

Taxonomy, time and geographic patterns

Chapter 2

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Abstract

A total of 1590 species of arthropods alien to Europe have already established on the continent, including 226 more or less cosmopolitan species of uncertain origin (cryptogenic). These alien species are dispersed across 33 taxonomic orders, including crustaceans, chilopods, diplopods, pauropods, Symphyla, mites, arachnids, and insects. However, insects largely dominate, accounting for more than 87% of the species, far in excess of mites (6.4%). Three of the insect orders, namely Coleoptera, Hemiptera and Hymenoptera, overall account for nearly 65 % of the total. The alien fauna seems to be highly diverse with a total of 257 families involved, of which 30 have no native representatives. However, just 11 families contribute more than 30 species, mainly aphids, scales and hymenopteran chalcids. For a number of families, the arrival of alien species has significantly modified the composition of the fauna in Europe. Examples are given. The number of new records of aliens per year has increased exponentially since the 16th century, but a significant acceleration was observed since the second half of the 20th century, with an average of 19.6 alien species newly reported per year in Europe between 2000 and 2008. This acceleration appears to be mainly related to the arrival of phytophagous species, probably with the plant trade, whereas the contribution of detritivores, parasitoids and predators has decreased. Some taxa have not shown any acceleration in the rate of arrivals. Asia has supplied the largest number of alien arthropods occurring in Europe (26.7 %), followed by North America (21.9%) but large differences in the region of origin are apparent between taxa. Once established, most alien species have not spread throughout Europe, at least yet, with 43.6 % of the species only present in one or two countries, and less than 1% present in more than 40 countries. Large differences also exist between European countries in the total number of alien arthropods recorded per country. Italy (700 species) and France (690 species), followed by Great Britain (533 species), host many more species than other countries. The number of alien species per country is significantly correlated with socioeconomic and demographic variables.

Keywords

aliens, arthropods, Europe, globalization, taxonomy, Asia, drivers of biological invasion

Introduction

Expanding world-wide trade, globalisation of economies and climate change are all factors that contribute to an accelerated international movement and establishment of alien organisms, allowing them to overcome geographic barriers (Hulme et al. 2008, Hulme 2009, Walther et al. 2009, Roques 2010). These alien species have already been shown to impose enormous costs on agriculture, forestry as well as to threaten human health and biodiversity (Williamson 1996, Wittenberg and Cock 2001, Pimentel et al. 2002, 2005, Vilá et al. 2009). Although terrestrial arthropods, and particularly insects, represent a large part of the alien species problem, they appear to have received disproportionately less attention compared to plants, vertebrates, and aquatic organisms, especially regarding their possible ecological impact (Kenis et al. 2009). Most of the works concerning alien terrestrial invertebrates have dealt with case studies of pests having a high economic or sanitary impact, such as gypsy moth (*Lymantria dispar* (L.)) in North America (Liebhold et al. 1992), Asian long-horned beetles (*Anoplophora* spp.; Haack et al. 2010), or Asian tiger mosquito (*Aedes albopictus* (Skuse); Eritja et al. 2005). More synthetic studies have been carried out at guild level (e.g., bark beetles; Brouckhoff et al. 2005) or at ecosystem level, especially for forest insects (Liebhold et al. 1995, Mattson et al. 1996, 2007, Niemelä and Mattson 1996, Langor et al. 2009). However, continental inventories of alien arthropod species, or even of alien insects, are still lacking in most regions, although such studies are needed to assess which taxonomic or bio-ecological groups of alien species are better invaders or more harmful to the economy or environment, and which ecosystems or habitats are at greater risk (Mondor et al., 2007).

In Europe, the potential problems caused by alien arthropods have traditionally been considered as less severe than in North America, Australasia or South Africa (Niemelä and Mattson 1996). As a result, unlike other groups of animals and plants, no checklist of alien terrestrial arthropods was available in any of the European countries until the early 2000s. However, in the last 20 years, several exotic pests of economic concern, to name a few, the western corn rootworm (*Diabrotica virgifera virgifera* LeConte), the red palm weevil (*Rhynchophorus ferrugineus* (Olivier)), the harlequin labybeetle (*Harmonia axyridis* (Pallas)), or the chestnut gall maker (*Dryocosmus kuriphilus* (Yasumatsu)), have invaded Europe, inducing more interest in the issue of alien arthropods. The horse-chestnut leaf miner, *Cameraria ohridella* Deschka and Dimić, an alien in Europe originating from the Balkans, has also raised much public concern because of its spectacular damage to urban trees in invaded areas of Central and Western Europe (Valade et al. 2009).

Thus, checklists of alien arthropods began to be compiled from 2002 onwards, successively covering Austria (Essl and Rabitsch 2002), Germany (Geiter et al. 2002),

the Netherlands (Reemer 2003), the Czech Republic (Šefrová and Laštůvka 2005), Scandinavia (Nobanis 2005), the United Kingdom (Hill et al. 2005, Smith et al. 2007), Italy (Pellizzari et al. 2005), Serbia and Montenegro (Glavendekić et al. 2005), Switzerland (Kenis 2005), Israel (Roll et al. 2007), Albania, Bulgaria and Macedonia (Tomov et al. 2009), and Hungary (Ripka 2010). However, a major advance in the knowledge of alien arthropod species established in Europe was the European project DAISIE (*Delivering Alien Invasive Species Inventories for Europe*) in 2008. Besides furnishing national and regional lists, this project provided for the first time an overview of the alien fauna of arthropods that has established on the continent. DAISIE identified a total of 1517 alien terrestrial invertebrates, of which 1424 arthropods. However, limited expertise in some taxa during the DAISIE project meant full coverage of all the terrestrial arthropods could not be achieved with the same level of precision. The working group formed on this occasion therefore decided to continue its activity over the next two years, enlarging its taxonomic scope and competencies, in order to provide the most exhaustive list of the alien terrestrial arthropods of Europe as possible, with detailed information about each species.

