**Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology**

**Official Journal of the Societa Botanica Italiana**

**ISSN: 1126-3504 (Print) 1724-5575 (Online) Journal homepage:** [**https://www.tandfonline.com/loi/tplb20**](https://www.tandfonline.com/loi/tplb20)



**Human influence on the flora of the Spanish Central Range**

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**To cite this article:** Álvaro Enríquez-de-Salamanca (2020) Human influence on the flora of theSpanish Central Range, Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 154:4, 474-480, DOI: [10.1080/11263504.2019.1635224](https://www.tandfonline.com/action/showCitFormats?doi=10.1080/11263504.2019.1635224)

**To link to this article:** <https://doi.org/10.1080/11263504.2019.1635224>



Published online: 04 Jul 2019.



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PLANT BIOSYSTEMS - AN INTERNATIONAL JOURNAL DEALING WITH ALL ASPECTS OF PLANT BIOLOGY 2020, VOL. 154, NO. 4, 474–480



<https://doi.org/10.1080/11263504.2019.1635224>



Human influence on the flora of the Spanish Central Range

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ABSTRACT

Mediterranean ecosystems have a high diversity of plants, especially in mountain areas; this diversity is especially high in the eastern sector of the Spanish Central Range, where Mediterranean and Eurosiberian species contact. Parts of these plants have been favoured by human activities throughout the last millennia, in an intentional or unintentional way. We have studied the composition of the flora of a valley in the Spanish Central Range to determine the human influence. Although it is a mountain-ous area, where the presence of synanthropic species should be lower than in territories with a strong human impact, we have identified a minimum of 20.7% of the plants favoured by human action, including alien (6.2%) and strict ruderals (14.5%), which may increase to 39.2% including plants grow-ing both in ruderal and non-ruderal habitats. The entrance of ruderal and alien plants continues cur-rently, especially through roadsides, and probably increases in the future, due to growing tourism and to climate change, which may influence the patterns of colonization and invasion of ruderal and alien plants, and the response of the native flora.

ARTICLE HISTORY

Received 22 October 2018 Accepted 17 June 2019

KEYWORDS

Alien plants; ruderal plants; anthropic colonisers; synanthropic plants; Spain

Introduction

The eastern sector of the Spanish Central Range has great geobotanical interest because it is the southern limit of the Iberian distribution of many Eurosiberian plants, while it houses a genuine Mediterranean flora (Hernandez and Sainz 1978). It is a late-glacial refuge, with the presence of relict species such as Fagus sylvatica L. (Lopez-Merino et al. 2008), while others already disappeared, such as Carpinus or Tilia (Schaad et al. 2014), due to the aridification of the climate in the Late Holocene (Jalut et al. 2009; Schaad et al. 2014) and the competition of Quercus pyrenaica Willd. (Franco et al. 1998). Mediterranean ecosystems, and especially mountain areas, have great diversity of plants as a result of successive processes of colonization and disappearance, which have been determined mainly by oscillations in the climate and human action (Allen 2003; Jalut et al. 2009).

The climate has fluctuated greatly throughout the Quaternary, leading to changes in the distribution of organ-isms and even genetic differentiation of populations (Hewitt 2000); even the Holocene has climate variability: humid, temperate and seasonal in the Early; wetter, colder and less seasonal in the Middle; and with increased aridification and seasonality in the Later (Jalut et al. 2009; Schaad et al. 2014). A new epoch, Anthropocene (Crutzen and Stoermer 2000; Waters et al. 2016), was defined in mid-20th century, characterized in the Mediterranean by increasing tempera-tures and droughts, and decreasing rainfall and runoff (Kovats et al. 2014). The current climatic changes result in the reduction of habitats and loss of summit species in the

mountains of the Mediterranean area (Gottfried et al. 2012; Pauli et al. 2012).

Until the Middle Ages, the composition of the flora of this area was exposed to a negligible human impact, but over the last ten centuries human activities, especially livestock, agriculture, transport and tourism, have modified it, incorpo-rating new species, introduced or synanthropic colonizers.

