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Pathways and vectors of alien arthropods in Europe Chapter 3

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Abstract

This chapter reviews the pathways and vectors of the terrestrial alien arthropod species in Europe according to the DAISIE-database. The majority of species (1341 spp., 86%) were introduced unintentionally, whereas 218 species (14%) were introduced intentionally, almost all of these for biological control purposes. The horticultural/ornamental-pathway is by far the most important (468 spp., 29%), followed by unintentional escapees (e.g., from greenhouses, 204 spp., 13%), stored product pests (201 spp., 12%), stowaways (95 spp., 6%), forest and crop pests (90 spp. and 70 spp., 6% and 4%). For 431 species (27%), the pathway is unknown. The unaided pathway, describing leading-edge dispersal of an alien species to a new region from a donor region where it is also alien, is expected to be common for arthropods in continental Europe, although not precisely documented in the data. Selected examples are given for each pathway. The spatiotemporal signal in the relevance of pathways and vectors and implications for alien species management and policy options are also discussed. Identifying and tackling pathways is considered an important component of any strategy to reduce propagule pressure of the often small and unintentionally translocated, mega-diverse arthropods. This requires coordination and clear responsibilities for all sectors involved in policy development and for all associated stake-holders.

Keywords

alien species, non-native species, pathways, vectors, Europe

3.1 Introduction

To become an alien species, boundaries of natural distribution ranges must be overcome with the help of man-made structures, goods and services. These activities and purposes are the pathways of invasions. A plethora of vectors, which are the agents of these translocations, is available to break new grounds and reach new areas. Interestingly, there is no common understanding in this separation in the biological invasion literature (e.g. Ruiz and Carlton 2003, Carlton and Ruiz 2005, Nentwig 2007, Hulme et al. 2008). In this overview, however, pathways are understood as the routes (including motivations to use them) and vectors as the physical objects (ships, plants etc) that carry species along. Several attempts to further classify pathways and vectors are available (e.g. Carlton and Ruiz 2005), but here I follow Hulme et al. (2008), who identified six principal pathways for biological invasions (Table 3.1). Only one of these is founded by intentional motivations, that is the deliberate release of organisms, with biological control as the most important example. The others are utilised unintentionally, accidentally and may come from any direction. These are escapes from contained environments and captivity; contaminants of commodities; stowaways, transported as hitch-hikers with vehicles and cargo; corridors, where transport infrastructure enables the spread of a species; and the unaided pathway, where an alien species conquers a nearby region under its own dispersal capacity. Evidently, these different pathways have major implications for risk assessment, regulations, management and control (Hulme et al. 2008, Hulme 2009).

Human-mediated translocations differ from natural dispersal by orders of magnitude both quantitatively and qualitatively as can be seen by island colonization rates (e.g. Gillespie and Roderick 2002, Gaston et al. 2003) and genetic consequences (e.g. Wilson et al. 2009). Also, the origin of the source differs as natural colonization usually happens from adjacent populations, whereas translocated individuals may come from all over the world.

In the DAISIE-database, three levels of pathways, are distinguished. At the first level, intentional and unintentional ambitions are classified. At the second level, pathways are identified, except that the contaminant, stowaway and corridor pathways are summarized as "transport". At the third level, these are further specified into broad categories (e.g. biological control, crops, horticultural/ornamental, forestry, stored products). In addition, at the second and third level, the category "unknown" is also used and assigned to 392 and 431 species, respectively (25–27%). This is a similar contingent as for the exotic insects in Japan (24%, Kiritani and Yamamura 2003). Introductions of species are not necessarily restricted to one pathway; many species can be considered "polyvectic" (Carlton and Ruiz 2005), transported by more than one pathway or multiple vectors. Accordingly, some species in the DAISIE-database were assigned to more than one pathway/vector. Furthermore, it has to be said very clearly that many assignments were only "best guess" or "most likely" assessments, deduced from the preferred habitats, food

Table 3.1. Pathway terminology and examples of vectors of terrestrial alien arthropod species in Europe.

