao1) for the old-growth stands (BPF) is about three times as high as for the post-fire (G I) and clear-cut (BPF) stands (Fig. 2).

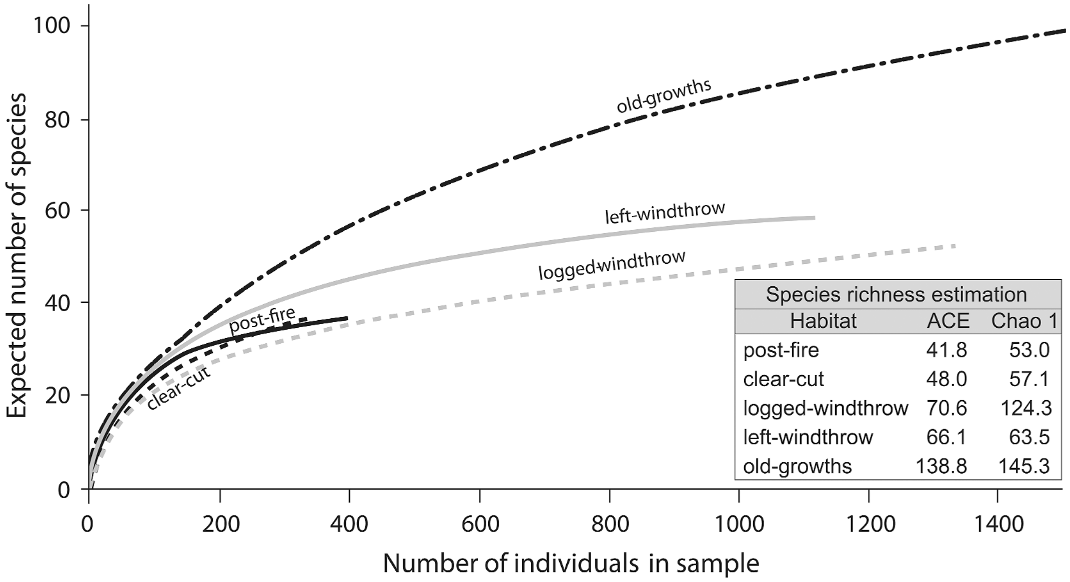
3.3. Similarity of scuttle fly communities

The similarity of the scuttle fly communities in the three compared plots in Garwolin Forest was

Table 2. Species abundances per site in Garwolin Forest in 2012 and 2013 and larval diet. Plot G I – post-fire, plot G II – not affected by fire, plot G III – control plot, not affected by fire. Dominant species[#], at least at one site type with at least 10 individuals, are shown in bold type.

