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Mini Review

Bombus terrestris, pollinator, invasive and pest: An assessment of problems associated with its widespread introductions for commercial purposes

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Abstract
Bombus terrestris L. (Apidae) is a native of temperate Eurasia and has been moved around the world since the 1800s. Dispersal of *B. terrestris* gained momentum in the 1980s when bees were reared artificially in Europe and supplied commercially for greenhouse pollination services. Very early after its commercial introduction, it was recognized that this species is invasive, can island hop to new locations and may disturb local ecosystems. The invasive characteristics of *B. terrestris* are: high migration ability, early seasonal emergence, high adaptability under adverse climatic conditions in various habitats, generalist or polylectic foraging strategies, enabling it to work a wide variety of flowers for resources, foraging over wide distances, a thermoregulatory metabolism that enables it to withstand low temperatures, no natural enemies to check population growth in areas outside its natural range, and it may develop two reproductive cycles in a year (bivoltine) in a newly colonized area. In addition, commercial bees produce more gynes and are better competitors than the local conspecific populations and may replace them in the likely event of an escape. The documented evidence on invasive impact of *B. terrestris* on natural ecosystems includes: negative interactions with local bee fauna, competition for nest sites with, and genetic contamination of, local *Bombus* spp., spread of parasites and pathogens and negative interactions with plant reproductive capacity. We discuss the possible measures that must be taken to minimize the *B. terrestris* invasion on local as well as on global levels.

Key words: *Bombus terrestris* L.; invasive species

WHAT IS *BOMBUS TERRESTRIS* AND WHY IT IS USED IN AGRICULTURE?

Bombus terrestris is a large (10–28 mm long), short-tongued (4.5–6.5 mm long) social bee of temperate Eurasia. Its general biology is well known (Sladen, 1912; Free and Butler, 1959; Alford, 1975; Goulson, 2003a). It can withstand adverse climatic conditions and, by its thermoregulatory abilities, can be active even on cloudy days when air temperatures are below 10°C (Heinrich, 1979) and when European honeybees (*Apis mellifera*) are unable to leave their hives.

B. terrestris has a great capacity for learning and is able to manipulate various types of flowers, including those with intricate systems (Stout et al., 1998). It visits flowers rapidly and may visit 20 to 50 small and simple flowers per minute and on red clover between 20 and 35 flowers per minute (Free, 1993). It is an efficient pollinator of a wide variety of native plants and of crops (Velthuis and Cobb, 1991; Free, 1993; Proctor et al., 1996; Velthuis and van Doorn, 2006) and is now important as a managed pollinator in greenhouses (Table 1). Even so, its short proboscis restricts the types of flowers that it can access legitimately and so, to extract deeply hidden nectar in tubular flowers, it often resorts to nectar robbing (Inouye, 1980) by piercing the corolla tube. Hasselrot (1952) pioneered techniques for rearing bumblebees, including *B. terrestris* and by the early 1980s methods for artificially rearing this species were developed in the

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Table 1. Advantages of *B. terrestris* as a commercial pollinator

Character	Reference
Highly efficient in open air crops	Velthuis and van Doorn (2006) Calzoni and Speranza (1998), Italy, open plum orchard Meynie and Bernard (1997), France, sunflowers in cages Porporato et al. (1995), Italy, green peppers, greenhouse Willmer et al. (1994), Scotland, raspberries, open field Chen and Hsieh (1996), Taiwan, tomatoes, greenhouse Free (1993), Europe and New Zealand, red clover, open fields Porporato et al. (1993), Italy, tomatoes, greenhouse
Available active all around greenhouse conditions	Ravestijn and van der Sande (1991); van Heemert et al. (1990); van der Eijnde and de Ruijter (1991); van der Eijnde et al. (1991); Abak et al. (1997)
More economic than hand-pollination	Tomatoes, Banda and Paxton (1991); Abak et al. (1995) Raspberries, Willmer et al. (1994) Eggplants, Abak et al. (1995) Peppers, Abak et al. (1997)
Highly efficient in open air crops	Almonds, avocados, Ish Am et al. (1998) Red clover, Europe, New Zealand, Free (1993)

Netherlands (Röseler, 1985) to the extent that today *B. terrestris*' colonies are a "ready made shelf product", easily suitable for marketing and transport to any given greenhouse or habitat (van der Eijnde et al., 1991; Free, 1993; de Ruijter, 1997; Velthuis and van Doorn, 2006; Winter et al., 2006, Kwon, 2008).