The aim of this article is to analyse the presence of synan-thropic species, both alien and native, in the Upper Jarama Valley, the area of greater botanical diversity of the eastern Spanish Central Range. We intend with that to quantify the human influence on the flora of this area, relating it to the history of its humanization.

Methods

Study area

The study area (Figure 1) is the Upper Jarama Valley in Madrid (Central Spain), a 25 km2 hillside between 1130 and 2045 m altitude, on metamorphic terrains. The lower parts are mainly covered with Quercus pyrenaica Willd. forests, with scattered Q. petraea (Matt.) Liebl. and a small Fagus syl-vatica L. forest, and the upper parts with Pinus sylvestris L. reforestations. There is only one village in the area, La Hiruela, and two more nearby.

The first signs of anthropic impacts in the area go back to 3740 BP (Franco et al. 1998; Lopez-Saez et al. 2014). There is evidence of the eventual presence of the Celtiberians, but the area was very little populated until the 11th century,

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| 2019 Societa Botanica Italiana |  |  |  |  |



Published online 04 Jul 2019

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Figure 1. Study area.

when the border of the Christian and Muslim kingdoms was displaced to the South, the area was repopulated, and live-stock settlements became small villages.

Palynological studies detect pinewoods between 4000 and 2000 years BP, but signs of deforestation have been apparent since the 11th century (charcoal debris and ruderal plants), with a sharp drop in the 14th century until disappearance (Franco 1995; Pardo and Gil 1997; Franco et al 1998; Franco et al. 2001; Lopez-Saez et al. 2014; Postigo-Mijarra et al. 2017). This disappearance is attributed to the burning of the pine-woods followed by grazing, a common practice at that time in Castile (Klein 1920). Hardwood forests were used for livestock rest, which prevented their disappearance; the only beech for-est had this use from the 15th century until 1961 (Lopez et al. 2003). Livestock gives rise to the entrance of ruderal species. There were also orchards near the village, where the coloniza-tion of weeds began.

From the 16th to the 18th century, the demand for wool declined and the population of Castile increased, making conditions favourable for agriculture (Drelichman 2009). The area did not have a good farmland, so it was promoted the cultivation of rye, even though the productivity was poor; however, crops were abandoned at the end of the 19th cen-tury. Rye crops return after the Spanish Civil War, in the 1940s, and the production of charcoal as well as the num-bers of livestock increased. But a very intense rural depopu-lation due to urban emigration began at the end of the 20th century, producing a drastic fall in livestock and the dis-appearance of cultivated land.

The communications were improved, with the construc-tion of roads in 1926, 1948 and 1981, and massive pine reforestations were carried out between 1958 and 1963, including several forest tracks; roads and tracks were import-ant routes for ruderal plant colonization.

In the last decades, a growing tourist industry has been developed. Visitors arrive mainly on weekends, which imply an increase in road traffic and the construction of paths, equipments and buildings. These works, as well as the increase in human presence, are also sources for the intro-duction and expansion of ruderal species.

Plant data, classification and grouping

The area has been studied floristically since the 19th century (Cutanda 1861). Throughout the 20th century, several flora studies were carried out (e.g. Bellot 1944; Rivas 1962; Mayor 1965; 1975; Hernandez and Sainz 1978; Ruiz et al. 1982), highlighting two exhaustive catalogues, one of the beech forest (Hernandez et al. 1983) and another of the Upper Jarama Valley (Enrıquez-de-Salamanca 1991). Subsequently, some floristic notes have been published (Allue et al. 1992; Enrıquez-de-Salamanca 2009; Baonza 2012, Baonza et al. 2015). The base for this study is the 1991 catalogue (Enrıquez-de-Salamanca 1991), updated and reviewed con-tinuously in time throughout the last 27 years, which cur-rently includes 648 taxa of vascular plants.

