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POLICY DIRECTION

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Coordinated species importation policies are needed to reduce serious invasions globally: The case of alien bumblebees in South America

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Abstract

1. The global trade of species promotes diverse human activities but also facilitates the introduction of potentially invasive species into new environments. As species ignore national boundaries, unilateral national decisions concerning species trade set the stage for transnational species invasion with significant conservation, economic and political consequences.
2. The need for a coordinated approach to species importation policies is demonstrated by the introduction of two bumblebee species into Chile for crop pollination, despite Argentina banning commercial importation of alien bumblebees based on expert opinion. The large garden bumblebee, *Bombus ruderatus*, was first introduced in 1982, and the buff-tailed bumblebee, *Bombus terrestris*, has been continually introduced since 1997 as part of the burgeoning bumblebee trade. Both species have subsequently invaded southern South America. Today, the consequences of the growth of the bumblebee trade for agricultural pollination ranks among the top 15 emerging environmental issues likely to affect global diversity.
3. Documented impacts of these invasions include the severe decline and local extinctions of the sole native Patagonian bumblebee, *Bombus dahlbomii*, pathogen transmission, flower damage and nectar robbing of native and cultivated plants.
4. *Policy implications*. The South American bumblebee invasions portrayed here should alert governments to the unintended consequences of the booming international bee trade. More broadly, this case demonstrates that one country's importation decisions can have policy implications for its neighbours without consultation. Regrettably, coordinated international measures to prevent species invasions are seldom considered in South America or elsewhere, despite existing legal frameworks. The bumblebee case and others provide stark evidence of the

pressing need for coordinated specific and general international policies concerning global species trade and their implementation.

KEYWORDS
Argentina, *Bombus terrestris*, Chile, convention on biological diversity, pathogens, pollination services, pollinator trade, species invasion

1 | INTRODUCTION

Invasive species ignore international boundaries, even those established along major geographical barriers. Given the many pernicious conservation, social and economic problems caused by invasive species (Bradshaw et al., 2016; Pejchar & Mooney, 2009), unilateral decisions by one country allowing importation of alien species can instigate international conflict and have profound impacts in neighbouring countries if those species become invasive. The increase in species introductions and the ensuing risk of biological invasions during recent decades have been fostered by the acceleration in global trade (Hulme, 2009; McNeely, 2006). To combat these risks, several multinational treaties and coordinated actions have been developed to limit species invasions and mitigate their consequences (Shine, Williams, & Gündling, 2000; Appendix S1). For instance, the European Union recently established clear guidelines (EU Regulation 1143/2014) to prevent the introduction of non-native invasive species and control their spread, as well as promoting the implementation of early-warning and surveillance systems and rapid eradication measures (Tollington et al., 2017). Nevertheless, many countries, especially those with developing economies, are infrequent participants in coordinated international measures to prevent species invasions, owing, in part, to limited social awareness of the associated problems (Nuñez & Pauchard, 2010; Speziale, Lambertucci, Carrete, & Tella, 2012).

The problem of the movement of invasive species across borders is particularly relevant on continents divided into many neighbouring countries and for countries that share extensive borders. For example, Chile and Argentina are divided by the world's third-longest international boundary (about 5,300 km), which extends mostly along the summits of the Andes and across the Magellanic Strait. Despite these geographical obstacles, these borders have been permeable to numerous invasive species introduced into one country or the other (Fuentes, Ugarte, Kühn, & Klotz, 2010; Jaksic, Iriarte, Jiménez, & Martínez, 2002). One example of invasive border crossing is the North American beaver (*Castor canadensis*), introduced on the Argentine side of Tierra del Fuego Island to establish a fur industry. After crossing the Magellanic Strait, it expanded its range into continental Chile (Graells, Corcoran, & Aravena, 2015). Along its path, this invader caused extensive tree mortality in South American beech forests both directly, via tree cutting, and indirectly, via its dam construction and resulting flooding (Baldini, Oltremari, & Ramírez, 2008). Other invaders, such as the German wasp (*Vespula germanica*), followed a true trans-Andean path to spread from Chile to Argentina (reviewed in Farji-Brener & Corley, 1998). Most of these introductions in southern South America occurred during the late 19th and first half of the 20th century, when the importation of wild or managed alien species for economic, aesthetic, or cultural purposes was unregulated and even officially promoted in some cases (Simberloff, Relva, & Nuñez, 2002).

