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Updating the distribution data of the Red squirrel (*Sciurus vulgaris* Linnaeus, 1758) in the province of Málaga (southern Spain)

Actualización de los datos de distribución de la ardilla roja (*Sciurus vulgaris* Linnaeus, 1758) en la provincia de Málaga (sur de España)

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Abstract

Between 2019 and 2022 we carried out a survey to update the distribution data of the red squirrel in the province of Málaga. Fifteen years after the last elaboration of the distribution atlas, it was likely that this forest species had expanded in step with the increase in forest mass in the province. The results show that the species has expanded in the province, increasing its distribution range between 24.8% and 27.7% and almost tripling the number of UTM grid squares. The species has colonised the region of Antequera, the mountains of the Arco Calizo Central and the banks of the Genil River in the north of the province. To the south it has expanded towards the urban environments of the city of Málaga and has begun its expansion towards the west. In the extreme northeast, the species has made less progress, colonising some new areas just beyond the limits of the Sierra Tejada, Almijara and Alhama Natural Park. Most of the new populations are geographically closer to the population at Montes de Málaga, which seems to have served as the main source population. In the eastern area, subtropical crops seem to function as a barrier limiting further expansion. We propose and discuss a series of hypotheses regarding the origin of the population and the need to undertake future studies of historical, genetic, and epidemiological distribution models.

Keywords: barrier, colonization, source populations, species expansion.

Resumen

Entre 2019 y 2022 se han realizado una serie de muestreos para actualizar la distribución de la ardilla roja en la provincia de Málaga. Quince años después de la elaboración de la última edición del atlas de distribución, era probable que esta especie forestal se hubiera expandido a la vez que ha ido aumentando la masa forestal en la provincia. Los resultados muestran que la especie se ha expandido en la provincia, aumentando su rango de distribución entre un 24,8% y 27,7% y casi triplicado el número de cuadrículas en las que está presente. La especie ha colonizado la comarca de Antequera, las montañas del Arco Calizo Central y las riberas del río Genil en el norte de la provincia. Hacia el sur se ha expandido hacia los entornos urbanos de la ciudad de Málaga y ha comenzado su expansión hacia el oeste. En el extremo nororiental, la especie ha progresado menos, colonizando algunas zonas nuevas poco más allá de los límites del Parque Natural de Sierra Tejada, Almijara y Alhama. La mayoría de las nuevas poblaciones están geográficamente más cerca de la población de los Montes de Málaga, que parece haber actuado como la principal población fuente. En el área oriental, los cultivos subtropicales parecen funcionar como una barrera que limita una mayor expansión. Se propone y discute una serie de hipótesis sobre el origen de las nuevas poblaciones y la necesidad de emprender futuros estudios con modelos de datos históricos, genéticos y epidemiológicos de distribución.

Palabras clave: barrera, colonización, expansión, población fuente.

Introduction

The red squirrel (*Sciurus vulgaris* Linnaeus, 1758) is a medium-sized rodent, with a conspicuous tail and ears, which is widely distributed throughout the Palearctic. It is a forest arboreal, herbivorous and granivorous species, habituated to deciduous and coniferous forest masses in the majority of its distribution area, and to mature pine forests in the Mediterranean region (Purroy 2017).

The species is common throughout Europe and Asia (Lurz *et al*. 2005), being also present in the Iberian Peninsula. In Portugal, the red squirrel historically occupied almost the entire country, but it disappeared in the 16th century (Ferreira *et al*. 2001). At the end of the 1980s (20th century) the squirrel began to recolonize the country (Petrucci-Fonseca & Mathias 1987), first in the northern third, between the Duero River and Galicia (Ferreira *et al*. 2001), then later expanding to the Tagus River, suggesting that this expansion occurred from the edges of the Spanish distribution area (Gomes *et al*. 2017). In addition, the species has been reintroduced in some urban parks in Lisbon, Porto and Coimbra (Vieira *et al*. 2015).

In Spain, the species occupies (almost continuously) the entire Euro-Siberian region and a large part of the Central System, being scarce on its eastern edge (García & Mateos 2008). It is present in the mountains of the northwest peninsular region (Talegón 2009), the Iberian System, as well as in some Mediterranean eastern areas (Purroy 2007). There are also populations in Murcia (Lucas *et al*. 2015) and in some urban parks in Madrid, where it was reintroduced in the 1980s and 1990s. A captive breeding program has existed since the 2000s, and currently a new reintroduction program is underway (Consejería de Medio Ambiente, Vivienda y Agricultura de la Comunidad de Madrid 2022). In Andalucía the species is present in the Betic System (Cazorla, Segura, Sierra Nevada, Tejeda, Almijara and Alhama, Filabres and Baza) and populations are also present in Montes de Málaga and Sierra Morena (Purroy 2007). It is currently a species that is not threatened and is listed as "Least Concern" (LC) by IUCN (Shar 2016).

Red squirrel populations in Málaga and Granada provinces arose from reintroductions carried out during the late 1970s and early 1980s. In 1977, the species was introduced in Sierra Nevada using specimens from Sierra María (Almería), which probably came from Cazorla populations (Palomares 1988). More squirrels were reintroduced during these years by ICONA in Sierra Almijara, Huetor and Filabres (Almería). The species expanded throughout Granada province and most of its littoral mountains (Moleón & Gil-Delgado 2003).