Firstly, we have classified the plants as alien or native. Alien plants may be archaeophytes, introduced before 1500,



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or neophytes, introduced later (Kornas 1990; Pysek 1995); in this area alien plants have been introduced especially since the 15th century, so almost all are neophytes. Alien plants can be introduced voluntarily (sowing or planting) or invol-untarily, and after the introduction they can naturalize, estab-lishing new self-perpetuating populations (Richardson et al. 2000) or not. Some native species have also been planted (for reforestation or crops), and the introduced individuals can expand spontaneously or not. We established the follow-ing categories: (i) native species growing spontaneously; (ii) native species that have also been planted; (iii) alien species planted or cultivated and naturalized outside the cultivation;

1. alien species planted or cultivated, but not naturalized;
2. alien species naturalized, introduced involuntarily, not through cultivation.

Secondly, for each taxon we have indicated the habitats where it has been found, defined according to their anthropic alteration. To define the types of synanthropic habitats in the study area, we have considered the human colonization, summarized above, supported with on-the-ground analysis. According to the processes of humanization of the territory, we identified three main types of synan-thropic habitats, associated with livestock, agriculture and roads. There is also an urban area, and two ditches, very localized, but botanically significant for the species associ-ated with them. According to these criteria, we established six types of habitats, five synanthropic and one not: (i) Roadside: road and track sides; (ii) Segetal: old crops, orchards and nearby areas; (iii) Livestock: grazed areas; (iv) Ditches; (v) Urban: parks, gardens or ornamental plantations;

1. Non-synanthropic habitats.

To carry out the analysis, we have made groups of homo-geneous plants, according to origin criteria (6 groups), and presence/absence in synanthropic habitats (22 groups), including in each group and category the number of taxa.

Data analysis

According to the classification of plants in groups indicated above, and the number of species in each category, we have done a cluster analysis to detect similarities between synan-thropic habitats. To make this analysis, we calculated the Morisita-Horn overlap index (Morisita 1959, modified by Horn

1966):

Table 1. Distribution of plants according to origin and synanthropic habitats.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CH | ¼ | S | 2 P2 | | iS¼1 xSiyi | | 2 | XY |  |
|  |
|  | Xi¼21 xi | |  |  | Yi¼21 yi | |  |
|  |  | P |  | þ | | P |  |  |  |

where X and Y are the total number of individuals in popula-tions X and Y, respectively, and xi and yi the number of indi-viduals of species i in each of these two populations. The advantage of this index is to consider the abundance of spe-cies, and not just the presence/absence as the frequently used Jaccard index (Chao et al. 2006).

Applying Morisita–Horn index by pairs, we constructed a dendrogram of synanthropic habitats, which shows their degree of similarity.

Results

Alien plants represent 6.2%, most of them (95%) introduced voluntarily, and only 2 (5%) involuntarily (Amaranthus retro-flexus L. and Erigeron canadensis L.); 30% of these species are naturalized, and of them 70% are ruderal. Native plants rep-resent 93.8%. Three native species have also been planted, Pinus sylvestris L., Rubus idaeus L. and Prunus avium L., the first two expanded from plantations. Taking into account the distribution by type of habitat, 60.8% of plants appear only outside synanthropic habitats, while 33% are partial or total ruderals (18.5% partial and 14.5% total). Most species appear in more than one type of synanthropic habitat: 20.4% in grazed areas, 15.0% in roadsides, 9.3% in segetal habitats and 0.8% in ditches (Table 1).

The dendrogram elaborated (Figure 2) shows the greatest similarity between roadside and livestock ruderal habitats (34%), and those with segetal (11%).

