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INVASION NOTE

Rubbish dumps as invasive plant epicentres

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Abstract It is widely known that disturbed areas favour plant species invasion. However, the presence and impacts of introduced plants at rubbish dumps and landfills are less clear. We conducted a literature review to evaluate current knowledge on introduced plants species at these sites to assess their potential role as invasion epicentres. Most of the studies we found (91%) were observational and only described plant species presence in multiple landscapes, including rubbish dumps or landfills. A minority of studies (< 20%) specifically focused on plant species at these sites but did not evaluate their potential as invasion epicentres. The 215 introduced plant species belonging to 57 families recorded at rubbish dumps or landfills underestimates true numbers given that most studies do not report the full list of species. Most species are invasive (> 95%) and included in the Global Invasive Species Database or the DAISIE list. One species, *Arundo donax*, is among the 100 worst invasive species in the world and eight more are listed among the 100 worst invasive species in Europe. Invasive species present at these sites may alter fire regimens, produce toxic and allergen effects, outcompete native species, act as agricultural pests, and lead to economic losses. Our results are a first step to include rubbish dumps and landfills in the agenda of ecologists and managers that study invasive species, especially since compost from these sites are now being used in agricultural practices, thus possibly spreading invasive species propagules to distant locations.

Keywords Alien species · Introduced plants · Exotic species · Invasion centres · Landfills · Rubbish dumps

Introduction

The environmental impacts produced by changes in land use create disturbed microhabitats where invasion processes are initiated (Hobbs and Huenneke 1992). Rubbish dumps or landfills, the final disposal sites of human waste, are disturbed places distributed worldwide, and have the potential to harbour and concentrate numerous species of birds, mammals, insects, parasites and bacteria, including invasive ones (Oro et al. 2013; Plaza and Lambertucci 2017). Moreover, they can be considered unique habitats that can sustain and increase the abundances and reproductive performance of both the animal and plant

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species that exploit these sites (Plaza and Lambertucci 2017; Ciesielczuk et al. 2015). Particularly in the case of plants, environmental changes produced by the multiple types of waste discarded at these sites (organic, inorganic, metals, ash, coal and biological waste) favour the growth of these species (Pietsch 2005; Ciesielczuk et al. 2015). Therefore, rubbish dumps and landfills may be considered potential invasion epicentres.

Every day people discard 3 million tonnes of waste around the world. By 2025, rubbish generated is expected to be 6 million tonnes per day and by 2100 it will exceed 11 million (Hoornweg et al. 2013). Despite this important expected increase of waste production and concomitant increase in waste disposal sites around the world, few studies have examined the potential role of rubbish dumps and landfills in harbouring and sustaining introduced plant species, which may favour, in turn, the plant invasion process. While several studies have shown the presence of a great variety of plant species at or near these sites, some of them introduced species (Pyšek et al. 2003), none have evaluated their importance as invasion epicentres. Therefore, a review on this topic is timely and necessary. Here we review the current knowledge on introduced and invasive plants species present at rubbish dumps and landfills (hereafter, dumps). We evaluate the families and species that are most studied at these sites, and their potential environmental impacts. Finally, we discuss the potential role of these sites as invasion epicentres.

Methods

We performed 3 different intensive bibliographic searches using Google Scholar and Scopus including all published papers until August 2017. First, we conducted a general search with the following terms: "LANDFILL*" OR " LAND FILL*" OR "RUBBISH DUMP*" OR "GARBAGE*" OR "WASTE*" AND "ALIEN PLANT*" OR "INVASIVE PLANT*" OR "INTRODUCED PLANT*" OR "NON NATIVE* PLANT*" OR "NON-NATIVE PLANT*" OR "EXOTIC PLANT" OR "VEGETATION". An additional search with the terms "LANDFILLS COUPLED WITH ALIEN PLANTS" was conducted. Lastly, we searched multiple combinations of the following terms: "LANDFILLS", "RUBBISH DUMPS", "GARBAGE", "ALIEN PLANTS", "INVASIVE PLANTS", "INTRODUCED PLANTS", "NON NATIVE PLANTS", and "VEGETATION". We did not restrict any of the searches by year or geographic location. We reviewed the first 1000 results of each search in the case of Google Scholar and all of the results in the case of Scopus, to include only those articles that mentioned the presence of introduced plant species at dumps. We also looked at the references of the articles we reviewed for additional papers not found in our searches.