In Málaga the species was also introduced in El Boticario estate (Montes de Málaga) by ICONA staff. Ten individuals coming from Cazorla were acclimated at the end of 1975 and released in 1976 (Juan Naranjo, personal communication). These individuals seem to be the origin of the Montes de Málaga population. Squirrels of Sierra Tejeda, the Nerja Caves and Maro Cliffs (the western continuation of Sierra Almijara towards Málaga) may be the natural expansion of the individuals reintroduced in Sierra Almijara. Since 1989 the species has occupied the entire Sierra Tejeda, Almijara and the Alhama Natural Park, and has expanded to neighbouring almond crops in Axarquía (Manuel Gil, personal communication).

The red squirrel has been able to experience a significant expansion in Málaga in recent years. Like other forest species, their populations seem to expand alongside increases in forest mass (Acevedo *et al*. 2011). In Málaga province, the forested area doubled between 1995 and 2007 (MITECO 2008), increasing almost 67% more in 2020 (MAPA 2021). The dominant species, making up 60% of the wooded forest area, is the Aleppo pine (*Pinus halepensis*) (Junta de Andalucía 2021). This increase in forest area benefits a species such as the red squirrel, which shows a preference for Aleppo pine forests in the Mediterranean area (Piqué 1997, Moleón & Gil-Sánchez 2003) while continuing to use other available pine species (Arrizabalaga *et al.* 2007) and preferring pine trees with an adequate degree of maturity or larger canopy size (Andreu *et al.* 2000).

Recent sightings and roadkill reports suggest an expansion according to the aforementioned increase in forest mass and the presence of squirrels in new locations in Málaga province, outside of the historical species' distribution range. These new locations include urban habitats colonised in the city of Málaga where the species has not been actively reintroduced (Barroso *et al.* 2021). Therefore, we hypothesise that the species may be expanding its range at a larger scale too - i.e. on a provincial scale - and colonising other natural spaces outside of Montes de Málaga. Here, we present the results of a provincial survey aiming to test this hypothesis. We have sampled a large part

of the province in order to update the distribution data of the species. After that, we also propose some hypotheses about the potential origins of the new populations and analyze the speed of colonisation.

Material and Methods

The study area included the eastern part of the Málaga province (from the western limit of the Guadalhorce valley, eastwards; Fig. 1). The study period spanned three years, from February 2019 to October 2022. We focused mainly on sampling the edges of the known distribution range of the species and the areas where environmental agents or naturalists had reported new live sightings or road-killed squirrels. When the presence of the species in a new location was confirmed, we sampled the neighbouring grids to assess possible expansion of the squirrels.

We used the 10x10 km UTM grid as a sampling unit. In each 10x10 grid, favourable habitat areas or patches were chosen in which to sample, these were previous locations identified by means of satellite images and *in situ* driven transects. When a grid did not host enough favourable habitats (large extensions of unfavourable cereal crops, olive groves or subtropical habitats; mainly in the central north and southeast of the province) it was considered *a priori* that the species would be absent. Nevertheless, if in these regions of unsuitable habitat existed some isolated forests or local patches of pine forest they were sampled. Inside each 10x10 km grid containing favourable habitats, three different points were sampled within each favourable patch. Pine stands and mixed pine and deciduous stands in natural areas, as well as in urban and peri urban areas, were also considered. Small forest islands surrounded by crops were considered if they were near the area of influence (within 6.5 to 9 km; Moleón & Gil-Sánchez 2003) of a confirmed squirrel population.

At every sampling point, two observers each carried out a transect of maximum 1 km in length (approximately five times the size of a squirrel's territory; Piqué 1997) to detect signs of squirrels. If the signs were detected at a shorter distance, the sampling stopped (Moleón & Gil-Sánchez 2003). The methods of Arrizabalaga *et al.* (2007) were followed by identifying remains of pine kernels and pine cones predated on by squirrels. Evidence of