Species	G I	G II	G III	Larval diet
Aenigmatias lubbockii (Verrall1877)	4	1	1	Zoophagous
***Anevrina unispinosa* (Zetterstedt 1860)**	**14**	**36**	**72**	Necrophagous
***Borophaga subsultans* (Linné 1767)**	**18**	**56**	**33**	Unknown
***Conicera similis* (Haliday 1833)**	**39**	**50**	**56**	Necrophagous
Conicera tibialis Schmitz 1925	4	1	1	Necrophagous
Gymnophora quartomollis Schmitz 1920			4	Necrophagous[$]
***Megaselia abdita Schmitz* 1959**	4	**10**	9	Necrophagous
Megaselia aequalis (Wood 1909)			1	Zoophagous
Megaselia albicaudata (Wood 1910)	2			Unknown
Megaselia altifrons (Wood 1909)	2		4	Saprophagous[$]
Megaselia berndseni (Schmitz 1919)		2		Mycophagous
***Megaselia brevicostalis* (Wood 1910)**	**70**	**25**	**11**	Polysaprophagous
Megaselia brevior (Schmitz 1924)			1	Unknown
***Megaselia campestris* (Wood 1908)**	**10**	**15**	**12**	Unknown
Megaselia diversa (Wood 1909)	1	1	1	Saprophagous[$]
Megaselia eisfelderae Schmitz 1948	5	7	3	Mycophagous
***Megaselia elongata* (Wood 1914)**	**36**	**22**	**19**	Zoophagous
Megaselia emarginata (Wood 1908)	0	1	0	Unknown
Megaselia flavicoxa (Zetterstedt 1848)	7	4	6	Zoophagous
Megaselia frameata Schmitz 1927		2		Mycophagous
Megaselia fumata (Malloch 1909)	1	1	4	Unknown
Megaselia fusca (Wood 1909)	4	3	2	Saprophagous
***Megaselia giraudii*-complex**	6	**19**	6	Polyphagous
Megaselia ignobilis (Schmitz 1919)	1			Unknown
Megaselia lata (Wood 1910)	7	3	4	Mycophagous
***Megaselia latifrons* (Wood 1910)**	**15**	**19**	**12**	Unknown
Megaselia longicostalis (Wood 1912)	5	5	9	Necrophagous
***Megaselia lutea* (Meigen 1830)**	4	9	**13**	Mycophagous
Megaselia major (Wood 1912)	1	1		Unknown
Megaselia manicata (Wood 1910)			1	Unknown
Megaselia meconicera (Speiser 1925)	3	2	4	Saprophagous[$]
Megaselia minor (Zetterstedt 1848)	6	2	6	Necrophagous
***Megaselia nigriceps* (Loew 1866)**	**13**	6	1	Saprophagous
***Megaselia obscuripennis* (Wood 1909)**	**13**	**10**	**10**	Zoophagous
Megaselia pleuralis (Wood 1909)	6	1	3	Polysaprophagous
Megaselia propinqua (Wood 1909)	4	4	4	Unknown
***Megaselia pulicaria* – complex**	**48**	**56**	**47**	Polysaprophagous
Megaselia pumila (Meigen 1830)	1		3	Mycophagous
Megaselia ruficornis (Meigen 1830)			2	Necrophagous
***Megaselia scutellaris* (Wood 1909)**	**16**	**19**	**16**	Mycophagous
Megaselia sylvatica (Wood 1910)			1	Mycophagous
Megaselia testacea (Lundbeck. 1920)			1	Unknown
Megaselia verralli (Wood 1910)	3	1	1	Unknown
Megaselia zonata (Zetterstedt 1838)	1	1	3	Unknown
Metopina oligoneura (Mik 1867)	1	2	2	Polysaprophagous
Phalacrotophora berolinensis Schmitz 1920	1	1	1	Zoophagous
Triphleba lugubris (Meigen 1830)			1	Zoophagous
***Triphleba luteifemorata* (Wood 1906)**	**20**	**25**	**33**	Necrophagous
Total no. of individuals per site	396	423	424	
Total no. of species per site	37	36	42	
Expected no. of species – ACE[£]	41.8	47.7	53.3	
Expected no. of species – Chao1	53.0	46.0	43.5	
Expected no. of species – Chao1 corrected	46.3	43.5	58.5	

Durska 2013. – $ Probable diet of larvae. – £ Abundance-based coverage estimator.



Species richness estimation		
Habitat	ACE	Chao 1
post-fire	41.8	53.0
clear-cut	48.0	57.1
logged-windthrow	70.6	124.3
left-windthrow	66.1	63.5
old-growths	138.8	145.3

Fig. 2. The expected cumulative number of scuttle fly (Phoridae) species as a function of number of sampled individuals in five habitat types. Estimated species richness, corrected for species unseen in samples, is given in the box. ACE (abundance-based coverage estimator) and Chao 1 are non-parametric, asymptotic species richness estimators for abundance-based data.

very high. The Sørensen index between G I and G II plots was the highest, and amounted to 0.92 (between G I and G III: *Sø* = 0.87; between G II and G III: *Sø* = 0.83).

The scuttle fly community recorded in the GF in the plot most affected by fire (G I) shows greater similarity to those in the clear-cut stand in Białowieża Primeval Forest and in the left- and logged-windthrow plots in Pisz Forest than to the community of scuttle flies in old-growth stands in Białowieża Primeval Forest (indices of similarity: Sørensen, Baroni-Urbani and Morisita-Horn) (Fig. 3 a, b, c).

3.4. *Megaselia* species and sex ratio

In the studied material, the species from the genus *Megaselia* constituted almost 80% ($S = 38$) of all recorded species, and the female individuals of this giant genus accounted for over 80% of the scuttle fly community associated with each plot in the GF (G I = 82.41%; G II = 84.41%; G III = 84.78%). The average male-to-female ratio of the genus *Megaselia* amounted to 0.13 (n = 8,222) (Table 1).