From each article that met the selection criteria, we extracted information about study location, type of study, and introduced families and species when available. We then evaluated the native and introduced range of each of these species and their potential impacts. To do this, we used several databases such as The Global Invasion Species Database list (GISD; a free, online searchable source of information about alien and invasive species that negatively impact biodiversity, http://www.iucngisd.org/gisd/), the DAISIE list (Delivering Alien Invasive Species Inventories for Europe, www.europe-aliens.org), and the Global Compendium of Weeds (GCW; a free, online searchable source of weed species information, http://www.hear.org/gcw/; Randall 2016).

We estimated the prevalence of families and species recorded at dumps studied in the articles we reviewed that specifically provided information at the family and species level. We calculated the prevalence as the number of articles in which a family or species was studied or recorded over the total number of articles found ($\times 100$). It is important to highlight that many studies only included the dominant species within the main text of the paper, and did not provide supplementary material with the full list of the species recorded at those sites. Therefore, this prevalence is based on the interest of the researchers that worked at those locations, and does not necessarily represent the actual prevalence of species at dumps. Finally, by analysing the collected data, we discussed the potential role of dumps as invasion epicentres considering the invasive behaviour and environmental impacts of the plant species and families studied or recorded in the articles included.

Results

We found a total of 62 articles that mentioned introduced plant species present at dumps. The vast majority were studies from Europe (59.7%), North America (21.0%) and Asia (12.9%), but we found studies from a wide geographic range including Africa (1.6%), Oceania (1.6%), South America (1.6%) and the sub-Antarctic islands (1.6%). More than 90% were observational studies that described introduced plant species distribution in multiple landscapes, including dumps. The remaining $\approx$ 10% included two review papers on the distribution of multiple plant species and four studies comparing genetic diversity of a single species, which included samples taken at dump sites (Supplementary material Table S1). Only around 20% of the studies (12) were specifically focused on plant species present at dumps. Two of these studies compared the presence of vascular plant species (some of them introduced) within a dump and its surroundings (Barnswell and Dwyer 2007; Rahman et al. 2013). In these studies, the frequency of introduced species was higher within the dumps than in the surrounding landscape, and some introduced plant species were present at these sites but not in the surroundings.

Eighty-five percent of the studies (53) specifically described the species and families recorded at those sites, and thus, these studies were used to estimate prevalence. We found 57 different families and 215 introduced plant species studied in dumps around the world (Supplementary material Table S2). It is important to note that these results represent an underestimation of the actual number of species, given the incomplete lists of species found in many articles (see "Methods"). The most prevalent family registered at these sites was Asteraceae (45.3%) followed by Poaceae (28.3%) and Fabaceae (26.4%) (Fig. 1). Most species were recorded in only one article, and a few articles recorded many species, up to 57 (Fig. 2a). In relation to the species that were more commonly recorded in dumps, few (9 species) were recorded at more than three sites, and almost all of them (179 species) were recorded at one or two sites (26 species) (Fig. 2b). The most prevalent species reported in dumps was False acacia (*Robinia pseudoacacia*) (13.2%), which was registered at seven different sites, followed by *Conyza canadensis*, *Erigeron annuus*, *Sisymbrium loeselii*, *Atriplex nitens*, *Heracleum mantegazzianum*, *Ambrosia artemisiifolia*, *Abutilon theophrasti*, and *Trifolium repens* (Fig. 2b).

Approximately 18% (39 species) of the introduced species found in dumps are listed in the Global Invasive Species Database list, and one species (*Arundo donax*) is categorized among the 100 worst invasive species of the world (Supplementary material Table S2). More than 93% (200 plant species) of the species we found are listed as invasive species on the DAISIE list for Europe, and almost 4% (8 species: *Acacia dealbata*, *Ambrosia artemisiifolia*, *Echinocystis lobata*, *Heracleum mantegazzianum*, *Impatiens glandulifera*, *Prunus serotina*, *Fallopia japonica and Robinia pseudoacacia*) are categorized among the 100 worst invasive species in Europe (Supplementary material Table S3).