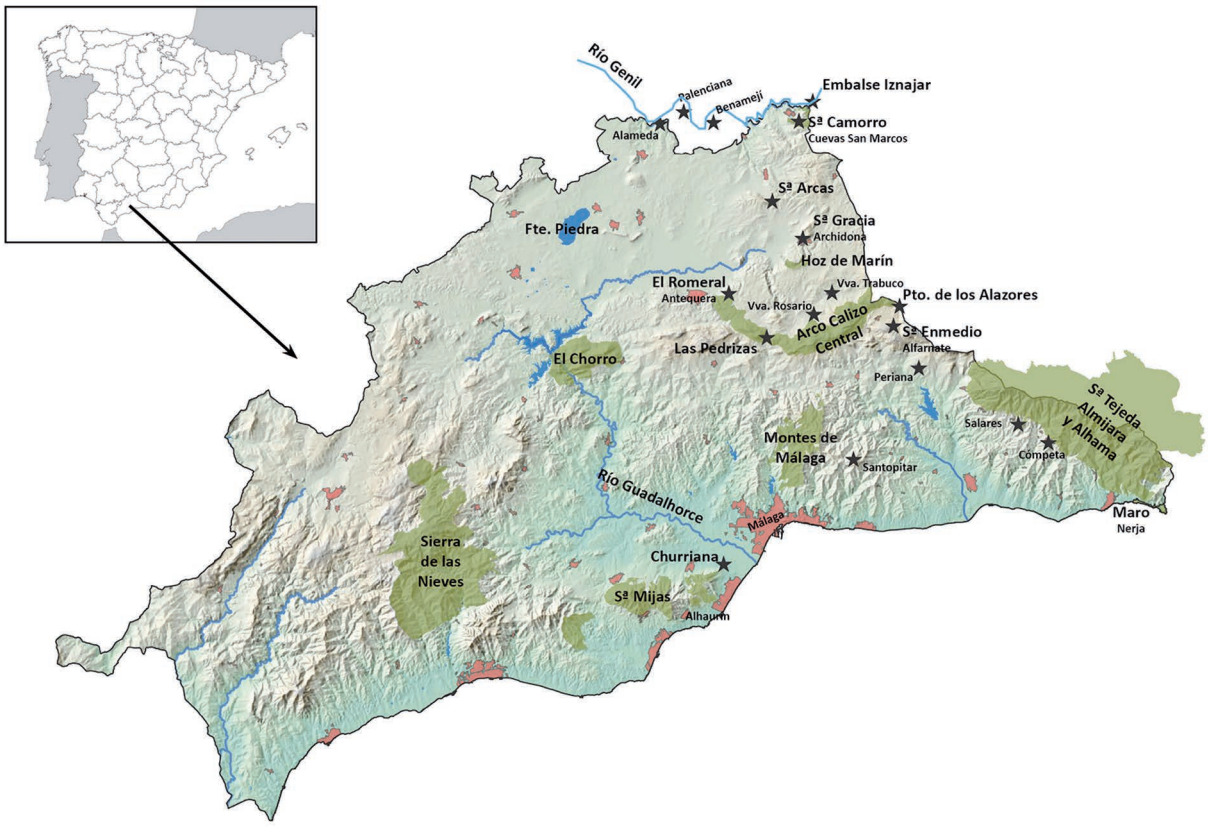

Figure 1. Location of the study area (Málaga province) in the south of the Iberian Peninsula and location of the main geographical locations and natural spaces named throughout the discussion.

possible nests was also considered as a positive sign of squirrel presence. To avoid possible confusion with rat nests, active squirrel nests were positively identified by confirming the remains of pine kernels or cones under the nests. Once a patch of pine forest with positive signs of squirrels was detected, we attempted to observe the animals directly as confirmation of their presence. This was achieved by waiting for a maximum of fifteen minutes, in silence, at different points near the detected signs. If the wait period proved negative for sightings, we returned on successive days until the squirrels were observed, for a maximum of three days. A new location was considered occupied only when signs were confirmed by the observation of squirrels. If no squirrels were directly observed, the location was considered only as a possible newly occupied habitat. The same criteria were considered (possible presence and location not secure occupied) if squirrels were observed but signs were nor detected. All sampling was carried out three hours after dawn or before dusk in accordance to the squirrel diurnal unimodal activity patterns (Piqué 1997).

At the new squirrel locations, dispersion distance and expansion speed were investigated. When a new population of squirrels (i.e., a new location with squirrels and isolated from neighbouring or previously known locations) was found, the distance to the nearest source population was measured, considering two criteria: 1) The three likely source populations known to exist in 2007: one at Montes de Málaga (UF25; 92,6 km to Sierra Tejeda and 94,7 km to Granada), another at Sierra Tejeda (VF17; 32,8 km to Granada) and the last at the northeast edge of Granada province (VG00). Distances between populations are calculated between centroids of the 10x10 km UTM grid referenced for each population. 2) The closest distance (in a straight line) to the outer limit of the known distribution range of those source populations. The distances from each sampling point (with a determined, secure population) to the three possible source populations were measured. Distance measurements were recorded from smallest to largest and shortest distance, corresponding to the closest source population, were chosen in each case. The distance was estimated as the modulus of the vector formed from the UTM coordinates of the source population and the new population. The expansion speed (kilometres per year) was estimated as the distance covered in the 15 years between 2007 and the end of this study in 2022.

We tested for differences in expansion speed between source populations. Due to small sample size, we used a Kruskal-Wallis, non-parametric test to look for differences (Fowler & Cohen 1992). We also used a Kruskal-Wallis post-hoc test for further comparisons between pairs of samples. All the means are given with their standard errors. All analyses were carried out using SPSS 24.0 (IBM 2016) statistical software.

Results

This survey examined 170 sampling points for the presence of red squirrels, of which 37.7% were positive (observed presence of red squirrels and signs of their presence), 3.5% possible presences (observed only signs of presence or squirrels without confirming signs) and the rest negative (Fig. 2). Of the positive sampling points, 91.4% were verified through direct observation of the species (secure presence detected). The remaining positives (8.6%) were considered as possible new sites, with signs or traces of the species, but without direct observation of red squirrels.

At a 10x10 km UTM scale we sampled 64 grids (63.4% of the 10x10 km UTM grids existing at Málaga province, n= 101). Seven grids (UG30, UG42, UG41, UF44, UF96, VF06 and VF16) were ruled out as unfavourable habitats and no sampling points were chosen within them. In addition, the VF09 grid was not sampled either, as its territorial coverage (0.4 km^2) in the province of Málaga is minimal. The species was present and confirmed in 16 new grids and maintains its historical distribution. In three additional grids there were signs that could not be confirmed with direct observation of the species. In the rest of the sampled grids the red squirrel and any signs of it were absent (Fig. 3).

With respect to the known distribution of 9 grids in 2007 (regarding the surface of the whole Málaga province) the species has increased its distribution range between 24.8% and 27.7%. Therefore, it currently occupies almost a quarter of the province, compared to a little less than a tenth that it occupied fifteen years ago. However, considering just the number of grids with secure presence of squirrels between 2007 and the present survey, the increase is about 178%. That is, the number of grids with squirrels has almost triplied.