Pathway	Motivation	Vectors	Examples
Release	Intentional	None	Biological control
Escape	Unintentional	None	Greenhouses
Contaminant	Unintentional	Food sources, ornamentals, vegetables, fruits, wood, animals, ...	Stored product pests, Wood-borers, Leaf-miners, Gall-producers, Endoparasites
Stowaway	Unintentional	Any cargo	Ants, Cockroaches
Corridor	Unintentional	Ships, cars	*Cameraria ohridella*
Unaided	Unintentional	None	Secondary spread from point of entry

plants or ecology, because the intimate pathway/vector of many arthropod species often remains ambiguous.

In this chapter, pathways and vectors of the terrestrial alien arthropods in Europe are reviewed, with the few alien aquatic insects included, but excluding other freshwater alien arthropods such as crayfish species. There are a multitude of further pathways relevant for the marine and freshwater environments (e.g. ballast water, hull-fouling) and for other organisms such as vascular plants and vertebrates (e.g. seed contamination, hunting, pets) (e.g. García-Berthou et al. 2005, Galil et al. 2009, Genovesi et al. 2009).

3.2. Intentional release

With few exceptions, terrestrial arthropods are not intentionally imported. Such exceptions are grasshoppers and crickets as pet food and – more significantly – domesticated honeybees (*Apis mellifera*) of different provenances (subspecies), which are used for breeding, with the aim of producing higher honey yields (Jensen et al. 2005, Moritz et al. 2005). The same is true for the bumblebee subspecies used for pollination in greenhouses (e.g., *Bombus terrestris dalmatinus* in the UK, Ings et al. 2006).

At the end of the 19th century, two saturniid moths, *Samia cynthia* and *Antheraea yamamai*, were introduced from Asia for silk production, but yields was not profitable enough for this to be continued. Both species persist locally in the wild in Europe with most populations being initiated by escapes or releases by amateur lepidoptera-breeders.

Intentional releases for human food consumption are more prevalent for organisms such as molluscs, fish and aquatic Crustacea (oysters, snails, crayfish, crabs), which are not included in this book. Also, there are no "game insects", and only a few pets. Further, there are no introductions of arthropods for aesthetic or conservation purposes (but see further below), a major pathway for other animal groups around the globe (e.g. Nentwig 2007). In the DAISIE-database, 218 species (14%) were introduced intentionally, almost all of these for biological control purposes (Table 3.2).

Table. 3.2. Pathways of the alien arthropod species in Europe, according to the DAISIE-database. Due to double entries the sum differs.

Pathway	Number of species (%)	
Intentional	218 (14%)	
Released		175 (11%)
Unintentional	1341 (86%)	
Animal husbandry		42 (2.6%)
Greenhouse escapees		204 (13%)
Crops		70 (4.3%)
Forestry		90 (5.6%)
Horticultural/Ornamental		468 (29%)
Leisure		13 (0.8%)
Stored products		201 (12%)
Stowaways		95 (5.9%)
Unknown		431 (27%)

3.2.1. Biological control: Ecology vs Economy

The most important pathway for deliberate release of terrestrial alien arthropods is biological control (BC). There has been some controversy about the pros and cons of this technique to control pest organisms (e.g. Howarth 1991, van Lenteren et al. 2006, Babendreier 2007, Murphy and Evans 2009). Whereas non-target effects are considered problematic by conservationists, these are often considered acceptable from an economic point of view. Hence, the underlying basic assumptions and intentions for this controversy are entirely different and comparisons awkward.

BC makes use of the "enemy-release" of introduced organisms, which are disburdened from their natural predators or parasites and boom in the new range. Subsequently, mass-reared releases of those enemies from the original area are conducted, aiming at permanent establishment and control of the pest organisms below damaging thresholds. Not particularly from a "pathway point-of-view", but from a general assessment of non-target effects, it is useful to distinguish between this classical BC and augmentative BC, where control is achieved by periodic releases without permanent establishment intended. Similarly, flightless strains of *H. axyridis* were released in the Czech Republic in 2003 to control for aphids with the goal of no further unaided spread (Brown et al. 2008).

In Europe, there are both success-stories and failures to report from intentional releases, with the former prevailing (e.g. *Encarsia formosa* used against whiteflies in greenhouses; *Trichogramma brassicae*, an "alien in Europe" used against European corn borer *Ostrinia nubilalis*; *Aphelinus mali* from North America used against the Woolly apple aphid *Eriosoma lanigerum*).