The information obtained from the GISD, DAISIE list and the GCW databases showed that the vast majority of introduced plant species studied at dumps ($>$ 95%) are classified as agricultural and naturalized weeds that have overcome biotic and abiotic barriers to survival and reproduction. Moreover, they produce negative economic impacts in agriculture, horticulture, turf, and nurseries (Richardson et al. 2000; Randall 2016) (Fig. 3). Almost a quarter of the species (51) compete with native plants. Some of the introduced plant species found at dumps have toxic effects, alter natural fire regimens, and produce hypersensitivity. The toxic effects that can be produced by 11.6% of the species (25) may affect the animals and humans that eat them (Fig. 3). There are 2.3% (5) of the species (*Bromus tectorum*, *Arundo donax*, *Cytisus scoparius*, *Pennisetum ciliare* and *Pinus contorta*), that alter fire regimens, increasing frequency in such a way that impedes native species regeneration (Brooks et al. 2004; D'Antonio and Vitousek 1992). Hypersensitivity effects, which impact human health via pollen or toxins, were reported in 2.3% (5) of the species. Finally, almost 7% (15) of the plant species are known as food resources for humans and animals (Fig. 3; Supplementary material Table S3).

Discussion

Although there were no studies focused on the potential role of dumps in plant invasion processes, we found a high number of introduced-invasive plant species recorded at those disturbed sites around the

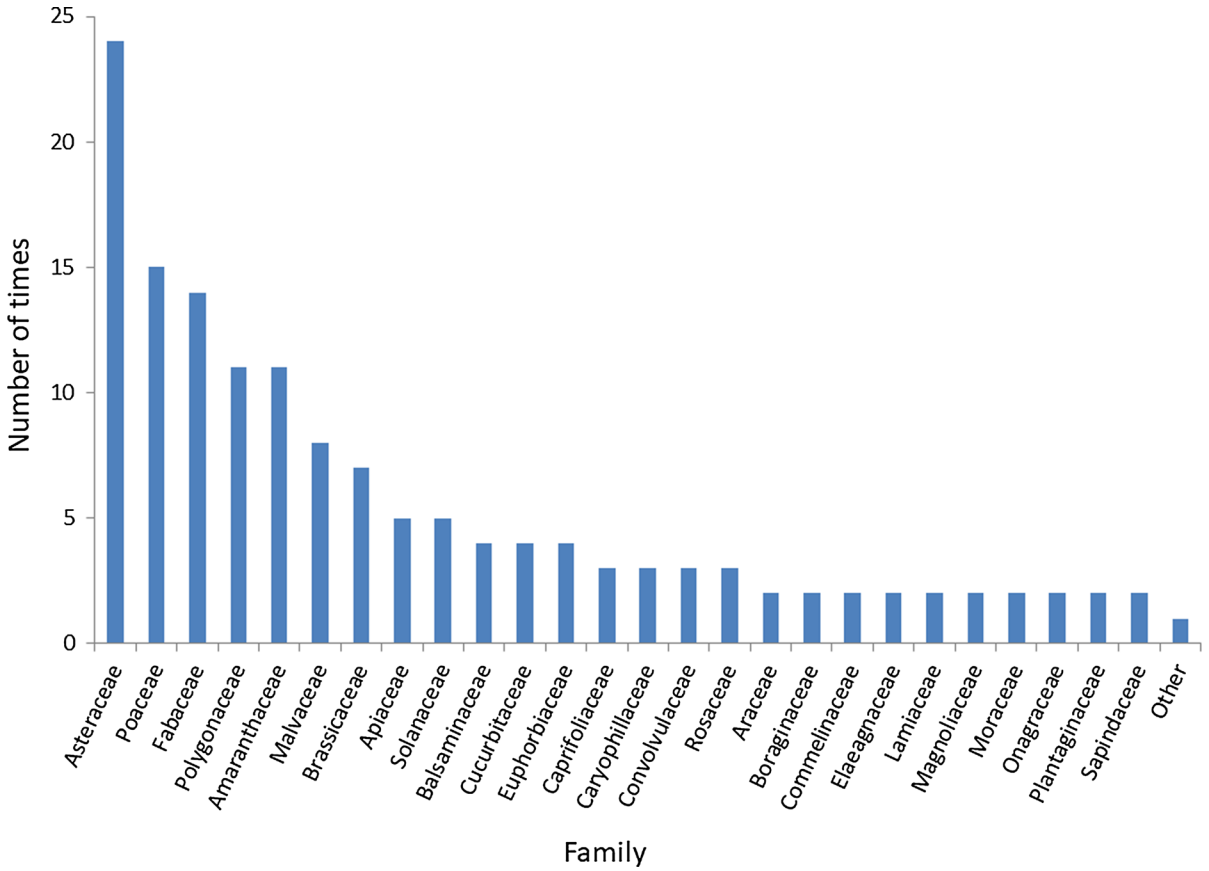

Fig. 1 Number of times a family was recorded in a study. 'Other' includes those families that were recorded in only one study (see more details in Table S2)