The update of the DAISIE list revealed in this book accounts for 1590 arthropod species alien to Europe, i.e. 166 more species, including both additions and deletions from the former list, and a much better coverage of taxonomic groups other than insects and spiders (i.e., mites, myriapods and crustaceans). In order to allow a comparison of their invasive patterns, the different taxonomic groups are presented separately in 21 chapters which have the same format. Because of the large number of species in some groups, these have been divided into several distinct chapters; i.e., four chapters for Hemiptera and five chapters for Coleoptera. Each chapter successively analyzes the taxonomy of the alien species component compared to that of the native fauna, the temporal trends of introduction, the biogeographic patterns, including both details of the region of origin and the distribution of the species in Europe, the pathways of introduction, the ecosystems and habitats which are invaded, and the economic and ecological impact of the biological invaders. At the end of each chapter, a table summarizes key information regarding all species in the taxa which are alien *to* Europe; i.e. of ascertained exotic origin or cryptogenic (see Chapter 1 for definitions): family, feeding regime, date and country of first record in Europe, invaded countries, habitats, plant or animal host, and one reference at least (usually that of the first record). In a number of cases, a second table includes a list and similar information for the species considered as alien *in* Europe; i.e. spreading to new countries within Europe, especially for species of Mediterranean origin recorded in more northern areas and species of continental Europe which have colonized islands. We did not provide such tables systematically. Indeed, it was difficult to ascertain for a lot of these species whether they have been introduced in other parts of Europe through direct or indirect human activity - and thus meet our definition of aliens (see Chapter I) - or they are naturally expanding, e.g. with global warming, or even if their native distribution range was incompletely known before their 'discovery' in these new areas.

The geographic range covered in this book is primarily Europe in geographic sense, with the main Mediterranean islands and archipelagos (Balearic Islands, Corsica, Sar-

dinia, Sicily, Malta, Crete, and the Ionian, North Aegean and South Aegean islands) and those of the North Sea (Aland, Svalbard) which are considered separately from the associated continental countries. Ireland was considered as a single biogeographic entity (i.e., Republic of Ireland plus Northern Ireland). Because of their possible importance as a first step for the invasion of continental Europe, the islands of the Atlantic Ocean (Madeira, the Canary Islands, The Azores Archipelago), were also included in the analysis but they may also correspond to a source of aliens of Macaronesian origin colonizing the European continent.

This substantial work allowed us to figure out the relative importance of the different taxa of alien arthropods in a standardized fashion to other groups as well as to compare their respective habitats (Pyšek et al. 2009), and environmental and economic impacts (Vilá et al. 2009). The present chapter presents the most important patterns exhibited by the terrestrial arthropods alien to Europe.

2.2 Taxonomy of arthropods alien to Europe

Alien terrestrial arthropods represent the second most numerous group of organisms introduced to Europe (Roques et al. 2009). A total of 1364 species originating from other continents have established so far, to which we add 226 more or less cosmopolitan species of uncertain origin (cryptogenic) for a total of 1590 species. Insects largely dominate this list, accounting for more than 87%, far in excess of mites (6.4%) (Figure 2.1). These alien species are dispersed across 33 taxonomic orders, including two orders of crustaceans, 10 of myriapods (three of chilopods, five of diplopods, one of pauropods and one of Symphyla), four of mites, one of arachnids, and 16 of insects. However, the relative importance of each order is highly variable (Figure 2.2). Three of the insect orders, namely Coleoptera, Hemiptera and Hymenoptera, overall account for nearly 65 % of total alien arthropods, representing 25.0%, 20.0% and 18.7%, respectively. The number of alien Hymenoptera established in Europe is thus much higher than previously considered (Daisie 2009). Diptera (6.2 %), Lepidoptera (6.1 %) Thysanoptera (3.3 %) and Psocoptera (3.1 %) have much lower importance as do Prostigmata mites (4.9 %- see Chapter 7.4) and Aranea (3.0 %), the only non-insect orders to exhibit more than 45 alien species. The other orders are anecdotal. It should be noted that some orders show no alien species whereas there are important components of the native fauna such as Trichoptera. More generally, at the order level, the taxonomic composition of the alien fauna significantly differs from that of the native European arthropod fauna. Calculations done on insects have revealed that establishment patterns differ between orders (Roques et al. 2009). Hemiptera are nearly three times better represented in the alien fauna than in the native fauna (20.0% vs. 8.0%). The alien entomofauna also includes proportionally more thrips (3.3 vs 0.6%), psocids (3.1 vs. 0.3%) and cockroaches (1.1 vs. 0.2%) than the native fauna, but much fewer dipterans (6.2 vs. 21%) and hymenopterans (18.7 vs. 25%). Differences are less pronounced for Coleoptera (25.0 vs. 30.0%) and Lepidoptera (6.1 vs. 10%).

