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Conservation biology issues for the commercial insect trade in Japan: bumblebees for agriculture and companion animal insects as examples

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Summary

Japan imports a wide range of insects and arthropods for industrial and companion animal purposes. The international transport of insects carries the risk that introduced species may become invasive alien species, threatening local ecosystems. It is also possible that the increased economic value of rare species may lead to overexploitation at the region of origin. Two iconic imported insects that have caused ecological problems in Japan are bumblebees for agriculture and companion animal beetles. Commodity colonies of the agricultural bumblebee *Bombus terrestris* have been imported since the 1990s and have made a significant contribution to agricultural production. As a result of its progressive feralisation, however, it has caused ecological impacts on native bumblebees through competition, hybridisation, and the introduction of alien parasites, as well as posing a risk to native plant reproduction. The species is currently permitted for agricultural use only in netted greenhouses. Imports of companion animal beetles flourished in the 2000s and the market size was thought to have reached the multi-billion-yen level. The popularity of rare species, in particular, led to a sharp rise in selling prices, and overhunting in and smuggling from their countries of origin became a problem. In addition, exotic species pose an ecological risk as invasive species, and if they become established in the natural environment of Japan it is suggested that they will have a serious impact on the ecosystem. At present there are no clear legal restrictions on the importation of foreign beetles, but the

government is trying to improve the ethical standards for the breeding of beetles through a campaign for sellers and breeders. In addition, imports of a variety of arthropods, such as tarantulas, centipedes and scorpions are becoming increasingly popular in Japan. Many of these transactions are carried out between individuals via the internet, making it difficult to ascertain the actual state of importation and breeding. These examples of insect importation problems in Japan raise issues for the future of international trade in commercial insects as follows: 1) overexploitation of species being collected in their native habitats due to their rarity; 2) smuggling and trafficking of species for which collection and sale is prohibited; 3) the risk of escaped individuals becoming established in the new location as alien species; and 4) the risk of introducing associated micro-organisms and parasites, which are often difficult to detect and overlooked.

Keywords

Alien species – Beetle – *Bombus terrestris* – Companion animal – Ecological risk – Endangered species – Pollinator.

Introduction

Currently, insects and other arthropods are traded internationally for a variety of purposes. One is the case of transfer for industrial use: natural enemies for biocontrol, agricultural pollinators, and insects for animal feed are examples. The other case is that of insects being transported as companion animals or for companion animals. This article focuses on the risks both before and after transport (as described in the Introduction of this issue [1]) posed by this trade, as well as conditions for transport considered unethical.

The biocontrol use has attracted attention in recent years as an environmentally friendly action that reduces the use of pesticides and greenhouse gases associated with food production, and the market size is expected to grow significantly in the future. For example, according to a new report published by REPORTOCEAN in 2021, the global biopesticides market is expected to reach US$ 19.85 billion by 2030, growing at a compound annual growth rate of 15.6% between 2020 and 2030 (2).

Pollination services have long been an integral part of agricultural production, and the commercial use of pollinators has a long history (3). In recent years, the commercialisation of bumblebees in particular has made remarkable progress. In 2006 when Velthuis and van Doorn (4) reviewed the state of the industry, the growth in commercial sales of bumble bee colonies had reached around one million in 2004 from its beginnings in 1988. It has certainly continued to expand since then, and the supply of bumble bee colonies is essential for global tomato production, among other horticultural products. Exact revenues from bumble bee colony sales are hard to estimate because the companies are private. However, since, for example costs of bumble bee colonies sold in Japan run from US$ 200–$300 per nest, the industry as a whole must be worth hundreds of millions of dollars.

As for the latter, companion animal insects, the market is expected to continue to grow, as the culture of raising insects has existed for a long time.

International trade in these insects effectively represents the deliberate introduction of alien species. In some cases, it can also lead to overexploitation of natural populations. In other words, international trade in insects involves a variety of environmental and ecological risks. It is important to accumulate scientific analyses of such risks in order to conserve insect biodiversity.

