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Importance of meteorological variables for aeroplankton dispersal in an urban environment

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Abstract

Passive wind dispersal is one of the major mechanisms through which organisms disperse and colonise new areas. The detailed understanding of which factors affect this process may help to preserve its efficiency for the future. Despite its interest, the analysis of factors affecting the aeroplankton dispersal in urban environments is rare in literature. We sampled the aeroplankton community uninterruptedly every 4 hours from 17 May to 19 September 2011 in the urban garden of Parco d'Orléans, within the campus of the University of Palermo (Sicily). Sampling was performed by means of a Johnson-Taylor suction trap with automatised sample storing. Weather variables were recorded at a local meteorological station. Overall, 11,739 insects were caught during the present study, about 60% of which belonged to the order Hymenoptera, with particular presence of families Agaonidae and Formicidae. The suction trap also captured specimens of very small size, and in some cases, species caught resulted in new records for Italy. Composition and abundance of the aeroplankton community was influenced by alternation of day/night, as well as by daily fluctuations of climatic variables, for example fluctuating temperature. The taxonomic diversity of the samples was also studied, and was higher when the wind blew from the nearby green area. Our findings confirm that passive transport of arthropods strictly depends on weather conditions, and that the presence of natural areas within the urban environment significantly contributes to raising aeroplankton diversity, eventually fuelling overall biodiversity at a local scale.

Keywords: *Johnson-Taylor suction trap, aeroplankton, arthropods, passive transport, meteorological variables*

Introduction

Passive wind dispersal is a major dispersion mechanism for many organisms; this has been noted since Aristotle's time (Duffey 1956), and many centuries later Charles Darwin (1839) also described this phenomenon for spiders, known by the term "ballooning", when he was in the Atlantic Ocean not far from Cape Verde Islands:

> in the morning the air was full of patches of the flocculent web […]. The ship was sixty miles distant from the land […]. Vast numbers of a small spider […] were attached to the webs. There must have been, I should suppose, some thousands on the ship. […] The little aeronaut as soon as it arrived on board was very active […].

Fungal spores, pollen granules and small arthropods are part of what it is called aeroplankton; these organisms may be transported for thousand of kilometres around the world, thanks to meteorological conditions (Johnson 1969; Drake & Gatehouse 1995; Pedgley et al. 1995; Gatehouse 1997). They take advantage of passive transport to guarantee their spatial diffusion. The wind has a fundamental role in their dispersal. Differently from larger sized species, the distribution of many small species (below 5 mm) may depend more on the wind than on biogeographical factors, also at long distances (Taylor 1974). Avian species, such as swifts, swallows and other birds, catch aeroplankton by means of their large mouth. This indicates that the aerial movement of insects and other organisms is an old and well-established behaviour. According to Taylor (1974), some species have a migratory phase

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and fly at high altitudes (up to hundred of metres above the ground) utilising strong winds, and passively move for long distances, spending less time than that normally used when flying at ground level (Johnson 1969; Drake & Gatehouse 1995; Pedgley et al. 1995; Gatehouse 1997). Some authors have reported the concentration of insects in horizontal layers, 50–200 m vertically, present both during the day and at night, and at altitudes ranging from few metres above ground during the night (Melnichenko 1936; Larsen 1949; Drake 1984; Drake & Farrow 1988; Drake & Rochester 1994) up to 2–3 km during daytime (Coad 1931; Hardy & Milne 1938; Glick 1939; Campistron 1975; Drake 1985). This phenomenon occurs typically in summer and depends on the soil type, vegetation and ground morphology (Burt 1998). Past studies have been carried out as some insect species were found to parasitise cultivated plants or to be noxious to human health (Pedgley 1982; Irwin & Thresh 1988; Drake & Gatehouse 1995; Pedgley et al. 1995), while others are beneficial as natural enemies of phytophagous species (Farrow 1981; Riley et al. 1987; Chapman et al. 2004a,b). Studies have shown that meteorological factors are the major cause of movements and dispersal of insects in the atmosphere (Johnson 1969; Schaefer 1976; Greenbank et al. 1980; Dickison et al. 1981, 1986; Neumann & Mukammal 1981; Pedgley 1982; Pedgley et al. 1982; Drake & Farrow 1988; Rainey 1989; Dingle 1996). An interesting example of passive wind transport is the diffusion of gall-inducing insects linked to a single plant species that in a few years spread through the Mediterranean area (Lo Verde 2002; Skuhravá et al. 2007; Lo Verde et al. 2009; Caleca et al. 2011); their diffusion could not occur without the aid of wind currents.