Occasionally, released enemies are aliens from other regions than their targets. In Europe, for example, the San Jose scale *Diaspidiotus perniciosus*, described from California, but introduced with infested trees or fruits from Asia, is considered a pest in commercial fruit orchards causing economic losses due to reduced yields. Negative effects are mitigated by application of Neem and other oils, but also by release of the North American parasitoid wasp *Encarsia perniciosi*, which is used for control in North America.

In general, however, the application of BC has been of subordinate relevance in Europe, compared to other regions of the world. The same is true for the application of other technologies where arthropods are released (SIT – Sterile Insect Technique; RIDL – Release of Insects carrying a Dominant Lethal), which may be applied to control alien agricultural pests and mosquitos (Thomas et al. 2000, Alphey et al. 2009).

Ex-situ conservation or reintroduction programmes in insects are still rare, but they do occur for some native species in Europe (butterflies in the UK: Oates and Warren 1990; *Erebia epiphron* in the Czech Republic: Schmitt et al. 2005; *Gryllus campestris* in the UK and Germany: Witzenberger and Hochkirch 2008). Recently, controversial discussions on assisted colonization have emerged in the context of protecting species from climate change by translocating and releasing them beyond their current range limits (e.g. Hoegh-Guldberg et al. 2008, Ricciardi and Simberloff 2009).

3.3. Unintentional release

The unintentional translocation of species is the most common pathway for alien arthropod species invasions into Europe (86% of the species, Table 3.2).

3.3.1. Escapes: Out of the Green

Arthropods are infrequently domesticated, reared and used as pets, although examples of tropical species do exist (e.g. tarantulas, walking sticks and leaves, leaf-cutting ants, millipedes). Establishment in the wild in Europe is highly unlikely for such species, even under severe climate change scenarios. However, escapes from captivity do regularly occur, although they are rarely noticed and published. Insects reared as living food for vertebrate pets (e.g. crickets, grasshoppers, mealworms) seem to be of limited significance, whereas pests and insects used for biological control in semi-contained environments, particularly greenhouses, are of much greater importance. Greenhouses are not escape-proof facilities for insects as confirmed by surveys in the areas surrounding such buildings (e.g. Vierbergen 2001, Aukema and Loomans 2005). Well-known examples include the Western Flower Thrips *Frankliniella occidentalis*, the Cotton Aphid *Aphis gossypii*, and the Cotton Whitefly *Bemisia tabaci*, all of which reproduce in the field in southern Europe but are restricted to greenhouses in western, central, or northern Europe. Serving as stepping stones, it is expected that some future invaders in Europe will be recruited out of this pool of species, particularly if climate warms as predicted. In the DAISIE-database, more than 200 arthropod species are listed as living in greenhouses.

One of the most famous stories of a greenhouse escapee is the Multicoloured Asian lady beetle or Harlequin ladybird *Harmonia axyridis*, termed the "most-invasive ladybird on Earth" (Roy et al. 2006). This large coccinellid beetle, native to East-Asia, was introduced to North America and Europe for aphid control in greenhouses, but escaped into the wild. It is a highly competitive intra-guild predator reducing and displacing native coccinellid species and other members of the aphid-feeding guild (Roy and Wajnberg 2008). Its subsequent unaided spread across much over Europe within just a few years (Brown et al. 2008) highlights the capacity of invasive alien species to successfully conquer naïve environments.

3.3.2. Contaminant: Going for a ride?

The contaminant pathway describes the unintentional transport of species within or on a specific commodity, contrary to stowaways, which are accidentally associated with any commodity. Stored product pests, for example, are translocated with the movements of the products and many species have subsequently achieved a cosmopolitan distribution. In Europe, 201 alien insect species (12%) were introduced as stored product pests, feeding on a variety of food sources (e.g. cereals, rice, seeds, nuts, fruits) with considerable economic damage, including species which are likely to have been introduced by human activities in neolithic or pre-Christian centuries, e.g. *Sitophilus granarius* and *Oryzaephilus surinamensis* (Levinson and Levinson 1994). In Europe and temperate regions in general, care of stored products achieves higher protection levels than in subtropical and tropical areas, where up to 10% of weight loss may occur, representing loss of nutritional quality, with associated impacts on human welfare (Rees 2004).