In Japan, there were two symbolic examples of ecological problems associated with the importation of insects. One is the problem caused by the importation of bumblebees, which are agricultural pollinators. The other is the problem caused by the massive import of stag beetles for companion animals. In this paper, the author introduces the background of these two cases, and the measures taken by the Japanese government for considering what should be applied to future international trade of insects.

Commercialisation of the European bumblebee *Bombus terrestris*

The European bumblebee, *Bombus terrestris*, is one of the most successful biological agents used for commercial pollination (Fig. 1). In Japan, use of the bumblebee, mainly for pollination of tomato, has increased since the bumblebee's introduction in 1991, and the number of commercial colonies used annually reached almost 70,000 up to 2004 (5).

[Place the Figure 1. here]

On the other hand, there have also been fears that introduced biological agents can become invasive alien species. There has been controversy in many countries over the possible ecological impacts of naturalisation of *B. terrestris* (6, 7). In Japan, many ecologists and entomologists have warned of the ecological risks posed by *B. terrestris* since its introduction (e.g., 8, 9, 10). In fact, a naturalised colony was found in Hokkaido in 1996 (10) and the number of captive colonies of *B. terrestris* escaping into the field from glass- or vinyl-houses in Japan has continued to increase, suggesting that the rate of invasion by the alien bee is increasing (11).

Risk and impact assessment of *B. terrestris*

The National Institute for Environmental Studies has studied ecological risks of the alien bumblebees in Japan in collaboration with other institutes, universities, private companies, and government. We considered four aspects of ecological risks posed by *B. terrestris*.

1) Competitive exclusion of native bumblebees

Initially, our field survey in Hokkaido showed that, in terms of niche overlap for limited nest sites, *Bombus hypocrita sapporoensis* and *Bombus diversus tersatus* were the two native species most likely to be affected by *B. terrestris* through competition for nest sites (12, 13). Furthermore, accumulated data on the spread of the distribution of *B. terrestris* in the field in Hokkaido since 2003 indicated that the alien bee had predominantly invaded human-modified areas such as agricultural land and residential areas. It had also recently affected natural habitats such as coastal and alpine grasslands (14). From this information, we concluded that *B. terrestris* had a high potential to competitively exclude native bumblebees in the field.

However, establishment of *B. terrestris* has so far been confirmed only in Hokkaido and has not been reported in more southern islands (Honshu, Shikoku, and Kyushu). Differences in the density and composition of flora as a food resource are considered to dominate the establishment potential of this species.

2) Inhibition of reproduction of native plants

We found that *B. terrestris* reduces the success of pollination of the Japanese endemic flower *Corydalis ambigua* in the field. Because the flowers of *C. ambigua* have long spurs, they are usually pollinated successfully by *Bombus ardens*, which possesses a long proboscis. However, because *B. terrestris*, which has a short proboscis, cannot reach the nectar at the bottom of the long spurs, it robs the nectar by gnawing a hole in the side of flower; this inhibits normal pollination and thus decreases the reproductive success of the plant. A field survey comparing the flowers visited by native bumblebees with those visited by *B. terrestris* showed that seed reproduction rates were significantly lower in the latter (15).

3) Reproductive interference by interspecies crosses

We verified that *B. terrestris* caused reproductive interference to native bumblebees in the field through crossing. Laboratory experiments showed that crosses between the queens of native species and males of *B. terrestris* resulted in the production of non-viable hybrid eggs; for all practical purposes these native queens were therefore rendered sterile (16). Additionally, analysis of the DNA sequences of the spermatozoa stored in the spermathecae of native queens caught before the start of spring nesting in Hokkaido Island and Tohoku district showed that about 30% of *B. hypocrita* queens had mated with *B. terrestris* males (Fig. 2). Given that a Bombus queen generally mates only once in her life, these high frequencies of interspecific mating with *B. terrestris* pose serious threats to the populations of native bumblebees in Japan (17).

[Place the Figure 2. here]

4) Carrying alien parasites

Alien parasites occasionally cause serious damage to native species. For example, the varroa mite, *Varroa destructor*, which is a virulent parasite of the European honeybee *Apis mellifera*, is native to eastern Asia, where it parasitises the eastern honeybee, *Apis cerana* (18). The mites were introduced into the Western Hemisphere from Japan and eastern Russia through the transportation of European honeybee colonies. The mite is now responsible for enormous losses of European bee colonies worldwide. There are more than 100 known parasite species (including viruses, fungi, protozoa, nematodes, insects, and mites) associated with bumblebees (19). It is possible that these parasites have already been carried into Japan in imported bumblebee colonies.

