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Review

Mitigating the anthropogenic spread of bee parasites to protect wild pollinators

Dave Goulson *, William O.H. Hughes

School of Life Sciences, University of Sussex, Falmer, Brighton BN1 9QG, United Kingdom

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ABSTRACT

Bees naturally suffer from a broad range of parasites, including mites, protozoans, bacteria, fungi and viruses. Some appear to be host-specific, but most appear able to infect multiple bee species, and some are found in insects outside of the Hymenoptera. The host range, natural geographic range and virulence in different hosts are poorly understood for most bee parasites. It is of considerable concern that the anthropogenic movement of bees species for crop pollination purposes has led to the accidental introduction of bee parasites to countries and continents where they do not naturally occur, exposing native bees to parasites against which they may have little resistance. In at least one instance, that of the South American bumble bee *Bombus dahlbomii*, this has led to a catastrophic population collapse. The main bees that are moved by man are the western honeybee, *Apis mellifera*, and two species of bumble bee, the European *Bombus terrestris* and the North American *Bombus impatiens*. We propose a range of mitigation strategies that could greatly reduce the risk of further impacts of the commercial bee trade on global bee health, including stricter controls on international movement of bees and improved hygiene and parasite screening of colonies before and after shipping.

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* Corresponding author.
E-mail address: d.goulson@sussex.ac.uk (D. Goulson).

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1. Introduction

The ecological and economic importance of bees and other insect pollinators is well known. Although the major human food crops (rice, wheat, barley, maize) are not reliant on them, insect pollinators benefit the production of 75% of crop species, providing a global pollination service estimated to be $215 billion p.a. (Gallai et al., 2009). The importance of bees for the production of many crops has led to the domestication and management of some species. The best known and most widespread managed pollinator is the western honey bee *Apis mellifera*. However, bumble bees (*Bombus* spp.) are more efficient pollinators of certain crops and several species of bumble bee are now produced commercially in factories for the pollination of a variety of fruit and vegetable crops in greenhouses, polytunnels and open fields, with over a million bumble bee colonies p.a. being produced and exported on a global scale. For a similar reason, certain solitary bees are also produced commercially for crop pollination, notably the alfalfa bee (*Megachile rotundata*) and various mason bees (*Osmia* spp.) (Delaplane et al., 2000).

The devastating impacts that non-native organisms have wreaked on native ecosystems surely ought to have taught us a lesson as to the risks of allowing release of alien species. The introduction of Nile perch to Lake Victoria, and the introduction of cane toads, prickly pear, rabbits, foxes, and cats amongst numerous others to Australia are well-known examples, but these are just the tip of the iceberg; for example Australia alone has nearly 3000 non-native species established in the wild (Alexander, 1996). A strong case can be made that alien species represent the biggest threat to global biodiversity after habitat loss (with climate change perhaps set to displace both) (Pimm et al., 1995; Ricciardi, 2007). The risks posed by non-native species have long been widely understood (Vila et al., 2010), and are reflected in various legal restrictions on the importation of such species to most countries (Pyke et al., 2008). However, there appears to have been a reluctance to regard bees as potential invasive species, presumably because of their widely-appreciated beneficial role as pollinators (Goulson, 2003). Hence deliberate and sometimes indiscriminate transportation and release of honeybees, bumble bees and various other bee species to new countries and regions began thousands of years ago and continues to recent times. As we shall see, this global transportation of bee species may pose one of the biggest threats to bee diversity worldwide, threatening the vital ecosystem service that they provide to crops and wildflowers. Mitigating this threat whilst still maintaining the valuable pollination services that managed bees provide is the challenge facing conservationists, policy makers, farmers and bee producers today. It is likely that some of these stakeholders are not even aware of this threat at present.

This paper is not a systematic review in that the studies included were not included based on preselected criteria. They were instead included based on the authors' knowledge of the subject area and online searches of Web of Science and Google Scholar.