Discussion

Alien plants in the study area account for 6.2%. We have compared this result with studies conducted in Europe, espe-cially in Spain and the Mediterranean region (Table 2). We found a great disparity in the results between studies, attrib-utable to methodological rather than territorial differences; for example, archaeophytes reach 31% in eastern France (Brun 2009) and 28% in Rzeszow (Pysek 1998), while in Portugal, there are 0.5% (Almeida and Freitas 2012) and in Greece 0.7% (Arianoutsou et al. 2010); and alien plants range

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | Ruderal | 1.1% |  |  |
|  |  |  |  | Naturalized | 1.6% | Non-ruderal | 0.5% |  |  |
|  |  | Voluntarily introduced | 5.9% | Not naturalized | 4.3% |  |  |  |  |
| Alien | 6.2% | Involuntarily introduced | 0.3% | Naturalized | 0.3% | Ruderal | 0.3% |  |  |
| Native | 93.8% | Non-ruderal | 60.8% |  |  |  |  |  |  |
|  |  | Ruderal o partially ruderal | 33.0% | Roadside | 15.0% | Partially ruderal | 18.5% | Roadside | 9.4% |
|  |  |  |  |  |  |  |  | Livestock | 13.3% |
|  |  |  |  | Livestock | 20.4% |  |  | Segetal | 3.7% |
|  |  |  |  |  |  |  |  | Ditch | 0.2% |
|  |  |  |  | Segetal | 9.3 % | Ruderal | 14.5% | Roadside | 5.6% |
|  |  |  |  |  |  |  |  | Livestock | 7.1% |
|  |  |  |  | Ditch | 0.8% |  |  | Segetal | 5.6% |
|  |  |  |  |  |  |  |  | Ditch | 0.6% |

The sum of percentages of ruderal habitats exceeds the total of each category because many species occur in more than one.

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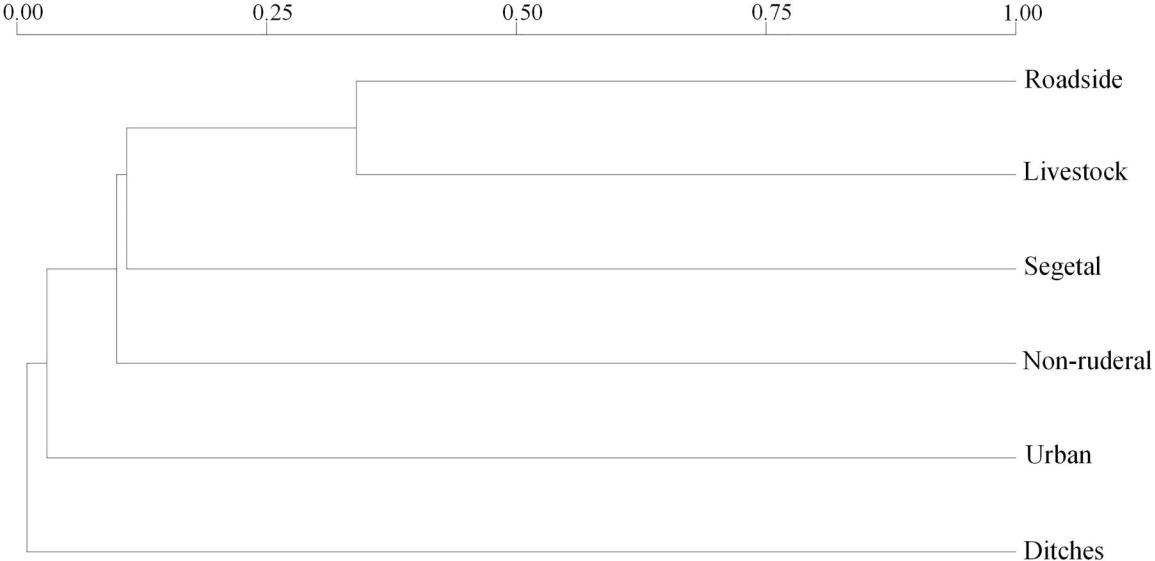


Figure 2. Dendrogram based on Morisita–Horn overlap index for habitats.

