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Nuptial flights of the seed-harvester ant *Messor barbarus* (LINNAEUS, 1767) (Hymenoptera: Formicidae) in the Iberian Peninsula: synchrony, spatial scale and weather conditions

Crisanto GÓMEZ & Sílvia ABRIL

Abstract

We describe the nuptial flights of the seed-harvester ant *Messor barbarus* (LINNAEUS, 1767) (Hymenoptera: Formicidae) across the Iberian Peninsula, using a total of 123 nuptial-flight observations from 2003 until 2009. Data from 2008 and 2009 were substantial enough to identify eight clusters of nuptial flights triggered by the same weather fronts. Our observations took place over seven weeks (1.75 lunar months) in September and October. Nuptial-flight clusters associated with the same front spanned a mean maximum distance of 637.6 ± 356.9 km, with a maximum distance of 1075 km. The influence of the direction of the rain fronts associated with the flights was not significant as we observed similar clustering for two Atlantic fronts from the south-west, three Mediterranean fronts from the south-east, and two Atlantic fronts from the north-west. We consistently found that the days with the highest number of flights occurred two to three days after the fronts, when the rain had stopped and the fronts had disappeared from the Iberian Peninsula.

Key words: Ants, Formicidae, nuptial flight, *Messor barbarus*, phenology, reproduction, synchrony.

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Crisanto Gómez (contact author) & Sílvia Abril, Departament de Ciències Ambientals, Universitat de Girona, Campus de Montilivi, E-17071 Girona, Spain. E-mail: crisanto.gomez@udg.edu; silvia.abril@udg.edu

Introduction

Reproduction is a key factor in understanding the population ecology of a species. For ants, nuptial flights are central to this process, ensuring outbreeding, the founding of new colonies and the colonization of new areas (HÖLLDOBLER & WILSON 1990, BAER 2011). Despite the ecological importance of ants (HÖLLDOBLER & WILSON 1990), there are few studies on the annual phenology of their alate flights. The key for understanding patterns in the mode of reproduction in ants is to know the distribution of their reproductive flights across space and time (e.g., TSCHINKEL 1991, 2011).

Several studies have shown that weather conditions play a major role in the timing of nuptial flights, i.e., flight synchrony, and subsequently on mating success (BOOMSMA & LEUSINK 1981, DEPA 2006, HELMS & HELMS CAHAN 2010). One of the commonest environmental triggers is rain, especially for species that occupy dry habitats such as deserts like the Mojave Desert (HELMS & HELMS CAHAN 2010), grasslands (BOOMSMA & LEUSINK 1981) and forest clearings (HÖLLDOBLER & WILSON 1990). Thus, recent rainfalls may be important by softening the soil for nest excavation, minimizing desiccation and acting as a cue for the start of the reproductive season (e.g., MORRILL 1974, HÖLLDOBLER 1976). Our study focused on the ant *Messor barbarus* (LINNAEUS, 1767), which is a harvester species that inhabits grasslands and dry habitats in the Mediterranean region. Its distribution area includes practically all the Iberian Peninsula except the north-western zone (BERNARD 1968, THE SITE FOR PALEARCTIC AND MACARONESIAN ANTS 2010). Nuptial flights of this ant species are probably the most noticeable swarming event in the Iberian Peninsula because of the size of sexual alates (males: 7 - 12 mm; queens: 9 - 15 mm), and are therefore easily observable in urban as well as rural areas every early autumn.

The literature about ant mating flights states that, for some species, nuptial flights take place on the same day over a vast area (DEPA 2006). However, studies of such flights usually cover areas smaller than a few thousand square metres (WOYCIECHOWSKI 1987, KASPARI & al. 2001a, b, DEPA 2006, DUNN & al. 2007, NOORDIJK & al. 2008, HELMS & HELMS CAHAN 2010). One exception is the work of BOOMSMA & LEUSINK (1981), which comprises observations from sites up to 160 km apart (Amsterdam – Schiermonnikoog, The Netherlands), where flights did not usually happen on the same day. These observations led us to ask how extensive the area of a single nuptial flight or cluster of associated flights for an ant like *Messor barbarus* can be. Large-scale synchrony of mating flights across the distribution area of an ant species could be viewed in support of hardwired intrinsic mechanisms keeping up species integrity, considering, of course, that this large-scale synchrony will also work locally.

