Bulletin OEPP/EPPO Bulletin (2013) **43** (2), 285–289 ISSN 0250-8052. DOI: 10.1111/epp.12040

A contribution to the inventory and study of the impacts of phytophagous insects found on *Baccharis halimifolia* in its introduced range in France

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Field surveys and a literature review were used to develop an initial inventory of phytophagous insects found on the invasive alien plant *Baccharis halimifolia* (Asteraceae) in its introduced range in France. A preliminary study provides the first quantitative data for the observed impact of *Ceroplastes sinensis* (Hemiptera: Coccidae) on the reproductive output of this invasive shrub.

Introduction

Baccharis halimifolia is a semi-deciduous shrub originating from the coastal areas of North America. It was first introduced into France during the 17th century in botanical gardens, for example in the royal botanical garden in Paris, the Jardin du Roi (Lamarck, 1817). Due to its silvery foliage and resistance to salt spray, it was widely recommended as an ornamental plant during the 19th century (Dupuis & Hérincq, 1884). It gradually became established at the beginning of the 20th century along the French and Spanish Atlantic coast (Coste, 1906; Thellung, 1916) and more recently along the Mediterranean coast (Amigo, 1983; Salabert & Gastesoleil, 1991). In Europe, it is now established in France, Spain, Italy, Belgium and the UK, and is considered as an invasive plant with major environmental impacts in France and Spain. *Baccharis halimifolia* produces a large amount of wind-dispersed seeds (over 1 000 000 per plant per year according to Panetta, 1977) and can form dense stands, reducing the species richness of invaded communities and the abundance of characteristic species. It mainly colonizes wet coastal habitats and is particularly invasive in *Juncus maritimus* communities (*Juncetalia maritimi*) in the upper saltmarshes (Caño *et al.*, 2012).

The enemy-release hypothesis considers that the success of highly invasive exotic species can be explained by release from the natural enemies that are thought to limit their impact and spread in their native ranges (Elton, 1958; Carpenter & Cappuccino, 2005). It is therefore of interest to monitor the colonization of alien plants by new natural enemies in their introduced range, and to check for potential impacts on survival of the plants. The aims of this paper are i) to contribute to the inventory of phytophagous insects found on *B. halimifolia* in France, based on the existing literature and on specific field surveys; and ii) to present preliminary measurements of damage on *B. halimifolia* caused by these natural enemies.

Surveyed area, identification methods and impact assessment

In a study conducted during spring and summer 2012 that aimed to assess the impact of *B. halimifolia* on native plant communities (Fried *et al.*, unpublished data), the opportunity was taken to collect systematically all phytophagous insects observed on this shrub. The study area encompassed the two main areas where *B. halimifolia* forms invasive stands in the Mediterranean area, at the mouths of two rivers: the Rhône in the Camargue and the Agly near Perpignan (Fig. 1). For reliable identification of scale insects, it is necessary to examine slide-mounted tenebrant females under a compound light microscope – for more technical information, see EPPO diagnostic protocols PM 7/55 *Rhizoecus hibisci* (EPPO, 2005); PM 7/70(1) *Maconellicoccus hirsutus* (EPPO, 2006); PM 7/82(1) *Margarodes prieskaensis*, *Margarodes vitis*, *Margarodes vredendalensis* (EPPO, 2007). For aphids, mounted microscopic wingless adults are also necessary for identification. Keys by Gill (1988) and Pellizzari & Camporese (1994) were used to identify scale insects; keys by Blackman & Eastop (2000, 2006) were used to identify aphids. The field survey was supplemented by a specific literature review. When damage was observed on *B. halimifolia*, the authors compared the reproductive output of the plant by choosing randomly a selection of attacked and non-attacked individuals. The numbers of inflorescences per shoot and the number of flowerheads per inflorescence were compared.

Results and discussion

Recorded phytophagous species

The field survey allowed the identification of four natural enemies of *B. halimifolia*, two soft scales and two aphids (Table 1). Aphids were observed only on young leaves of new shoots without significant damage detection (Fig. 2).