2 | ALIEN BUMBLEBEE IMPORTS AND INVASIONS IN SOUTH AMERICA

Bumblebees (*Bombus* spp.) are important pollinators in most temperate regions, and since the 1980s, the commercial trade of bumblebee colonies has burgeoned to satisfy increasing demand for pollination services in open-field and greenhouse crops (Goulson, Nicholls, Botías, & Rotheray, 2015). In many cases, imported bumblebees have escaped management and established as alien species in the wild, becoming invasive in some cases (Evans, 2017; Goulson, 2010; Morales, 2007). Indeed, the invasion of bumblebees associated with the growth of the bumblebee trade for agricultural pollination ranks among the top 15 emerging environmental issues likely to affect global diversity (Sutherland et al., 2016).

Chile and Argentina clearly illustrate the transnational consequences of bumblebee invasion. Chile has participated in the bumblebee trade, allowing the importation of two alien bumblebee species, *Bombus ruderatus* and *Bombus terrestris*, for crop pollination (Ruz, 2002). In contrast, neighbouring Argentina has repeatedly rejected requests to import alien bumblebees for commercial use (Velozo, 2013; Velthuis & Van Doorn, 2006). Both species have now invaded Argentina with widespread negative impacts (e.g. Arbetman, Meeus, Morales, Aizen, & Smagghe, 2013; Morales, Arbetman, Cameron, & Aizen, 2013; Sáez, Morales, Ramos, & Aizen, 2014; Schmid-Hempel et al., 2014).

Long-tongued *B. ruderatus*, currently a declining species in parts of its native European range (Kosior et al., 2007), was first introduced into New Zealand more than a century ago. From there, about 300 queens were released at two sites in south-central Chile in December 1982 and November 1983 for red-clover pollination (Arretz & Macfarlane, 1986). Subsequently, this bee became invasive and now its range extends more than 400 km southward along both sides of the Andes. Coincidentally, populations of *Bombus dahlbomii*, the only bumblebee native to southern South America, declined in NW Patagonia (Morales et al., 2013).

The introduction and subsequent spread of this alien bee was just the preamble of a more serious and pervasive bumblebee invasion. In

FIGURE 1 Alien *Bombus terrestris* robbing flowers of native *Fuchsia magellanica* in a temperate forest in southern South America. Intensive nectar robbing of long tubular flowers is one of several negative impacts of this invasive species. Photo credit: J. Combs

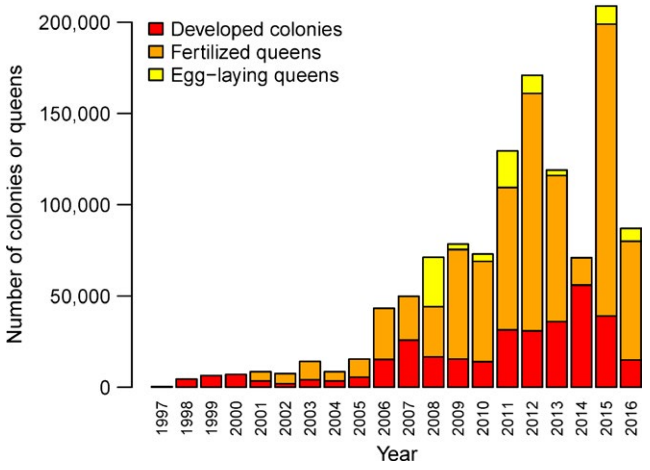

FIGURE 2 Numbers of colonies and inseminated queens of *Bombus terrestris* imported into Chile since it was first introduced in 1997, as of June 2016. Data from the Servicio Agrícola Ganadero of Chile (SAG, 2016; see Aizen et al., 2018 for the complete dataset)

1997, colonies of European, short-tongued *B. terrestris*, reared commercially in Belgium and Israel, were imported into several localities in northern and central Chile for the pollination of greenhouse tomatoes (Montalva, Dudley, Arroyo, Retamales, & Abrahamovich, 2011; Ruz, 2002). During 1998, a field trial of the efficacy of *B. terrestris* for avocado pollination allowed its establishment in the wild (Figure 1). This event sparked one of the most extensive invasions in recent times. In 2006, queens and workers were first observed on the Argentine side of the Andes near San Martin de los Andes, in Lanín National Park (Torretta, Medan, & Abrahamovich, 2006). During the last decade, this species expanded its new South American range to the southern-most tip of the continent in Tierra del Fuego (more than 2,000 km from the original introduction sites) and from the Pacific to the Atlantic coasts across the Patagonian steppe (Morales et al., 2016; Rendoll-Carcamo, Contador, Saavedra, & Montalva, 2017). Niche models predict the spread of *B. terrestris* northward along the Andes to Bolivia and Perú, as well as east to the Argentine Pampas and then northeastward into Uruguay and southern Brazil along the Atlantic coast (Acosta, Giannini, Imperatriz-Fonseca, & Saraiva, 2016). In addition to southern South America, this bee species has also invaded Japan, New Zealand and Tasmania (Goulson, 2010; Morales, 2007).