The dispersion analysis shows that 66.6% of the new red squirrel populations (Antequera,

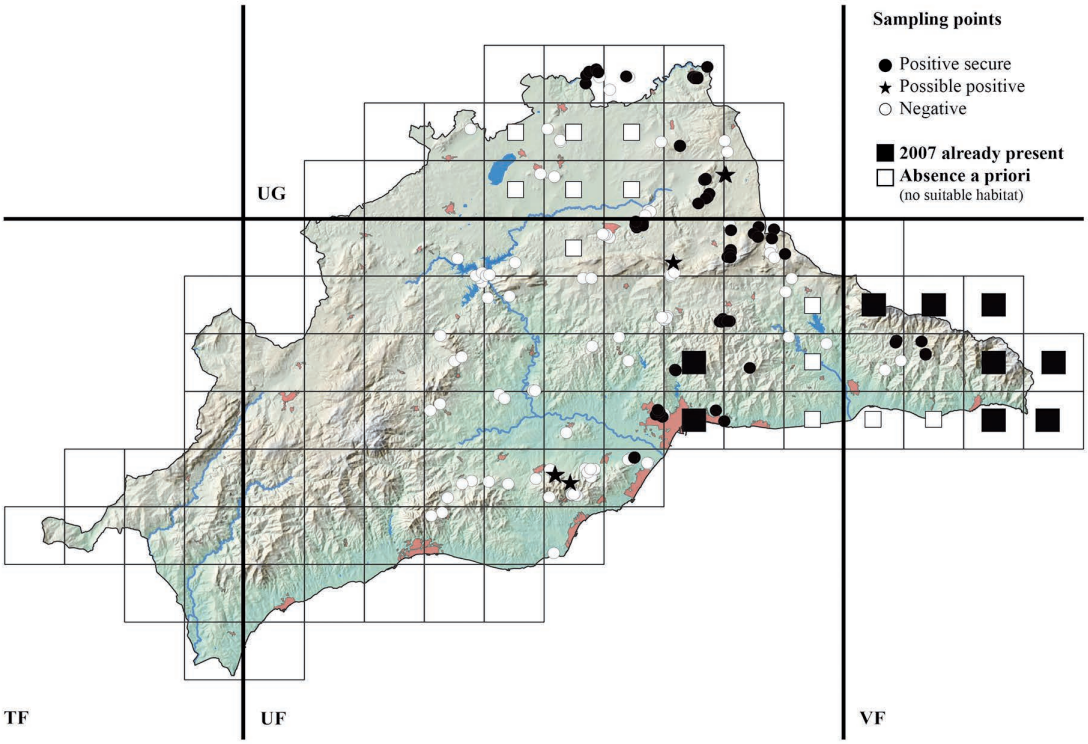

Figure 2. Sampling points used during the 2019-2022 red squirrel survey in Málaga province. Two kinds of absences were considered: a) *a priori*, when the 10x10 km square does not host suitable habitat; and b) when after sampling a favorable region or local habitat patch no squirrel signs were found.

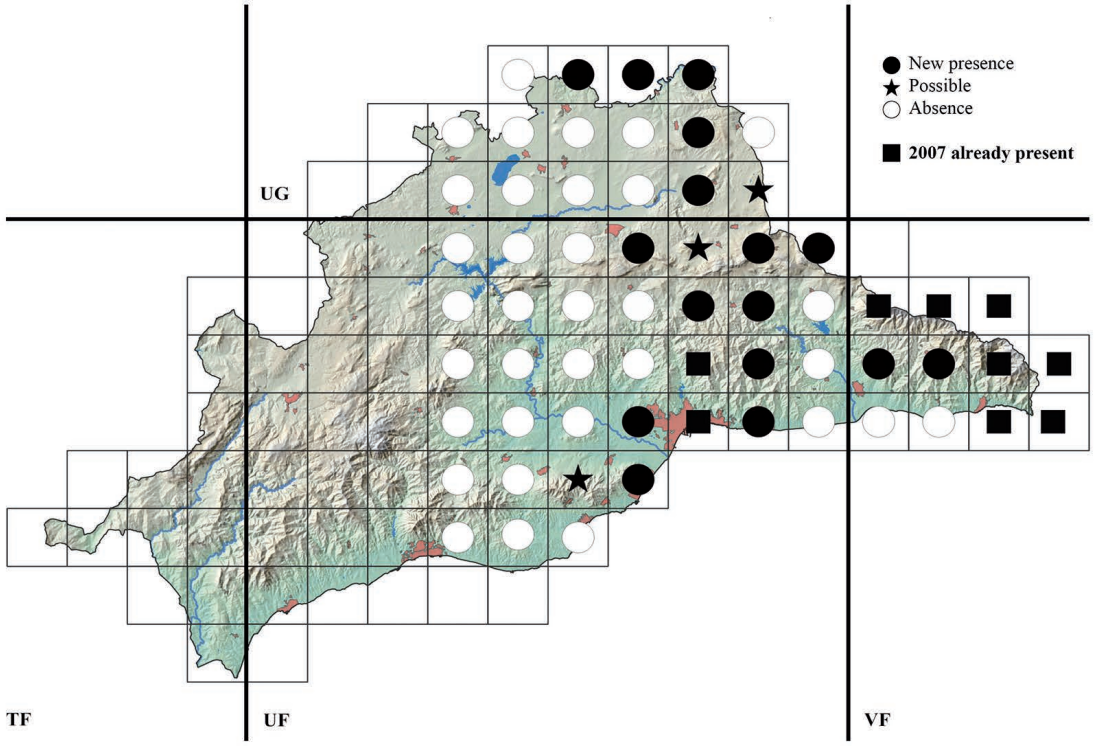

Figure 3. Presence of the red squirrel in Málaga province at 10x10 km UTM grid scale, updated in 2022.