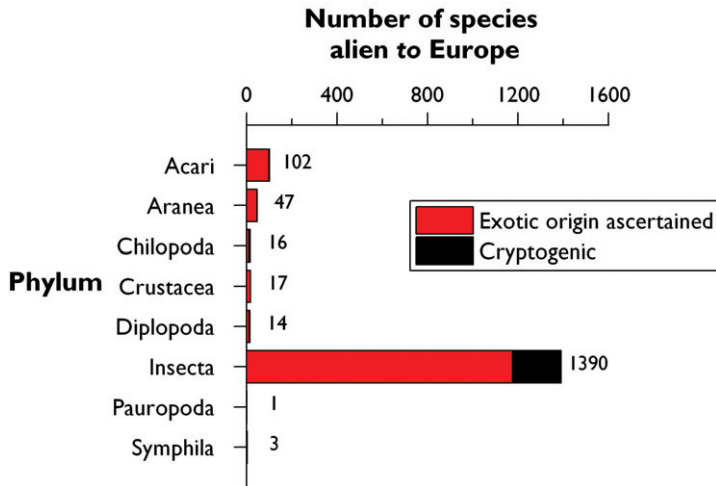


Figure 2.1. Relative importance of the different phyla in the 1590 species of arthropods alien to Europe. Species of ascertained exotic origin and cryptogenic species are presented separately. The number to the right of each bar indicates the total number of alien species observed per phylum.

The alien fauna seems to be highly diverse with a total of 257 families involved. However, only 38 of these families contribute 10 and more alien species, while 11 families more than 30 species (Figure 2.3). These 11 families mostly include hemipterans comprising aphids (Aphididae with the highest number of alien species - 102 spp.) and scales (Diaspididae and Pseudococcidae), as well as hymenopteran chalcids used for biological control such as Aphelinidae (63 spp.) and Encyrtidae (55 spp.), mites (Eriophyidae), and thrips (Thripidae). All of these except snout beetles (Curculionidae) and ants (Formicidae) are tiny arthropods. Noticeably, whilst these families dominate the alien fauna of arthropods, they are less intercepted by the phytosanitary quarantine services at European borders. A comparison done by Roques (2010) between interceptions and establishments of alien species in Europe during the period 1995 – 2005 for the alien insects and mites associated with woody plants in Europe has revealed that the major families of invaders were largely undetected (e.g. aphids, midges, scales, leafhoppers and psyllids). In contrast, the groups which were predominantly intercepted (e.g. long-horned and bark-beetles), actually made little contribution to the established alien entomofauna. Similar results were obtained at country level for Austria, the Czech Republic, and Switzerland (Kenis et al. 2007).

For a number of families, the arrival of alien species has significantly modified the composition of the fauna presently observed in Europe. First, a total of 30 families had no representatives in Europe before the arrival of aliens. These include seven families of myriapods (Henicopiidae - 5 spp., Haplodesmidae, Rhinocricidae, Oryidae, Siphonotidae, Oniscodesmidae, Pseudospirobolellidae, Spirobolellidae, Trigoniulidae - 1 sp. each), four mite families (Listrophoridae - 4 spp., Myocoptidae, Pyroglyphidae and Varroidae - 1 sp. each), and one spider family (Sicariidae - 2 spp.). For insects, no native species existed for three alien families of psocids (Lepidopsocidae - 5 spp., Psyl-

