

Update on the invasion status of the Argentine ant, *Linepithema humile* (Mayr, 1868), in Madrid, a large city in the interior of the Iberian Peninsula

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Abstract

New geolocated records of the invasive ant *Linepithema humile* (Mayr, 1868) are added to the previous references for the city of Madrid and its surroundings, and the possible causes of the occurrence and permanence of this species in urban areas are discussed. The data collection corresponds to a series of samplings carried out for the last three years in green areas of the city, bibliographic searches, citizen science platforms and personal communications. To date, eleven locations in the urban area of Madrid and four points outside the city have been registered. The city of Madrid is undergoing a colonisation by the Argentine ant, although it is not widespread yet, since observations over time and space are isolated and apparently unrelated. However, this species has a great capacity to disperse and establish new colonies, mainly human-mediated through the transport of goods, plants, gardening tools, etc. Considering the numerous colonizable urban green areas in the city that can provide the necessary conditions for its expansion, the Argentine ant should not be underestimated, and immediate action is strongly recommended.

Keywords

Formicidae, green areas, introduced species, invasive species, new records, Spain, urban environment

Introduction

The Argentine ant, *Linepithema humile* (Mayr, 1868), is a well-known and widely studied organism due to its highly potential as an invasive species (Wetterer et al. 2009; GISD 2015). This ant presents a wide range of strategies, such as its characteristic interspecific aggressiveness, polygynic and polydomic colonies and a large number of individuals per nest, which gives it a greater capacity to establish new settlements, indirectly and profusely aided by humans (Suarez et al. 2001; Carpintero et al. 2004; Ward et al. 2005). The cosmopolitan and dominant behaviour of this ant (McGlynn 1999) allows it to displace other native species, both in naturalised environments (Kennedy 1998; Carpintero et al. 2014) and urban areas (Touyama et al. 2003; Holway and Suarez 2006; Stringer et al. 2009). In this context, and due to the potential damage that this species can cause in new environments, it is important to monitor the spatial distribution of the Argentine ant.

In the Iberian Peninsula, *L. humile* has a predominant coastal distribution (Espadaler and Collinwood 2001; Espadaler and Gómez 2003), but there are several records of its presence in inland provinces: Badajoz, Córdoba, Madrid, Orense, Salamanca, Sevilla, Soria and Zaragoza in Spain, (Obregón and Reyes-López 2016; <http://mirmecologia.jimdo.com>), and other references including Penalva do Castelo, the most inland locality of Portugal according to Silva Dias (1955). These locations attract our attention when, in terms of biogeography, they correspond to inland regions that may pose a challenge to the survival of this species by presenting unfavourable conditions for its activity, such as cold winters or lack of humidity when they are far from a coastal Mediterranean climate (Espadaler and Gómez 2003). This climatic unsuitability could be a limiting factor for the expansion of the Argentine ant in inner regions of the Iberian Peninsula, as shown by the potential distribution modelling work by Roura-Pascual et al. (2006, 2009), but it may not have a plausible effect in cities, where most of the inner recorded evidence occurs.

In this way, green areas, parks, and botanical and private gardens located in urban environments provide microhabitat scale conditions, in terms of humidity, food and shelter resources, which not only allow but also favour the development of Argentine ant colonies (Martínez et al. 1997). These locations often have in common the presence of irrigation systems and nutritious plants for Hemiptera Sternorrhyncha (aphids, whiteflies and scale insects) (Greenberg et al. 2006; Mgocheki et al. 2009; Powell et al. 2010), where ants can easily supply the colony by acquiring sugary substances and water. On a landscape scale, the Urban Heat Island effect could be another driver for the permanence of the Argentine ant in cities along with other characteristics corresponding to a finer scale (e.g.: green areas features). This effect is a valuable factor to explain the insect community structure (McGlynn et al. 2019) since the temperature increase associated with it has been shown to be beneficial for the subsistence of native thermophilic species (Menke et al. 2011; Kaiser et al. 2016) as well as for the maintenance of invasive species (Borden and Flory 2021).

The present article compiles all the records of the Argentine ant, *L. humile*, obtained from various samplings across the city of Madrid and its surrounding areas between 2018 and 2020, including previous information from the bibliography, citizen science web platforms and personal communications. The aim of this study was to update the available information on the Argentine ant in the city of Madrid and nearby locations.

Methods

Records of the Argentine ant, *L. humile*, were searched and catalogued from different sources, involving mostly green areas in the city of Madrid and its surroundings. These references were obtained from: (i) the bibliography (B, Table 1), (ii) consultations with the citizen science platform 'Biodiversidad Virtual' (BV; <https://www.biodiversidadvirtual.org>), where it was possible to request georeferenced data associated to photographs of *L. humile*, (iii) personal communications (P), and (iv) survey data (S).