The primary crop of interest for pollination by bumblebees world-wide is greenhouse tomato (*Solanum lycopersicum*, Kevan et al., 1991; Dogterom et al., 1998; Morandin et al., 2001a, b, c; Velthuis and van Doorn, 2006; Winter et al., 2006 and references given to *B. terrestris* below). As for many plants in the Solanaceae, pollination is effected through buzz-pollination by pollen collecting bees (Buchmann, 1983). Tomato flowers do not secrete nectar. The bees, foraging from commercially provided hives, visit the flowers and gather pollen. They hang upside-down from the flowers by gripping the poricidal anthers with their mandibles and in that position they vibrate their flight muscles, which makes an audible buzz and releases the pollen through the pores of the anthers onto their venters. The bees groom the pollen into their corbiculae for transport back to the hive. It is important to note that in North America *B. terrestris*' imports are not allowed and native species of *Bombus* are used commercially with equal success (Kevan et al., 1991; Meisels and Chaisson, 1997; Dogterom et al., 1998; Morandin et al., 2001a, b, c; Winter et al., 2006).

The combination of the adaptability of *B. terrestris* and the available technology to mass-produce colonies cheaply, has made this species a commercially valuable pollinator and, in some situations, a substitute for the less flexible honeybee (de Ruijter, 1997; Velthuis and van Doorn, 2006). *B. terrestris* is an efficient as well as economic pollinator of various crops under greenhouse and open-field conditions (Table 1). There is also evidence that product quality is improved by pollination with *B. terrestris* (Table 1).

This behavior may detract from its value as a pollinator of some crops (Free, 1993). *B. terrestris* was imported into New Zealand in the 1880s to service seed production of red clover. It has since become naturalized (Montgomery, 1951; Donovan and Weir, 1978; Dunning, 1986). The characteristics of this bee, both natural and manageable, contribute to its recent and rapid distribution internationally (van der Eijnde and de Ruijter, 1991; de Ruijter, 1997; Griffiths, 2004; Velthuis and van Doorn, 2006; Winter et al., 2006). The proven value of *B. terrestris* for pollination seems to have resulted in little consideration to the development of parallel technologies for pollinators indigenous to places where *B. terrestris* is not native, except in Canada and the USA (see references above). In Australia native blue-banded bees (*Amegilla* spp.) are being developed for glasshouse pollination

(Bell et al., 2006; Hogendoorn et al., 2006, 2007) although horticulturists have been pressing to introduce *B. terrestris* to Australia for some time (Goodwin and Steiner, 1997; Cooke, 2001; Carruthers, 2003, 2004; Griffiths, 2004). The bans against import of *B. terrestris* into Canada and the USA recognize the well-known risks associated with imports of exotic species, their escape, invasive and pest potentials (Winter et al., 2006). Calls have been made by the international scientific community for all nations to extend the Canadian, American, and Malaysian approaches to imports of pollinators (e.g. Kang and Karim, 1982; Resolution at Apimondia 1997).

THE BIOTIC POTENTIAL FOR *BOMBUS TERRESTRIS* TO SPREAD?

Human beings have changed the world by purposely or accidentally introducing animals and plants far beyond their natural ranges. Even so, many human attempts to introduce species to parts of the world where they do not occur naturally have failed. In other instances, human care is required for species to persist outside their ranges. Those species that have become naturalized may be beneficial, especially to agroecosytems (e.g. various biocontrol agents and some pollinators (Batra, 1984), but more often they are notorious as pests. For example, there are many examples of the long term damage caused to Australian ecosystems from the introduction of exotic species that were initially promoted as essential and beneficial for the economy (Low, 1999). Many such species were introduced without adequate research into their potential impacts and subsequently they became serious pests (e.g. rabbits, foxes, cane toads, prickly pear, Low, 1999). It is usually impossible to eradicate established populations of introduced species, and difficult and costly to control their populations, thus it is important that thorough impact assessments are carried out in relation to proposals to introduce exotic species. For pollinators, the Malaysian example of the careful importation of the oil palm pollinating weevil from West Africa serves as exemplary (Kang and Karim, 1982).There are various international protocols, rules, treaties, and the like that are intended to prevent repetition of past mistakes of intentional, but ill-considered, even illegal, introductions (including of pollinators and their diseases and unintentional introductions through carelessness).