Archidona, Arco Calizo Central and urban squirrels at Málaga city) were closest in distance to the Montes de Málaga (10.7 ± 1.6 km) population; 18.5% to the population at Granada (those located in the north of the province, near the Genil River and the Sierra del Camorro at Cuevas de San Marcos; 43.5 ± 3.5 km); and the rest (14.8%) to the population at the western edge of Sierra Tejeda (6.7 ± 3.3 km).

Expansion speed was significantly different between populations with different sources (H= 13.027; g.l.= 2; p= 0.001). Squirrels coming from Montes de Málaga advanced at 0.7 ± 0.1 km/year; those from Granada at 2.9 ± 0.2 km/year and those from Sierra Tejeda at 0.5 ± 0.2 km/year. Testing for differences in expansion speed from squirrels only coming from Montes de Málaga or Sierra Tejeda (excluding the northern part of the province) revealed no significant difference in the expansion speed (Kruskal-Wallis post-hoc test; H= 4.889; g.l.= 1; p= 0.795). In these cases, the average distance colonised was 9.1 ± 1.2 km and the average speed 0.7 ± 0.1 km/year.

Discussion

From Montes de Málaga, the squirrel has colonised areas to the south, north, and east. To the north there are populations in Los Frailes (Colmenar) and the Antequera region. Los Frailes is part of the natural park (the north border), and it is likely that this population already existed and had previously gone unnoticed, since the site has continuity with the pine forests present in the grids which were already known in 2007. Towards the east, the squirrel occupies more localised patches of pine forest near the natural park; or the more isolated pine forest patch of Santo Pitar, near El Borge; and the pine forests on the banks of the headwaters of the Olías stream.

In the Antequera region the squirrel is occupying the existing pine forests from Archidona to Antequera, between Hoz de Marín and Romeral natural spaces, but not from the Guerrero stream and the existing pine forests near the Peña de los Enamorados, as well as from the forest viewpoint of Antequera, where pine forests are younger than in the other locations. In Archidona the species also occupies the Sierra de Gracia pine forest, at the foot of the town's castle. Notably, there is a population of red squirrels north of Archidona, in the nearby Sierra de Arcas, occupying a small and isolated pine forest among olive trees, at the foot of a wind farm.

Expansion westwards from Antequera seems not to have taken place. Although there are recorded sightings of the species in the Pinar del Hacho, the peri-urban park of the city, close to the Sierra de Chimeneas, we have not been able to verify its presence or find signs or traces that confirm it. The species neither seems to have colonised the pine forests of the Sierrecilla de Humilladero and the southern Sierra de Mollina, both to the north of Antequera. In these cases, large expanses of olive groves and no available corridors could explain the absence of the species in habitats which are, *a priori,* also favourable.

As a result of the present survey, we have also been able to verify a significant squirrel expansion in the urban centre of Málaga and its surroundings which is logical because many green areas in the city are located to the south of the Montes de Málaga natural park. It should be noted that Vargas *et al.* (1978) did not find red squirrels on Monte Victoria, and they are currently in that area as well as in Gibralfaro. To the east, squirrels are present on Monte San Antón and in the pine forests of El Candado golf course, where they are frequently seen at the clubhouse. To the west, the squirrels have reached the pine forests of the Teatinos stream, close to the gardens of the Castañón de Mena military residence and the Laguna de la Barrera. A little further south, there is another isolated population in the gardens of La Cónsula (Churriana), almost at the foot of the mountains that start in Torremolinos and continue to Mijas.

Finally, it should be noted that the squirrel has been sighted to the southwest of Montes de Málaga, in the mountains of Alhaurín el Grande and Mijas (José A. Díaz and José C. Atienza, personal communications). A squirrel skull also appeared in a tawny owl (*Strix aluco* Linnaeus, 1758) pellet in Alhaurín de la Torre (Antonio J. Plaza, personal communication). However, samplings carried out on both the northern and southern faces of these mountains (from Jabalcuza to Jarapalos and Alhaurín golf, including urban zones like Pinos de Alhaurín) did not return positive results, as we were unable to detect even signs of a squirrel population here. Considering that the sightings are reliable, because they come from environmental agents and recognised naturalists, it is likely that the individuals sighted were pioneer specimens that did not manage to settle. In addition, recent fires (July 2022) in that region may also have hampered the

expansion of the red squirrel in those mountains. Nevertheless, we have considered the UF55 grid as probable partly because of these sightings and because it is the natural expansion route for the existing population at Churriana.

The expansion has also reached the northern regions of the province and the municipalities bordering the province of Córdoba. There are squirrels in the pine forests on the banks of the Genil River, between Alameda, Palenciana, Benamejí and Iznájar. The Genil river may serve as a dispersal corridor from the eastern limit of the province, or as a connection to the Granada province populations. There is other population of squirrels in Cuevas de San Marcos, both in the Sierra del Camorro and in the pine forests bordering the Iznajar reservoir. It's possible that, from there, they use the river to colonise the western zone, provided the banks have suitable pine forests. The westernmost, northern population is located on the border between Alameda and Palenciana, before the Genil River enters the province of Sevilla towards the Malpasillo reservoir.