Other pest species are strictly associated with the exchange or trade of their host plants (e.g. ampelophagous species feeding exclusively on grapevines - *Viteus vitifoliae*, *Scaphoideus titanus*; species feeding exclusively on palms - *Rhynchophorus ferrugineus*, *Diocalandra frumentii*; monophagous leaf-miners and gall-producers - *Parectopa robiniella*, *Phyllonorycter robiniella*, *Dryocosmus kuriphilus*) and therefore directly related to these vectors.

Other examples include phytophagous species translocated with ornamentals or horticultural host plants (e.g. scales and aphids) and xylophagous bark- and wood-infesting insects, above all beetle larvae, feeding in living trees. One of the best known examples is the Citrus longhorned beetle *Anoplophora chinensis*, which has repeatedly been reported infesting Bonsais imported from China. Larvae of *A. chinensis* and more often of the Asian longhorned beetle *Anoplophora glabripennis* were also intercepted with wood packaging material (see Haack et al. 2010 for a review). Recognizing the relevance of this vector enforced adoption of the International Standard for Phytosanitary Measures No. 15, which sets standards for thermal and chemical treatment of wood packaging material used for international trade. Although now found in lower numbers, living beetles are still being intercepted, indicating some gaps in this procedure.

Roques (2010) assembled examples of the possible introduction of alien insects during major international events such as the 2004 Olympic Games in Athens, where imported palm trees were widely planted and coincided with the first arrival of the red palm weevil *Rhynchophorus ferrugineus*.

The most striking example of contamination is associated with the introduction of the Potato (Colorado) beetle, *Leptinotarsa decemlineata*, to Europe. Spanish conquistadors in the 16th century brought the potato plant from South America to Europe, although it was not appraised as a human food source until the mid-17th century. After a severe decline of potato cultivation in Ireland in 1845–1857, caused by the introduced potato blight fungi *Phytophthora infestans*, emigrants brought the plant to North America, where the beetle exploited the new host plant. Between 1876 and 1922, the beetle was subsequently introduced into Europe on several occasions, not being able to establish in European potato fields until 1922, when it succeeded in France. The beetle has since spread east throughout Europe and Asia, reaching China in the 1980s (Alyokhin 2009). It should also be noted that the Colorado beetle was involved in propaganda to defame Great Britain and the United States of America during World War II and the Cold War.

Kenis et al. (2007) found that the majority of alien insects for Austria and Switzerland were contaminants and stowaways, with, in decreasing order, host plants (40% of which on ornamentals and 20% on vegetables and fruits), stored products and wood material as the main sources. Similar results were obtained with interceptions documented by EPPO between 1995 and 2004 (Roques and Auger-Rozenberg 2006). Altogether, introductions of arthropods with ornamental and horticultural plants and plant material, cut flowers, vegetables, and fruits, clearly preponderate in the DAISIE-data (29%, Table 3. 2). It is self-evident that there is a taxonomic bias with the type of commodity. For example, plant-feeding species (e.g. aphids, scales) are closely associated with ornamental plants, whereas wood-boring species (e.g. scolytids, cerambycids) are linked to living and dead wood imports. A rather uncommon invasion history pertains to the inadvertent introduction of the nearctic waterboatman *Trichocorixa verticalis* into Portugal and Spain. It is likely to have happened with the import and release of Eastern Mosquitofish *Gambusia holbrooki* for mosquito control (Sala and Boix 2005).

Living organisms as well as commodities can be contaminated. For example, many haematophagous alien arthropod species (e.g. Culicidae, Siphonaptera, Phthiraptera, Ixodidae) host parasites and pathogens and serve as reservoir, carriers or biovectors of human and animal infectious diseases. Moreover, phytophagous alien arthropod species (e.g. Hemiptera) may transmit plant pathogens (e.g. phytoplasmas, viruses).

Several examples are associated with beekeeping. Both endoparasites (the tracheal mite *Acarapis woodi*) and ectoparasites (the notorious *Varroa*-mite *Varroa destructor*), inquiline scavengers (the Small Hive Beetle *Aethina tumida*, captured only once in Europe and eradicated in quarantine in Portugal), and bacterial and fungal diseases (chalkbrood, foulbrood, nosemosis) are exchanged throughout the globe through honeybee imports (e.g. Sammataro et al. 2000, Coffey 2007).