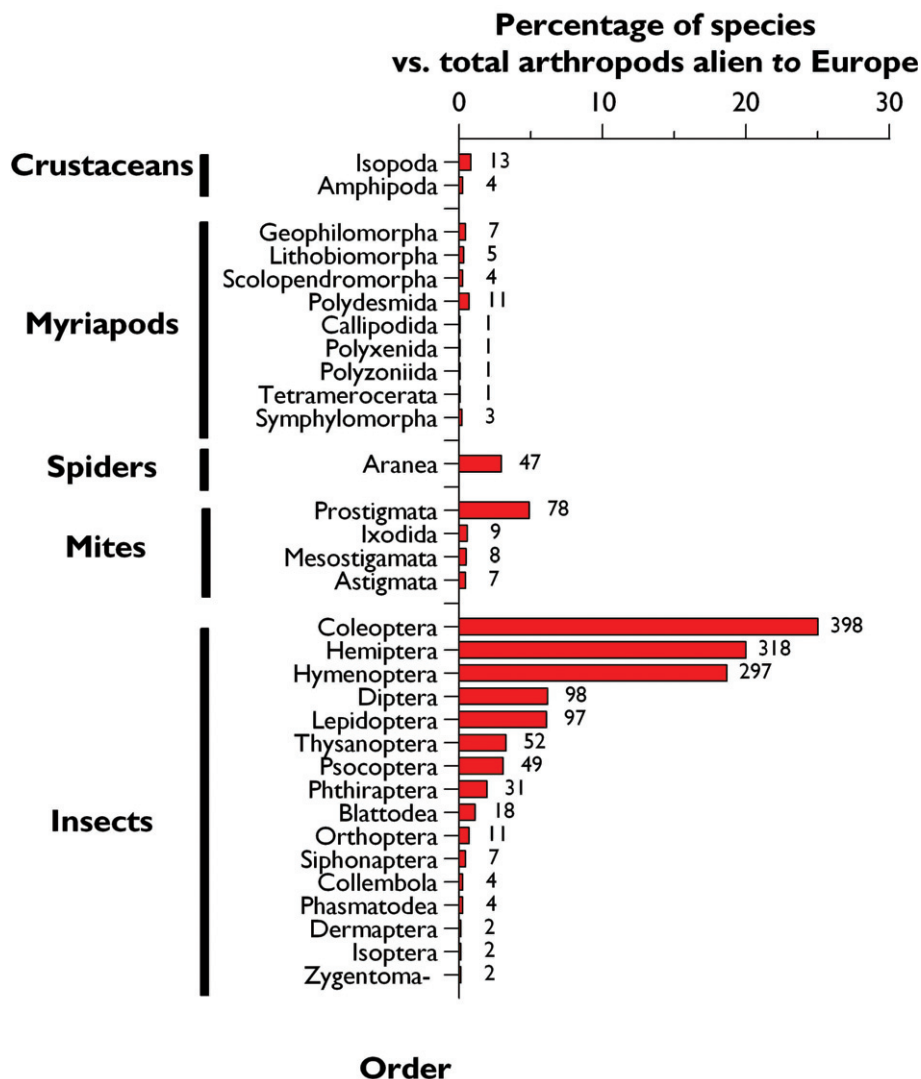


Figure 2.2. Relative importance of the different taxonomic orders in the 1590 species of arthropods alien to Europe. Species of ascertained exotic origin and cryptogenic species are summed. The number to the right of each bar indicates the total number of alien species observed per order.

lopsocidae - 5 spp., and Psoquillidae - 3 spp.), three lice families (Gliricolidae - 2 spp., Gyropidae and Trimenopidae - 1 sp. each), two Blattodea families (Blaberidae - 10 spp., and Blattidae - 6 spp.), two scale families (Phoenicococcidae and Dactylopiidae - 1 sp. each), two beetles families (Ptylodactylidae or little ash beetles - 2 spp. and Acanthonemidae or toe-winged beetles - 1 sp.), one lepidopteran family (Castniidae - 1 sp., the palm moth *Paysandisia archon* (Burmister)), one Phasmatodea family (Phasmatidae - 4 spp.), one family of Hemiptera Auchenorrhyncha (Acanaloniidae - 1 spp.), and one thrips family (Merothripidae - 1 sp.).

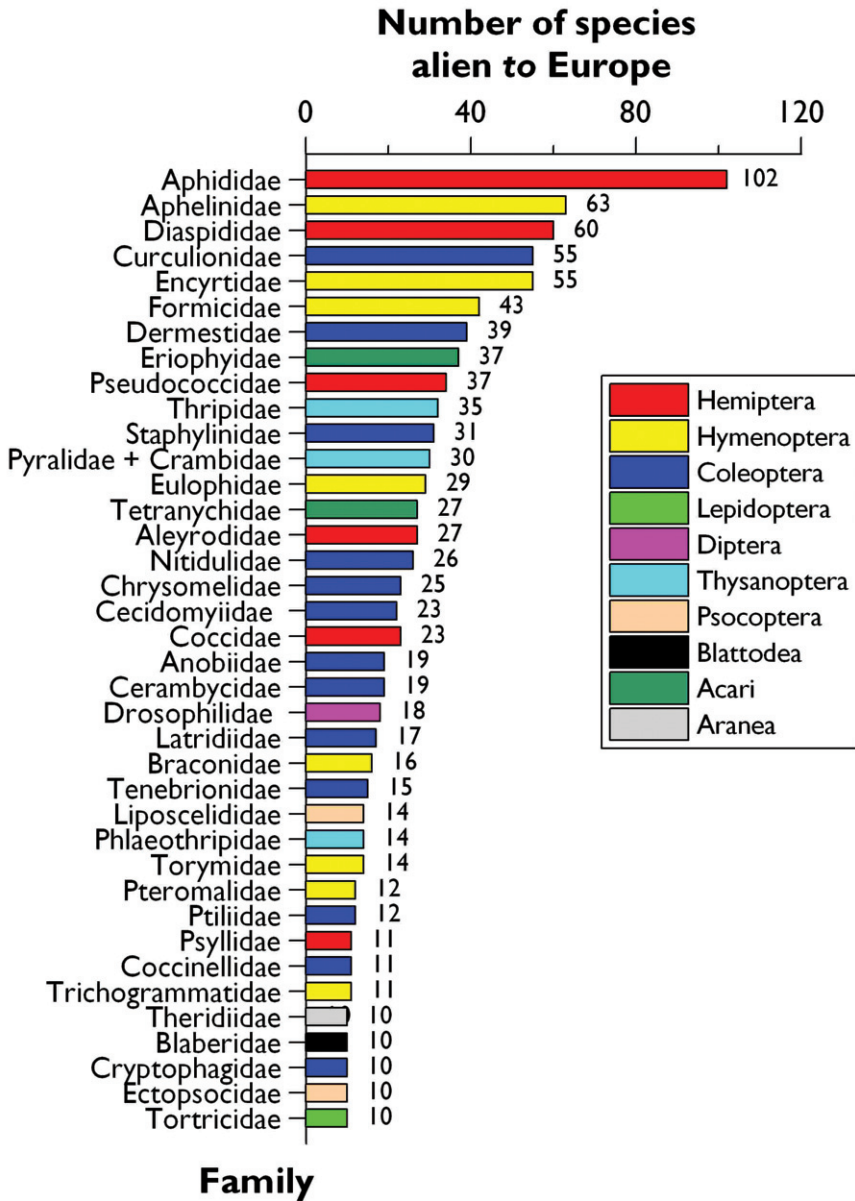


Figure 2.3. Families of arthropods contributing most to the fauna alien to Europe. Only the families with numbers of alien species equal to 10 or more are shown. Corresponding taxonomic orders are indicated by different colors. The number to the right of each bar indicates the total number of alien species observed per family.