The survey data correspond to a series of samplings in green areas of the city carried out from 2018 to 2020, between May and September of each year. Three locations do not correspond to green areas but to streets, where the same sampling protocol was applied (S, Streets, Table 1). Due to the large number of parks within the city limits (nearly 200), a representative sample of them was obtained through a cluster analysis following Hair et al. (1999). For this purpose, a series of factors was obtained from different types of variables (Table 2), through a principal component analysis. A dendrogram which grouped sets of the 200 parks in the city of Madrid was built (matrix based on Euclidean distances, Group average amalgamation) and a threshold was set to establish a reasonable number of parks to sample. During 2018, a total of 13 green areas were chosen to be surveyed. Samplings were then carried out in another 7 green areas as well as in some of the previous parks during 2019 and 2020 in order to continue monitoring the ant fauna of the parks and gardens of Madrid, selecting them randomly from the cluster groups or because the presence of the Argentine ant was known. Each green area was visited at least 2 times and ants were collected from a variety of habitats (ground surface, under stones and stumps, walls, trees, etc.) over a period of time proportional to the size of the parks. A logarithmic curve was established to achieve the sampling effort in the largest parks (approximately, a minimum of 25 minutes for an area of 1 hectare or less and a maximum of 180 minutes for parks of more than 140 hectares). The logarithmic curve had been previously tested in the *urban Butterfly Monitoring Scheme project* (uBMS, 2018), as suggested by Constantí Stefanescu (personal communication). The formula was $t = (\text{LN}(\text{hec}) + 0.75) * 30$, where t is the search time and hec the hectares that the park occupies.

Ants were directly sampled with an aspirator, and pitfall traps were used to maximise the sampling effort whenever they could be set due to impracticable ground conditions or when permits could not be obtained (Agosti and Alonso 2000). Ants were

Table 1. Localities where samplings have been carried out and/or the Argentine ant has been registered. Classification of localities (city of Madrid and surroundings): B, the species has been registered according to bibliographic references (Collingwood and Yarrow 1969; Martínez et al. 1997; Ruiz-Heras et al. 2011); BV, the species has been registered, according to the citizen science platform ‘Biodiversidad Virtual’; P, the species has been registered through personal communication, according to information given by a pest control company (N. Trotta leg.), by J. Reyes, J. Arcos, K. Gómez and M. Sierra or by other citizens; S, survey data from exhaustive ant sampling. Presence/Colony extension: the confirmed presence of the species in each locality and the area occupied by ants in squared metres if known. ✓: confirmed presence; no presence: no Argentine ants have been found after an exhaustive sampling. Pitfall traps: whether pitfall traps could be set. Time spent: minutes of sampling effort. N° of visits: number of times each area was surveyed.