The ultimate agent of Colony Collapse Disorder (CCD) known from North America, Europe and Asia is still under debate (e.g. Ratnieks and Carreck 2010) and it may well be a multi-triggered phenomenon, which causes the complete disappearance of adult worker bees of a colony. Beside environmental causes (e.g. pesticides), several diseases and pathogens are suspected to contribute or elicit CCD, e.g. *Nosema ceranae*, a microsporidian native to Asia and suspected to have host-switched to the European honeybee (Klee et al. 2007, Higes et al. 2009).

3.3.3. Stowaways: Where do you want to go today?

Stowaways are unintentionally introduced organisms that are related to transport infrastructure and vehicles, but independent of the type of commodity. Translocation with ballast water or soil movement are typical examples. In terrestrial environments, any cargo transported by air, water or land has the potential to move species beyond their natural range and habitat boundaries. Several cockroach species, e.g. *Blatta orientalis* and *Periplaneta americana*, are typical stowaways, having been translocated worldwide. Kiritani and Yamamura (2003) argued that passenger hand luggage arriving in airplanes to Japan may contain one consignment infested by fruit flies each day. Roughly two thirds of the intercepted pest species at US ports of entry between 1984 and 2000 were associated with baggage, and a further 30% with cargo (McCullough et al. 2006). However, to a certain extent, the separation between the contaminant and the stowaway pathway is ambiguous or not mutually exclusive.

Roques et al. (2009) cites the Asian tiger mosquito *Aedes albopictus* as an example of the stowaway pathway, this species being translocated as eggs and larvae within any small amount of standing water. Water within used tyres or ornamental plants (lucky bamboo *Dracaena* spp.) is a cause of the trans-continental introduction of *A. albopictus* to Europe, North America, Africa and Australia (e.g. Reiter 1998). Short-distance dispersal seems to be limited to passive transport by cars and trucks, or movement of infested tyres and plants (Scholte and Schaffner 2007). Establishment in other parts of Europe is very likely within the next decades, supported by climate change (Schaffner et al. 2009). *Aedes albopictus* is a vector of several viruses (e.g. Dengue, Chikungunya, West Nile) and of increasing relevance for Europe (Scholte and Schaffner 2007, van der Weijden et al. 2007). The movement of used tyres is also likely to be responsible for the most recently introduced mosquito species, *Ochlerotatus atropalpus*, native to North America and detected in several European countries (France, Italy, Netherlands), where it was subsequently eradicated (Scholte et al. 2009).

Many insects are attracted to light and most transport hubs (airports, seaports) are illuminated during night-times, increasing the probability of translocation with vehicles after boarding a vector. For example, it is speculated that the attraction to light facilitates the repeated introduction of adult *Diabrotica virgifera* with aircrafts from

North America to Europe, because of regular "first" records of the species in the vicinity of airports. From there the species spreads unaided depending on habitat (maize fields) availability.

Ants (Formicidae) are among the most invasive organisms globally, particularly hazardous on oceanic islands (e.g. Holway et al. 2002, Lach and Hooper-Bùi 2010). Entire colonies with gynes and workers may be translocated as stowaways with soil and litter accompanying ornamental plants, with logs or with other commodities offering shelter. The majority of introduced ants in the USA have been detected on plant material (Suarez et al. 2005). Some of the characteristic traits of tramp ants, e.g. preference for disturbed habitats, polygyny, budding, small body size, support successful translocation and subsequent establishment around the globe (e.g. McGlynn 1999). In Europe, the Argentine ant *Linepithema humile* and the garden ant *Lasius neglectus* are currently considered to be of prime importance (see Kenis and Branco, chapter 5). Whereas the former was introduced as a stowaway with unknown commodities to Europe (Madeira and mainland Portugal) in the 19th century (Wetterer et al. 2009), the origin (likely Asia Minor), pathway and vector (eventually contaminant of garden soil) and successful secondary spread of the latter are still under debate (Ugelvig et al. 2008).

Two more examples of Hymenoptera, initially introduced as stowaways, are the oriental mud dauber *Sceliphron curvatum* and the Asian hornet *Vespa velutina*. The former was introduced in the late 1970s via air cargo from Central Asia to Austria and produces conspicuous mud nests in which paralysed spiders are provisioned as food supply for the developing larvae (Schmid-Egger 2004). The latter was only recently detected in France, probably introduced with pieces of pottery from China (Villemant et al. 2006). These two species have subsequently spread rapidly, unaided, and may be of increasing relevance to native sphecids, hornets and honeybees.