The aims of the present study were: 1) to describe the relationship between weather conditions across the Iberian Peninsula and the timing of the nuptial flights of *Messor barbarus*, and 2) to assess the area over which single nuptial flights or clusters of closely associated nuptial flights occur.

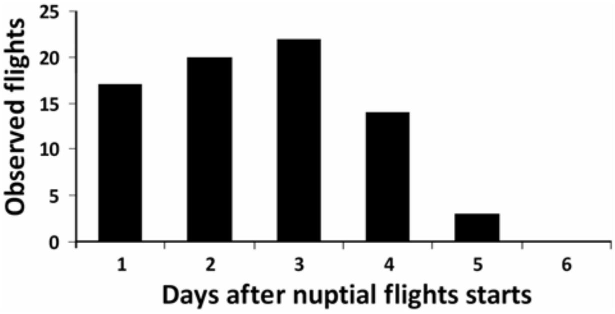

Fig. 1: Cumulative number of flights observed during the days following flight-cluster starts. The flight observations used come from the eight nuptial-flight clusters that we were able to identify (one in 2007, two in 2008 and five in 2009; n = 76).

Material and methods

We used data from two different sources: a database created by professional and non-professional myrmecologists, and a meteorological database.

The first source was the "Alados" database available at the website of COMUNIDAD DE AFICIONADOS A LAS HORMIGAS (2010), at lamarabunta.org. Members of the Foro Lamarabunta and of the Iberian Association of Myrmecology (AIM) have been uploading to this site their observations on ant nuptial flights since 2003 (including some observations from the authors of this study, who are themselves members). This database includes different variables such as the date, site, ant species, general comments on other circumstances and the recorder's personal identification. Data from 2007 to 2009, the years for which enough observations were available, were used to describe clusters of nuptial flights of *Messor barbarus* in the Iberian Peninsula. The criteria used for grouping flights into clusters were: number of days, day with the highest number of observations, mean and maximum distance between sites of observation for the event and the day with the highest number of observations.

The second source of information was the SMC (Meteorological Service of Catalonia) (2010) website, which provided us with the meteorological conditions recorded during the days with nuptial flights, as described above. We used Meteosat satellite images of the Iberian Peninsula (SMC 2010) (© EUMETSAT, 2009, Meteosat (M-9) Imagery supplied by the Meteorological Service of Catalonia) to identify the position and movements of rain fronts both during the nuptial flight events and on the previous day. In this case, we only had access to data from 2008 and 2009. We focused on the day preceding the event and on the day with the highest number of observations, and associated every nuptial flight event with the rain front (Atlantic or Mediterranean) that triggered it.

Results

Flight synchrony: We used a total of 123 nuptial flight observations of *Messor barbarus* for the analysis and description. Out of all the observations, 50% were from 2009. Nuptial flights were observed continuously over a seven-week period (1.75 lunar months – based on a calendar of four-week lunar months) in September and October. Between 2003 and 2009, 93% of the flights were observed during this period (98% for the year 2009).

Flight clusters: We defined a nuptial-flight cluster as a period of time (days) when continuous nuptial flights were observed. On that basis, we were able to identify eight nuptial-flight clusters (one in 2007, two in 2008, and five in 2009) that lasted between three to five days (Fig. 1), with an average of 3.9 ± 0.8 days, and a mean number of flight observations by cluster of 9.5 ± 5.6, ranging from 6 to 22 (Tab. 1). The mean (± SD) maximum distance be-

Tab. 1: Descriptive data of the nuptial-flight clusters observed. Information for each cluster: date, associated rain front, duration (in days), number of observations (n) and maximum distance between observation sites for the entire cluster ($Dist_{max}$). Information for the days with the highest number of observations: date, number of observations and maximum distance between sites. SD = standard deviation.