Sampling areas	Location	Classification	Presence/ Colony extension	Date of sampling	Pitfall traps	Time spent (min)	Nº of visits
City of Madrid: green areas							
Casa de Campo Park (east side)	40°25.020'N, 3°44.040'W	B	✓	2011	–	–	–
		S	✓ / 11816 m ²	2018–2019	Yes	184	3
Madrid Río Park (Central part)	40°25.133'N, 3°43.340'W	P	✓	Prior to 2019	–	–	–
		S	✓ / 54494 m ²	2019–2020	Not practicable	122	2
Real Jardín Botánico de Madrid	40°24.660'N, 3°41.460'W	BV	✓	2016	–	–	–
		S	✓ / 2857 m ²	2018–2019	Not practicable	91	2
del Norte–CarmenTagle Park	40°28.843'N, 3°41.734'W	S	✓ / 377 m ²	2018	Yes	121	3
Enrique Tierno Galván Park	40°23.312'N, 3°40.961'W	S	✓ / 1974 m ²	2018	Yes	143	3
Sorolla Museum Gardens	40°26.120'N, 3°41.540'W	S	✓ / 830 m ²	2020	Not practicable	25	2
Campus Moncloa, North side	40°26.930'N, 3°43.688'W	S	No presence	2010–2019	Yes	Continuous monitoring	3+
Bellas Artes Gardens	40°26.410'N, 3°41.425'W	S	No presence	2018	Yes	25	3
Campo del Moro Gardens	40°25.068'N, 3°43.089'W	S	No presence	2018	Yes	119	3
Berlín Park	40°27.026'N, 3°40.547'W	S	No presence	2019	No	76	2
Cuña Verde de la Latina Park	40°24.048'N, 3°44.620'W	S	No presence	2018	Yes	158	3
Pradolongo Park	40°22.545'N, 3°42.384'W	S	No presence	2019	No	156	2
Roma Park	40°24.988'N, 3°39.762'W	S	No presence	2018	Yes	101	3
Emperatriz María de Austria Park	40°22.741'N, 3°43.422'W	S	No presence	2018	Yes	156	3
Entrevías Urban Park	40°22.224'N, 3°40.107'W	S	No presence	2018	Yes	104	3
Eugenia de Montijo Park (part 2)	40°23.032'N, 3°45.014'W	S	No presence	2018	Yes	69	3
Forestal de Valdebebas Park	40°29.466'N, 3°37.994'W	S	No presence	2019	No	184	2
Forestal de Vicalvaro Park	40°24.476'N, 3°35.894'W	S	No presence	2018–2019	Yes	135	3
Juan Carlos I Park	40°27.642'N, 3°36.324'W	S	No presence	2018	Yes	184	3
Quinta de Torre Arias	40°26.688'N, 3°37.190'W	S	No presence	2018	Yes	115	3
City of Madrid: Streets							
Campus Moncloa, east side, Rector Royo–Villanova Street	40°27.120'N, 3°42.960'W	B	✓ / Unknown	1991–1992	–	–	–
		P	Unknown	2019	Not practicable	–	–
Valmojado Street, Aluche Neighbourhood	40°23.220'N, 3°45.540'W	P	✓ / Unknown	24/01/2004	Not practicable	–	–
Alfonso XII Street, Jerónimos Neighbourhood	40°24.660'N, 3°41.333'W	S	✓ / 2440 m ²	2018–2019	Not practicable	25	2
Príncipe de Vergara Street	40°25.382'N, 3°40.826'W	S	✓ / 225 m ²	2020	Not practicable	25	2
Nueva España Neighbourhood (various streets)	40°27.560'N, 3°40.358'W	BV	✓	2011	–	–	–
		S	✓ / 93290 m ²	2019–2020	Not practicable	157	3
Outside the city of Madrid							
Aranjuez	40°2.220'N, 3°36.300'W	B	✓	1952–1968	–	–	–
		P	✓ / Unknown	2019	–	–	–
Pozuelo de Alarcón	40°27.50'N, 3°48.28'W	B	✓	1952–1968	–	–	–
Pozuelo de Alarcón, Vereda de las Columnas Street, El Paular Neighbourhood	40°27.50'N, 3°48.28'W	P	✓ / Unknown	2020	Not practicable	–	–
Rivas–Vaciamadrid	40°21.540'N, 3°32.820'W	B	✓	2011	–	–	–
		P	✓ / Unknown	2010	–	–	–
Villanueva de la Cañada, Villagolf residential area	40°26.700'N, 3°59.880'W	P	✓ / Unknown	2019	Not practicable	–	–

Table 2. Variables used in the park selection process sorted by type, with a brief description.

Type	Variable	Description
Geographical	Latitude and longitude	Georeferences of the park centroid
Spatial	Area and perimeter	Surface spatial attributes
	Orientation	Ratio between longitude and latitude differences.
	Shape	Ratio between perimeter and area. It gives an idea of the edge effect.
Management	Timetable	Opening hours
	Type of management	'Naturalised' or 'garden' type of management
Urban matrix	Distance between parks	Distance between park centroids
	Distance to city centre	Distance from park centroids to centre of the city (centroid of all parks)
	Distance to wildlife sources	Corresponding to large naturalised areas*.
	Surrounding green areas	Surface of other green areas in buffers of 100 m, 250 m, 500 m, 1000 m, 1500 m, 2000 m, 2500 m and 5000 m

*'Monte de El Pardo' and the main Protected Natural Spaces surrounding the city of Madrid: Middle Course of the Guadarrama River and its surroundings, Axes of the Lower Courses of the Manzanares and Jarama Rivers, and the Upper Basin of the Manzanares.

identified to genus or species level whenever possible, following Gómez and Espadaler (2007) and Lebas et al. (2017). All the specimens were placed in vials containing 70% ethanol and were deposited in the 'Colección de Entomología UCM' (UCME).

Those sites where *L. humile* was found were properly surveyed to measure the surface area covered by each colony. To assess the expansion limits of the colony, workers of Argentine ant were searched and mapped until they were no longer seen after having walked through the area in concentric circles, moving 50 to 100 metres away from the ant trails. The extent of the colony reflected in QGIS software (QGIS 2021) means that no Argentine ants were found beyond the boundaries of the polygon (see Fig. 3).

Results

The presence of the Argentine ant was recorded in a total of eleven points within the urban area of the city of Madrid and four peripheral locations (Fig. 1), which shows the historical and geographical background of this invasive ant in Madrid (Table 1).

The bibliographic search resulted in three documents that located the presence of the Argentine ant in five locations (B, Table 1). Data from the citizen science platform resulted in two locations (BV). We obtained six records from personal communications from the following persons: J. Reyes, J. Arcos, K. Gómez, M. Sierra, or anonymous citizens and a pest control company (N. Trotta leg.) (P). While three of them can be considered new records, the other three confirm bibliographic data. Finally, we can point out six new locations from the survey data (S), not previously recorded by other methods.