4. Discussion

In previous studies I found that several species of Phoridae preferred the disturbed areas while others were found to be more numerous in the intact forests (old-growth stands) (Durska 2003, Durska *et al.* 2010, Durska 2013). Moreover, the open-area species of scuttle fly communities respond in a parallel way to different disturbances (Durska 2013). A similar response to disturbances (clear-cutting, grazing and burning) was also found for spider and carabid faunas (Gibson *et al.* 1992, Coddington *et al.* 1996, Zulka *et al.* 1997, Moretti *et al.* 2002, Fernández & Costas 2004, Huber & Baumgarten 2005).

As was documented in previous studies (Durska 2013 and literature therein) for scuttle fly communities in pine forests of the Polish Lowland, specimens of *Megaselia* ($S = 38$) constituted the largest part of the material collected in Garwolin Forest (Table 1). The species affecting functional diversity analyses (Fontaine *et al.* 2006, Hillebrand & Matthiessen 2009) are the *Megaselia* species, as females of this genus accounted for over 80% of all the communities found in the three sampled plots (G I, G II and G

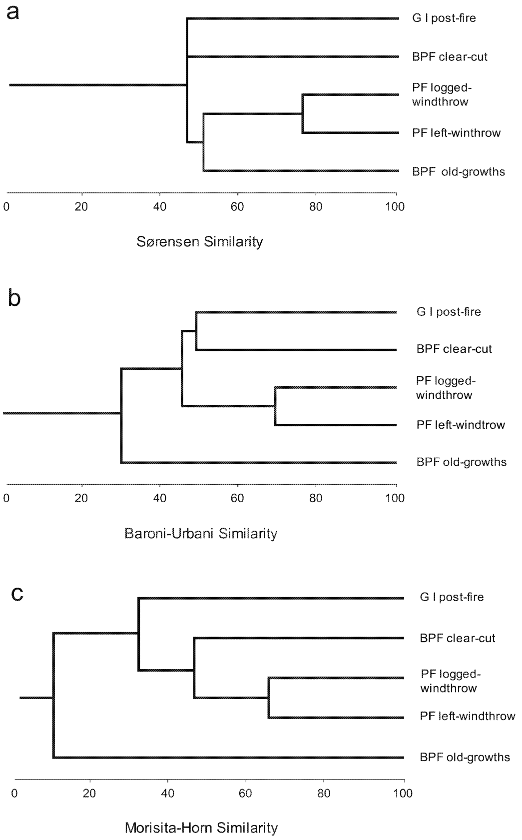


Fig. 3. Cluster analyses of pine forests, using the indices of similarity (presence/ absence of species), showing that post-fire habitat (G I), young pine plantation (BPF clear-cuts) and post-windstorm habitats (PF logged-windthrow and PF left-windthrow) shared relatively similar scuttle fly communities, while intact forest stand (BPF old-growths) composes a second group. – a. Sørensen Similarity. – b. Baroni-Urbani Similarity. – c. Morisita-Horn Similarity.

III) in the Garwolin Forest (Table 1). The male-to-female sex ratio using the yellow pan method reached 0.13, in contrast to data obtained from habitats after wildfires in *Castanea sativa* forests in the Swiss Alps (emergence traps), and in a hemiboreal forest in Tyresta near Stockholm (Malaise traps), where males predominated (Prescher *et al.* 2002, Durska *et al.* 2010). It is worth adding that the sex ratios of Phoridae obtained in field collection, compared to those from rearings, are often dominated by one sex (Disney 1994). Furthermore, both dominants of open area habitats, *M. brevicostalis* and *M. verralli* were found in great numbers during studies in old-growth pine stands (yellow pans placed at the ground level) in Białowieża Primeval Forest (Durska 1996, Durska unpubl.). Based on the above data, it can be concluded that the differences in sex ratios obtained in these studies are related not only to the behaviour between the sexes, but also to the trapping method (Table 1, 2) (Disney 1994, Prescher *et al.* 2002, Durska *et al.* 2010, Durska 2013).

