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Ecological integration of eucalypts in Europe: Interactions with flower-visiting birds

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ABSTRACT

The degree of ecological integration of an exotic species depends on the emergence of new interactions with the host community, either antagonistic or mutualistic, such as pollination. This will determine the impact of the new species on the host community (positive or negative, direct or indirect) as well as the capacity of the new species to sustain biodiversity.

Eucalypts are the most widely planted trees in the world and depend on pollination by animals for seed production. Blue gum (*Eucalyptus globulus*), one of the most commonly used and a dominant tree in NW of Spain, where this study has been conducted, is pollinated mainly by birds in its native range. In Europe pollination is mainly insect mediated, there are no specialized nectar-feeding birds and ornithophily (plant adaptation for bird pollination) is extremely rare (only recognized for one species, a Tertiary relict). Nevertheless, opportunistic nectar-feeding has been occasionally observed for some European songbirds.

In this study, we determine the prevalence and strength of the interaction between eucalypts and birds by analyzing the occurrence and abundance of pollen in birds captured in mist nets in mixed landscapes with eucalypt plantations.

Eucalypts represented the most important flower resource for the flower-visiting bird community. Eucalypt pollen was present in 171 individuals belonging to 19 bird species (out of the 485 birds captured in 33 species) and represented 98.2% of all pollen recorded. The large pollen loads found are indicative of frequent eucalypt flower use by the bird community.

This study provides a good example of the ecological integration of a widely planted forestry species. The frequency of eucalypt pollen in birds points to the widespread use of this novel resource by birds and to the high ecological relevance of this interaction. The establishment of this novel interaction may favor seed production and, with it, population regeneration and spread of this exotic tree.

1. Introduction

As we enter the Anthropocene, more of the Earth's land surface is covered by human-dominated ecosystems (Foley et al., 2005; Vitousek et al., 1997). Natural ecosystems are increasingly degraded or altered while novel ecosystems emerge as a consequence of human action (Hobbs et al., 2013). Despite their increasing importance, human-dominated systems still receive little attention from ecologists.

Biotic changes are pervasive, with species extinctions and introductions occurring at an accelerated rate. The movement of organisms around the world gather together species that had never met before and have evolved separately. Alien predators meet new preys that may be naive to their hunting techniques (Salo et al., 2007), alien plants find new herbivores that have to cope with their defences (Keane and Crawley, 2002; Parker et al., 2006), or have to attract new pollinators that may be adapted to different floral morphologies or rewards (e.g. Geerts and Pauw, 2009). Thus, new interactions between alien and native species may be formed; interactions that may be antagonistic (such as competition, predation and herbivory) or mutually beneficial (such as pollination and seed dispersal). The degree of ecological integration or naturalization of alien species depends on the emergence of these new interactions. This will determine the biotic resistance and facilitation of the host community to the establishment and spread of new species (Levine et al., 2004; Richardson et al., 2000), as well as the capacity of new species to sustain biodiversity and cause impacts (positive or negative, direct or indirect) on the host community.

Land conversion is a major driver of biotic changes (Foley et al., 2005; Turner et al., 2007). While natural forests are declining in many parts of the world, tree plantations are expanding worldwide,

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now reaching c. 30% of total forested area in Europe (excluding the Russian Federation; FAO, 2010). Eucalypts have become the most widely planted hardwood in the world, mostly for paper production (FAO, 2010). Originally from Australia and New Guinea, eucalypts have been introduced in all continents, with the only exception of Antarctica, reaching c. 20 million ha planted (FAO, 2010). In Europe, eucalypts are only planted in large scale in Spain and Portugal (c. 1.5 million ha.), with *Eucalyptus globulus* Labill., *Eucalyptus camaldulensis* Dehnh., and, recently, *Eucalyptus nitens* (H. Deane & Maiden) Maiden as the most important species. In Spain, the most important forestry region is in the NW (Galicia; Manuel and Gil, 2002), where *E. globulus* makes c. 30% of the forested area (other eucalypts are scarce) and has multiplied its cover by c. 10 times over the last 30 years, both by intentional planting and natural spread (MAGRAMA, 2011). *E. globulus* is pollinated mainly by birds in its native range (Hingston et al., 2004a, 2004b), in contrast with *E. camaldulensis* and *E. nitens*, which are mainly insect pollinated (Hodgson, 1976; Ottewell et al., 2009). To attract birds, *E. globulus* flowers produce c. 100 times more nectar than a close relative, the insect-pollinated *E. nitens* (Hingston et al., 2004a). Ornithophily (i.e. plant adaptation for bird pollination) is common in Australasia, as well as in the Neotropics, Africa and Asia, where highly specialized nectar-feeding birds, such as hummingbirds, sunbirds or honeyeaters, are abundant. In Europe, however, no specialized nectar-feeding birds are present and ornithophily is extremely rare among plants, being recognized only for one native species (*Anagyris foetida* L., Fabaceae, a Tertiary relict present in Southern Spain; Ortega-Olivencia et al., 2005). Plant pollination in Europe thus chiefly depends on insects. Nevertheless, some European songbirds are known to visit flowers in search for nectar, insects or pollen (reviewed in Silva et al., 2014), and visits to introduced ornitophilous plants have been observed occasionally.