Nine of the 23 localities exhaustively sampled in the city of Madrid during the last three years showed the presence of *L. humile* (39.1% of the locations sampled;

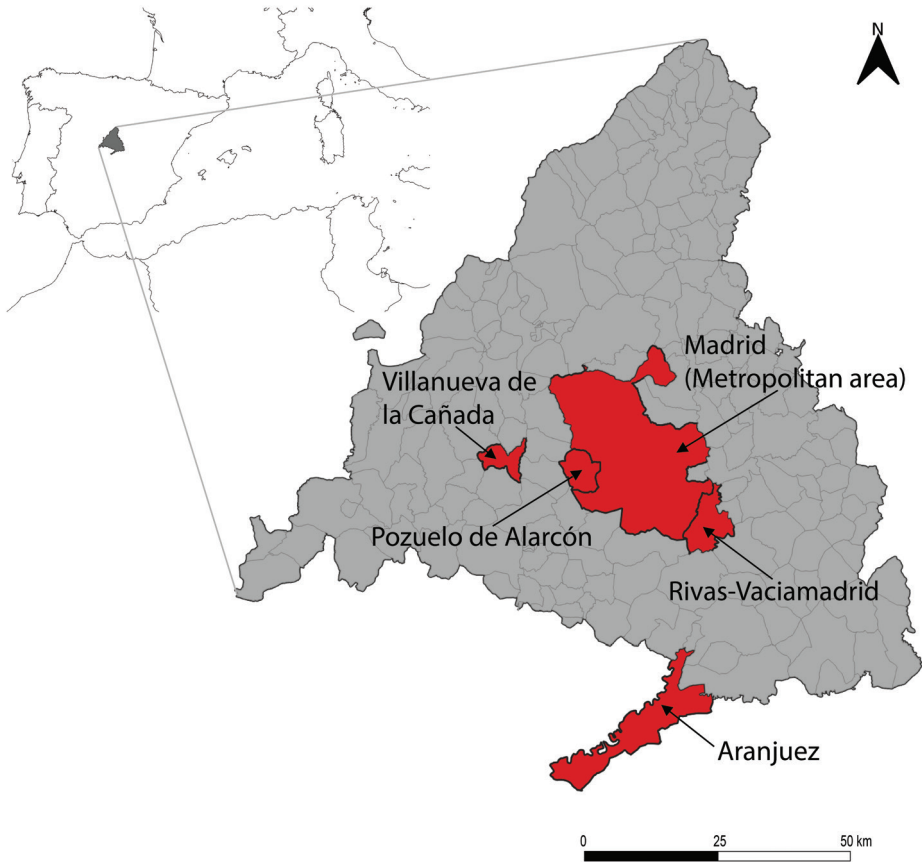


Figure 1. Municipalities (in red) where the Argentine ant has been recorded in the Community of Madrid.

S, Table 1). Six out of these nine places corresponded to green areas. Within the city limits, the species had previously been registered in a park located in the west (Casa de Campo Park; Ruiz-Heras et al. 2011) and found in two other locations in the centre and northwest of the city (BV, Table 1). *A priori*, the presence did not seem to show any geographic pattern, since they were found scattered throughout the city, although more abundant on the periphery (Fig. 2). The presences observed in other localities in Madrid and surrounding areas do not present a clear geographical pattern either but are spread over several points. The locations listed below correspond to the Argentine ant colonies observed in the city of Madrid and its surroundings.

Enrique Tierno Galván Park and Del Norte-Carmen Tagle Park

Enrique Tierno Galván Park is located in the south of the city ($40^{\circ}23.312'N$, $3^{\circ}40.961'W$). With a size of 41 hectares, it is considered a large park. An Argentine