world. Almost all of these species affect agricultural practices and result in economic losses (Pimentel et al. 2005). This, together with the presence of one of the 100 worst invasive species in the world and eight among the 100 worst invasive species in Europe, urges the consideration of the potential role of dumps as invasion epicentres. Thus, our results highlight that dumps harbour and sustain populations of dangerous invasive species that may potentially spread to surroundings areas. The vast majority of the studies we found were only descriptive and conducted in Europe and North America. This is not surprising as these regions produce the most scientific publications on introduced species (Speziale et al. 2012), but highlights the need for increasing research on this topic around the globe. However, differences in dump management between developed and developing countries exist, with less management of waste in the latter (Hoornweg and Bhada-Tata 2012; Hoornweg et al. 2013). Thus, this topic is particularly relevant and timely in these regions.

The most prevalent family recorded in rubbish dumps was Asteraceae, followed by Poaceae and Fabaceae. Given these families are in the top plant families of the world they are expected to be highly represented in dumps as well. Moreover, species belonging to these families are capable of colonizing highly disturbed sites with nutrient enrichment and polluted soils (Del Río et al. 2002; Lake and Leishman 2004). In addition, many species belonging to Asteraceae and Poaceae produce high numbers of seeds adapted to wind dispersal (Judd et al. 1999). Therefore, dumps, which have high levels of organic and inorganic material, contamination and soil removal, could favour the colonization and development of introduced plant species belonging to families that are adapted to these conditions and that could easily reach the surroundings by wind dispersal.

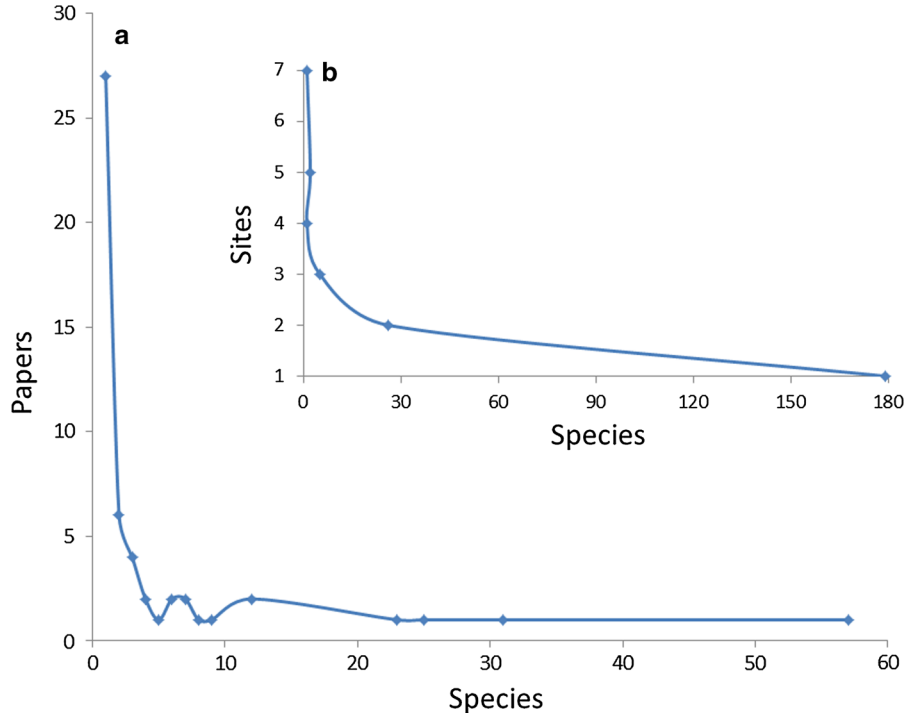

Fig. 2 **a** Relationship between the number of species recorded per study and the number of studies that recorded a certain number of species. Note that only a few studies recorded several plant species, whereas many studies only worked on one or two species. **b** Similar relationship but for the number of dumps (sites) in which a certain number of species was recorded

