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Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France

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ABSTRACT

Private gardens are an important food source and refuge for animals in urban areas because they represent a large part of the green space. It has been shown that garden management regime (water use, floral composition) may impact the species they shelter. However, due to access restrictions, lack of regulations and the difficulty of data collection on private property, the impact of management practices and in particular pesticide use has seldom been assessed in private gardens. Using data collected in the framework of a nationwide participatory monitoring scheme in France, we assess here, for the first time, the effect of private garden management on two important groups of flower-visiting insects, i.e. butterflies and bumblebees, at a large scale. We show that the correlation between butterfly and bumblebee abundance and use of insecticides and herbicides is negative, whereas the use of Bordeaux mixture (fungicide approved for organic use), fungicides and anti-slugs is positively correlated with butterfly and bumblebee abundance. We hypothesize that herbicides have an indirect negative impact on insects by limiting the amount of available resources, and that the Bordeaux mixture, fungicides and slug repellants have an indirect positive impact on these insects by fostering healthier plants, probably offering higher level of resources to pollinators. Moreover, we show that the impact of pesticides varies according to the landscape, the negative effect of insecticides being more important in highly urbanized areas. Overall, our results show that gardener practices can have a positive impact on flower-visiting insects, even in a highly anthropized, urban landscape.

1. Introduction

Private gardens represent an important part of green spaces in cities, e.g. 23% in Sheffield (UK), (Gaston et al., 2005), or 36% in Dunedin, New-Zealand (Mathieu et al., 2007). Representing nature oases in cities, green spaces are known to positively influence human health and wellbeing (Fuller et al., 2007; Gross and Lane, 2007; Gaston et al., 2007). Furthermore, it has been suggested that private gardens might mitigate the impact of urbanization on biodiversity (Goddard et al., 2010). Even if each garden taken individually is too small to be of biological importance, gardens taken as a whole can be an important component of urban floristic diversity (Thompson et al., 2003; Smith et al., 2006b; Loram et al., 2008; Stewart et al., 2009) and provide important sources of food and shelter for birds (Cannon et al., 2005; Davies et al., 2009), wild bees (Fetridge et al., 2008; Samnegård et al., 2011) and amphibians (Gaston et al., 2005). Private gardens can also provide landscape connectivity for plants and animals (Rudd et al., 2002; Sperling and Lortie, 2010; Vergnes et al., 2012, 2013). However, they may also have a negative impact on the environment: for instance, Dehnen-Schmutz et al. (2007) and Marco et al. (2010) have shown that ornamental plants cultivated in private gardens could be an important vector of plant invasions. Assessing the role of private gardens in maintaining urban biodiversity still requires an understanding of the factors driving the biodiversity hosted within these private areas.

Landscape and local scale factors may impact urban biodiversity. Pardee and Philpott (2014) showed that presence of native plants in gardens but also landscape characteristics, such as amount of semi-natural area in the landscape, influence urban bee diversity. Similar results were shown for British moths (Bates et al., 2013). Furthermore, Bergerot et al. (2011) showed that the level of urbanization in the landscape surrounding private gardens was a strong driver of the diversity and composition of butterfly communities in gardens, with lower species richness and lower occurrence of feeding specialists in strongly urbanized sites. On

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the other hand, Smith et al. (2006a), found that the extent of green space around gardens only occasionally explained the abundance of 22 invertebrate groups, and that most variables correlated with abundance occurred at the scale of the garden itself. These seemingly contradictory results might arise from temporal and spatial variability, or from a lack of power of the analysis performed. Untangling the local and landscape effects on insect diversity in gardens might require larger datasets encompassing various garden types and levels of urbanization.

Another difficulty of studying private gardens is that they are unregulated habitats with various water and chemical use intensity and vegetation structure. Moreover, these characteristics are generally unknown, depending on each gardener's own decisions (Mathieu et al., 2007). Although the effect of management practices on private gardens has been little studied, it has been shown that increased pesticide use on residential yards may negatively impact the environment (Robbins et al., 2001). Direct effects on species abundance in private gardens have seldom been studied, but available results suggest it could be important, especially because their use in gardens is unregulated and the amount private gardeners use may be significant. Smith et al. (2006a) included pesticide use in their study of invertebrates in urban gardens at a city scale, but this factor was pooled in a global management intensity index including several variables, such as weeding, pruning, watering or bird feeding. Such an aggregated index of management intensity makes it difficult to identify the components that most affect biodiversity. More specifically, Byrne and Bruns (2004) and Cheng et al. (2008) have revealed the negative impact of pesticides on non-target soil microfauna, whereas Politi Bertoncini et al. (2012) have shown it on floristic composition, and Stewart et al. (2009) found a negative correlation between lawn management intensity, including use of phytochemicals, and the presence of various plant species in urban lawns. There are a few citizen-science studies that have investigated bumblebees or Lepidoptera in private gardens (e.g. Lye et al., 2012; Bates et al., 2013); however, to our knowledge, the impact of pesticide use on biodiversity, and especially flower-visiting insects, has never been studied in private gardens at a large scale and in different landscape contexts.