Two grids with possible presence deserve mention. One location is Puerto de las Pedrizas (UF79), where two squirrels have been found as roadkill. However, we were not able to detect even signs of red squirrels in the pine forests that surround this road junction, nor in the small patches of pine forest that surround Villanueva de Cauche and Fuente de la Hiedra. Possibly they were just animals in the process of dispersal. The other grid with possible presence (UG80) is in the existing holm oak (*Quercus rotundifolia*) forests to the west of Archidona, which reach the A-92M towards the area of the Archidona lagoons. In that area, there is a riparian forest within the holm oak forest, containing isolated pine patches in which we have detected signs of, but not observed these animals.

The two aforementioned areas seem to be the logical continuation to the west of the red squirrel settlements that we have been able to confirm in the Sierras del Arco Calizo Malagueño, close to Granada. Yus *et al.* (2007) do not mention this species in these mountains. However, between Sierra de Camarolos and Sierra de San Jorge we have found well-established populations on the north face (Villanueva del Rosario and Villanueva del Trabuco). These populations reach the Puerto de los Alazores, already on the border with Granada. From the Cerezo stream to the source of the Guadalhorce river, in the Los Cien Caños, there are squirrels in pine forests with appropriate maturity. The squirrels go up to the Hondonero and Pindongos areas and down the opposite side to the Alfarnate valley, where they reach the Sierra de Enmedio and the pine forests that surround the Vilo peak (just to the west, near Puerto del Sol), although this seems to be the limit of their distribution in that area, with few signs found.

The already known squirrel population located on the Málaga part of the Sierra Tejeda, Almijara and Alhama Natural Park, has colonised two new grids on the outer edge of the protected area. There are squirrels in the expansions surrounding the urban area of Cómpeta as well as in and around the village of Canillas de Albaida (VF17); and in the walnut trees and isolated pine patches that border the Salares stream, close to the village (VF07). In these locations, the squirrels clearly come from populations already established in the natural park and do not seem to have spread further south or west (to Periana, Viñuela and the Guaro valley), probably due to large expanses of subtropical crops and the lack of a suitable habitat.

The results of the dispersion analysis are approximations only, as the analysis inherently presents a series of limitations. Firstly, it is an oversimplification to assume that the squirrels advanced in a straight line. It is much more likely that they used natural corridors that do not necessarily follow linear paths. Secondly, we don't know for certain what the source populations are in each case. The shortest distance criterion provides an assumption of the source that is not necessarily accurate or true. Finally, it is likely that the process has been progressive, that new pioneer populations have been the sources of successive colonisations, and not that colonisation occurred all at once between origin and destination as supposed here. If the process has been progressive, the speed of expansion may not have been the same in each stage, there may have been differences between years.

In all cases, it is likely that the distance, and therefore also the expansion speed, is underestimated in this study. Palomares (1998) estimated an expansion speed of between 1.3 to 3.3 km/year and Moleón & Gil-Sánchez (2003) of 1.5 km/year, both of which are higher than those reported in this study (except in the case of the population in the north of the province). Nevertheless, our approximation suggests that the source population

of Montes de Málaga is the one that most likely generated the majority of the new populations, as it is more connected through natural habitats with its surroundings than the source population at Sierra Tejeda, which is much more isolated by subtropical crops to the south and to the west. Estimated dispersion ranges from these two source populations fall within a maximum of 9 km, estimated by Moleón & Gil-Sánchez (2003). The origin of the populations in the north of the province remains much more doubtful. All this emphasises the need to develop predictive models of connectivity that allow more realistic approximations.

The new populations of red squirrels detected in this study seem to be the result of expansion of those already existing in 2007. This raises several questions. Firstly, which new populations came from Montes de Málaga and which came from Sierra Tejeda? It appears that those peripheral to Montes de Málaga came from there, and that those in the surroundings of the Sierra Tejeda, Almijara and Alhama Natural Park (and probably those of the Arco Calizo Central) came from the old eastern population. However, from the Puerto de la Pedrizas northwards, towards the settlements of Archidona, Antequera and those in the north of the province, new populations may be representative of expanded populations from both Montes de Málaga and Sierra Tejeda, since Puerto de las Pedrizas may have been the convergence point of these two population expansions. Only a genetic analysis could clearly determine the origin of these new populations.

This question leads us to a second hypothesis. If historical releases in Almijara and El Boticario were small, there should be a high degree of consanguinity in both original populations (at Montes de Málaga and Sierra Tejada) which would also occur in other populations (Lucas *et al.* 2015). Derived from this assumption, a third hypothesis can be proposed: if these populations have been connected, the mixed generations existing in the north of the province should have greater genetic variability. Nevertheless, the original data on the sizes of the original populations and the levels of consanguinity are weak and based only in interviews with rangers who participated in those releases, so these are only assumptions that, in any case, raise hypotheses that could be tested in the future and clarify the origins of Málaga squirrels.

Finally, the question arises as to why or if there were really no squirrels in the province prior to these releases. Interviews with inhabitants of rural areas carried out during sampling in the Antequera area suggest that squirrels have always been present there. It is a logical assumption that historically there must have been populations in this region, and it's possible that these squirrels went unnoticed in 2007. Furthermore, if there were indeed no squirrels in the province of Málaga in 2007, when and why did they disappear? Distribution studies based on historical data (Clavero *et al.* 2022) are necessary for this species, and the geographic dictionary of Madoz (1846-1850) may be a good starting point.