Studies of aeroplankton composition and dispersal are still rare, due to difficult sampling techniques; nevertheless, according to some authors (e.g. Smith 2013), these kinds of studies are urgently needed.

The aims of the present work are: (i) to study and describe the composition of aeroplankton and its variation from spring to autumn; and (ii) to test which climatic variables affect dispersal and diversity in the aeroplanktonic community. In contrast to most previous studies, sampling was carried out in an urban area, subdivided into different time slots.

Material and methods

Sampling methods and study area

The sampling area was located inside the garden "Parco d'Orléans". The trap was placed on the roof of the Entomology Building, at ca. 10 m above ground,

in one area surrounded by citrus groves and adjacent to the urban park "Fossa della Garofala". This area is mainly covered by arboreal vegetation, made up of *Platanus, Tilia* and *Ficus*, 6–8 m high. Monitoring of aeroplankton lasted 4 months, from 17 May to 19 September 2011 (only when weather conditions were unfavourable or electric current was lacking was the instrument stopped; this happened for a total of 20 days – that is, 15% of the trapping period). Power aspiration was carried out with a Johnson-Taylor insect suction trap (Johnson & Taylor 1955a,b; Johnson 1969); the trap remained constant for all of the sampling period and was programmed at the same suction speed, with a time interval of 4 hours. The collected material was divided per time slot and was preserved in vials and identified in the laboratory to the order level, in some cases to the family or species level, with the aid of a stereomicroscope. Meteorological data (temperature, pressure, humidity, wind speed and wind direction) were collected on an hourly basis from SIAS (Servizio Informativo Agrometeorologico Regione Siciliana) weather station in Palermo, close to the university campus. The city of Palermo lies on the northern coast of Sicily and has a pure Mediterranean climate, with a mean rainfall of 741 mm/year, mainly concentrated in the autumn and winter months. Monthly mean temperatures oscillate between 14.75°C (min) and 21.58°C (max). Rainfall and temperature values refer to the mean climate of the last 30 years (ilmeteo.it 2015).

Statistical analyses

We explored weather parameters affecting the aerial dispersal of different orders of arthropods by fitting generalised linear models (GLM) with negative binomial distribution to compensate for zero-inflated data series. The dependent variable was the daily number of capture of each order, and as predictors we considered a range of continuous climatic predictors (temperature, air pressure, air humidity, wind strength and direction), as well as the effect of the Julian date and moment of the day (hour) on the capture probability. Given the overwhelming importance of the factor temperature obtained in our preliminary analyses (details not shown), we also considered in the model the interaction terms of this variable with both Julian date and hour. We performed a GLM for each arthropod order separately, with the exception of Hymenoptera which was divided into family Agaonidae and non-Agaonidae samples, given that absolute number of Agaonidae captured was huge compared to the total number of captured Hymenoptera (68.58%) and that this family emerged only late in the season, so that was biasing analyses on

the effect of the weather parameter on the presence in the aereoplankton of the entire order. Furthermore, the model for Agaonidae was performed considering time series starting from 9 August instead of 17 May as was done for the other series, thus analysing the weather conditions only during the emerging period.