There have been various cautions voiced from the scientific community about moving pollinators beyond their native ranges (Crane, 1982; Kevan, 1986, 1999, 2003; Goulson, 2003b; Thorp, 2003). Organisms that can become naturalized share some characteristics. Those that become pests variously compete with other native organisms, consume or otherwise cause destruction of native or farmed organisms, become threats to human well-being, or are nuisances.

Does *B. terrestris* have characteristics that allow it to become naturalized easily outside its natural range? Can *B. terrestris* become a pest, as Dafni (1998) has suggested?

B. terrestris has various characteristics that prove its capacity to be a successful invasive species following its introduction, namely:

A high dispersal ability is characteristic of invasive and pestiferous species

This trait, when accompanied with highly invasive abilities even from very few founders (Allen et al., 2007; Schmid-Hempel et al., 2007), means that there is a high potential for rapid spread (Hergstrom et al., 2005 and references therein but see MacFarlane and Gurr (1995) that in New Zealand large numbers of queens are required to successfully colonize an area). *B. terrestris* can spread rapidly; 90 km/year in New Zealand (Hopkins, 1914), 25 km/year (Hingston et al., 2002) in Tasmania. Buttermore (1997) warned, in reference to Tasmania, that “of course, external influences such as predatory habits by birds, availability of food, competition from other insects, and deliberate introduction by people into these areas, make the rate of spread unpredictable”. Hingston et al. (2002) showed that in the nine years since its introduction, the range of *B. terrestris* now includes all of Tasmania’s major vegetation types and an area of c. 30,000 km^2.

Early seasonal emergence

Early seasonal emergence, particularly of queens (Sladen, 1912; Prys-Jones and Corbet, 1991; Matsumura et al., 2004; Ings et al., 2005; Inoue et al., 2008) and long activity periods (Inari et al., 2005; Japan) could deplete spring resources before local species of *Bombus* (and other bees) are able to establish nests. In Israel, *B. terrestris* queens were seen at Mt. Carmel throughout the year except January (A.D., personal observations) and in Tasmania queens were seen throughout the year, except in June, and workers and males were also founds in all months except July and August (Goulson et al., 2002). *B. terrestris* is active throughout the day beginning before and ending after most of the foraging bouts of native bees (Goulson, 2003a).

High adaptability provides an invasive or pest species the capacity to become widespread and problematic

B. terrestris is highly adaptable as shown by its generalist foraging habits and broad environmental tolerances. Thus, it can establish under adverse climatic conditions in various habitats (Semmens et al., 1993; Hingston and McQuillan, 1998b; Hingston et al., 2002; Ruz, 2002 (Chile); Hergstrom, et al., 2005 (Tasmania); Hingston, 2006a; Torretta, et al., 2006 (Argentina).

Generalist foraging preference

B. terrestris is a generalist or polylectic forager that can utilize a wide variety of flowers for resources (nectar and pollen) within (Müller, 1883; Sladen, 1912; Free and Butler, 1959; MacFarlane, 1976; Proctor et al., 1996) and outside its natural range (Dafni and Shmida, 1996; Semmens, 1996a, b, 1998; Hingston and McQuillan, 1998a; Ne'eman et al., 2000; Matsumura et al., 2004; Goulson and Hanley, 2004). It may use simple flowers but can learn to manipulate and exploit complex flowers (Stout et al., 1998). Moreover, it can take advantage of deep tubular flowers by piercing corollas to illegitimately obtain nectar that (Free, 1993; Stout et al., 2000; Matsumura et al., 2004; Dohzono et al., 2008).

Broad ecological tolerances

B. terrestris (like all members of the genus *Bombus*) has a thermoregulatory metabolism which enables it to withstand low temperatures (Heinrich, 1979; Goulson, 2003a) and to be active in winter in countries that are warmer than its native region, which is established, such as Chile (Ruz, 2002), Tasmania (Semmens, 1996a) and New Zealand (Donovan and Weir, 1978).