It is well known that disturbances can promote species richness in forests (Similä *et al.* 2002, Sippola *et al.* 2002). The present results showed that the majority of species in the three plots in Garwolin Forest were the species of small body size with sapro/mycophagous larvae and a multivoltine life cycle (Table 2). The same results were found by Durska *et al.* (2010) and Durska (2013). In addition, the species richness of the scuttle fly community after anthropogenic disturbances in the fire-affected plot in the GF (G I) and in the young pine plantation in BPF were remarkably similar to each other and lower than those found in habitats with natural disturbances (up to 1.7 times lower than post-windstorm habitats and three times lower than old-growth stands.) (Fig. 2). Furthermore, when comparing scuttle fly communities after anthropogenic fire (Garwolin Forest – G I: $n = 1{,}243$; $S = 48$) with scuttle fly communities after natural fire (wildfire in Tyresta Forest near Stockholm, $n = 8{,}051$; $S = 112$), the same *Megaselia* species were dominant (Tyresta Forest: *M. nigriceps*, *M. pulicaria*-complex and *M. brevicostalis*) (Durska *et al.* 2010). *Megaselia pulicaria*-complex and *M. brevicostalis* were also dominant in the post-wildfire scuttle fly communities in *Castanea sativa* forests in the Swiss Alps (Prescher *et al.* 2002).

Despite the fact that the three plots in Garwolin Forest were situated at a short distance, the response of the flies to the disturbance, in this case fire, was species-specific. Four dominant *Megaselia* species (the polysaprophagous *M. brevicostalis*, saprophagous *M. nigriceps* and, zoophagous *M. elongata* and *M. obscuripennis*) were found in the highest numbers in the plot the most affected by fire (G I) (Table 2). Many scuttle fly species are known to be very sensitive to changes in their habitat, especially to climatic conditions (Folgarait *et al.* 2007). During dry seasons, the characteristic dominant species of open-area habitats, *M. brevicostalis* reaches its abundance peak much earlier than in years when humidity is typical (Disney *et al.* 1981). Furthermore, also *Megaselia verralli*, another characteristic dominant scuttle fly species in communities in the pine plantations (clear-cut) of the Polish Lowland as well as in the post-wildfire habitats in the *Castanea sativa* forests (Swiss Alps), was found in the fire-affected plot (GI). However, the number of individuals was extremely low (*n* = 3) (Table 2) (Prescher *et al.* 2002, Durska 2006, 2009, 2013).

Polysaprophagous and saproxylic *M. pleuralis* (Godfrey & Disney 2002), an extraordinarily abundant species after the wildfire in Tyresta Forest (near Stockholm) and also dominant in the clear-cut habitat in BPF as well as in the logged-windthrow habitat in PF, reached the highest abundance in the fire-affected plot (G I) in Garwolin Forest (Durska *et al.* 2010, Bonet *et al.* 2011, Durska 2013). Three *Megaselia* species (i.e. *M. nigriceps*, *M. elongata*, *M. obscuripennis*) were also the dominant species in the scuttle fly community collected in Karkonosze National Park (Poland) using bark traps placed on spruce and on pine logs in unaffected forests, both with *Fomitopsis pinicola* (Sw.) P. Karst (Polyporales) (Durska unpubl.).

Flying zoophagous arthropods are known as one of the most fire-resistant groups with the highest resilience to fire (Wikars 2001, Hanula & Wade 2003, Parr *et al.* 2004, Arnan *et al.* 2006). *Megaselia elongata* with zoophagous larvae were most abundant on the most fire-affected plot (G I) compared to the two other plots (G II and G III) (Table 2). Furthermore, the ant parasitoid *Aenigmatias lubbockii*, reached the highest numbers in the most fire-affected plot (G I). Prescher *et al.* (2002) also found a high number of individuals (*n* = 18) of the genus *Aenigmatias* (i.e. *A. dorni* Enderlein) after wildfires in the *Castanea sativa* forests (Swiss Alps). The hosts of *A. lubbockki* (*Formica* ants) avoid shaded nest locations because they have high thermal requirements.

Species composition after fire varies depending on fire intensity. In addition, some insect species are associated with canopy fire, some with the amount of vegetation and shrub cover, and some with how much time has passed since the fire occurred. Furthermore, some species are not dependent on fire or vegetation cover (Rodrigo *et al.* 2008). When comparing the species composition of scuttle fly communities after different disturbances, the community in the fire-affected plot (G I) in Garwolin Forest shows the greatest similarity to those from the habitats after anthropogenic disturbances, i.e. the clear-cut stand in BPF and the logged-windthrow plots in PF. Similarity to the communities in the left-windthrow plots in Pisz Forest was less. The least similar community to that in the fire-affected Garwolin Forest plot (G I) was found in the undisturbed old-growth stands in Białowieża Primeval Forest (Fig. 3) (Durska 2013).