Table 2. Results on alien flora in European studies.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | Alien |  |  |  |  |
| Country | Region | |  | Total | Archaeophytes | Neophytes | | References |  |
| Austria, Czech R., Germany, Poland | 54 cities in these countries | | 40.3% | | 15.2% | 25.1% |  | Pysek (1998) |  |
|  |  |  |  | (19.7–59.7) | (6.5–28.0) | (10.9–47.5) | |  |  |
| Czech Republic | All the country |  | 34.9% | | 8.4% | 26.5% |  | Pysek et al. (2002, 2012) |  |
| Europe | Central Europe |  | 10.0–20.0% | |  |  |  | Kornas (1990) |  |
|  | All Europe |  | 13.5% | | 30.8%a | 12.8%a | | Weber (1997) |  |
| France | Eastern France |  | 50.7% | | Brun (2009) |  |
|  | Corsica |  | 17.1% | |  |  |  | Natali and Jeanmonod (1996) |  |
| Greece | All the country |  | 5.2% | | 0.7% | 4.5% |  | Arianoutsou et al. (2010), |  |
|  |  |  |  |  |  |  |  | Dimopoulos et al. (2016) |  |
| Italy | All the country |  | 19.5% | | 1.9% | 17.6% |  | Galasso et al. (2018) |  |
|  | Campania |  | 12.0% | | 2.2% | 9.8% |  | Del Guacchio and La Valva (2018) |  |
|  | Friuliu-Venezia G | All the region | 5.8% | |  |  |  | Martini and Poldini (1995) |  |
|  |  | Mountain area | 3.6% | |  |  |  | Martini and Poldini (1995) |  |
|  | Sardinia |  | 38.8% | | 8.5% | 30.3% |  | Camarda et al. (2016) |  |
| Portugal | All the country |  | 17.9% | | 0.5% | 17.4% |  | Almeida (2012); Almeida and Freitas (2012) |  |
| Spain | All the country |  | 10.1–13.5% | |  |  |  | Vila et al. (2001); Sanz et al. (2004) |  |
|  | Andalusia | All | 12.0% | |  |  |  | Dana (2010) |  |
|  |  | Almeria |  | 4.0–5.0% |  |  |  | Dana et al. (2001) |  |
|  |  | Western | 6.0% | |  |  |  | Almeida (1987) |  |
|  | Aragon | All |  | 9.0–10.0% |  |  |  | Sanz et al. (2009) |  |
|  |  | Huesca |  | 7.0–8.0% | 2.8% | 4.7% |  | Sanz et al. (2006), Sanz (2009) |  |
|  | Asturias |  | 21.5–21.9% | |  |  |  | Cires et al. (2006), Gonzalez (2007) |  |
|  | Balearic Islands |  | 15.9% | |  |  |  | Moragues and Rita (2005) |  |
|  | Basque Country |  | 20.8% | | 0.4% | 20.4% |  | Campos and Herrera (2009) |  |
|  | Castile-Leon | All |  | 9.0–10.0% |  |  |  | Sanz et al. (2008) |  |
|  |  | Segovia |  | 8.4–8.6% |  |  |  | Sanz and Gonzalez (2005) |  |
|  | Canary Islands |  | 32.7% | |  |  |  | Acebes et al. (2004) |  |
|  | Catalonia |  | 12.2%1 | |  | 7.0%2 |  | 1Casasayas (1989); 2Pino et al. (2005) |  |
|  | Galicia |  | 14.0% | |  |  |  | Romero (2007) |  |
|  | Valencian Community | | 20.0% | |  |  |  | Sanz et al. (2010) |  |
| a7.1% of undetermined alien. |  |  |  |  |  |  |  |  |  |

from 5.2% in Greece to 59.7% in Rzeszow. Our results are similar, e.g. to those from Greece, Friuliu-Venezia (Italy) or, in Spain, Andalusia (Almeria, Western Andalusia), Aragon (Huesca) or Castile-Leon (Segovia).

Ruderal plants account for one third of the total flora, a lit-tle more than half partially ruderal and the rest strictly ruderal; this result is consistent with other authors who indicate that ruderal plants represent a large fraction of plant diversity (Bartomeus et al. 2012; Huseyinoglu and Yalcin 2017).

Increased disturbance of the environment leads to increased number of ruderal and invasive plants, and also cli-mate change favours them; Biondi et al. (2012) detect in Italy an increment in the populations of nitrophilous plants related to the increase in average annual temperature, and Pysek and Mandak (1997) an increase of 26.3% in alien spe-cies in the Czech Republic between 1982 and 1995, due to increased tourism, higher number of garden plants, and a building boom.