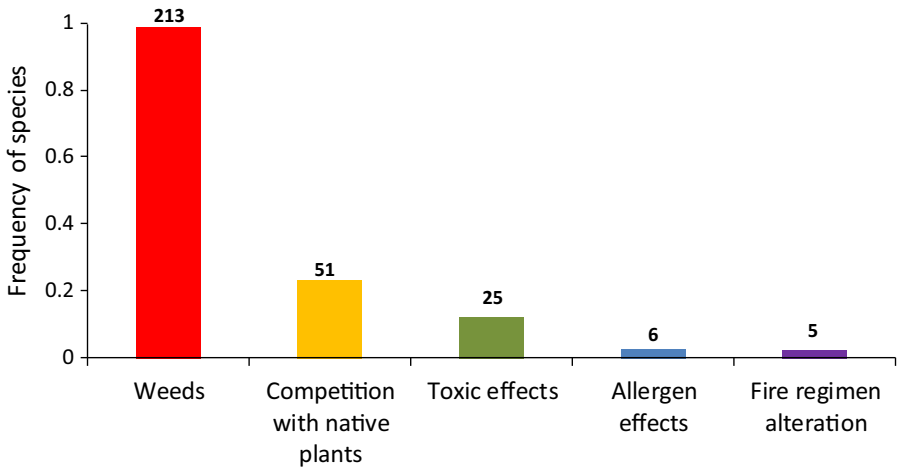

Fig. 3 Frequency of impacts produced by introduced plant species found in rubbish dumps (numbers over bars represent the absolute number of species that produce each impact). Impacts include weeds, outcompeting native species, producing toxic or allergenic effects for humans or other animals, and fire regimen alteration. Note that a species can have more than one environmental impact, so the number of impacts is not equal to the number of species

Most of the species prevalent at dumps as cited in the literature affect agricultural practices and compete with native plants. The USA (United States of America) spends 120 billon dollars a year in invasive species control activities (Pimentel et al. 2005). Species like *Robinia pseudoacacia* can poison humans and livestock, producing gastroenteritis, abdominal pain, posterior paralysis and ultimately death, especially in horses (Cortinovis and Caloni 2013). Similarly, *Heracleum mantegazzianum* produces a

phytotoxic sap, which when in contact with human skin and combined with UV radiation causes burns (Thiele and Otte 2007). Moreover, the presence of species that can enhance the frequency of fires could produce important ecological impacts, such as the conversion of grasslands commonly used for grazing livestock to abandoned areas dominated by invaders (Brooks et al. 2004; D'Antonio and Vitousek 1992). In the USA alone, the loss of productive areas due to *Bromus tectorum* invasion represents a loss of 350–370 million dollars/year (Gurusiddaiah et al. 1994).

Almost none of the studies we found focus on the potential role of these sites as invasion epicentres. However, Barnswell and Dwyer (2007) and Rahman et al. (2013) reported higher quantities of introduced plant species within a landfill than in the surrounding area, and concluded that the surroundings do not contribute to the flora present at this site. This suggests that dumps may sustain invasive species populations, probably originating from propagules arriving with the waste, particularly derived from food and garden plants, and thus may act as a beach head for the invasion process. In an era with a pressing need of achieving sustainable food security (West et al. 2014), the strategy of reducing food waste would additionally help reduce the synergy between landfills and introduced species.

Rubbish dumps can act as potential invasion epicentres, providing invasive species propagules to the surroundings, but also to distant sites through different pathways. The presence of seed banks of non-native species can favour the arrival of invasive species into the surrounding landscape (Kim and Lee 2005), particularly from the Asteraceae and Poaceae families. This may be favoured by the high emission of CO_2 and nitrogen compounds, adding to the high temperatures present at these sites, which can produce gigantism and rapid encroachment of plant species (Ciesielczuk et al. 2015). In addition, dumps can favour the invasion process at distant sites through compost carrying viable seeds (Grundy et al. 1998). This compost is usually produced with bio waste discarded at these sites (Andersen et al. 2010; Pietsch 2005) and then used in agricultural and gardening practices, beginning new invasions far away from dump sites.

In summary, dumps can sustain populations of introduced and invasive species around the world, which produce multiple economic, environmental and health impacts. Dumps may favour the spread of these species to the surrounding landscape, but also to distant sites. It is thus important to consider these facts when evaluating potential management recommendations, but also in the design of future research on the subject. Additional questions to be addressed in future studies include for instance: Are there differences in biomass and number of introduced plant species according to the type of waste management performed? Are there introduced families and species more adapted to survival and spread in these sites? At which rate do plants dispersed from dumps naturalize and invade surrounding environments? Can the presence of introduced plant species in these sites favour the spread of other introduced species like insects, rodents or species from higher trophic levels? In the current scenario of waste overproduction, where it is expected that the number of rubbish dumps and landfills will strongly increase (Hoornweg et al. 2013), it is important to specifically evaluate the role of these areas as plant invasion epicentres to improve policy related to waste management.

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