In some other families, alien species could be over-represented. This is especially true for scales, where aliens now represent nearly half of the total Diaspididae fauna observed in Europe (60 out of 130 species - 44.6 %), a third of the Coccidae fauna (23 out of 70 species - 32.3 %), and a fourth of the Pseudococcidae fauna (37 out of 141 species

- 25.7 %). Similar high proportions of aliens are observed for psocids (Pachytroctidae - 66.7%, Ectopsocidae - 57%, and Liposcelidae - 26.4 %), hemipterans (Aleyrodidae - 39.1 % and Adelgidae - 36.0 %), hymenopterans (Agaonidae - 40.0 %, Aphelinidae 24.2 %, and Siricidae - 23.8%), and saturnid lepidopterans (30.0 %). Even if the relative proportions are lower, the arrival of a large number of alien species has also largely modified the faunal taxonomic structure in dermestid beetles (21.9 % of aliens), tetranychid mites (15.1 %), drosophilid flies (14.8 %), and encyrtid chalcids (7.2 %).

2.3 Temporal trends of arrival in Europe of alien arthropods

Some alien arthropods were introduced to Europe long ago accompanying human movements. For instance, a number of ectoparasites of humans and early-domesticated animals such the head louse (*Pediculus capitis* De Geer), the crab louse (*Phthirus pubis* (L.)), the cat flea (*Ctenocephalides felis felis* (Bouché)), the rat flea (*Xenopsylla cheopis* (Rothschild)) or the human flea (*Pulex irritans* L.) are probably allochthonous in Europe, having arrived in ancient times with their hosts (Mey 1988; Beaucournu and Launay, 1990). Thus, *Pulex irritans* was shown to have been present in Europe since the Bronze Age at least, having been found in remains of lake dwellings in the French Jura, dating back to 3100 B.C. (Yvinec et al. 2000). Fragments of insects related to stored products were also found in Roman and Viking graves (e.g., *Sitophilus granarius*; Levinson and Levinson 1994). However, unlike plants and other animal groups, a clear identification of the *archaeozoans** has appeared difficult for arthropods. Therefore, we only qualified as aliens the *neozoan** species, i.e. those having likely been introduced after 1500.

The introduction of alien arthropods is usually accidental, the release of biological control agents remaining limited, as well as the escape of arthropod 'pets' from captivity (see Chapter 3). Thus, the introduction phase is rarely observed and pathways of introduction are poorly known. Consequently, an alien arthropod is usually discovered when it is already established, spreading and causing damage. The precise date of arrival in Europe is not known for most species. Even conspicuous species, such as the Asian long-horned beetle, *Anoplophora glabripennis* (Motschulsky), have been reported with a delay of at least 3–5 years since establishment (Herard et al. 2006). However, taking into account these caveats, the date of first record in Europe- the single temporal datapoint usually obtainable- may be used as a proxy for the date of first arrival.

The date of first record in Europe, relying on published papers, could be obtained for 1421 of the 1590 alien species (89.4%). The number of new records per year appears to have increased exponentially since the 16th century, but a significant acceleration was observed during the second half of the 20th century (Figure 2.4a). As a probable result of globalization, this trend is still increasing with an average of 19.6 alien species newly reported per year in Europe between 2000 and 2008; i.e., a value nearly double the 10.9 species that were observed per year during the period 1950- 1974.

In order to understand better this process, we decompose the values according to the feeding regime of the alien species (Figure 2.4b). Fluctuations in the number of

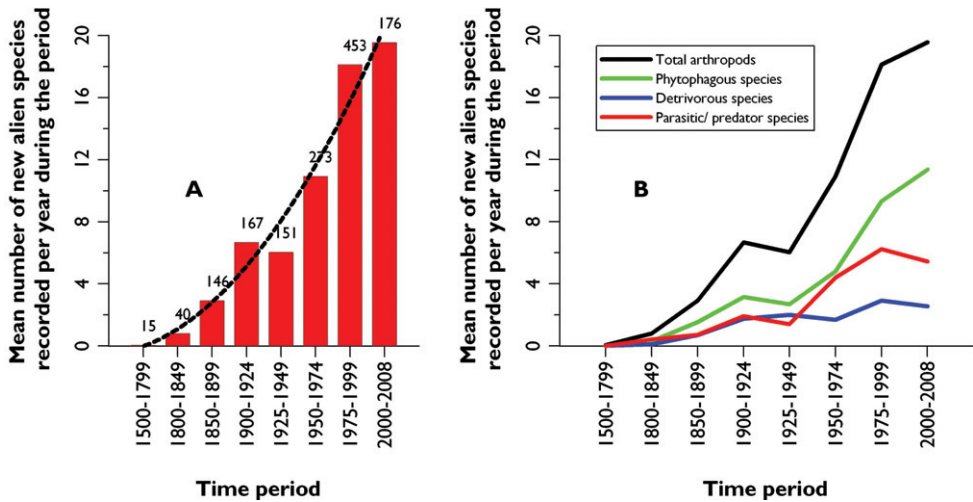


Figure 2.4. Temporal changes in the mean number of new records per year of arthropod species alien to Europe from 1500 to 2008. **A** Total arthropods (Best fit: $y = -0.411 - 0.407x + 0.304x^2$; $r^2 = 0.965$) **B** Detail per feeding regime.