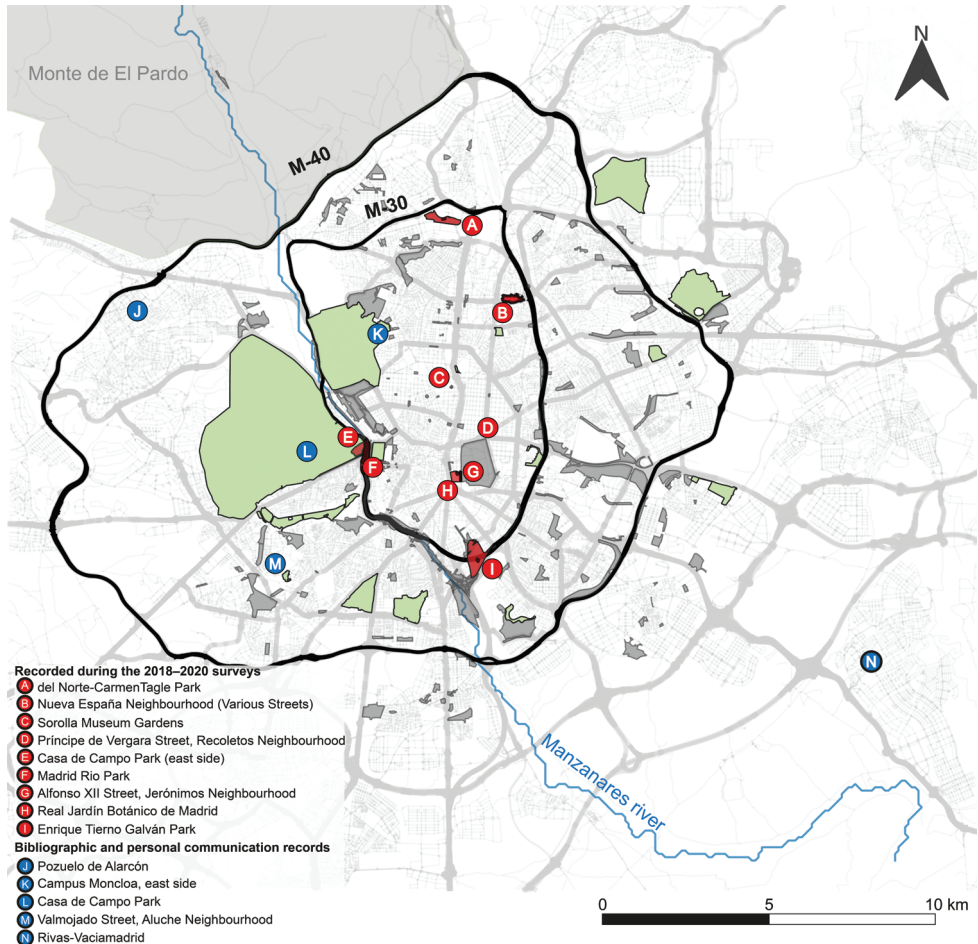


Figure 2. Locations of the Argentine ant in the city of Madrid. The letters in red circles correspond to locations where the Argentine ant has been recorded during the 2018–2020 surveys (areas in red). Letters in blue circles indicate bibliographic and personal communication records. The green areas correspond to parks and gardens that have been thoroughly sampled and where *Linepithema humile* has not been found, except for the eastern corner of the Casa de Campo Park (E). The light grey areas are green areas (parks and gardens) that have not been sampled and are capable of harbouring colonies of the Argentine ant.

ant colony was found, with its foraging tracks extending over almost 2000 square metres, where the water supply remained constant (with irrigation systems covering the grass meadows). The colony had access to plants with aphids and elements where the species could take shelter and walk easily, such as cobblestones and road gutters (Fig. 3A).

Del Norte-Carmen Tagle Park is located in the north of the city of Madrid (40°28.843'N, 3°41.734'W), extending over 20 hectares. The colony foraging area covered approximately 380 square metres, including areas of irrigated meadows and cobblestones with ornamental shrub vegetation (Fig. 3B).

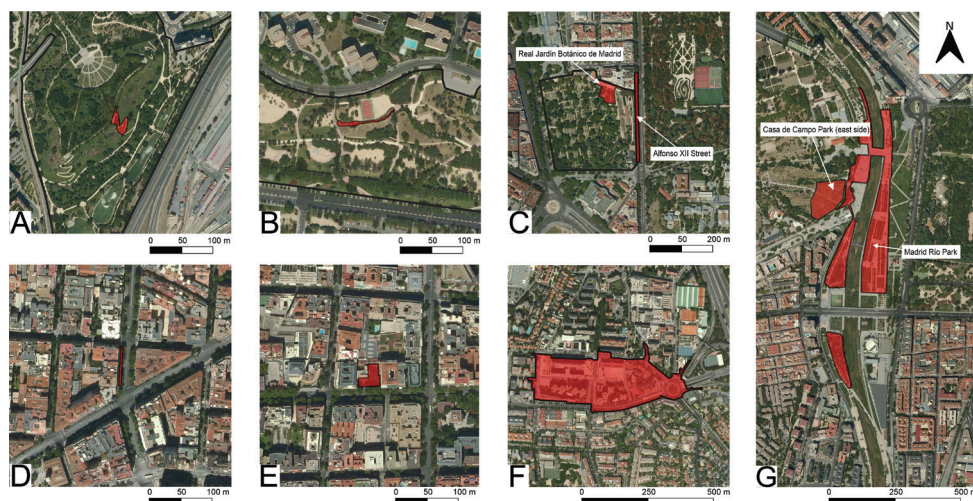


Figure 3. Colony extension and foraging areas of the Argentine ant in nine locations of Madrid. **A** Enrique Tierno Galván Park **B** del Norte-Carmen Tagle Park **C** Real Jardín Botánico de Madrid and Alfonso XII Street **D** Príncipe de Vergara Street **E** Sorolla Museum Gardens **F** Nueva España Neighbourhood **G** Casa de Campo Park (east side) and Madrid Río Park.