3.3.4. Corridors: Like a rolling stone

The corridor pathway highlights the role transport infrastructures play in the introduction of alien species; shipping canals are the most important example. Gilbert et al. (2004) have shown that the spread of *Cameraria ohridella* in Germany was related to the highway routes, Pekar (2002) argues that the spread of the spider *Zodarion rubidum* was facilitated by the railway system and there is anectodal evidence for repeated northwards transport of the flightless Southern Oak Bush Cricket (*Meconema meridionale*) and the Speckled Bush-Cricket (*Leptophyes punctatissima*) with cars along highways from Southern Europe. Although infrastructure networks undoubtedly contribute to the distribution of alien terrestrial arthropod species in Europe, it seems to be of subordinate relevance and is often intermingled with the contaminant/stowaway pathway.

3.3.5. Unaided: One day I'll fly away

The unaided pathway describes leading-edge dispersal, that means situations where spread results in alien species arriving in a new region from a donor region where it is also alien. This holds true for many alien arthropods occurring in the wild in Europe, being introduced once and spreading after successful establishment. Several examples were mentioned in the chapters above, although this is not reflected in the DAISIE-database (Table 3. 2). Unaided spread often follows initial introduction by one of the other pathways into Europe, although long-distance dispersal events may contribute to the distribution patterns and accelerate rates of spread, as shown for the horse chestnut leafminer *Cameraria ohridella* in Germany and France (Gilbert et al. 2004, 2005). The chestnut gall wasp *Dryocosmus kuriphilus* was introduced with infested plant material from China to Italy and is now spreading unaided to neighbouring countries, but may also bridge larger distances with transport of infested plant material.

Dispersal capacities of arthropods can be impressively high. The conifer seed bug *Leptoglossus occidentalis* and the Harlequin ladybird *Harmonia axyridis* spread over much of Europe within just a decade (e.g. Lis et al. 2008, Rabitsch 2008, Brown et al. 2008) presumably on their own wings. In addition, repeated and independent introductions from the area of origin and/or secondary introductions from the alien range over long distances undoubtedly occur, but such events are difficult to prove and require specific techniques (e.g. molecular biology) (e.g. *Diabrotica virgifera* – Miller et al. 2005, Ciosi et al. 2008).

Controversy surrounds the definition of the alien status of species extending their range due to recent anthropogenic climate change. As long as they utilize the beforementioned pathways, e.g. are translocated with vehicles, but then find suitable climate conditions to establish populations, they should be considered alien. If a species extends its range unaided, but only colonizes disturbed or secondary habitats under strong human influence, such species may be considered as alien. Particularly in arthropods, however, it is sometimes difficult or even impossible, to unambiguously identify the boundaries of the natural range of a species. Historic introductions of today's cosmopolitan species, taxonomic impediment and the lack of recording schemes for most groups cause a high degree of uncertainty in the delimitation of the native range of some species. Host plant distribution, habitats, and molecular techniques may serve as a clue for disentangling factors (e.g. Kavar et al. 2006, Valade et al. 2009).

Unaided dispersal is also often assumed for modelling rates of spread of alien species. Liebhold and Tobin (2008) provided examples for the radial rate of spread in alien insects, which span from 1 to 500 km year^{-1}. In Europe, the western flower thrips *Frankliniella occidentalis* stays ahead with up to 249 km year^{-1} (Kirk and Terry 2003). However, in many if not most cases, additional pathways including long-distance dispersal or at least a combined stratified dispersal need to be taken into account for more realistic scenarios of spread (e.g. Gilbert et al. 2004 for the horse chestnut leafminer *Cameraria ohridella*).

3.4. Future trends and management

There is no reason to assume a decrease in people's movements and restrictions in the transport of goods in the near future. Biological homogenization will tie continents and biodiversity, increasing species richness locally and decreasing it globally; the rate of change will be much more rapid than the hypothesised formation of Neopangaea (Scotese 2001). The ultimate consequences of such a process for the functioning of ecosystems and their services to mankind are far from being well understood.