Despite its invasiveness, *B. terrestris* is still being imported into Chile. Unlike its European relative, *B. ruderatus*, which was introduced in small numbers during only two consecutive years, *B. terrestris* has been continuously and increasingly introduced into Chile since 1997, totalling about 1,200,000 developed colonies and inseminated queens as of June 2016 (Figure 2). More than 200,000 colonies and queens were imported from bumblebee factories in Belgium, Slovakia and Israel during 2015 alone. Despite growing doubts about the effectiveness of *B. terrestris* as an avocado pollinator (Fried, 1999), it is now increasingly used in Chile for blueberry pollination in open fields (Vieli, Davis, Kendall, & Altieri, 2016), in addition to its regular use for pollination of tomato and other crops in greenhouses (Estay, 2007; Montalva et al., 2011).

Interestingly, at least one colony of *B. terrestris* was introduced in Argentina in the early 1990s for experimental pollination trials, being held for quarantine at the headquarters of INTA, the Argentine National Agriculture Institute, in Castelar, Buenos Aires Province. However, following the advice of entomologists and bumblebee specialists, this colony was destroyed and introduction of this species was not pursued further (A. Abrahamovich, personal communication, 3 July 2017). In 2006, a request to import commercial colonies of the North American species *Bombus impatiens* from the United States to Argentina was rejected by the National Service for Agrifood Health and Quality of Argentina (SENASA) (Ref. CUDAP EXP-S01-0059495/2006 in SENASA Note DNPV No. 408, 16 June 2017, to CLM; see also http://www.senasa.gob.ar/cadena-vegetal/hortalizas/produccion-primaria/control-biologico/listado-de-agentes-evaluados-0). This decision was based on a risk analysis led by SENASA that included technical advice from insect, pest and bumblebee specialists (e.g. Morales & Aizen, 2006a). The successive rejections of the introduction of non-native bumblebees in Argentina led to the industrial rearing and commercialization of *Bombus atratus*, a bumblebee native to South America north of Patagonia, for crop pollination (http://www.brometan.com.ar/NewSite/pagina.php?slug=bombus-atratus, see also Velozo, 2013). These events resulted in the establishment and invasion of southern South America by two alien bumblebees.

3 | PRESENT AND POTENTIAL FUTURE IMPACTS OF A MASSIVE BUMBLEBEE INVASION

Invasive bees can be highly damaging to the environment (Goulson, 2003, 2010). In particular, the invasion of *B. terrestris* has caused

severe impacts on natural and agricultural ecosystems of southern South America. First, *B. terrestris* caused the decline of the native *B. dahlbomii*, directly or indirectly, in all the regions not previously invaded by *B. ruderatus*, including southern Patagonia and central Chile (Morales et al., 2013; Schmid-Hempel et al., 2014; Smith-Ramírez et al., 2014). Today, *B. dahlbomii* has been extirpated from many localities, prompting its recent recognition as an endangered species (Morales et al., 2016). Second, *B. terrestris* also caused the decline of the first introduced bumblebee, *B. ruderatus*, most probably via pathogen transmission. Introduced *B. terrestris* likely brought and aided the spread of internal protozoan parasites and tracheal mites to southern South America, infecting *B. ruderatus* and remaining populations of the native bumblebee (Arbetman et al., 2013; Arismendi, Bruna, Zapata, & Vargas, 2016; Schmid-Hempel et al., 2014). Third, the invasion of *B. terrestris* might be boosting the spread of alien plants (Morales & Aizen, 2006b). For instance, the pollination and reproductive success of scotch broom (*Cytisus scoparius*) in Nahuel Huapi National Park, Argentina, seem to have been favoured by this invasive bumblebee (Morales, Sáez, Arbetman, Cavallero, & Aizen, 2014). Fourth, high abundance of *B. terrestris* has increased nectar robbing and flower damage of both native and cultivated flowers. For example, between 80% and 100% of the flowers of hummingbird-pollinated *Fuchsia magellanica* can be robbed in sites invaded by *B. terrestris* (Figure 1), whereas no nectar robbing has been recorded in non-invaded sites (Combs, 2011). Nectar robbing of raspberry flower buds by *B. terrestris* also decreases nectar availability for foraging honeybees, with potential effects on honey production (Sáez, Morales, Garibaldi, & Aizen, 2017). Furthermore, raspberry fruit size in commercial fields in NW Patagonia has decreased as a consequence of increased style breakage associated with excessively frequent visitation by *B. terrestris* (Sáez et al., 2014). Despite clear and mounting evidence of severe environmental and agricultural costs of this bumblebee invasion, the economic benefits of massive importation of *B. terrestris* for Chilean farmers are unclear and have yet to be assessed. For instance, deployment of commercial colonies of *B. terrestris* to pollinate open-field crops in southern Chile is becoming a common practice, even though crop fields seem to be already saturated with wild colonies of this invasive bee (Figure S1).