As expected, we found an endoparasitic mite, *Locustacarus buchneri*, in introduced colonies of *B. terrestris* in Japan in 1999 (20). The average infestation rate in bee colonies imported from the Netherlands and Belgium was 20%. We investigated the status of infestation by this tracheal mite in natural populations of Japanese native bumblebee species and commercial colonies, collected and introduced respectively between 1997 and 2002. We detected the mites in natural populations of two species (*B. hypocrita sapporoensis* and *B. hypocrita hypocrita*) (infection rates were ~5% individuals) and in commercial colonies (infection rates were ~20% colonies). Because the Japanese native bumblebees *B. hypocrita sapporoensis* and *B. hypocrita* were once exported to Europe for commercialisation, these results indicate that bumblebee commercialisation has caused overseas migration and cross-infestation with parasitic mites among natural and commercial colonies (21, 22).

The ecological and physiological burden of tracheal mite on bumblebees has not been experimentally confirmed so far (Tsuchida K, personal communication). In addition, no case of *Nosema* protozoa, which has been reported to cause disease to bumblebees in other countries, has been reported to infect native populations from commodity colonies.

Control of invasive alien bumblebees

Since it has been scientifically concluded that the imported bumblebee is an invasive species with various harmful effects on native species, the Ministry of the Environment of Japan has decided to legally regulate this species. However, it was difficult to completely ban *B. terrestris* because it is an essential agent for agricultural production. The Government decided to allow the introduction of this species for agricultural use only. Farmers can use this species in greenhouses with netting for control measures of escape of bees (23) (Fig. 3).

[Place the Figure 3. here]

In addition, the National Institute for Environmental Studies has been developing a chemical control method utilising IGR (Insect Growth Regulator) agents for eradicating *B. terrestris* populations established in the wild. We are investigating a chemical treatment method for *B. terrestris* using its ecological characteristics as a social insect. Workers sprayed with pesticides while foraging in the field return to the hive and expose the larvae and queen in the hive to the pesticide, thereby inhibiting the production of a new queen (24).

The Ministry of Agriculture, Forestry and Fisheries is recommending the use the native bumblebee species *B. ignitus* as an alternative pollinator of tomato plants. However, the natural distribution of *B. ignitus* is limited to parts of the Japanese islands of Honshu and Kyushu; it does not inhabit Hokkaido, where the use of *B. terrestris* is the greatest in Japan and therefore the need for an alternative pollinator is most urgent. Even a native species poses a risk of acting as an invasive alien species when it is transported artificially beyond its natural habitats. The first potent impact could be genetic introgression caused by crosses between natural and commercial colonies. Through DNA analysis we have already found genetic diversity among local populations of *B. ignitus*; this observation indicates the need to account for the genetic endemism of *B. ignitus* before using commercialised colonies of it (25).

Furthermore, recent shortages in the supply of the European honeybee, *A. mellifera*, all over Japan are increasing the demand for the use of bumblebees as alternative pollinators of various agricultural crops in addition to tomato; diversification of use could make the ecological risks posed by commercial bumblebees more difficult to control.

Commercialisation of beetles as companion animals in Japan

In Japan, in particular, the culture of breeding beetles as companion animals has been deeply rooted for a long time, and since the 2000s a large number of exotic beetles have been imported and sold. The Plant Protection Law of Japan prohibited the importation of beetles, but the prohibition was suddenly lifted in 1999 and the importation of the Australian Rainbow beetle *Phalacrognathus muelleri* began. Since then, the number of foreign beetle species permitted for importation has continued to increase and by 2004 had exceeded 700. The size of the market was estimated to be no less than several billion yen in 2004, with some estimates reaching as high as 10 billion yen (26). The global economy and the wave of liberalisation of world trade are thought to have played a major role in this accelerated importation of beetles.