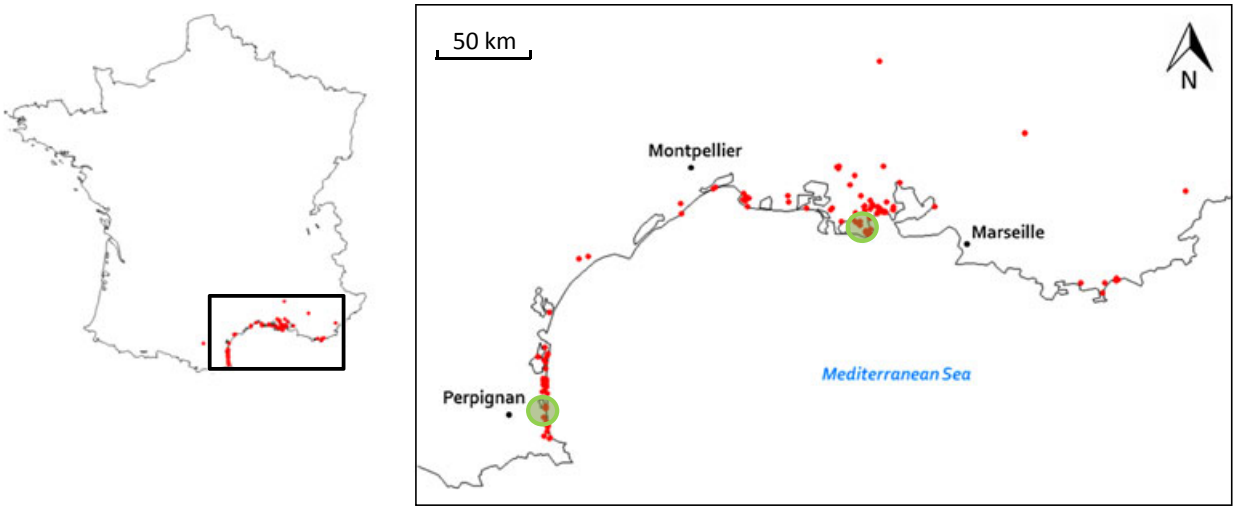

Fig. 1 Distribution of *Baccharis halimifolia* in the French Mediterannean area and locations of the surveyed area. Dark points (red online) show locations with *Baccharis halimifolia* (CBNMed, 2012); large circles (green online) show the area studied.

Table 1 Phytophagous insects found in the French Mediterranean range of *Baccharis halimifolia* and their characteristics (all four species are non-regulated pests)

Species	Family	Origin	Distribution	Main host plants
Ceroplastes sinensis	Coccidae	Neotropical (Central America)	Western part of Mediterranean Basin, Black Sea, Oceania, Chile, etc.	*Citrus* spp., many ornamental plants
Saissetia oleae	Coccidae	Afrotropical	Throughout the Mediterranean basin and regions with Mediterranean climate; cosmopolitan indoors	*Citrus* spp., *Olea europaea*, *Nerium oleander*, many ornamental plants
Aphis fabae	Aphididae	Temperate regions of Northern hemisphere	Northern hemisphere, South America, Africa	Polyphagous on a wide range of secondary hosts including many crops, e.g. beans, sugar beet
Aphis spiraecola	Aphididae	Probably Far Eastern	Worldwide	Polyphagous, especially on Caprifoliaceae, Asteraceae, Rosaceae, Rubiaceae and Rutaceae (major pest on *Citrus* spp.)

Fig. 2 *Aphis fabae* on young shoots of *Baccharis halimifolia*.

Aphis fabae Scopoli, 1763 (Hemiptera: Aphididae), the black bean aphid, was found in all study sites. It is a very widespread species in the temperate regions of the Northern hemisphere and also in South America and Africa. In Europe, its major plant host is *Euonymus europaeus* and it has a wide range of secondary hosts, including many crops. It is in particular a major pest of field bean (*Vicia faba*) through direct feeding damage. *Baccharis halimifolia* was already listed among host plants for *Aphis fabae* (Blackman & Eastop, 2006); however, this widespread aphid species was not observed during the first large survey of phytophagous insects found on *B. halimifolia* in its native range (Palmer & Bennett, 1988).