total arthropods newly arriving per year in Europe appear to be strongly dependent on the increasing arrival of phytophagous species, especially during the last ten years. In contrast, the number of detritivores and parasitoids/ predators has appeared to decrease during this last decade, and contributed much less to the overall increase, whereas these three feeding guilds had contributed more or less equally during the first half of the 20th century. After the period 1950- 2000 when alien parasitoids and predators markedly increased probably in relation with the wave of releases of biological control agents, the explosion of ornamental trade since the 1990s is likely to have triggered the arrival of alien phytophagous arthropods, as has been shown for insects related to woody plants (Roques 2010). Specific analyses per taxa have confirmed these tendencies. Whereas the arrival of mites (see Figure 7.4.2), scales (see Figure 9.3.2.), flies (see Figure 10.2) or lepidopterans (see Figure 11.2), which are mainly phytophagous groups, has revealed a similar acceleration in the number of newly recorded aliens during the last period, no such trend has been observed for the parasitic lice and fleas (see Chapter 13.4), nor for the detritivorous Blattodea (see Chapter 13.3).

2.4 Biogeographic patterns of arthropod species alien to Europe

Origin of the species alien to Europe

A precise region of origin was ascertained for 1271 species (79.9%) of the 1590 alien arthropod species, while 93 species were only known to be native to tropical or subtropical regions. The remaining 226 cryptogenic invertebrates are mostly cosmo-

politan species for which there is no agreement regarding their area of origin. This is particularly true for stored products pests and for some ectoparasites on cattle and pets that occur on other continents. A few other cryptogenic species have appeared in Europe without having been detected elsewhere. However, data on their phylogeography, population ecology, parasitoids and dispersal biology strongly suggest that they originate from another continent. The horse-chestnut leaf miner, *Cameraria ohridella*, is illustrative of the difficulty in identifying the native range of such species. Whereas this leaf miner was previously considered as an extra-European alien, recent genetic studies indicate that it originates from the southern Balkans (Valade et al. 2009).

Asia has supplied the major part of the alien arthropods occurring in Europe (26.7%) followed by North America (21.9%) (Figure 2.5). Analysing specifically insect data per time unit has revealed that the relative contribution of Asia and North America was stable over time (Roques et al. 2009). During the periods 1950–1989 and 1990–2007, 29% and 21% of the established insects were of Asian and North American origin respectively. The contribution of tropical and subtropical areas is surprisingly important. The overall contribution of species from Australasia, Africa, Central and South America in combination with species of undefined tropical areas represents 37% of all alien insects in Europe. While we agree that insect species coming from these areas are not just native to tropical ecosystems, this proportion is nevertheless outstanding.

Unlike the temporal trends, the regions of origin do not differ significantly between feeding regimes. Asia is the main region of origin for alien phytophages, parasitoids/ predators and detritivorous species although a bit less important for the latter group (Figure 2.5).

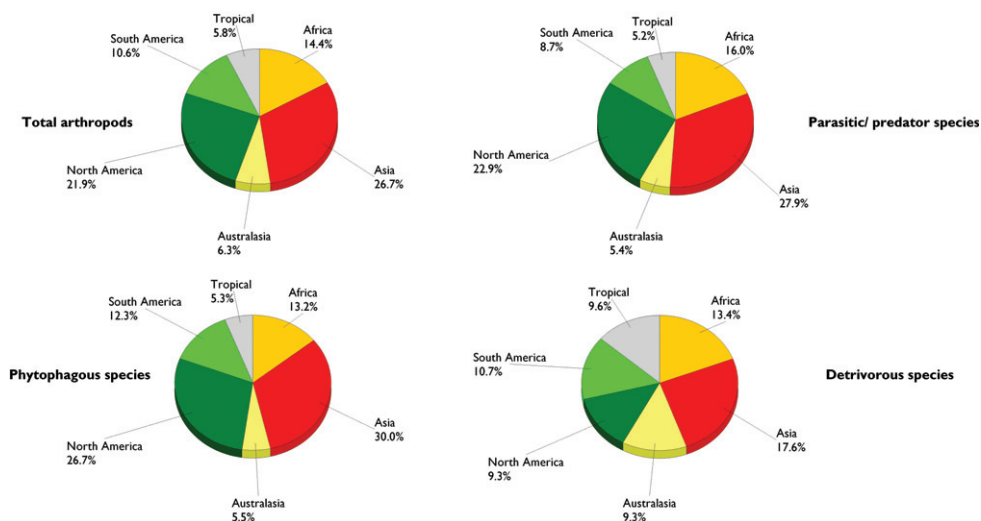


Figure 2.5. Region of origin of the 1590 arthropod species alien to Europe. Total arthropods and break-down per feeding regime are presented. Percentages of the total per category are shown under each region.

However, a comparison of the native range of species from the different orders revealed significant differences ($\chi^2 = 388.26$; $P = 0.0000$). Most mites (51.5% - see Figure 7.4.3), hymenopterans (32.3 % - see Figure 12.3), and dipterans (30.6 % - see Figure 10.3) have arrived from North America whilst 37.2 % of lepidopterans (see Figure 11.3) and 31.5 % of hemipterans have originated from Asia. Coleoptera have come from various regions, including a significant component from Australasia (9.5%) mostly linked to the introduction of *Eucalyptus* and *Acacia* spp. in the Mediterranean regions of Europe. Coleoptera also represent a large proportion of the cosmopolitan stored product pests that are predominantly of tropical or subtropical origin.