Restricted access to private gardens and the difficulty of data collection on biodiversity and management in this habitat probably accounts for the paucity of research on this topic. When collecting data in private gardens, citizen science is an efficient tool because garden owners can directly provide the data (Cooper et al., 2007). Based on a nationwide citizen survey on private gardens in France, we assess here the relative impact of local scale factors (i.e. garden structure and management) and landscape composition (i.e. proportion of urban area) on two groups of pollinating insects, butterflies and bumblebees. We specifically measured the impact of pesticides on these insects, depending on the type of pesticide (e.g. herbicide, molluscicide, insecticide), and quantified this impact relatively to other factors, such as garden characteristics and urbanization level. We hypothesized that gardening practices would have a larger impact on insect abundance in densely urbanized districts than in more rural districts.

2. Material and methods

2.1. Insect data

Data came from two citizen monitoring schemes: the French garden butterfly observatory and the French bumblebee observatory (http://vigienature.mnhn.fr/). For these nationwide programs, citizens identify and count butterflies and bumblebees in their garden between March and October, following a simple protocol and a closed list of 28 common species or species groups of butterflies (see Appendix A for full species list and mean abundances) and 11 bumblebee morphospecies (i.e. recognizable taxonomic units based on external morphology, which may not correspond to species – see Appendix B for full morphospecies list and mean abundances). No constraint on the frequency of observation is imposed, and volunteers record online each month the maximum number of individuals of each species/morphospecies seen simultaneously in the garden during the previous month. To reduce heterogeneity in the dataset due to non-independence between individual detection probability for species seen in groups, all monthly abundances that were above 10 (0.4% of all data) were leveled to a maximum value of 10 (Julliard et al., 2006). Visit frequency per month in each garden was recorded. We used data collected from 2009 to 2011 in 3722 gardens for the butterfly monitoring and 1119 gardens for the bumblebee monitoring. About 95% of gardens monitored for bumblebees were also monitored for butterflies. Due to the impossibility of assigning a species to a morphospecies with certainty for bumblebees, we only used total bumblebee abundance in analyses. For butterflies, we also only used abundance in analyses, because diversity and abundance were strongly correlated ($\rho = 0.9$).

2.2. Garden data

Volunteers recorded variables on garden structure and management. Garden structure was described as (1) garden area, (2) an index of nectar resources, calculated as the number of types of flowering plants in the garden, among a closed list of 12 species/plant types (i.e. Buddleja, *Centaurea* sp., *Valeriana* sp., *Pelargonium* sp., lavenders, crucifers, nettles, bramble, ivy, clovers, aromatic plants, fruit trees); this list was built with plants non-specialists can easily identify and that are common in gardens, and that offer resources (food or shelter) to butterflies, (3) an index of garden naturalness, this was calculated as follows: in the garden description, the observer states whether the garden has fallow, nettles, ivy and/or brambles (these three plants being usually considered as weeds by gardeners), dead trees and stems. Each of these items was scored one if present, zero if absent, and the naturalness index was calculated as the sum of these scores.

The use (or not) of herbicide, insecticide, fungicide, Bordeaux mixture (fungicide based on copper sulfate and approved for organic use), anti-slug and fertilizer defined garden management as reported by observers. They had to characterize their use of the different chemical types as "often", "seldom" or "never": however, only ca. 1% reported a regular ("often") use of pesticides. For this reason, we used only two classes, "use" or "no use" of each of the chemicals.

2.3. Landscape data

Data were recorded in gardens located in ca. 3000 different districts ("communes") out of 36,570 in France (Fig. 1). The mean area of a district in France is 15 km^2. We characterized the landscape of each district using CORINE land cover map (CLC project co-ordinated by the European Environmental Agency) dated 2006. CLC is established from satellite images with a resolution of 1:100,000 and includes 44 land cover classes grouped into five main (level-one) categories: urban areas, agricultural areas, forests and semi-natural areas, wetlands and water bodies. For each garden we quantified the proportion of urban areas in the district.

2.4. Data analysis

Independence between garden structure, management and landscape variables was tested with Pearson's correlations. For