		Global cluster data			Days with highest number of observation data		
Flight-cluster dates	**Rain front origin**	**Duration (days)**	**n**	**$Dist_{max}$ (km)**	**Date**	**n**	**$Dist_{max}$ (km)**
16.-18.IX.2009	SE Mediterranean	3	6	187	16.IX.2009	4	176
22.-24.IX.2009	SE Mediterranean	3	5	174	23.IX.2009	3	11
29.IX.-2.X.2009	SE Mediterranean	4	12	615	30.IX.2009	7	615
06.-10.X.2009	NW Atlantic	5	11	360	8.-9.X.2009	4	360
21.-25.X.2009	NW Atlantic	5	22	1075	23.X.2009	11	912
21.-24.IX.2008	SW Atlantic	4	6	860	21.-22.IX.2009	4	410
12.-14.X.2008	SW Atlantic	3	6	940	13.X.2008	4	940
02.-05.X.2007		4	8	890	05.X.2007	3	250
Mean		3.9	9.5	637.6		5.0	459.3
SD		0.8	5.7	356.9		2.7	337.6

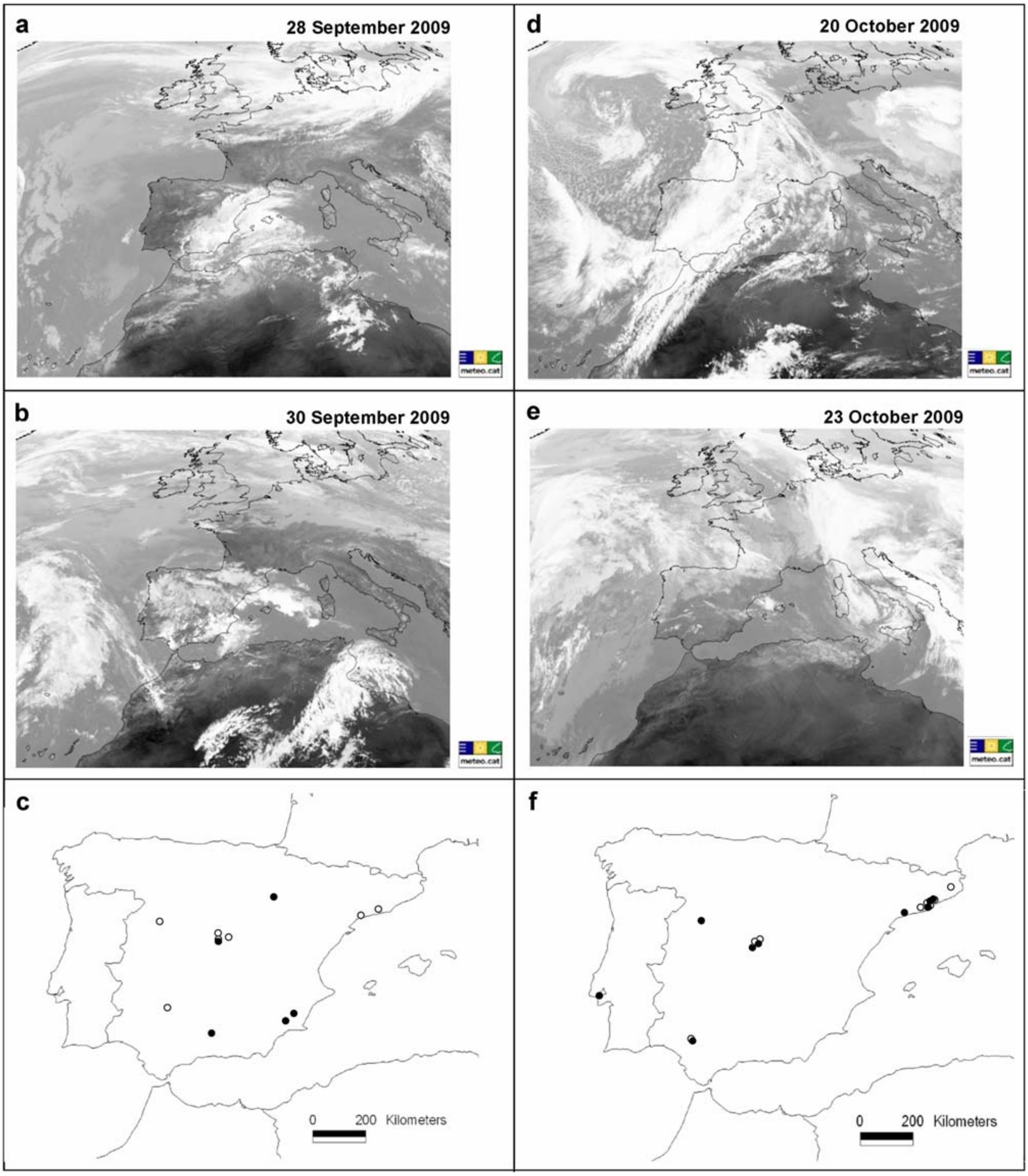

Fig. 2: Representative examples of Meteosat satellite images (© EUMETSAT, 2009, Meteosat (M-9) Imagery supplied by the Meteorological Service of Catalonia) taken during two nuptial-flight clusters in September and October 2009: (a) and (d) weather conditions on the day before the start of the nuptial-flight clusters E1 and E2, respectively; (b) and (e) weather conditions during the day with the highest number of flights during flight clusters E1 and E2, respectively; (c) and (f) the number of flight observations at specific sites for the E1 and E2 clusters, respectively (white dots: sites with the highest number of observations; black dots: observations for the remaining days). The first cluster was related to a south-east Mediterranean rain front, and the second to a north-west Atlantic front.