Patterns of spread

Once established, most alien species have not spread throughout Europe, at least yet. We used the presence in a country as a proxy of the invaded range because it appeared impossible to get sufficient data for a quantitative assessment of this invaded range area for most alien species. A total of 694 species (i.e., 43.6 %) have not invaded more than one country/ island additional to the one where they arrived, and 63.6 % are present only in five European countries (Figure 2.6). Less than 1% (12 out of 1590) of the alien arthropods are present in more than 40 countries; among these are the melon and cotton aphid, *Aphis gossypii* Glover, and several beetles associated with stored products especially seed bruchids (e.g., *Callosobruchus chinensis* (L)). Detritivorous species appeared to have dispersed significantly more (8.5 ± 0.5 countries) than phytophagous species (7.1 ± 0.3) and parasitoids/ predators (5.5 ± 0.3) (Kruskal-Wallis test. $F_{2,1598} = 10.97$; $P = 0.0000$).

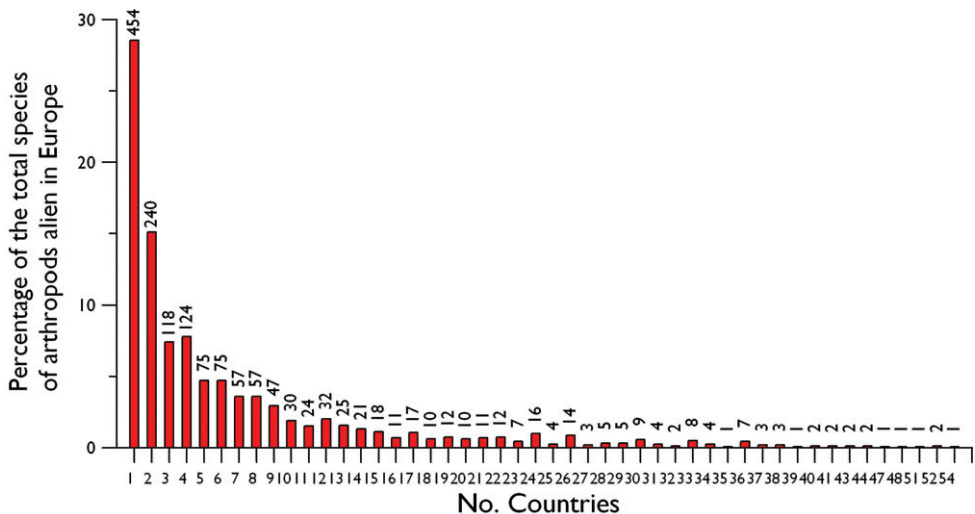


Figure 2.6. Geographic spread of the arthropod species alien to Europe expressed as the number of countries colonized by these species and their frequency.

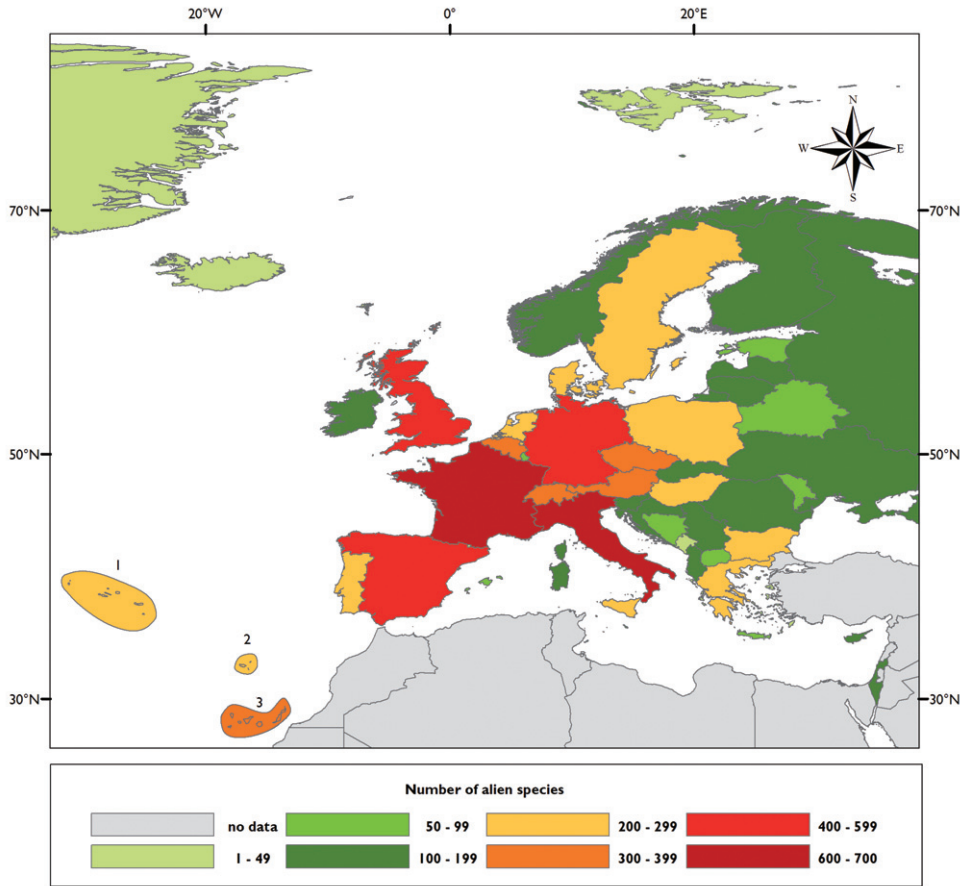


Figure 2.7. Comparative colonization of continental European countries and islands by dipteran species alien to Europe. Archipelagos: **1** Azores **2** Madeira **3** Canary islands.