Forest fires have many implications for biological diversity and not all species suffer from fire. It is known that the speed of recovery after fire is related to the fire intensity, and some invertebrates and fungi are dependent on or favored by fire (Dahlberg 2002, Saint-Germain *et al.* 2004, Penttilä *et al.* 2013). The larvae of saprophagous and mycophagous *Megaselia* species, including *M. frameata* found in Garwolin Forest (G II) and in Tyresta Forest near Stockholm, are feeding or breeding in polypore fungi (Disney 1994). Moretti *et al.* (2006) found that the functional groups, i.e. the ground–litter saprophages and the saproxylophages, recovered in 6–14 years after a single fire. Futhermore, Penttilä *et al.* (2013) demonstrated that after fire, polypore species of dead wood recovered to the pre-fire level six years after the fire and were more abundant in the semi-natural stand, with a larger amount and variety of dead wood than in the managed stand. The way dead wood is formed (natural or anthropogenic processes) influences the polypore fungi. The results of the study were consistent with other studies which showed that wood-inhabiting fungi seem to be adapted to disturbances and are connected with open-area habitats (Penttilä *et al.* 2013). The successional pathways of sapro/mycophagous Phoridae, especially from the genus *Megaselia,* seem to be inseparably related (ecological niche) to the stages of succession of the polypore fungi on dead wood created after disturbances (Speight 1989, Disney 1994, Disney & Pagola-Carte 2009, Ulyshen & Hanula 2010, Komonen *et al.* 2014).

The sun-exposed microhabitats arising after natural and anthropogenic disturbances are suit-

Table 3. Expression profile of heat shock proteins genes (Hsp) of larvae (1 h at 39 °C) and the functions of small heat shock proteins (sHsp).

Genes	*Drosophila melanogaster*	*Megaselia scalaris*	Functions of heat shock proteins[#]
Hsp22	53.1	Induction	Cell protection against oxidative stress
Hsp23	6.1	3.5	Control of ecdysis and metamorphosis
Hsp26	2.9	0.2	Protective role in nervous system
Hsp27	0.1	1.2	Stress resistance, partly block apoptosis
Hsp40	0.1	2.3	Co-factor of Hsp70, i. a. thermoadaptation

#) Mestril *et al.* 1986, Morrow *et al.* 2004, Awofala *et al.* 2011 and references therein, Zhao *et al.* 2011 and references therein.

able for those scuttle fly species which are sapro/mycophagous or predators/parasitoids of other mycophagous invertebrates. *Megaselia flavicoxa* and *M. obscuripennis*, parasitoids of sciarid larvae (fungus gnats) (Disney 1994), were found in the highest numbers in the plot most affected by fire in Garwolin Forest (G I). *Megaselia flavicoxa* was previously found in the post-windthrow habitat in Pisz Forest (*n* = 39) and in the old-growth habitat in the Białowieża Primeval Forest (*n* = 1) (Durska 2013). On the other hand, *M. obscuripennis* was also found in the traps deployed directly after wildfire (Tyresta Forest near Stockholm) on spots exposed to strong heat-related soil destruction (Durska *et al.* 2010). As was found previously, the mycophagous species of the scuttle fly communities reached a higher abundance in young pine plantations (clear-cut plots) and logged-windthrow habitats than in the old-growth and left-windthrow plots (Durska 2013: fig. 4.). High similarity of the scuttle fly communities found in the plot after fire (G I) in Garwolin Forest, in young clear-cut plots (BPF), and in logged-windthrow areas (PF) is not surprising as these three habitat types have common features: similar insolation and humidity (see: Durska 2013) as well as fungi at the same phase of succession (i.e. about 3 years after disturbance) (Kaila *et al.* 1994, Stokland & Larsson 2011, Ottosson *et al.* 2014).

The present study is the continuation of research on the scuttle fly communities inhabiting disturbed areas in pine forests of the Polish Lowland. The studies on Phoridae of fire-affected areas in Garwolin Forest were conducted using the same method of trapping (yellow pans) and in a similar habitat (pine forest). Both studies were also conducted about 3 years after disturbance, i.e. with a similar stage of secondary succession with similar above ground-below ground interactions. Thus, it is assumed that the species-specific similarity in response to disturbances remains plausible (De Deyn & Van der Putten 2005, Durska 2013).

The *Megaselia* species are the winners in disturbed, sun-exposed habitats and seem to be more stress-tolerant than other genera of scuttle flies. Moreover, a greater resistance to stress and disturbance in *Megaselia* females (very high abundance in disturbed habitats, see: Durska 2013) could be linked to differences in body lipid accumulation and, even more likely, a better evolutionary adaptation to high temperature (Table 1) (Bauerfeind *et al.* 2014, Malewski *et al.* 2015).