Real Jardín Botánico de Madrid, Alfonso XII Street and Príncipe de Vergara Street

In the Real Jardín Botánico de Madrid (Royal Botanical Garden; 40°24.660'N, 3°41.460'W), the presence of the Argentine ant confirmed a previous record (Biodiversidad Virtual 2016; Fig. 4A). To date, a single colony has been detected, with workers traversing several metres outside the exhibition greenhouse and circulating inside it in search of nectariferous plants (Fig. 3C).

A colony was also detected on Alfonso XII Street (40°24.660'N, 3°41.333'W), adjacent to the Real Jardín Botánico de Madrid. The workers may have come from inside the Jardín Botánico itself, which would act as a focal point, since several entrance trails to the possible nest were identified on a wall on the even-numbered side of the street, where a line of ants extended over approximately 300 metres (Fig. 3C). Near this location, on Príncipe de Vergara Street (40°25.382'N, 3°40.826'W), another trail of Argentine ants was spotted covering 70 metres on the sidewalk and occupying the tree pits (Fig. 3D).

Sorolla Museum Gardens

Approximately 830 square metres are occupied by the Argentine ant in the garden in front of the Sorolla museum (Fig. 3E), located near the city centre (Fig. 2; 40°26.120'N, 3°41.540'W). This green space is surrounded by walls and the ants do not occupy the adjacent street.

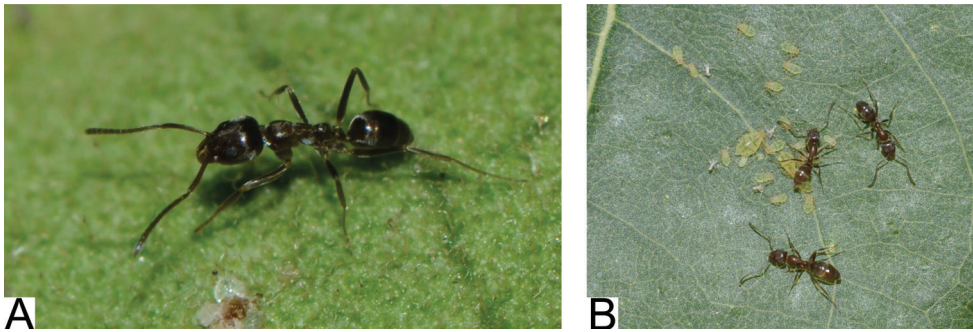


Figure 4. Argentine ant workers photographed in the city of Madrid. Both photographs belong to the citizen science platform ‘Biodiversidad Virtual’. **A** Real Jardín Botánico of Madrid, by José Fernández (Biodiversidad Virtual 2016). **B** Puerto Rico Street, Nueva España Neighbourhood, by Álvaro Izuzquiza (Biodiversidad Virtual 2011).

Nueva España Neighbourhood (Chamartín District)

A highly widespread Argentine ant population was found along the streets and gardens of Nueva España neighbourhood, in Chamartín District, with an approximate area of 9.3 hectares ($40^{\circ}27.560'N$, $3^{\circ}40.358'W$; Fig. 3F). The knowledge of this location was possible thanks to a previous record that located the sighting of *L. humile* on Puerto Rico Street (Biodiversidad Virtual 2011; Fig. 4B). Based on these data, it was possible to determine the expansion borders of this large colony, which occupies practically all the blocks in the area between Príncipe de Vergara Street, Alfonso XIII Avenue and Costa Rica Street. In addition, trails of workers were found at various points beyond these main roads. Again, private landscaped spaces, walls, urban gardens, tree pits, and ornamental shrub formations were found to be the preferred areas for the expansion and foraging habits of these ants.

Madrid Río Park

Another location where the Argentine ant is relatively abundant corresponds to a section of the Madrid Río Park, mainly between El Puente del Rey and El Puente de Segovia (two bridges over the Manzanares river), including the Virgen del Puerto Gardens, although the presence of the ant extends beyond these points ($40^{\circ}25.133'N$, $3^{\circ}43.340'W$). *Linepithema humile* presence was noticed by members of “Tecnormigas”, a group of ant fans from Madrid (M. Sierra *pers. comm.*) and verified on the ground, where numerous areas occupied by ants were detected along a wide extension on both sides of the Manzanares river (Fig. 3G).

Other records in the city of Madrid: Ciudad Universitaria, Casa de Campo Park and Aluche Neighbourhood

This ant species is cited in the bibliography on a residential area at the eastern end of Ciudad Universitaria, northwest of the city (Martínez et al. 1997; Fig. 2). According to the

authors, the colony occupied a private garden where ants could take advantage of artificial irrigation and had access to resources inside the houses. We were not able to confirm the presence today since entry was restricted. Likewise, the Argentine ant is cited in another bibliographic reference in the Casa de Campo Park (Ruiz-Heras et al. 2011; Fig. 2), although it has been found in a small portion of the park only on the east side (Fig. 3G), despite the exhaustive samplings carried out in the area in recent years. Southward, there is another *L. humile* record located on Valmojado Street (40°23.220'N, 3°45.540'W), in Aluche Neighbourhood, observed in 2004 (K. Gómez *pers. comm.*; Fig. 2).