tween observation sites by cluster was 637.6 ± 356.9 km, with a maximum distance of 1075 km between Girona (Girona province, Spain) and Camas (Sevilla province, Spain) during the fifth cluster of 2009, and a minimum distance of 174 km. The mean (± standard deviation, SD) maximum distance between observation sites during the day with the highest number of observations was 459.3 ± 337.6 km, ranging from 11 to 940 km. The highest number of flight observations occurred two or three days after the cluster started (Fig. 1). We calculated a mean (± SD) of 5.0 ± 2.7

flight observations for the days with the highest number of observations (Fig. 1).

Three kinds of rain fronts were associated with the flight clusters of the years 2008 and 2009. Two south-west Atlantic fronts were associated with the two clusters in 2008. For the year 2009, three clusters were associated with south-east Mediterranean fronts and two with north-west Atlantic fronts. All the nuptial flights occurred following a rain event, and there were flights after all the rain events analyzed. In Figure 2, we can observe the rain-front position the day before the start of the nuptial-flight cluster and during the day with the highest number of observed flights for two different clusters. One of them corresponds to a north-west Atlantic front and the other to a south-east Mediterranean front. In the two cases, the day before the flight started, the front was positioned just over or crossing the Iberian Peninsula. Meanwhile, during the day with the highest number of observations the rain had stopped and all the fronts had disappeared or were far from the Iberian Peninsula.