Chilean regulations continue to allow importation of thousands of colonies of *B. terrestris* each year (Figure 2), fuelling the ongoing invasion of this species despite clear evidence of negative impact. In particular, the spread of pathogens from *B. terrestris* to both native bees and managed honeybees (Arbetman et al., 2013; Maharramov et al., 2013; Plischuk, Meeus, Smagghe, & Lange, 2011; Schmid-Hempel et al., 2014) implies that continued importation of this alien bumblebee risks introducing new diseases that remain undetected with regular sanitary screening (Graystock et al., 2013). As a consequence, consideration of biological control or management practices in neighbouring countries, such as Argentina, to lessen this risk will be futile as long as imported colonies continue to be introduced into Chile.

4 | THE SOUTH AMERICAN BUMBLEBEE CASE IN THE CONTEXT OF OTHER TRANSNATIONAL INVASIONS

The invasive-species literature documents many examples of deliberate introductions of alien species into one country and the subsequent spread to adjacent countries, sometimes with devastating impacts on recipient ecosystems. For example, the African honeybee, *Apis mellifera scutellata*, was introduced to Brazil during the 1950s for hybridization with traditionally managed European subspecies to produce managed honeybee colonies better adapted to tropical conditions. However, the African honeybee rapidly established in the wild and spread throughout the Americas, from central Argentina to southern United States. The African honeybee is now the dominant flower visitor in a variety of habitat types and is impacting the pollination of wild plants and crops (reviewed in Morales, Sáez, Garibaldi, & Aizen, 2017).

Other examples of transnational invasions include several mammalian carnivores, such as the North American mink, *Neovison vison*, and raccoon, *Procyon lotor*, and the Asian raccoon dog, *Nyctereutes procyonoides*. All of these species were introduced into Europe for their fur or as pets and have since invaded at least 10 European countries (Genovesi, Bacher, Kobelt, Pascal, & Scalera, 2009). For instance, *c.* 9,100 individuals of the Ussuri raccoon dog (*N. p. ussuriensis*) were introduced into European regions of the former Soviet Union between 1929 and 1955, invading neighbouring countries and currently reaching Western Europe. The raccoon dog is now widespread in Northern and Eastern Europe and has become the most common medium-sized carnivore in Finland. Throughout its alien range, it is suspected of negatively impacting the native fauna through predation, competition and pathogen transmission (Kauhala & Kowalczyk, 2011).

Unlike these and other transnational invasive species, the ongoing invasion of South America by *B. terrestris* has several distinctive, troubling features that make it an important global example (IPBES, 2016). First, this invasion is perpetuated by ongoing intentional systematic and large-scale importation of propagules, rather than resulting from incidental "trial and error" introduction (Figure 2). Second, this invasion is commercially driven, supported both by companies that profit financially from exportation of a potentially invasive species and by an agricultural industry that assumes yield benefits from importation of a demonstrated invasive species (Velthuis & Van Doorn, 2006). Third, although more studies are needed, the biological invasion portrayed here has several well-documented, rather than presumed, negative environmental impacts. Therefore, the general lessons of this case should concern policy makers globally and alert governments about the costs of importing alien bumblebees or any other pollinator.

5 | POLICY IMPLICATIONS AND RECOMMENDATIONS

The case of *B. terrestris* illustrates that permits granted to import species in one country will likely impact other neighbouring countries.