Other records in the Community of Madrid: Villagolf-Villanueva de la Cañada residential area, Pozuelo de Alarcón, Rivas-Vaciamadrid and Aranjuez

Outside the urban district of Madrid, individuals of *L. humile* were found in private gardens in the residential area of Villagolf, 25 kilometres west of the capital (40°26.700'N, 3°59.880'W; Fig. 1), whose presence was reported to the authors by a pest control company in 2019 (N. Trotta *leg.*). In Rivas-Vaciamadrid (40°21.540'N, 3°32.820'W), in the southeast of the city, the species was observed in a landscaped street prior to 2011, according to J. Reyes (Ruiz-Heras et al. 2011 and recent *pers. comm.*; Fig. 2), but more recent surveys are needed to verify the expansion limits of this colony. Likewise, considered one of the oldest citations of this ant in the interior of the Iberian Peninsula (between 1952 and 1968), Collingwood and Yarrow (1969) had already sighted the presence of this species in the towns of Pozuelo de Alarcón and Aranjuez (Fig. 1). Its presence has recently been registered again in these two locations: in a private property in Pozuelo de Alarcón (near 40°27.500'N, 3°48.280'W; Vereda de las Columnas Street, El Paular Neighbourhood), where the owners had been noticing its presence since several years ago as the ants usually invade the garden and come indoors in winter, besides that they are spread around the neighbourhood, and in the urban environment of Aranjuez (40°2.220'N, 3°36.300'W). In this case, the ornamental trees and other typical urban elements serve as a source of resources for these ants (J. Arcos, *pers. comm.*).

Discussion

This article compiles for the first time new and previously known records of the Argentine ant in the city of Madrid and its surroundings. It shows a worrying situation that has not been previously considered and must be urgently addressed. The fact that *L. humile* has reached localities in the interior of the Iberian Peninsula, moving away from a coastal range, is unusual for a natural expansion (Espadaler and Gómez 2003). The silent expansion of *L. humile* through the different interior locations could be favoured by anthropogenic action through the movement of the species mediated by the transport of goods, gardening tools, ornamental plants, etc., as suggested by numerous authors (Suárez et al. 2001; Ward et al. 2005; Obregón and Reyes-López 2016). In general terms, the city of Madrid is undergoing a premature stage of colonisation by

the Argentine ant, although its presence has been recorded accidentally for a minimum of three decades (at least since 1991). Since observations in time and space are isolated and apparently unrelated to each other, entry and translocation of propagule-bearing elements are presented as the most probable hypothesis to explain ant dispersal, along with natural processes of spread of ants from other colonisation points.

Thus, we propose two ways in which the expansion can occur within the city itself: (i) directly, since reproduction takes place by budding (Hölldobler and Wilson 1990), so natural splits of a main colony that establishes new settlements increase the area of influence (e.g., what could be happening in a large area such as Nueva España Neighbourhood or Madrid Río Park); (ii) indirectly, due to the maintenance of green areas. Considering that many of the colonies are located in different points of the city separated in many cases by kilometres apart, a plausible explanation is the entry and translocation of garden elements, which act as vectors carrying potential colonising propagules from infested to non-infested areas. This situation enables a rapid colony expansion and facilitates the dispersal of these colonies, involving numerous zones and different sizes of green spaces (ranging from flower boxes, tree pits and patches of grass to large parks, wastelands and forest areas) as pointed out by Forte (1956) in the metropolitan areas of Western Australia. To date, the likelihood that the Argentine ant is using the sewage system to facilitate the passage from one street to another has been discarded, although it may be happening in the city of Barcelona (J. Arcos *pers. comm.*). Even so, it has been observed that in certain parks they use drains to connect foraging areas and thus avoid the paths used by vehicles and people.

The locations where the Argentine ant has been found in Madrid have a number of common characteristics that could allow it to survive and expand. Artificially irrigated areas offer an almost constant supply of moisture, which, combined with food resources that can be found in parks, gardens and even indoors, makes these areas highly valuable sites for nesting and foraging. Parks that are heavily disturbed (mowed and irrigated with sprinklers) are more likely to harbour exotic species like *L. humile* (Walters 2006) compared with more naturalized areas and urban forests (Clarke 2008). In addition, buildings and other urban elements could serve as a refuge in colder times of the year, when colonies spatially contract in winter (Heller and Gordon 2006; Abril et al. 2008). One of the possible causes of the Argentine ant persistence in cold cities of Minnesota and Illinois (United States), with a very similar latitude to Madrid, is that they overwinter in heated buildings (Gordon et al. 2001; Hartley and Lester 2003). In short, the micro-environments generated in cities, the lack of a natural vegetative structure or the Urban Heat Island effect, can lead generalist species, which often include invasive species, to colonise and better adapt to urban environments (Menke et al. 2011; Ducatez et al. 2018). In the medium to long term, cities could become 'reservoirs' from which an invasive species, such as the Argentine ant, could colonise adjacent anthropized spaces and even natural areas (Borden and Flory 2021).