Pathogen, parasite and predator release

Species that become invasive outside their natural ranges are often not held in check by local biotic agents. In areas outside its natural range, *B. terrestris* has few or perhaps no natural enemies to check population growth (Buttermore, 1997; Hingston and McQuillan, 1998a; Goka, 2010).

High reproductive capacity

In its native range *B. terrestris* is univoltine (Alford, 1975; Prys-Jones and Corbet, 1991), but it may develop two reproductive cyles in a year (bivoltine) in a newly colonized area (Donovan and Weir, 1978 for New Zealand; Buttermore, 1997; Hingston et al., 2002 for Tasmania). This adaptation may enhance *B. terrestris*' reproductivity and invasiveness. Commercially produced colonies of *B. terrestris* produce more gynes than do the local conspecific populations which could be swamped upon contact (Ings et al., 2006 for Great Britain).

Large home ranges

Because *B. terrestris* forages widely, its effects on the landscape are thought to be great (with respect to competitive interactions with other pollinators, and for pollen flow and population effects on plants). Workers may travel 1,500 m (Osborne et al., 2007); 1,750 m (Walther-Hellvig and Frankl, 2000) to 4 km (Goulson and Stout, 2001; Inari et al., 2005) from their nests and in Israel pollen of cultivated plants have been found on *B. terrestris* at a distance of 5 km from the nearest garden (Dafni and Shmida, 1996).

Flexible nesting preferences

B. terrestris is adaptable and readily accepts artificial nests (Prys-Jones and Corbet, 1991; Matsumura et al., 2004). Thus, it can be presumed that it is less susceptible to nest-site shortages than other species (Matsumura et al., 2004). *B. terrestris* queens may also be a social parasite and invade nests of other *Bombus* species (Sladen, 1912; Matsumura et al., 2004; Inoue et al., 2008).

DOES *BOMBUS TERRESTRIS* HAVE THE POTENTIAL TO BE A PEST OUTSIDE OF ITS NATURAL RANGE?

From the foregoing, it is apparent that *B. terrestris* has a number of characteristics that would dispose it becoming invasive and a pest outside its natural range. Could it become pestiferous? A pest may be defined as an organism that is sufficiently abundant that its activities adversely impact human activities or environmental stability (Peterson, 2003). The major concerns surrounding *B. terrestris* are environmental.

The classical case is the spread of *B. terrestris* in New Zealand. It was introduced in 1881 and after five years, it was found to have spread into natural habitats. The speed of its spread was estimated as 90 km/year (Hopkins, 1914) but its ecological impact has never been assessed.

In Israel, *B. terrestris* was introduced commercially in the early 1990s and ten years later it had become the dominant bee on Mt. Carmel, especially following forest fires (Dafni and Shmida, 1996; Ne'eman et al., 2000; Potts et al., 2001). In Japan, it was introduced in 1991 and was found in the wild five years later (Goka, 1998) and it continues to spread (Matsumura et al., 2004). The rapid spread of *B. terrestris* was observed in Tasmania as early as two years after its introduction in 1990. There, it quickly occupied various habitats and exploited the flowers of several native species (Semmens et al., 1993; Buttermore, 1997; Hingston and McQuillan, 1998a, b; Stout and Goulson, 2000; Hingston et al., 2002; Hergstrom et al., 2005). Table 2, which documents invasions and the growing use of *B. terrestris* in various countries and in different climatic conditions, leads us to predict more escapes and spread of *B. terrestris*.

However, recently its potential to vector novel parasites and pathogens to other species of *Bombus* (Goka et al., 2008) provides an insidious note to the risks of its anthropogenically expanding range. The danger of pathogen spillover from commercially reared *B. terrestris* to native species of *Bombus* in North America is already proven (Colla et al., 2006; Otterstater and Thompson, 2008). Clearly, with this new information more introductions of *B. terrestris* to regions outside its natural range have to be considered with a great care.