A clue could come from the work carried out in Portugal, which investigated when the species disappeared from the country and the possible reasons for its disappearance, between which are hunting and the lack of adequate habitat (Mathias & Gurnell 1998). Furthermore, red squirrels can suffer viral diseases (Meredith & Romeo 2015) and their populations can be controlled by viral episodes (Everest *et al.* 2014), providing another hypothesis to explain how a population could disappear from large areas while maintaining small and isolated populations in refuge areas (Finglan *et al.* 2022). It's possible that this has happened in this region in the past. Unfortunately, there is a lack of epidemiological data on red squirrels in Málaga and probably in much of Andalucía. However, the risk of possible emergence of red squirrel adenoviruses in the Iberian Peninsula exists (Côrte-Real *et al.* 2020) and is a matter of concern for future conservation of the species. All these reflections lead us to emphasise the importance and need for future genetic and epidemiological studies of red squirrels in Andalusía.

The red squirrel may play an important role in forest environments, both as an ecosystem engineer (Kimberley & Leaver 2015) and as prey for endangered species (Purroy 2017). For these reasons, it is important to consider developing predictive models of possible dispersal routes; the role played by highways and large extensions of crops as expansion barriers; and the use of river courses as dispersion corridors. These models could aid in the management of habitats and facilitate the species expansion into areas of interest. In this study we have verified that the species has not yet crossed the barrier of the Guadalhorce valley to the west, being not yet present in natural spaces such as El Chorro. However, if it were to colonise this region, the red squirrel could easily reach the forested areas in the west of the province, including large areas

of suitable habitat in Sierra de las Nieves and its surroundings, where the species could contribute valuably to the conservation of this forested park and the communities of endangered predators that populate it.

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References

Acevedo P., Farfán M.A., Márquez A.L., Delibes-Mateos M., Real R. & Vargas J.M. 2011. Past, present and future of wild ungulates in relation to changes in land use. *Landscape Ecology*, 26: 19-31. DOI: 10.1007/s10980-010-9538-2.

Andreu J., Llimona F. & Espelta J.M. 2000. Predació de l'esquirol (*Sciurus vulgaris*) sobre el pi blanc (*Pinus halepensis*) a la Serra de Collserola. Pp. 219-223. In: F. Llimona, J.M. Espelta, J.C. Guix, E. Mateos & J.D. Rodríguez-Teijeiro (eds.). *I Jornades sobre la Recerca en els sistemes naturals de Collserola: aplicacions a la gestió del Parc*. Consorci del Parc de Collserola, Barcelona.

Arrizabalaga A., Montagud E. & Torre I. 2007. Identificación de las piñas y piñones de pino piñonero (*Pinus pinea* Linnaeus, 1753) abiertos por la ardilla roja (*Sciurus vulgaris* Linnaeus, 1758). *Galemys* 19 (NE): 189-201.

Barroso L., Sendra E., Duarte J., Díaz-Ruiz F. & Farfán M.A. 2021. La ardilla roja (*Sciurus vulgaris*) en la ciudad de Málaga. *Resúmenes XV Congreso SECEM*, Córdoba, pp. 12.

Clavero M., García-Reyes A., Fernández-Gil A., Revilla E. & Fernández N. 2022. Where wolves were: setting historical baselines for wolf recovery in Spain. *Animal Conservation* DOI: 10.1111/acv.12814.

Consejería de Medio Ambiente, Vivienda y Agricultura de la Comunidad de Madrid. 2022. *La Comunidad de Madrid libera, en colaboración con el Zoo de Madrid, seis ardillas rojas tras su recuperación en el Centro de Recuperación de Animales Silvestres.* <https://www.zoomadrid.com/content/dam/zoo/files/press-room/np-hacking-ardilla-roja-2022.pdf>. Downloaded on 20 October 2022.

Côrte-Real J.V., Lopes A.M., Rebelo H., Lopes J.P., Amorim F., Pita R., … & Abrantes J. 2020. Adenovirus emergence in a red squirrel (*Sciurus vulgaris*) in Iberian Peninsula. *Transboundary and Emerging Diseases* 67: 2300-2306. DOI: 10.1111/tbed.13627.

Everest D.J., Shuttleworth C.M., Stidworthy M.F., Grierson S.S., Duff J.P. & Kenward R.E. 2014. Adenovirus: an emerging factor in red squirrel *Sciurus vulgaris* conservation. *Mammal Review* 44: 225-233. DOI: 10.1111/mam.12025.

Ferreira A.F., Guerrero M., Álvares F. & Petrucci-Fonseca F. 2001. Distribución y aspectos ecológicos de *Sciurus vulgaris* en Portugal. *Galemys* 13 (NE): 155-170.

Finglan K., Ward S.J., Bates A.J. & Bremner-Harrison S. 2022. A systematic review into the suitability of urban refugia for the Eurasian red squirrel *Sciurus vulgaris*. *Mammal Review*, 52: 26-38. DOI: 10.1111/mam.12264.

Fowler J. & Cohen L. 1992. *Practical statistic for field biology*. Wiley and Son, Chichester, 227 pp.

García P. & Mateos I. 2008. Datos sobre el estatus de la ardilla roja *Sciurus vulgaris* Linnaeus, 1758 en la Sierra de Gata (Salamanca). *Galemys* 20: 35-44.