There are few molecular-based researches on ecological problems connected with temperature, insect species abundance and geographical distribution (Leather *et al.* 1993, Johanson *et al.* 2009). The scuttle flies, dominating in open-area habitats, are lured by heat, smoke, carbon dioxide and other volatile compounds to open-areas abundant in dead wood, which is decomposed by fungi to organic matter rich in the limiting factor, phosphorus (Klocke *et al.* 2011, Luke *et al.* 2014). Furthermore, phosphorus, as essential for life, is also required for the synthesis of heat shock proteins, which protect each living cell against heat stress and other stresses in a disturbed habitat (Jiang *et al.* 2009).

During my concurrent studies on the polyphagous *M. scalaris* (Loew) and *Drosophila melanogaster* Meigen (control group), after exposing the larvae to high temperatures exceeding 39 °C, expression of *Hsp* genes was compared. Among others, it was found that the expression profile of *Hsp* genes is species-dependent and down-regulated for the three heat shock protein genes *Hsp*22, *Hsp*23 and *Hsp*26 of *M. scalaris* when compared to *D. melanogaster* (Table 3) (Malewski *et al.* 2015). The same results were obtained in the studies on necrophagous *M. abdita* (found in G I, G II, G III – Table 2), the species native to Central Europe (Malewski & Durska unpubl.).

Available literature stresses how heat shock proteins ensure survival under conditions of environmental stress, which in the absence of a defensive reaction can lead to irreversible changes in, and permanent damage to, cells (Mestril *et al.* 1986, Morrow *et al.* 2004, Awofala *et al.* 2011, Zhao *et al.* 2011).

Perhaps the dominant, scuttle fly species, which prefer disturbed, open-area habitats rich in phosphorus (Mulder *et al.* 2013), can be strongly influenced by a genotype-by-temperature interaction, related to the expression of heat shock protein genes (Luke *et al.* 2014, Malewski *et al.* 2015). Significant ecological issues could be resolved if molecular studies would be applied (Johnson *et al.* 2009).

5. Conclusions

Overall, the study revealed and confirmed a high similarity of scuttle fly communities inhabiting sun-exposed forest areas destroyed by anthropogenic fire to the communities after other kinds of disturbances (Durska 2013). The winners in the habitat following fire proved to be sapro/mycophagous *Megaselia* species (Disney 1994). Due to this conclusion, similar preferences of the scuttle fly species for disturbed habitats could be explained by a similar matrix structure of the inhabited areas (ca. 3 years after disturbance), characterized by a similar community of fungi, as a source of organic matter (Speith 1989, Worrall *et al.* 1997). Fungi provide a large amount of phosphorus, which is an extremely limited resource (Visanuvimol & Bertram 2011) for the small-bodied scuttle flies in ephemeral habitats (Reaves et al 1990, Elsner *et al.* 2000; De Deyn & Van der Putten 2005, Jiang *et al.* 2009; Prevedello & Vieira 2010, Luke *et al.* 2014).

The present study indicates that the resilience (i.e. recovery over time) and resistance (i.e. heat stress tolerance) of the scuttle flies to anthropogenic and natural disturbances and their quick recolonization of sun-exposed areas (Durska 2013) could be an evolutionary adaptation to high temperatures (Malewski *et al.* 2015).

Acknowledgements. I wish to thank Matthias Buck for his critical review of the previous version of the manuscript. I would like to thank an anonymous reviewer for the valuable suggestions and helpful comments. I thank Marcin Zalewski and Jolanta Wytwer for their kind advice on a previous version of this manuscript. I am grateful to Dr R. Henry L. Disney for his invaluable support during my work on Phoridae. I wish to thank Miłosława Barkowska-Sokół for help in statistical analyses, and Jodie Baltazar, who kindly improved the English. I also thank Krzysztof Gagla for his valuable assistance with the sorting of the material. Finally, I would like to thank Andrzej Bartha and Jadwiga Kocyba for their help with the graphic art of figures. The author benefitted from SYNTHESYS support made available by the European Community – Research Infrastructure Action under the FP6 Structuring the European Area Programme AT-TAF 543 and SE-TAF 1833. My research on Phoridae is supported by a grant from National Science Centre (NCN) (nr 2011/01/B/NZ8/03005).

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