This unusual boom has even led to criminal smuggling of rare or endangered species from every corner of the world (27). For example, in Japan one can buy a rare species of stag beetle, *Dorcus antaeus*, native to Bhutan, Nepal and India, although in these countries it is absolutely prohibited to collect any wild organisms. The price of this beetle was incredibly once as high as 600,000 Japanese yen (5,000 US dollars) per individual. As there is no law in Japan prohibiting importation of insects even from such prohibited areas, many Japanese insect collectors or traders have gone abroad to smuggle stag beetles. The other very popular beetle for collectors in Japan is *Lucanus cervus akbesianus*, a rare subspecies found only in the Amanos Mountains of southern Turkey. The Amanos Environmental Protection Association has warned that overharvesting is pushing this beetle toward extinction (28).

Large rhinoceros beetles inhabiting South America are also very popular in Japan, with Hercules and Saturn longhorned beetles, *Dynastes hercules* and *Dynastes satanas*, reportedly being illegally collected in countries where insect collecting is banned and exported to Japan in large numbers (29). These beetles are endangered species in South America, especially the Saturn longhorn beetle, which is regulated under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

For those cases where illegal transport of beetles has been detected in Japan, reports reveal a highly problematic method of transport from the point of view of bioethics, such as wrapping the live insects in plastic wrap so that they cannot move and then putting them in suitcases.

Ecological risks of introduced stag beetles as invasive alien species

Many ecologists and entomologists have warned about ecological risks that will be caused by the rise in insect trade. At the beginning of the importation of exotic beetles, not only the general public but also even many entomologists thought that tropical large insects could not pass the winter in Japan if they escape into the field. However, almost all stag beetles in tropical and subtropical areas actually inhabit relatively high altitudes, where the climate is not so different from that of Japan (30). Furthermore, almost all stag beetles spend their larval stage in decayed trees or in soil that are more stable habitats than open air. These ecological characteristics suggest that many species of exotic stag beetles have the potential to be naturalised in Japan (30). Therefore, we must consider and assess ecological impacts that will be caused by the naturalisation of exotic stag beetles.

The native stag beetles with an ecological niche similar to that of exotic stag beetles will certainly suffer serious and direct impacts. The wild populations of Japanese native stag beetles already are rapidly decreasing because of artificial disturbance of habitats and some species are close to endangered (31). Furthermore, our research indicated that *Dorcus titanus*, a widespread stag beetle species from the Japanese archipelago to Southeast Asia, has subspecies lineages with distinct genetic differentiation in morphology and DNA sequence on each island, diverged through millions of years. Experimental crossbreeding of these subspecies has been shown to produce fertile hybrids, suggesting that the escape of foreign companion animals into the wild may lead to genetic introgression and consequent loss of genetic endemism (Fig. 4) (26).

[Place the Figure 4. here]

Parasite invasion accompanying importation of stag beetles

The third impact will be unknown species of parasites brought by the exotic beetles into Japan, spreading disease among Japanese beetle populations. As the parasites of stag beetles have been little investigated, it is very difficult to estimate the ecological risks caused by the invasion of parasites.

But the author and others have investigated genetic variation of an endoparasitic mite, *Coleopterophagous berlesei*, which is one of the most common mites living on the surface of stag beetles (32). The results of this analysis suggest that each of the diverse species and lineages of stag beetles has its own unique parasite (Fig. 5). The translocation of stag beetles to different habitats may turn these parasites into invasive alien species (26, 32, Goka K. unpublished).

[Place the Figure 5. here]

We have confirmed by rearing experiments that the larvae of two native Japanese species, *Dorcus (Macrodoreas) rectus* and *D. titanus pilifer*, have the ability to fix nitrogen in the air (33, 34). The fixation capacity is most likely due to some microorganisms associated with the larvae. It has been suggested that only adult females of the stag beetle have an organ called mycangia and pass useful microorganisms to the next generation (35), and it is possible that microorganisms involved in nitrogen fixation are vertically transmitted by this mechanism. These findings suggest that symbiotic microorganisms are unique to each species and local population of stag beetle. Stag beetles are considered to play an important role in the material cycle of the forest, including nitrogen fixation; the risk is that the introduction and release of alien species will disturb the symbiotic relationship between stag beetles and microorganisms endemic to each region and as result affect the material cycle system of forests.