Pollination of weed

Several studies have shown that introduced social bees are effective pollinators of weeds (Simpson et al., 2005 and references therein). Simpson et al. (2005) note that the introduction of novel pollinators could lead to increased seed production of introduced plants that currently lack an efficient pollinator ('sleeper weeds') causing proliferation of these weed species. This is likely to be a major threat in Australian ecosystems. Bumblebees could prove the ideal pollinator for several introduced plant species there that currently occur in low densities, and for plants that have not as yet 'straddled the garden fence' and become pests. For example, bumblebees are specialized pollinators of foxgloves (*Digitalis purpurea*) in Europe (Faegri and van der Pijl, 1979; Barth, 1991). In Australia foxgloves are naturalized in some parts (e.g. near Bargo, NSW (Harden, 1992)) but as yet are not found in high densities probably because of limited seed production. Foxgloves are however abundant on disturbed soil and roadsides in New Zealand,

Table 2. The spread of *B. terrestris*

Countries with commercial suppliers	Evidence of spontaneous spread after introduction	Countries in which *B. terrestris* was introduced with no evidence of spontaneous spread
Netherlands	Tunisia	Saudi Arabia
Belgium	Korea	Jordan
Spain	Uruguay	South Africa
Israel	Russia*	Great Britain
Russia		
New Zealand	Mexico	
France	Malta*	
Great Britain	Turkey*	
	Morocco	
	Taiwan	
	Israel*	
	Poland*	

* *B. terrestris* is also native in this country.

where introduced bumblebees have been present since the 1800s. Because of its preference for disturbed areas, foxglove invasions could seriously hamper revegetation by native plants. Other potential weed species that might be boosted include buzz-pollinated species belonging to the Solanaceae, many of which are poisonous- and prickly, noxious-weed species that could cause problems to the dairy and cattle industries (e.g. *Datura* spp.), *Tecoma stans* (Bignoniaceae), *Rhododendron ponticum* (Ericaceae), *Chamaecytisus palmensis* (Fabaceae) and *Polygala myrtifolia* (Polygalaceae). Recently, a correlation was found between bumblebee density and seed production in yellow lupine (*Lupinus arboreus*) (Stout et al., 2002), *Agapanthus praecox* (Hingston, 2006b), *Buddleia davidi* (Hingston, 2007) and maybe also *Rhododendron ponticum* (Hingston, 2007) in Tasmania. *Rhododendron ponticum* forms tall, dense shrubs that shade out native species. Apart from boosting sleeper weed species, pollination by *B. terrestris* could cause an increase of problems with already existing weeds, for example blackberry (*Rubus fruticosus*), gorse (*Ulex europeus*), broom (*Cytisus scoparius*) and Paterson's Curse (*Echium vulgare*) (Rademaker et al., 1997). These concerns have prompted the successful public nomination of bumblebees as a key threatening process to the New South Wales and Victorian governments.

THE THREAT OF *BOMBUS TERRESTRIS* SPREAD, OR WHY WORRY ABOUT IT?

From the foregoing, it is clear that *B. terrestris* is an invasive species wherever it has been introduced and studies have been made (New Zealand, Israel, Tasmania, Japan, Chile, Argentina). All recent evidence shows negative aspects of *B. terrestris* invasion into natural habitats (Table 3). *B. terrestris* may interfere with the flora as well as with the fauna at both community and population levels, displacing native pollinators and probably changing the capacity of some native plants to reproduce at normal rates. All of this evidence of the negative implications of it massive invasion lead us to consider *B. terrestris* as a pest in Israel, Japan and Tasmania.

We are not familiar with any study which shows any positive or even neutral intervention of *B. terrestris* in natural ecosystems, but Goodwin and Steiner (1997) concluded, concerning the possible introduction of *B. terrestris* into mainland Australia for pollination of horticultural crops, that: "Bumblebees are as likely to have a positive impact on Australian ecology as a negative one, but in either case it is a drop in the bucket compared with the effect of habitat destruction created by man… The impact of bumblebees on crop yields, however, will be immediate and substantial… Australia will not be able to sustain the market share in Australia, let alone compete for export market. Bumble pollination is an essential part of the necessary yield increase". Although their suggestion for potentially high proximate gain for the greenhouse tomato industry rings true, the risks associated with cheaper Australian greenhouse tomatoes for local markets (field tomatoes do not require insect pollination) have not been investigated. It is highly unlikely, given the evidence from other introductions and the above, that *B. terrestris* would be beneficial to the natural Australian environment, there appears to be no need of it in mainstream Australian agriculture and alternatives with native species are being developed (e.g. Hogendoorn et al., 2006). The remark about anthropogenic habitat destruction is a "red-herring" and not germane to the discussion regarding the impacts of *B. terrestris* on Australian landscapes. The current available evidence does not support Goodwin and Steiner's views (e.g. see Hingston et al., 2002).