2. A brief chronology of bee introduction events

The honeybee *A. mellifera,* thought to be native to Africa, western Asia, and southeast Europe, was domesticated in pre-history and has since been deliberately introduced to every continent except Antarctica (Michener, 1979). Some of the most significant landmarks in their spread include their shipment to the Americas in about 1620 (Buchmann and Nabhan, 1996), to Australia in 1826 (Doull, 1973) and to New Zealand in 1839 (Hopkins, 1911). The honeybee is now arguably the most widespread species on Earth, after man. Four bumble bee species, *Bombus hortorum*, *Bombus terrestris*, *Bombus subterraneus* and *Bombus ruderatus*, were introduced from the UK to New Zealand in 1885 and 1906 to pollinate red clover (Hopkins, 1914). Numerous *Megachile* spp. and *Osmia* spp. were introduced to North America from Europe and Asia during the twentieth century, often for reasons that are unclear (reviewed in Goulson, 2003). *B. ruderatus* was introduced from the naturalized population in New Zealand to Chile in 1982 and 1983 for pollination of red clover (Arretz and Macfarlane, 1986) and by 1994 had spread to Argentina (Abrahamovich et al., 2001).

In the mid 1980's, commercial rearing of the European species *B. terrestris* began, primarily to supply pollination for glasshouse tomatoes, and this quickly became a global trade (Velthuis and van Doorn, 2006) which sparked a new wave of bee introductions. In the early 1990's *B. terrestris* became established in Japan, having escaped from commercial glasshouses (Inoue et al., 2008; Nagamitsu et al., 2007). The species arrived in Tasmania in 1992 from New Zealand, though the mechanism of transport remains unknown (Buttermore, 1997; Stout and Goulson, 2000). In 1998, *B. terrestris* was deliberately introduced to Chile (from Europe rather than New Zealand or Tasmania), despite the presence of native *Bombus* species. It has since spread to Argentina and continues to advance both north and south in South America (Schmid-Hempel et al., 2014). The extent of exportation of *B. terrestris* from Europe is considered commercially sensitive and so is hard to establish, but it is likely that they are currently being exported to many other countries where they have not yet become established. In North America the commercial bumble bee trade focussed on *Bombus impatiens*, a species native to the east of the continent but which was moved outside its native range, as far afield as Mexico where it has established in the wild (Vergara, 2008).

These introductions pose a number of risks, including: competition with native species; hybridisation with native species; disruption of plant–pollinator interactions; improved pollination of non-native plants; and the spread of parasites to native species (reviewed in Goulson, 2003). This last threat is arguably the most serious. Emergent parasites represent one of the most significant threats to biodiversity and spillover of parasites from introduced organisms to native species can be particularly damaging, either because novel species or strains of parasite are introduced or because the increased density of hosts leads to higher prevalence (Daszak et al., 2000; Cunningham et al., 2003).

3. An overview of bee parasites

Bees naturally suffer from a broad range of parasitoids and parasites, the later including protozoans, fungi, bacteria and viruses. Because of their commercial importance, by far the majority of research has focussed on those associated with honey bees and to a lesser extent with bumble bees, with very little known about the parasites of other wild bee species (Goulson, 2003). Some bee parasites, such as Deformed Wing Virus (DWV) and *Nosema ceranae*, have broad host ranges and are able to infect both honey bees and bumble bees whilst others, such as *Crithidia bombi* or *Paenibacillus larvae*, are seemingly specific to one or the other (Genersch et al., 2006; Genersch, 2010; Graystock et al., 2013a). Natural parasites undoubtedly play an important but poorly-understood role in influencing the population dynamics of their bee hosts, but invasion by non-native parasites has the potential to lead to more dramatic effects since we would expect their novel hosts to have little resistance (Daszak et al., 2000; Rosenkranz et al., 2010). The risk is likely to be greatest when the natural host(s) of the parasite is closely