A coordinated approach is urgently required to avoid and halt transnational species invasions with potential and realized conservation, economic and even political consequences. In particular, policies concerning the importation of potentially invasive species must be established regionally among neighbouring countries with suitable habitat. To be effective, such policies should be founded on detailed scientific knowledge of the relevant biology and ecology of the species and their likely environmental impacts after introduction. Similarly, the control or eradication of invasive alien species needs to be approached in a combined effort by all countries involved, as unilateral investment and action will be futile. Coordinated risk assessments and the application of the precautionary principle (e.g. Moore & Gross, 2012) are essential components of a regional policy aimed at avoiding transnational invasions.

Regulation of managed pollinator trade is one of the recent recommendations adopted by the Conference of the Parties (COP, 2016) of the convention on biological diversity (CBD), signed by 196 countries, including Argentina and Chile and countries from which *B. terrestris* colonies are exported. This recommendation is based on information from the Intergovernmental Platform on Biodiversity and Ecosystem Services assessment on pollinators (IPBES, 2016). It also falls within the scope of the objective of preventing the introduction and establishment of invasive species highlighted in the CBD's Strategic Plan for Biodiversity (Dicks et al., 2016). Therefore, there is increasing awareness that the rapid growth in the transnational trade of pollinators, and of bumblebees in particular, merits international attention, because of its global environmental consequences (Sutherland et al., 2016).

Policy makers abroad have already acknowledged the negative impacts of importing *B. terrestris* colonies. For example, national regulations prevent the introduction of this species into the United States (Goulson, 2010) and Australia (Moore & Gross, 2012). Japan listed *B. terrestris* as a major invasive species in 2006, and further introductions are not allowed without permission from the Japanese Ministries of Agriculture and the Environment (Reade, Goka, Thorp, Mitsuhata, & Wasbauer, 2016). Other studies have raised concerns about the consequences for the United States of introducing this alien bumblebee into Mexico and Canada, indicating the need for a coordinated tri-national strategy to prevent the importation of this and other potentially invasive species (Winter et al., 2006). A project of the Global Environment Facility hosted by the Chilean Ministry of the Environment recently included *B. terrestris* among alien invasive species that should be controlled (http://gefespeciesinvasoras.cl/abejorro-europeo-o-abejorro-comun/). Unfortunately, this recommendation has not led to banning or regulating ongoing importation of *B. terrestris* into Chile, even though the methods for rearing the native, endangered *B. dahlbomii* in captivity for use as a greenhouse crop pollinator have been developed by the Chilean Institute of Agriculture (INIA; Estay, 2007). On the other hand, *B. terrestris* has not been listed yet as an invasive species in Argentina, despite scientific evidence certifying its invasive status and impact there (Arbetman et al., 2013; Morales et al., 2013; Sáez et al., 2014; Schmid-Hempel et al., 2014).

Despite the negative impacts arising from the introductions of *B. ruderatus* and *B. terrestris*, coordinated actions for preventing further invasions in southern South America could be implemented in the near future. Both Chile and Argentina have regulations regarding invasive species, and a bi-national treaty on the environment was signed in 1991 that could provide a legal framework for such coordination (Appendix S2). This treaty specifically compels each party to refrain from unilateral actions that could cause environmental prejudice to the other. Although this treaty does not specifically refer to invasive species or their impact, it promotes coordinated actions on different issues such as climate change, use of shared water resources and preservation of biological diversity (https://www.leychile.cl/Navegar?idNorma=8593&idVersion=1993-04-14). In practice, Chile and Argentina have begun to coordinate efforts to eradicate the North American beaver from Tierra del Fuego Island (Sanguinetti et al., 2014; Appendix S2). A more advanced step forward would be the implementation of joint risk assessments prior to accepting any importation of exotic species, an approach adopted recently within the European Union (Appendix S1). Other countries in temperate South America, such as Uruguay and Brazil, could also participate in this multinational agenda. In turn, this regional agenda could be embedded within a global regulatory framework on species trade. In the case of managed pollinators, this should involve both countries with prospects to, or already importing them, and the countries hosting companies that rear them commercially. The bumblebee story reported here provides stark evidence of the pressing need for such coordinated international efforts to objectively evaluate the economic costs and benefits and potential ecological impacts of introducing novel organisms.

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AUTHORS' CONTRIBUTIONS

M.A.A. led the writing of the manuscript. All authors conceived this project, contributed substantially to the drafts and gave final approval for publication.

DATA ACCESSIBILITY

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.nj54m (Aizen et al., 2018).

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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