There is a spatiotemporal signal in the relevance of pathways and vectors. Whereas soil was used as ship ballast in earlier days of European colonization (e.g. Vazquez and Simberloff 2001) this was replaced by ballast water in later years. With the construction of bigger and faster ships, even more organisms were translocated rapidly and with the advent of aircrafts this rate was yet further accelerated. Fast transit enables more species to survive transport and subsequently establish successfully in new regions. In addition, continental, land-locked areas became easily accessible (Mack 2003). Asia has recently gained increasing relevance as a country of export globally (Roques 2010) and as a donor region of alien species, particularly for insects associated with woody plants introduced to Europe (Roques et al. 2009). New trends in the ornamental trade by changed consumer behaviour has created new markets. Only two decades ago, bonsais were rare in European households, but have become a recent fashion; sales are increasing in most areas. Generally, the horticultural/ornamental pathway is of paramount significance for the alien arthropods of Europe (Kenis et al. 2007, Table 3. 2) and there is ample scope for enhancing existing plant protection services (e.g. by increasing personnel at points of entry) and providing best-practice guidance to the ornamental trade industry. It has been shown, however, that interception and establishment data of alien insects for Europe differ significantly (Kenis et al. 2007, Roques 2010). This discrepancy may eventually be explained by the changed relevance of pathways and time-lag phenomena (Crooks 2005). In any case, it demonstrates that additional endeavours are necessary to abate undesirable effects on ecology and economy.

Import and export of goods follows economic rules and global trade mirrors biological invasion patterns (e.g. Levine and D'Antonio 2003, Taylor and Irwin 2004, Kobelt and Nentwig 2008, Westphal et al. 2008, Roques et al. 2009). Chiron et al. (2009) showed such a pattern for bird introductions on both sides of the "iron curtain" in Europe and it is expected that a similar pattern will be found for arthropods. However, information on introduction dates, number of propagules, etc. are usually lacking for arthropod invasions, so that such analyses are difficult to achieve.

Anthropogenic climate change acts upon several levels of biological invasions (e.g. Walther et al. 2009, Thomas and Ohlemüller 2010). It may directly change the realized climatic niche of species, cause habitat shifts (e.g. stepping-stone scenarios) and range shifts in latitude and altitude. Ødegaard and Tømmerås (2000) showed that eight out of 25 alien ground-beetle species used compost heaps as stepping-stones for subsequent establishment in the wild in northern Europe. Global climate change, however, may further act indirectly in changing trade and consumer habits, influencing invasion pathways and vectors by creating new opportunities and depleting traditional routes.

Species-specific eradication plans are a legally binding obligation in the plant health sector and – to some extent – also in the human and veterinary medical sectors. Regulation and harmonization in Europe, however, lags far behind other regions (Hunt et al. 2008) and this is even worse for species of environmental concern. Thinking of arthropods as a mega-diverse group it is highly likely that numbers and impacts of alien species will increase worldwide.

For invasive species management, it is pivotal to tackle pathways, especially in the case of small and unintentionally translocated arthropod species. For example, Skarpass and Økland (2009) proposed measures of how to reduce introduction risk of bark beetles with timber imports. Whereas considerable knowledge has been accumulated for marine pathways, one has to conclude, in agreement with Lockwood et al. (2007), that surprisingly little information is available on the exact magnitude, direction and variation of terrestrial pathways. This is especially true for Europe, where targeted research on invasion pathways should be encouraged. Following identification of the most important pathways, relevant vectors need to be thoroughly tested for their likelihood of interception (e.g. quarantine) or disruption (e.g. import ban or special obligatory and certified treatments) aiming at reducing propagule pressure. There are different options for action to be taken between maximal prevention at border controls and free trade. However, it has to be assumed that "vector management serves as a filter and not as a wall to exotic species" (Carlton and Ruiz 2005: 48).

Anoplophora species provide instructive examples of how obligatory management actions are dealt with in practice in Europe. The reasonable goal of complete eradication is hampered by the implementation of national legislations, by costs borne by individual countries, and repeated introductions as a consequence of the single market policy. A united Europe should opt for better coordination, the polluter-pays-principle, an alien emergency fund, and clear responsibilities. Ultimately, a dedicated independent agency is necessary to deal effectively with biological invasions in Europe (Hulme et al. 2009).

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