Aphis spiraecola Patch, 1914 (Aphididae), the spiraea aphid or green citrus aphid, was found only in Torreilles, near Perpignan (Fig. 1). It probably originates from Far East and has become widespread in North America since the early 20th century and in the Mediterranean region since approximately the end of the 1930s. It now has a worldwide distribution. Its main plant hosts are *Spiraea* spp. (Rosaceae) and *Citrus* spp. (Rutaceae), on which it is a major pest. It has secondary hosts in more than 20 families. As is the case for *A. fabae*, this species is also a vector for more than 30 plant pathogenic viruses of various crop species (citrus, bean, pea, crucifers, curcurbits, potato, etc.). According to the literature reviewed, *A. spiraecola* is reported for the first time on *B. halimifolia*, but it was already known to occur on *Baccharis trineura* (Blackman & Eastop, 2006). Eleven other species of the Aphididae family are listed on *B. halimifolia* throughout the world (Blackman & Eastop, 2006), but mainly in North America (Palmer & Bennett, 1988).

Saissetia oleae Olivier, 1791 (Coccidae), black scale, was found on *B. halimifolia* in two sites in Camargue (Domaine de la Pallissade, They de Roustan). This species is of Afrotropical origin and has spread all over the Mediterranean Basin (Pellizzari & Germain, 2010). In France it is distributed outdoors along the Mediterranean coast (including Corsica) and indoors all over the country on ornamentals (for a complete distribution see ScaleNet, 2012). Occasionally it can be harmful to olive (*Olea europaea*) and citrus (*Citrus* spp.), but it is usually controlled by natural enemies (predators and parasitoids). On *B. halimifolia*, it leads to the development of fungi (sooty mould) and appears to weaken some individuals, but this appears only very locally in Camargue (They de Roustan). *Saissetia oleae* is known to feed on *B. halimifolia* in its native range (Palmer & Bennett, 1988).

Ceroplastes sinensis Del Guercio, 1900 (Coccidae), Chinese wax scale, is of neotropical origin (Pellizzari & Germain, 2010). It was found only in Torreilles in the Reserve Naturelle de la Ribère, but it occurred in very large populations, frequently having more than 10 individuals per shoot (Fig. 3). The Chinese wax scale belongs to a group of five *Ceroplastes* present in the Mediterranean basin. All except the native *Ceroplastes rusci* (Linnaeus, 1758) are invasive species. In Europe, *Ceroplastes sinensis* is distributed mainly

Fig. 3 Larval instars (10-05-2012) on *Baccharis halimifolia* (A) and adult females (B) of *Ceroplastes sinensis.*

in the Western Mediterranean countries and in the east part of the Black Sea (for a complete distribution see ScaleNet, 2012). In France it is distributed outdoors along the Mediterranean coast (including Corsica), with some records on the Atlantic coast and indoors. Chemical control may sometimes be necessary in citrus groves but, as for black scale, this species is regulated mostly by natural enemies already present.

Both soft scales have also been reported on *B. halimifolia* in Gironde (France) on the Atlantic coast in the early 2000s (Dauphin & Matile-Ferrero, 2003). In this area, *Saissetia oleae* was considered to be quite common on *B. halimifolia*, while *Ceroplastes sinensis* was reported for the first time in only two sites. Since then, the latter species has been observed in many other locations in Gironde and seems to have become

Fig. 4 Comparison of the reproductive output of attacked (left) and healthy (right) individuals of *Baccharis halimifolia*. Attacked individuals showed fewer flowerheads per inflorescence and senescent leaves appeared more rapidly.

widespread on *B. halimifolia*, although never very abundant and without significant damage observed (P. Dauphin, pers. comm., 2013). In addition, an unidentified wax scale insect species has been reported in Spain, in the Basque range of *B. halimifolia* (Caño *et al.*, unpublished data).

Observed damage for Ceroplastes sinensis

Wax scale insects such as *C. sinensis* are sap feeders that can weaken the plant they colonize, especially at the end of summer (September), when their activity was observed to reach its peak in the studied area (Réserve Naturelle de la Ribère, Torreilles). Analysis of the reproductive output showed that the number of inflorescences of *B. halimifolia* per shoot was significantly reduced from 56.0 (±8.3) for healthy individuals to 17.6 (±3.4) for individuals colonized by *C. sinensis* (Wilcoxon test, $P = 0.01$, $n = 10$ shoots) while the number of flowerheads per inflorescence also decreased significantly from 108.9 (±44.3) to 12.6 (±6.1) (Wilcoxon test, $P < 0.001$, $n = 50$ inflorescences). The senescence and fall of leaves also appeared to occur earlier on attacked individuals. The effects of *C. sinensis* on *B. halimifolia* are illustrated in Fig. 4.