Eucalypt introduction in Europe dates back to the early 19th century, although its massive planting for pulpwood production only started after the mid-20th. The first published observation of bird visitation to eucalypt flowers in Europe is, to the best of our knowledge, from the late 1970s (Yeatman, 1978). Since then, several authors have documented the use of eucalypt flowers by birds (e.g. Tellería and Galarza, 1991; Calviño-Cancela, 2013), and studies analyzing pollen loads in spring-migrating birds, en route or upon arrival at breeding sites, have shown abundant eucalypt pollen, despite study sites being far from eucalypt plantation areas (Cecere et al., 2011a; Laursen et al., 1997; Provost et al., 2012; Wood et al., 2014). However, no quantitative study has yet been carried out in areas of eucalypt introduction, thus precluding any conclusion on the frequency of flower use by birds.

In this study, we aim at determining the prevalence and strength of the interaction between eucalypts and birds by analyzing the occurrence and abundance of pollen in birds captured in areas with presence of *E. globulus*. Our objective is to determine what bird species interact with eucalypt flowers, what is the proportion of individuals that use them and what is the relative importance of this resource for birds. We also aim at determining the temporal pattern of flower usage compared to that of eucalypt flower availability.

2. Materials and methods

2.1. Study sites

The study was carried out in two sites that are two constant effort bird ringing stations operated by the bird ringing group Anduriña (see Acknowledgements) in NW Spain (Darbo: 42°15′48.01″N 8°47′46.97″W; Coiro: 42°16′29.60″N 8°46′16.61″W). The stations are located 2.5 km apart in mixed landscapes, typical of rural areas in NW Spain and many parts of Europe (Lomba et al., 2015), with agricultural land, abandoned fields, native forest patches, forestry plantations (of *E. globulus* and *Pinus pinaster*) and scattered houses with their gardens. The two sites differed in the surface covered by *E. globulus*. In Coiro, *E. globulus* stands covered 19.5% of the area comprised within 300-m distance from mist nets (total area of 31.3 ha), with a minimum distance between mist nets and *E. globulus* trees of c. 50 m. In Darbo, *E. globulus* stands covered 7.9% (of an area of 17.7 ha) and the minimum distance between mist nets and *E. globulus* trees was c. 200 m. The difference between study sites in the total area comprised within 300-m distance from mist nets (31.3 ha in Coiro and 17.7 ha in Darbo) is due to the different arrangement of mist nets, which results in different degree of overlapping in the 300-m radius area surrounding them.

2.2. Reproductive biology of eucalypts

Eucalyptus spp. flowers are protandrous (thus avoiding autogamy; i.e. pollen transfer between anthers and stigma of the same flower) and parthenocarphy is absent in this genus (Pryor, 1976), which means that seed production depends on pollen transfer between flowers. In addition, cross-pollination (pollen transfer between different individuals) produces more seeds with higher viability than self-pollination, and increased growth rate and lower mortality of offspring (Hardner and Potts, 1995). The open cup-shaped flowers of eucalypts facilitate access to nectar for a wide variety of visitors. Flowers are visited mainly by birds and insects in their native ranges, although the relative importance of these groups varies among *Eucalyptus* species. It depends on floral morphology and rewards, as well as mildness of weather during the flowering period (Ford et al., 1979; Griffin, 1982). Eucalypts with smaller flowers and lower nectar production (flower size and nectar production are correlated) are predominantly insect-pollinated, whereas those with larger flowers and higher nectar production are mostly bird pollinated (Davis, 1997; Ford et al., 1979). In addition, birds are more important pollinators than insects during winter in areas where this season is too cold and wet for insect activity (Ford et al., 1979). *E. globulus*, the species present at the study sites, has the typical characteristics of bird-pollinated eucalypts (Davis, 1997; Ford et al., 1979; Griffin, 1982): it produces large flowers (the largest among Tasmanian eucalypts, with capsules 15–30 mm in diameter; Williams and Potts, 1996), with large amounts of nectar and mostly in winter and early spring. To attract birds, *E. globulus* flowers are 2–7 times bigger and produce c. 100 times more nectar than *E. nitens*, an insect pollinated close relative (Hingston et al., 2004a).

2.3. Bird trapping and pollen quantification

We set nine 12-m long nets in Darbo, making a total of 108 m arranged in three 36-m long lines. In Coiro, we set six 12-m long nets, making a total of 76 m arranged in four lines of 12 m or 24 m. Mist nets were operated one day per month in each site, from dawn to dusk, usually on two consecutive Saturdays: the closest to the 15th day of each month and the next one (weather permitting, avoiding rainy and windy days). The study was carried out between March 2014 and April 2015 (i.e. 14 months). All trapped birds were ringed.

For all birds captured, we collected pollen grains attached to the bill and surrounding feathers (forehead, chin and cheeks). For this, we used a lab spatula impregnated with a glycerine-based gel, which was then transferred to microscope slides (Beattie, 1971). When the amount of pollen was too much for one slide, we used two slides, or transferred a subsample of the whole amount to