The location of Nueva España Neighbourhood (Fig. 3D) can be highlighted due to the large area occupied by the Argentine ant, where an advanced level of settlement can be observed. This colony may have originated at the time of the first record (Bio-

diversidad Virtual 2011) and possibly earlier. It is in this location, as well as in Alfonso XII Street next to the Real Jardín Botánico de Madrid, Madrid Río Park and Sorolla Museum Gardens where a clear displacement of other species, relatively common in the rest of the urban environment of Madrid, can be noticed. In fact, typical urban species such as *Lasius grandis* Forel, 1909, *Messor* cf. *structor* (Latreille, 1798), *Pheidole pallidula* (Nylander, 1849), *Plagiolepis pygmaea* (Latreille, 1798), *Tapinoma* cf. *nigerrimum* (Nylander, 1856) or *Tetramorium* cf. *caespitum* (Linnaeus, 1758) are again present once the expansion limits of *L. humile* become blurred. In some of these borders, fights with *T. cf. nigerrimum* were observed. This dominant species has been shown to be a competitor that offers resistance to the Argentine ant by decreasing the probability of its rapid colonisation and survival (Blight et al. 2010).

In Enrique Tierno Galván Park, Del Norte Park and Real Jardín Botánico, the colonies are relatively small in extension, but their surroundings are potentially colonisable, given the structure and elements of these green areas. In addition, it should be considered that the city of Madrid has more than 200 green areas integrated into the urban matrix that may be considered attractive for this species, with a variety of suitable places for the Argentine ant to establish, depending on the park size, the level of irrigation, the refuges, etc. In these circumstances, the invasion of this species is taking place slowly but surely.

Therefore, given the strong likelihood that the Argentine ant will continue colonising the city of Madrid and the rest of the surrounding locations and given the negative effects that its presence may have on the diversity of other ant species (Touyama et al. 2003; Holway and Suarez 2006; Stringer 2009; Achury et al. 2020) and other arthropods (Walters 2006) in urban settings, this paper calls for a joint action by researchers, managers and competent authorities to propose studies and solutions that help stop the expansion of this invasive ant.

Various methods have been used to control the Argentine ant, generally in natural environments and agricultural systems, mainly based on insecticides and toxic baits (Forschler and Evans 1994; Klotz et al. 2003; Daane et al. 2006; Choe et al. 2014). In an urban context, the greatest challenge may be the difficulty in applying treatments in a heterogeneous environment that not only involves parks and other green areas, but also a diverse set of small and inaccessible enclaves, infrastructures, buildings, houses and other private properties. Despite this, a large number of successful eradication programmes for invasive ants have been carried out in urban or industrial locations (Hoffman et al. 2016), and it is also noteworthy the progress being made in terms of improving bait treatments that reduce non-target effects (Cabrera et al. 2021).

Certainly, the best strategy that can be carried out, as mentioned by several researchers (Carpintero et al. 2004; Ward et al. 2005; Angulo et al. 2007; Stanley et al. 2008), is prevention by detecting and eliminating the propagules transported by humans, apart from an active aggressive and eradication management strategy (Silverman and Brightwell 2008; Vanderwoude et al. 2021). In this sense, preventive measures may include routine checks of agricultural or gardening equipment, work tools and transport vehicles. An option that should be seriously considered is the implementation of monitoring programmes with citizen participation in order to detect new

outbreaks and areas susceptible to invasion, observe the expansion of colonies, and study the influence on the diversity of other ants and invertebrates and vice versa (e.g., analyse whether any natural agent can decrease the expansion of the Argentine ant). Several citizen science projects have shown to be effective in the search for invasive and native ants (Lucky et al. 2014; Castracani et al. 2020) and could be applied in the case of the Argentine ant since it is a ubiquitous and conspicuous species that can be easily identified in the field and by photography. Such measures should be taken before facing a more widespread invasion.

Conclusion

The presence of the Argentine ant in Madrid and its surroundings reveals a gradual entry and a silent expansion within the city in recent years. Since it is likely that there will be new entries or movements of this species in the form of nest relocations, applying a monitoring system that involves citizens, researchers and local authorities should be really advantageous. These actions would prevent the city from becoming a 'reservoir' for the species, reducing the long-term chances of new enclaves being colonized by the Argentine ant, such as naturalized environments near the city.

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