Regulation of the introduced stag beetles

As mentioned above, there was a concern about the risk of ecological impact if exotic beetles become wild in Japan's natural environment, and from the viewpoint of biodiversity conservation, it was discussed in Japan that restrictions should be imposed on the importation and sale of exotic beetles. However, many individuals had already been imported and were already being kept in many households. Imposing sudden restrictions would possibly lead to mass dumping of captive animals. The Government of Japan, in consultation with a group of experts, decided to launch a campaign aimed at breeders to improve the ethics of breeding beetles. Their message: "Do not let them escape and keep them until the end of their lives". Fortunately there have been few reported cases of exotic beetle species being naturalied in Japan.

Other concerns; Tarantulas, Centipede, Scorpions and more

Japan also imports a large number of other arthropods as companion animals. In particular, tarantulas, which are popular as companion animals internationally (36), are rapidly gaining popularity in Japan (Fig. 6). Most of these arachnids are imported from the wild, and this has led to the constant smuggling of species classed as endangered under CITES. In fact, spiders account for the largest proportion (about 90%) of arthropods intercepted by Japanese Customs (37).

[Place the Figure 6 here]

Other popular species include centipedes and scorpions, which are caught abroad and sold on the internet every day. Buying and selling via the internet between individuals makes it very difficult to trace imported species and detect illegal sales. The ecological information on these arthropods has not yet been fully investigated, and it is not possible to assess the impact of overexploitation on wild populations at their source or the ecological risk they pose as alien species if they are released or escape in the importing country.

Conclusions

In view of the various problems and risks posed by agricultural pollinators and companion animal insects in Japan as described in this paper, we need to pay attention to the following types of risk when trading insects for commercial use:

1) Overexploitation of species being collected in their native habitats due to their rarity

2) Smuggling and trafficking of species for which collection and sale is prohibited

3) The risk of escaped individuals becoming established in the new location as alien species

4) The risk of introducing associated micro-organisms and parasites, which are often overlooked.

In Japan, a high proportion of people have experience of keeping insects, but general awareness of the problems of invasive species caused by the sale and keeping of insects is not very high (38). However, arthropods are an important group of organisms that support the foundations of ecosystems, and their conservation requires greater attention and care in the future.

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Fig. 1

***Bombus terrestris* visiting flowers on Trifolium repens. (Photo by National Institute for Environmental Studies)**

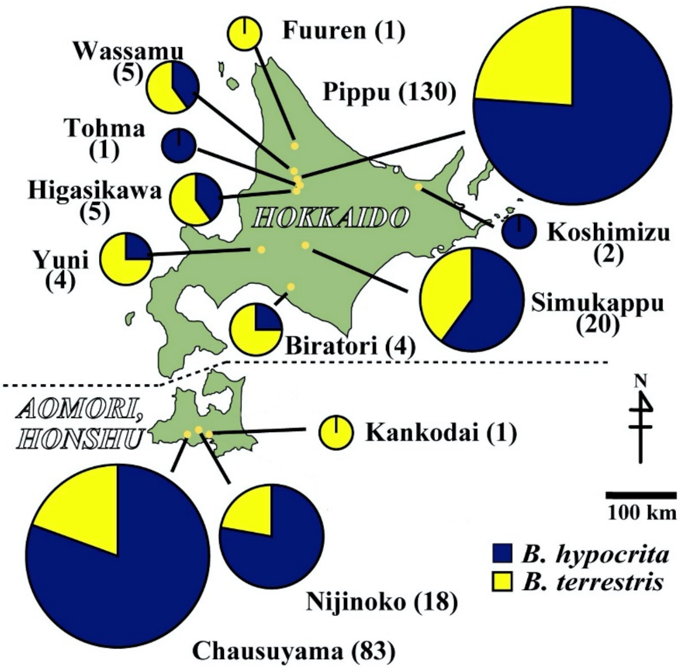

Fig. 2.