Finally, we considered how the same factors mentioned above influenced the diversity of the composition of the aereoplankton. To do so, we first calculated the Simpson diversity index (*D'*) for each sample by the formula:

$$D' = 1 / \sum (n_i/N_i)^2 \qquad (1)$$

where n_i is the number of capture items of a given order and N_i is the total number of captured items in that sample. This index has 1 as minimum value (lowest diversity) and presents no limit on the maximum value. We analysed effects on *D'* performing a GLM like the ones mentioned above, but given the normal distribution of this variable we run a Gaussian instead of a negative binomial model.

All models were performed in the package MASS (Venables & Ripley 2002) of R 3.1.2 (R Development Core Team 2014).

Results and discussion

Composition and phenology of aeroplankton

On the whole, we obtained 11,739 arthropods belonging to eight orders (eight Insecta and one Arachnida): Hymenoptera, Diptera, Homoptera, Thysanoptera, Heteroptera, Lepidoptera, Coleoptera, Neuroptera and Araneae. Occurrence phenology of each group is

shown in Figure 1. The highest number of specimens belonged to the order of Hymenoptera, 7332 individuals (ca. 62.4% of all sampled arthropods); the abundance of this order was mainly influenced by the high number of species of the families Agaonidae (a total of 5125 specimens) and Formicidae (with 200 specimens). Agaonidae specimens were identified as *Odontofroggatia galili* and *Parapristina verticillata*; both are pollinators of *Ficus microcarpa*, ornamental species well represented in the Parco d'Orléans.

The second most important order was Diptera, with about 20% of the total number of sampled individuals, with a clear peak in July (Julian days 45–52, Figure 1). Families of Diptera found in the samples included Cecidomyiidae, Chironomidae, Culicidae, Psychodidae and Tephritidae.

Homoptera was the third order in numerical importance, with 1417 individuals, 50% of which belonged to the family Aphidae. Their maximum presence was between 17 and 31 May (Figure 1), with 624 individuals, of which 577 (93% of total) were aphids; in the following period, numbers were low and more or less uniform. The presence of aphids during this time interval is similar to that reported in different studies performed during spring, summer and autumnal dispersal all over Europe, carried out to monitor the diffusion of viruses possibly borne by these species (Dewar et al. 1980; Taylor et al. 1981; Tatchell et al. 1988; Harrington et al. 1990; Basky & Harrington 2000; Ferrara et al. 2001; Coceano et al. 2009).

Orders with lower presence in samples were (reported in decreasing order): Thysanoptera, Heteroptera, Lepidoptera, Coleoptera, Neuroptera and Araneae. The period of maximum captures of
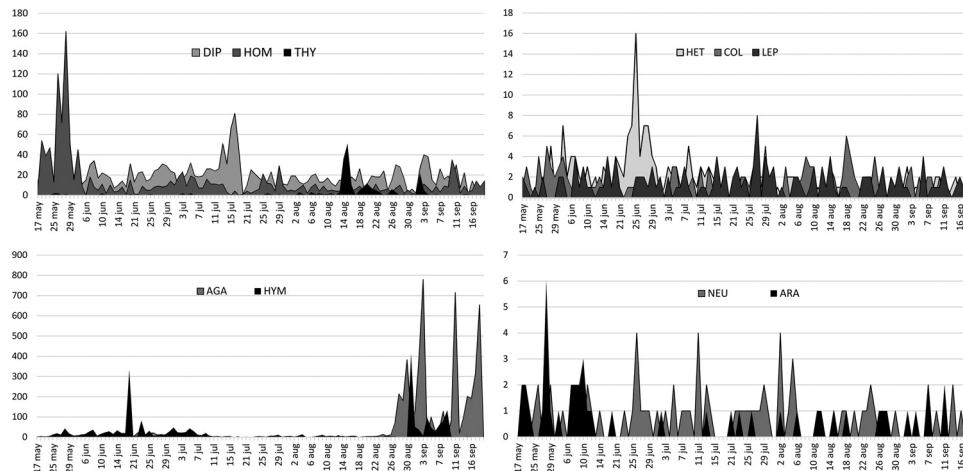

Figure 1. Phenology of the presence in aeroplankton of the different groups. DIP: Diptera; HOM: Homoptera; THY: Thysanoptera; HET: Heteroptera; COL: Coleoptera; LEP: Lepidoptera; AGA: Agaonidae; HYM: Hymenoptera; NEU: Neuroptera; ARA: Araneae. Vertical axis shows daily number of capture; note the different scale in each graph.