In the 1 ha area where *C. sinensis* was observed in the Réserve Naturelle de la Ribère, 35 dead individuals of *B. halimifolia* were counted. These were covered with mummies of *C. sinensis* and probably were killed by this scale insect. This represented less than 0.01% of the estimated number of *B. halimifolia* individuals found throughout the 30 ha in the Réserve Naturelle de la Ribère. The dead individuals were often young shrubs with a mean height of 1.53 m (±0.52; min = 0.80 m; max = 2.70 m), which is smaller than the mean population size of the total sampled population (mean = 2.06 m ±0.59; min = 0.86 m; max = 3.35 m). Other individuals initially appeared to be dead, but new shoots were observed arising at the bases of the shrubs. This shows a strong resprouting capacity after such herbivory attacks.

Implications for the biological control of B. halimifolia

This survey confirms the relatively low number of phytophagous insects able to feed on *B. halimifolia*. Westman *et al.* (1975) found that even in the native range of the species, the overall level of herbivory was low. In the Morbihan department, in the South of Brittany (France), about 50 years after establishment, the number and abundance of phytophagous insects identified on *B. halimifolia* were still significantly lower compared with native co-occurring shrubs (Mallard, 2008). *Baccharis* species are known to produce secondary metabolites with antifeedant activity on non-adapted phytophagous insects (Cifuente *et al.*, 2002).

This study also revealed that at least one wax scale species, *C. sinensis*, showed a capacity to alter the fertility of *B. halimifolia* and to lead to some mortality. However, *C. sinensis* is polyphagous and considered a crop pest, as is the case for the other phytophagous insect species recorded on *B. halimifolia* in France. It is therefore not possible to consider them as relevant biological control agents. Given the high reproductive output of *B. halimifolia* and the relative effect of *C. sinensis*, it is unlikely that this natural enemy alone will limit the establishment and spread of *B. halimifolia* at the regional scale. Furthermore, as observed in citrus groves, populations of *C. sinensis* may be regulated by predators and parasitoids after a given time of establishment. In Australia, the biological control management launched against *B. halimifolia* during the 1960s has not been effective in all regions, and alternative com-

plementary control methods are necessary (Sims-Chilton Nikki & Panetta, 2011).

Despite these known limitations, as longer-term effects of the presence of *C. sinensis* on *B. halimifolia* are currently unknown, it would be interesting to study further its spread and impact to assess more precisely to what extent the effect of *B. halimifolia* could be reduced at local scale. From a theoretical point of view, this case study is an interesting example of interactions between several invasive species (Zavaleta *et al.*, 2001)

Une contribution à l'inventaire et à l'étude des impacts des insectes phytophages trouvés sur *Baccharis halimifolia* dans son aire d'introduction

Des études de terrain ainsi qu'une recherche documentaire ont été utilisées pour mettre en place un inventaire initial des insectes phytophages trouvés sur une plante exotique envahissante *Baccharis halimifolia* (Asteracées) dans son aire d'introduction en France. Une étude préliminaire fournit les premières données quantitatives pour les impacts observés de *Ceroplastes sinensis* (Hemiptera: Coccidae) sur le succès reproducteur de cet arbuste envahissant.

Вклад в инвентаризацию и изучение воздействия насекомых-фитофагов на *Baccharis halimifolia* в границах ареала его интродукции во Франции

Для разработки исходного перечня насекомых-фитофагов, обнаруженных на инвазивном чужеродном растении *Baccharis halimifolia* (Asteraceae) в границах ареала его интродукции во Франции, использовались полевые обследования и обзор литературы. Предварительное исследование позволило получить первые количественные данные по воздействию *Ceroplastes sinensis* (Hemiptera: Coccidae) на результаты репродукции этого инвазивного кустарника.

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