Discussion

This study is the first to report synchronized nuptial flights of ants over distances of more than a thousand kilometres. It covers an area of 190,000 km^2, spanning half the distribution area of *Messor barbarus* in the Iberian Peninsula. This kind of data implies more than population-level information, supporting the idea of a hardwired intrinsic integrity mechanism of this ant species. Of course, sexual alates of this ant species are not able to fly one thousand kilometres, but when the meteorological and physiological conditions are adequate, the behaviour of colonies is the same along the distributional area. This is an example of geographic and temporal synchrony. The duration of the nuptial-flight observation period was 1.7 lunar months in the Iberian Peninsula (36 - 43° N), comparable to what was observed in Northern Holland, The Netherlands for four ant species (1.5 lunar months at 53° N) (BOOMSMA & LEUSINK 1981), in Michigan (USA) for an 18-ant species assemblage (1.6 lunar months, at 42° N), and in Colorado (USA) for *Formica obscuripes* FOREL, 1886 (2.2 lunar months at 38° N) (KASPARI & al. 2001b). Latitudinal variation may be important in the timing of mating flights (KASPARI & al. 2001b). The Iberian Peninsula does not have a wide latitudinal range (36 - 43° N) and the mating flights occurred regardless of latitude. The point of entrance of the rain fronts on the Peninsula and their path across it were what determined if the flights began earlier in the south or the north. The mating flights of the same cluster were observed within virtually the whole latitude range of *M. barbarus* in the Peninsula (Fig. 2c and f).

Messor barbarus is an ant species typical of Mediterranean dry ecosystems. It inhabits dry and sunlit places and often has its nuptial flight after rainfall, but not much more information is known about those mating flights. The soil is moistened after the rainfall and therefore easier to excavate (HÖLLDOBLER & WILSON 1990). This is one of the reasons why moisture constrains phenology (KASPARI & al. 2001b) as in the case of *Pogonomyrmex rugosus* EMERY, 1895 in North American deserts (HELMS & HELMS CAHAN 2010). In contrast, in the case of *Manica rubida* (LATREILLE, 1802) in Poland, no rainfall was observed during the 24 hours preceding the flight, and only occurred after the flight, on the same or on the next day (DEPA 2006). This makes sense because in such relatively moist climates digging new chambers may be easier for *M. rubida*.

Anticyclonic weather conditions with low wind velocities are considered optimal for nuptial flights (BOOMSMA & LEUSINK 1981). In our case, the days with the highest numbers of flights were indeed those with anticyclonic conditions, after a low pressure front had passed over the Iberian Peninsula. No single rain-front type was associated with nuptial flights, indicating that *Messor barbarus* colonies were generally just waiting for proper weather conditions to fly, irrespective of where the front causing these conditions came from.

The kind of data used in this work may have some shortcomings. For example, the people who made the observations are not all professional myrmecologists and could have had difficulty identifying the species. In the case of AIM members who participated in the observations, all had followed or participated in training workshops on the taxonomy of Iberian ants. These training programs are organized annually by the AIM-Lamarabunta forum, and the teachers are recognized experts in ant taxonomy. Another approach that could be used to resolve any doubts about identification is to share potential concerns online with other members, and to send samples to the professional and expert members of the association. It should also be mentioned that people who add their flight observations to the database participate throughout the year and not just on the days when a flight is expected, which avoids possible bias in the observations.

We know of some ornithological studies based on data obtained by professionals and amateurs, such as studies of long- and short-distance bird migrations obtained thanks to bird-banding campaigns or bird captures. Here we present the results and analyse the data obtained by people who, although non-professionals, are undoubtedly on the way to becoming expert myrmecologists with experience on the Iberian Peninsula. This collaboration allowed us to obtain a large amount of good quality data, which could not have been collected by professional myrmecologists alone.

Finally, two questions are to be considered in the future. First, as a next step, in-depth explorations of Iberia-wide nuptial flights, and thus more detailed information of integral parts of the mating flight (i.e., time of day, location of mating – air, ground –, if the queens start nests alone or in groups) will be helpful for understanding the colony cycle and how their mating flights compare to those of congeners. Second, and more general, if such potential species-integrity-stabilising mechanisms are weather dependent indeed, the large-scale synchrony of flights might get poorer if weather conditions start getting locally more different, as can be expected from the ongoing climate change.

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