WHAT TO DO?

Most countries have quarantine regulations and legislation and international agreements to control the possible adverse effects of introductions, and most have special regulations concerning the import/export of agricultural insects especially agents considered for release for biocontrol of pests. Many countries are signatories to international phyto- and zoo-sanitary agreements that also pertain to stemming the international flow of pests and diseases. As far as we are aware, many countries have no specific legal restrictions on the import or export of bees as commercial pollinators. Nevertheless, trade in exotic pollinators may be contraventions of international phyto- and zoo-sanitary agreements and similar conventions. Some countries are careful and unwilling to import exotic pol-

Table 3 The environmental threats of *B. terrestris*' spread

Threat	Evidence and references
Negative interactions with local bee fauna	Depletion of floral resources (Dafni and Shmida, 1996, Israel; Hingston, 2007, Tasmania; Matsumura et al., 2004, Japan). Displacement of local bee species (Dafni and Shmida, 1996, Israel; Hingston and McQuillan, 1999; Hingston, 2007, Tasmania; Matsumura et al., 2004, Japan), possible through resource competition (Hingston and McQuillan, 1999; but see Nagamitsu and Kenta, 2007; Nagamitsu et al., 2007).
Competition on nest's sites	*B. terrestris* competes and also occupies nesting sites of local *Bombus* species (Matsumura et al., 2004).
Genetic contamination of local *Bombus* species	*B. terrestris* has the capacity to copulate with local *Bombus* species (Goka, 1998, 2010; Kanbe et al., 2008, Japan). *B. terrestris* may cause genetic contamination of local subspecies (Ornosa, 1996, Spain). *B. terrestris* mate with the local endemic *B. canariensis*, a threat to biodiversity (van der Eijnde and de Ruijter, 2000). *B. terrestris* in Mediterranean islands are, significantly, genetically differentiated from continental populations. "DNA data from Canary islands calls for protection against importation of *B. terrestris* of foreign origin for pollination" (Estoup et al., 1996).
Invasion and spread of parasites and pathogens	Parasitic protozoans and endoparasitic mites were already found in *B. terrestris* introduced colonies (Goka, 1998, 2010; Goka et al., 2000, 2001, 2006; Okada et al., 2000; Schmid-Hempel et al., 2007; Yoneda et al., 2008). Recent epizootic of protozoa (*Nosema* spp.) in cultured *B. occidentalis* colonies in western North America may have come about through transfer from other *Bombus* species in commercial rearing facilities (Winter et al., 2006).
Disturbances with the reproduction of the local flora	Less effective pollination and reduction of seed set when *B. terrestris* is a main visitor (Ne'eman and Dafni, 1999; Ne'eman et al., 2000; Hingston et al., 2004; Kenta et al., 2007) as well as fruit quality (Kenta et al., 2007). Reducing pollination, piercing and robbing flowers, possibility to interfere with the plants' reproductive success (Hingston and McQuillan, 1998a; Hingston, 2007). Disruption of native plant-pollinator systems may precipitate reduced seed set in native plants. In Australia, several native plant species have co-evolved with, and are dependent on, one or two species of bird or insect pollinators (e.g. Hopper and Burbidge, 1986; Gross, 1992, 1993a, b; Houston, 1993). The presence of bumblebees could decrease the density of these natural pollinators, through competition for nectar and direct displacement. In the long term, this could jeopardize fruit and seed availability (Gross and Mackay, 1998). A decrease in seed production through direct displacement of native bees by honeybees has been demonstrated to occur in *Melastoma affine* (Gross and Mackay, 1998).
Rapid invasion rate	Spread rate 90 km/year in New Zealand (Hopkins, 1914), 12.5 km/year in Tasmania (Buttermore, 1997).

linators without proper and scientific consideration. In Canada and the USA the introduction of foreign bumblebees is prohibited and only local species are reared (de Ruijter, 1997; Winter et al., 2006). Malaysia was extremely careful in its scientific assessment of the risks of importing the oil palm pollinating weevil (*Elaeidobius kamerunicus*) from West Africa (Kang and Karim, 1982), and like many countries has strict regulations about the movement of honeybees (*Apis* spp.) because of the risk of transmission of diseases and affecting other indigenous insects and plants.