Lepidoptera, Heteroptera and Neuroptera lay between the second half of June and the first half of July, while that of Coleoptera was during the second half of May (Figure 1).

Influence of meteorological variables

General linear models confirmed that the number of sampled arthropods increased proportionally with atmospheric pressure and declined with the increase of relative humidity and wind speed (Table I). This latter variable influenced the highest presence of some sampled orders: we found an inverse correlation between the number of captured specimens and wind speed; the highest number of captures occurred with wind speeds between 0.50 and 3.00 m/s, with a maximum peak of over 3000 individuals within the interval 0.50–1.00 m/s (Figure 2). The relation between the wind speed and the number of captured individuals was caused by lower efficiency of trapping when strong winds were blowing, and organisms probably were being transported to higher altitudes (Chapman et al. 2008). The volume of air sampled by the trap at different wind speeds (0–5 m/sec) is demonstrated by the following linear regression: air sampled (m³/min) = 14–2.2 $\star$ wind speed (m/sec) (r^2 = 0.82; df = 4; p = 0.95) (Taylor & Palmer 1972). Plotting Simpson diversity index with wind direction showed that the highest number of arthropods was captured when winds blew from the north-west (Figure 3). This wind direction probably brings higher numbers of arthropods because it is blowing from the exact direction in which the adjacent green areas to University building are located. This finding suggests that the presence of even small green patches within urban landscapes is important in maintaining arthropod diversity (Rudd et al. 2002; Braaker et al. 2014).

During the sampling period, a low number of spiders were also collected, mainly during the second half of May. In Switzerland (Canton Vaud), the higher peaks of aerial drift by spiders were between February and November, in particular between summer and autumn (Blandenier et al. 2013).

Weather parameters statistically determined dispersal abilities and diversity of the aeroplanktonic community, but to a different extent depending on the orders and weather variables studied. In particular, the role of temperature *per se* turned to be low, while it assumes significant effects if associated to date or hour of day. In particular, while advancing during the year the temperature gains in importance

Table I. Results of negative binomial generalised linear models (GLM) exploring factors affecting composition of aeroplankton. Only significant estimates, with standard errors in parentheses, are shown. Italics indicate significance at the 0.001 level. $\star$Agaonidae series was only analysed from 9 August instead of 17 May like the other series.

	Hymenoptera (Agaonidae)$\star$	Hymenoptera (not Agaonidae)	Diptera	Lepidoptera	Heteroptera	Coleoptera
A Temperature (°C)	−1.328 (0.568)					
Pressure (hPa)		0.094 (0.031)			0.073 (0.032)	
Humidity (%)	−0.050 (0.019)			0.026 (0.011)		
Wind direction (°)						
Wind speed (m/s)		−0.348 (0.126)	−0.185 (0.065)	−0.379 (0.182)		
Julian date				0.052 (0.024)		
Hour	0.852 (0.261)					
Temperature $\star$ Date	0.015 (0.005)			−0.002 (0.001)		
Temperature $\star$ Hour	−0.039 (0.011)					