IBM. 2016. *IBM SPSS Statistics for Windows, Version 24.0*. Armonk, New York.

Rocha R.G., Vieira B.P., Rodrigues V. & Fonseca C. 2017. Public engagement offers insights on the Eurasian red squirrel distribution. *European Journal of Wildlife Research*, 63: 87. DOI: 10.1007/s10344-017-1145-y.

Junta de Andalucía. 2021. *Sistema de Información sobre el Patrimonio Natural de Andalucía, SIPNA.* Publicación 2020. <https://portalrediam.cica.es/descargas?path=%2F01_CARACTERIZACION_TERRITORIO%2F08_SIPNA%2FSIPNA_Pub2020>. Downloaded on 20 October 2022.

Kimberley J. & Leaver L.A. 2015. Strategic decisions made by small mammals during scatter hoarding, cache recovery and cache pilferage. Pp. 51-66. In: C.M. Shuttleworth, P.W.W. Lurs & M.W. Hayward (eds.). *Red squirrels: Ecology, Conservation & Management in Europe*. European Squirrel Initiative.

Lucas J.M., Prieto P.< & Galián J. 2015. Red squirrels from south-east Iberia: low genetic diversity at the southernmost species distribution limit. *Animal Biodiversity and Conservation* 38.1: 129-138. DOI: 10.32800/abc.2015.38.0129.

Lurz P.W.W., Gurnell J. & Magris L. 2005. *Sciurus vulgaris*. *Mammalian Species* 769: 1-10. DOI: 10.1644/1545-1410(2005)769[0001:SV]2.0.CO;2.

Madoz P. (1846-1850). *Diccionario geográfico-histórico-estadístico de España y sus posesiones de Ultramar*. Madrid, 16 volúmenes.

Mathias M.L. & Gurnell J. 1998. Status and conservation of the red squirrel (*Sciurus vulgaris*) in Portugal. *Hystrix* 10: 13.19. DOI: 10.4404/hystrix-10.2-4126.

Meredith A.L. & Romeo C. 2015. Disease and causes of mortality in red squirrel population. Pp. 115-128. In: C.M. Shuttleworth, P.W.W. Lurs & M.W. Hayward (eds.). *Red squirrels: Ecology, Conservation & Management in Europe*. European Squirrel Initiative.

Ministerio de Agricultura, Pesca y Alimentación (MAPA). 2021. *Distribución general del suelo según usos y aprovechamientos.* <https://www.mapa.gob.es/estadistica/pags/anuario/2020/CAPITULOS%20PDF/AE20-C03.pdf>. Downloaded on 20 October 2022.

Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). 2008. *Tercer Inventario Forestal Nacional (IFN3).* <https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ifn3.aspx>. Downloaded on 20 October 2022.

Moleón M. & Gil-Sánchez J.M. 2003. Distribución, vías de introducción, expansión y apuntes sobre la taxonomía de las poblaciones de ardilla roja (*Sciurus vulgaris*) en la provincia de Granada (SE de España). *Acta Granatensis* 2: 45-54.

Palomares F. 1988. Notas sobre la distribución y expansión de la ardilla común en Sierra Nevada, sureste de España. *Doñana, Acta Vertebrata* 15: 254-259.

Petrucci-Fonseca F. & Mathias M.L. 1987. On the occurrence of the red squirrel *Sciurus vulgaris*, Linnaeus, 1758 in Portugal (Rodentia, Sciuridae). *Mammalia*, 51: 613-615.

Piqué J. 1997. *Ecoetologia i biologia de l'esquirol (Sciurus vulgaris, Linnaeus, 1758) en dos hàbitats de predictibilitat alimentària contínua que difereixen en l'abundància d'aliment*. Tesis Doctoral. Universitat de Barcelona, Barcelona. 341 pp.

Purroy F.J. 2007. *Sciurus vulgaris* Linnaeus, 1758. Pp: 378-380. En: L.J. Palomo, J. Gisbert & J.C. Blanco (eds). *Atlas y Libro Rojo de los Mamíferos Terrestres de España. Dirección General para la Biodiversidad,* SECEM-SECEMU, Madrid.

Purroy F.J. 2017. Ardilla roja - *Sciurus vulgaris*. En: Enciclopedia Virtual de los Vertebrados Españoles. A. Salvador & I. Barja (eds.). Museo Nacional de Ciencias Naturales, Madrid. http://www.vertebradosibericos.org/.

Shar S., Lkhagvasure D., Bertolino S., Henttonen H., Kryštufek B. & Meinig H. 2016. *Sciurus vulgaris*. The IUCN Red List of Threatened Species 2016: e.T20025A115155900. DOI: 10.2305/IUCN.UK.2016-3.RLTS.T20025A22245887.en. Accessed on 09 February 2023.

Talegón J. 2009. Aproximación a la distribución de la ardilla roja (*Sciurus vulgaris* Linnaeus, 1758) en la provincia de Zamora (noroeste de España). *Galemys* 21: 51-64.

Yus R., Torres M.A. & Botella F. 2007. *Por la dorsal Bética*. Ceder Axarquía, Vélez Málaga, 301 pp.

Vargas J.M., Blasco M. & Antúnez A. 1978. Los vertebrados del monte Victoria. *Jábega* 21: 73-79.

Vieira B.P., Fonseca C. & Rocha R.G. 2015. Critical steps to ensure the successful reintroduction of the Eurasian red squirrel. *Animal Biodiversity and Conservation* 1: 49-58.

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