The warnings and precedents are clear, yet the pressure to export *B. terrestris* to more and more exotic destinations continues. Several measures need to be considered before such exports and imports are allowed. These measures apply to all pollinators considered for import (Ings et al., 2006)

1) National benefits resulting from pollinator import should be evaluated through environmental, social and economic analysis with particular attention to the precautionary principle and intergenerational equity.

2) Environmental risk assessment of such an import should be undertaken (Ings et al., 2005). The Malaysian example of import of the oil palm pollinating weevils serves well (Kang and Karim, 1982). One condition of any pollinator import (including that of *B. terrestris*) should be a survey on the potential impact of the introduction (see Ings et al., 2006). This is especially important in regions with high numbers of unique and endemic flora and bee fauna (e.g., South Africa, Australia, Madagascar, Canary Islands) and where there are sleeper weeds. In Japan, an ecological risk assessment of *B. terrestris* has recently and legally restricted their importation through the new statute the *Invasive Alien Species Act* (2007) Japan.

3) The lack of indigenous pollinators with potential for practical application must be proven. The potential for domestication or encouragement of indigenous pollinators has been proven for *Bombus* spp. (Dogterom et al., 1998; Morandin et al., 2001a, b in Canada; Asada and Ono, 1996; Goka, 1998 in Japan), *Xylocopa* (Hogendoorn et al., 2000 in Australia) and *Amegilla* (Bell et al., 2006; Hogendoorn et al., 2006, 2007 in Australia). It is also strongly suggested to domesticate local subspecies of *B. terrestris* (when available) to avoid genetic contamination with imported subspecies (Ings et al., 2006).The known successes of the use of leaf-cutting bees, *Megachile rotundata* (accidentally introduced into North America), various orchard bees, *Osmia* spp., and other species in crop pollination, serve as other examples (Bohart, 1972; Parker et al., 1987; Torchio, 1987, 1994; Kevan et al., 1990; Richards, 1993).

4) If, after steps 1, 2, and 3, the importation of an exotic pollinator is recommended, then legislation should be applied (enacted, modified, or specified) to control the zoo-sanitary quality of the pollinator. The health certification should be a precondition to any commercial export and/or distribution of commercial colonies as is the case for shipments of honeybees (*Apis mellifera*) in many countries. Quarantine and inspection services should be established by the importing and exporting country. The responsibility and onus for the eradication of escaped bumblebees should lie with the industry that is using this species and not with the public. The costs of a 'clean-up' for escaped *B. terrestris* could be phenomenal given their likely facilitation of weed pollination. For example, weeds already cost Australia $3,554–4,532 billion per annum in control and lost production (Sinden et al., 2004), and an Australian government report conservatively estimated that if nine current sleeper weeds were not eradicated they could eventually cost $100 million dollars annually in lost agricultural production (Brinkley and Bomford, 2002). Bumblebees have the potential to exacerbate the eradication program for many weed species, e.g. gorse.

5) Specifically with respect to pollination services in enclosed spaces, e.g. greenhouses, pollinator domiciles should be designed specifically to minimize the likelihood of escape (e.g. for *Bombus* queens mechanical restriction in the beehive entrance which may reduce the in out traffic (Thompson, 1997; Thorp, 2003; Griffiths, 2004; Ings et al., 2006; Hingston, 2007; Yoneda et al., 2007) and perhaps hormonal treatment and thorough containment, destruction and disposal of the pollinators after they have served their purpose. Control measures for dealing with escapees must be formulated and should include control measures/protocols, responsible authorities and penalties for misuse or deliberate release of the bees.

In summary, we have collated and evaluated much of the considerable information on the ecology and impacts of *B. terrestris* on native ecosystems. In concert with many scientists worldwide we urge governments to exercise extreme caution and to implement the precautionary principle in any requests for live importations of *B. terrestris*. However, in some parts of the world, for example Australia, Canary Islands, South Africa and South America the risks to the native biota are assessed here as too great to warrant the risk of live importations.

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