Paternity of spermatozoa stored in queen's spermatheca of Japanese native bumblebee, *Bombus hypocrita* analysed by using nuclear DNA sequences. Number in parenthesis is sample number (17)

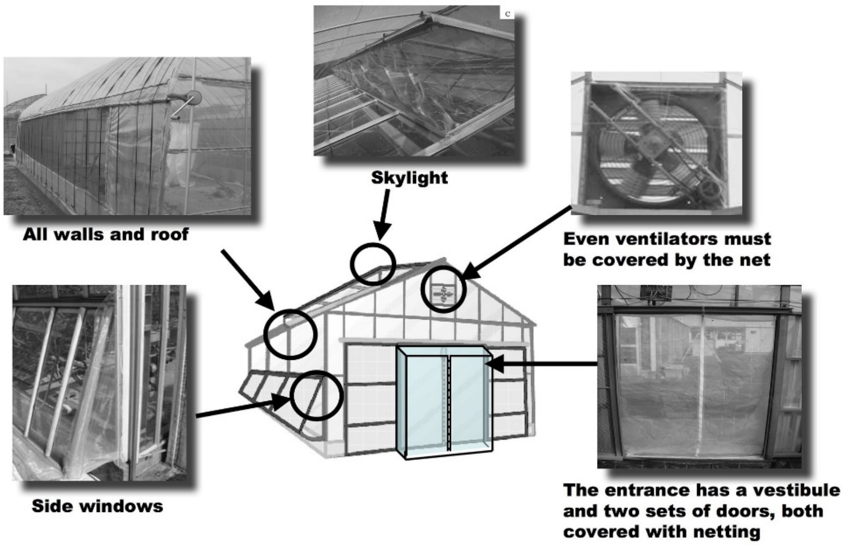

Fig. 3.

Covering glasshouses with nets to prevent the escape of *B. terrestris*: Japanese Government Accreditation Scheme (23)

Fig. 4.

The cross between a male of *Dorcus titanus castanicolor* of Japan and a fumale of *D. t. titanus* of Indonesia (left), and an F1 hybrid male obtained from the cross (right). (Photo by K. Goka)

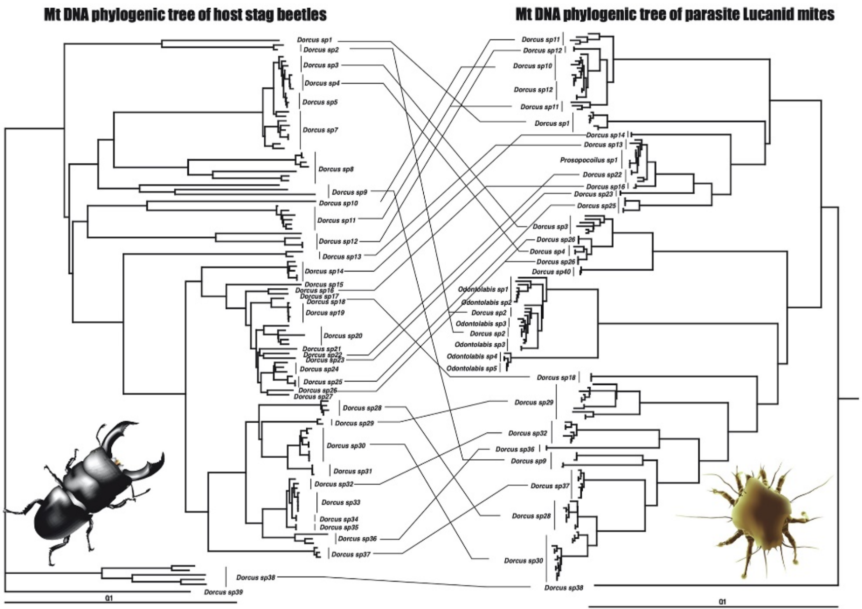

Fig. 5.

Phylogenetic associations between host Dorcus species and parasitic mite *C. berlesei*, based on NJ trees of mtDNA CO gene sequences. (Goka et al. 2004 [26?] **with unpublished data)**

Fig. 6.

Examples of tarantula imports and sales in Japan (Photo by T. Sato)