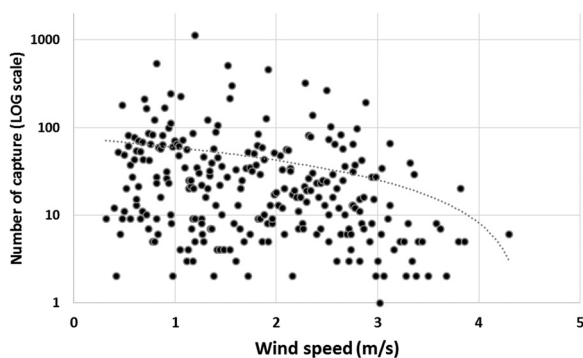|	Araneae	Neuroptera	Homoptera	Thysanoptera	Total captures	Diversity index (Simpson' D)
B Temperature (°C)						
Pressure (hPa)					0.040 (0.016)	
Humidity (%)	−0.036 (0.018)			−0.043 (0.019)	−0.015 (0.005)	
Wind direction (°)						0.002 (0.001)
Wind speed (m/s)		−0.997 (0.269)		−0.870 (0.269)	−0.240 (0.065)	−0.187 (0.063)
Julian date					−0.022 (0.010)	
Hour				0.480 (0.228)	0.166 (0.052)	
Temperature $\star$ Date					0.002 (0.001)	
Temperature $\star$ Hour				−0.020 (0.009)	−0.008 (0.002)	

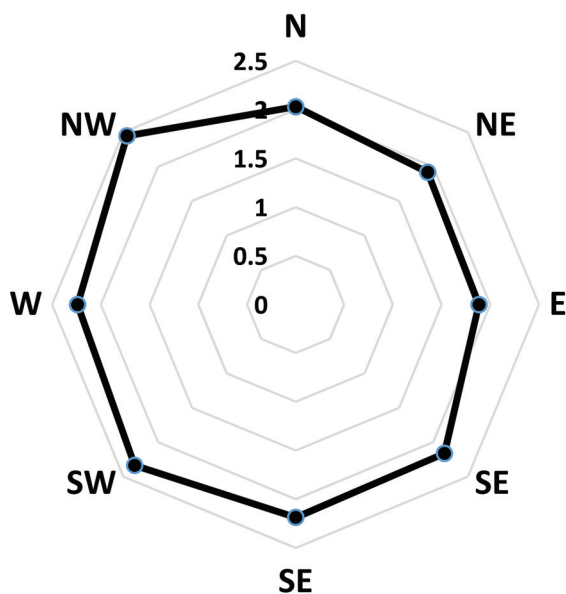Figure 2. Effect of wind speed on the total number of captures.

Figure 3. Association between wind direction and diversity of the taxa composing aeroplankton in the University campus of Palermo. Diversity of the sample is expressed with the Simpson index, growing numbers corresponding to higher diversity of the samples.

as a factor driving dispersal, while within a day its role was more important in the early day.

Passive wind dispersal as a dispersion mechanism of insects

Our results confirm that values of wind speed above 3 m/s may be considered particularly disadvantageous for the aeroplankton that disperses better at lower speeds (see also Taylor 1974). Most airborne insects are very small and distances that they cover may be very long, even if difficult to calculate. Some long-flying individuals may originate from hundred or thousands of kilometres away (Johnson 1969;

Riley et al. 1987; Drake & Gatehouse 1995; Pedgley et al. 1995; Gatehouse 1997). An important consequence of movements by arthropods in the atmosphere is the possibility to explore and colonise greater areas and different habitats through passive transport. Aerial transport plays an important role in the colonisation of new zones; furthermore, it enables arthropods to overtake natural barriers such as oceans, lakes, high mountains and deserts. It seems obvious that a species driven by wind may settle into a site only if it finds its habitat (e.g. host plant). According to Reynolds et al. (2013), some common species tend to occur frequently in aerial samples while other less common or rare species are not usually caught. Actually, we collected both common and rare species, or those at least considered rare until now, or previously unrecorded in Italy. In fact, small allochthonous species, American, Australian and African, are more and more frequently being recorded in the Palaearctic region (Carapezza & Cusimano 2014; Cusimano et al. 2014). This is probably mainly due to increased anthropogenic transport of organisms; later, wind speed and direction facilitate dispersal of the aeroplankton.

Acknowledgements

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