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In our study area, ruderal plants associated with livestock stand out, which is logical in a territory with grazing activity during the last ten centuries. The second most important group is roadside ruderals, currently the main source of entry of new species; more than a dozen species have appeared in recent decades in roadsides. Also, we detect the greatest cor-relation between these two groups.

Roadways are important entry points for non-native spe-cies in natural habitats (Dostalek et al. 2016), especially in mountainous areas (Pollnac et al 2012), and similarly for ruderal species. This colonization is so important that road-less areas are significant refuges for native species (Gelbard and Harrison 2003). Vegetal seeds and propagules of vegeta-tive reproduction are implanted at the roadsides, beginning strong competition with local plants (Frenkel 1970); if they thrive, they will expand into the adjacent vegetation (Harrison et al. 2002), with their frequency decreasing with increasing distance from the road (Amor and Stevens 1976; Tyser and Worley 1992). Processes that favour plant entrance are road construction (which involves earthworks) and vehicle circulation during the operation (which transport seeds and propagules on the wheels). Lonsdale and Lane (1994) found cars that carried up to 789 seeds and 15 spe-cies, concluding that the movement of seeds by tourist cars may be partly responsible for weed infestations.

Roadsides are currently the main entry points for new species in this area; livestock and agriculture have decreased, while the number of tourists increases, most of whom arrive by car. Some plants have colonized roadsides in this area recently, being very rare; in the future they could expand or disappear (e.g. Melilotus albus Medik. and M. officinalis (L.) Pall.). Also, there are plants in nearby roadsides that should colonize the area in the short or medium term (e.g. Fumaria officinalis L. or Cymbalaria muralis G. Gaertn., B. Mey & Schreb.).

Forest tracks also have facilitated the entry and expansion of ruderal plants, rare in non-ruderal communities (e.g. Santolina rosmarinifolia L.). Recreational trails (especially in the beech forest) are another way of entry and dispersion of ruderal plants, a process also detected by Potito and Beatty (2005) in Colorado (US).

Segetal ruderals have a lower weight due to a shorter agricultural activity, developed mainly between the 18th and 20th centuries, with strong oscillations. The abandonment of cereal crops in the 1960s, and the recolonization by scrub-lands (mainly Adenocarpus complicatus (L.) J. Gay, Erica arborea L. and Calluna vulgaris (L.) Hull), had led to a gradual rarefaction of segetal plants. Martini and Poldini (1995) detect a rarefaction or disappearance of archaeophytes belonging to Secalinetea since 1945 in NE Italy, due to changes in cultivation form, compared with an increase of New World plants. Many segetal ruderals associated with cer-eal crops are therophytes, with lower persistence than peren-nial plants, which would explain their decrease due to competition.

Ditch ruderals, very scarce, depend on the water of an irri-gation ditch and a channel of an old flour mill, both aban-doned today; they have not capacity to expand outside

those areas, and surely disappear if they stopped carry-ing water.

Conclusions

Analysing the flora of the study area we have identified a 6.2% of alien species, 14.5% of plants growing only in ruderal habitats, and 18.5% growing in ruderal and non-ruderal habitats. That implies a minimum of 20.7% of the flora favoured by human action (alien and strict ruderal), which may increase to 39.2% (including plants from ruderal and non-ruderal habitats). These results reveal the strong human influence in the flora even in territories without high anthropic pressure; certainly the studied area is mountainous and with a late human colonization, so the presence of syn-anthropic species must be lower than in more human-ized areas.

The entrance of ruderal and alien plants continues cur-rently, especially through roadsides, as evidenced by the presence of colonizing plants entered in recent years. This colonization will probably increase in the future due to growing tourism, and also to climate change, which may influence the patterns of colonization and invasion of ruderal and alien plants, and the response of the native flora.

Disclosure statement

No potential conflict of interest was reported by the author.

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