Large differences also exist between European countries in the total number of alien arthropods recorded per country (Figure 2.7 and 2.8). Italy (700 species) and France (690 species), followed by Great Britain (533 species), host many more species than other countries. The same ranking is obtained when the number of alien species per km² is considered. Differences in sampling effort may have affected the analyses. However, the number of alien insects is significantly and positively correlated with country surface area ($r = 0.3621$; $P = 0.0384$). More westerly countries and islands appear in general relatively more colonized. The number of alien species significantly decreases with the longitude of the countries' centroids ($r = -0.6988$; $P = 0.0038$) whereas latitude does not seem to have a significant influence ($r = -0.378$; $P = 0.168$). Islands also host proportionally more alien species than continental countries relative to their size (Kruskal-Wallis test on the number of alien species per km²; $F_{1,53} = 6.20$; $P = 0.0160$) but this is independent of the coast length ($r = 0.174$; $P = 0.384$). In continental countries, bordering the sea does not influence the number of alien insect spe-

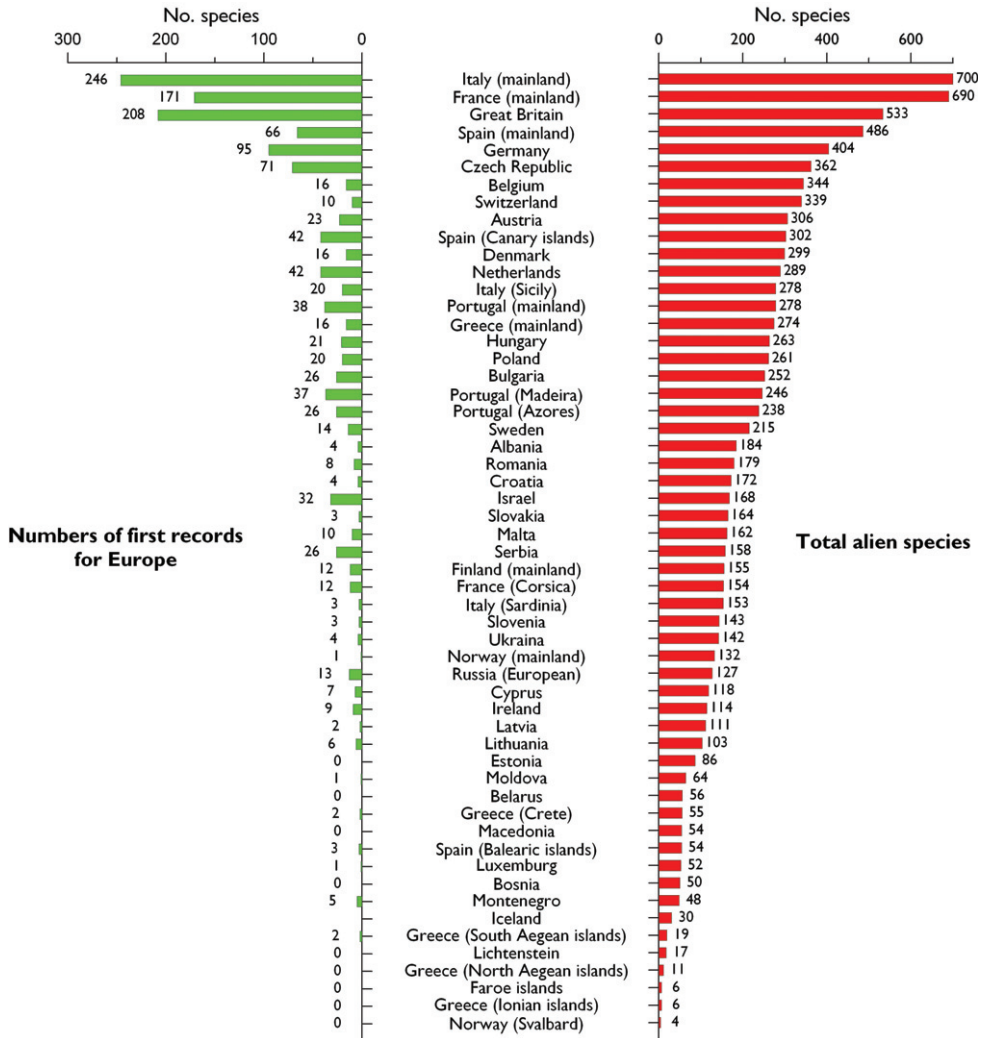


Figure 2.8. Comparison between the number of first records for Europe observed for the alien species in a country (left) and the total number of alien species now present in the country (right).

cies ($P=0.6404$). In addition, the country or island where a species was first recorded in Europe has been identified for 1399 species out of the 1590 alien arthropods (Figure 2.8). The same country ranking was obtained as for the total number of arthropods present per country. Indeed, there is significant correlation ($r=0.8745$; $P=0.0000$) between the two values.

However, much stronger correlations exist between the number of alien arthropods in a country and the total volume of merchandise imports of the country ($r=0.875$; $P=0.0000$), the density of the road network ($r=0.7578$; $P=0.0001$), and the size of the human population ($r=0.5918$; $P=0.0047$). These results confirm the decisive importance of socioeconomic and demographic drivers in arthropod invasion.

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