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Exotic Insects in Italy: An Overview on Their Environmental Impact

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1. Introduction

Hundreds of alien arthropods, native to different continents or introduced from other parts of Europe, have been recorded in Italy in the last few decades (Jucker et al., 2009; Pellizzari & Dalla Montà, 1997; Pellizzari et al., 2005). Italy is at high risk of introduction of exotic insects, particularly because of the country's climatic conditions, which support many subtropical species, and its position in the middle of the Mediterranean Sea, which makes Italy a commercial and tourist crossroad. Invasion is a normal ecological process, but it can be incentivized by human activities with processes far more rapid than those that occur in purely native systems. Biological invasion by exotic species is considered one of the main threats to the loss of biodiversity; it can cause enormous damage in terms of socio-economic costs, harm human health, and result in ecological losses (Kenis et al., 2009). The rise in economic costs can be attributed to yield losses, in agriculture and horticulture, or to increases in the production costs for pest management. The severe economic impact of these species is evident: the crudest estimate of the total known monetary impact of alien species in Europe is close to 10 billion euros annually (COM, 2008). Moreover, the damage to human health leads to major costs connected to control programs and public health measures. Damage is due to irritation and disease transmission by hematophagous species, or to allergies, and other maladies by other groups of insects.

The introduction of a species affects the ecosystem of the new habitat in different ways: the invasive species can be a herbivore, predator, or parasitoid, and can compete with indigenous species via different interactions (competition, disease transmission, hybridization). The major pathways of arthropod migration are indeed accidental, represented by different means of transports, the trade in ornamental plants and other goods, and tourism; natural climatic events can also be responsible for the movement of arthropods. We likewise have to consider that sometimes the introduction of the invasive species is voluntary, and even if the insect itself is helpful, can become a serious threat to a country's biodiversity. The deliberate introduction into the new environment can be for productive purposes or as a control agent (the classical biological control, based on importation of natural enemies from the country of origin of the exotic pest). *Rodolia cardinalis* (Mulsant), imported in California in the late 19th century to control cottony cushion scale, has ever since been a textbook example illustrating the accomplishments of biological control.

2. Factors influencing alien species establishment and spread

Only some alien arthropods become significant as an outcome of invasion; whether this happens depends both on the species and on the susceptibility of the invaded ecosystem. Moreover, once the species has settled, damage can be heavy only when the population is sufficiently numerous. Activities such as agriculture, logging, and grazing enhance the establishment of exotics by creating disturbed sites for colonization (Sakai et al., 2001). However, we consider the climate, the hosts, the presence of natural enemies, the reproduction strategies, and habitat fragmentation as the factors that strongly influence the settlement of the alien species in the new environment and make it invasive.

2.1 Climate

Among the factors that influence the settlement and the invasiveness of a species, one of the most important is the climate and, consequently, the synchronization of the lifecycle in the new habitat. The climate effect is more evident in arthropods because they are poikilothermic, which means that temperature strongly influences their development.

A species may arrive in a new potential habitat, but the differences between the season and the instar of development of the insect may not allow the species to survive and settle. There have been many interceptions of dangerous pests that would not have even survived in the new habitat. *Leucinodes orbonalis* Guen. (Lepidoptera, Pyralidae), which was included in the European and Mediterranean Plant Protection Organization (EPPO) Alert List after more than 120 interceptions of infested *Solanum* fruits imported from Asia and Africa were made by several EPPO member countries (EPPO, 2011), can be reported as an example of this lack of synchronization in Italy. In our country the species was detected as larvae during phytosanitary control on easter eggplant fruits at Milan Airport in winter (Jucker et al., 2007), a period not suitable for insect development. We cannot exclude the possibility, however, that arrival in a more favorable season would allow this species to settle.

Sometimes a species of tropical or sub-tropical origin that cannot survive winter in a temperate climate can overcome this difficulty by entering greenhouses or houses. *Trialeurodes vaporariorum* (Westwood) (Hemiptera, Aleyrodidae), *Leptoglossus occidentalis* Heidemann (Hemiptera, Coreidae), and *Harmonia axyridis* Pallas (Coleoptera, Coccinellidae) are just a few examples of the application of this strategy in Italy. *T. vaporariorum,* accidentally introduced into Europe and Italy in the middle of the 19th century, is originally a sub-tropical species; although it can withstand slight frost for a short time, it overwinters in glasshouses in areas of colder climate. *L. occidentalis,* discovered near Vicenza in Northern Italy in autumn 1999 (Tescari, 2001), and *H. axyridis,* reared and introduced as a biocontrol agent (Pervez & Omkar, 2006), can survive in unfavorable low temperatures by entering houses at the onset of cold weather in search of a protected site to spend the winter.

Global warming can also influence alien species settlement (Perrings et al., 2010). Climate change, in fact, is expected to alter biodiversity, causing variation in phenology, genetic composition, and species ranges, and affecting species interactions and ecosystem processes both in autochthonous and in exotic species (Sutherst, 2000). Global warming could provide new opportunities for introduction to areas where, until recently, introduced species were not able to survive. The Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Diptera, Tephritidae), a highly polyphagous quarantine pest that probably originates from sub-Saharan Africa, has limited its distribution to areas under the 41st parallel. In northern Italy, with its normal climate conditions, the insect is not able to overwinter in the field at

preimaginal stages, although adults can survive indoors and at temperatures higher than 10-12°C for prolonged periods (Rigamonti, 2004). However, global warming may allow stable colonization of *C. capitata* populations at higher latitudes than at present.
Moreover, a country's climatic situation can be favorable to a major or minor number of generations per year; it can influence the oviposition period, number of eggs, preimaginal development, and adult survival, and it can also make a species more or less aggressive. An example is *Lissorhoptrus oryzophilus* Kuschel (Coleoptera, Erirhinidae), one of the major insect pests in rice-growing regions of the United States, China, Japan, and Italy. This species is univoltine in many areas, including Italy, but it can be bivoltine or multivoltine in regions where the climate is warmer (Chen et al., 2005; Lupi et al., 2007; Shang et al., 2004).

2.2 Host

There are numerous examples of successful adaptation to Italian environments because of the presence of valuable hosts. We have to consider that many invading species are polyphagous, so they have a higher potential of establishment than do monophagous or oligophagous species.
Sometimes in the country of origin the insect coevolves with its host, and the development on other hosts in different countries (either varieties or species) leads to major damage. One of the first invasive agricultural insect pests that hit the Italian economy in the past was the American vine phylloxera, *Viteus (=Daktulosphaira) vitifoliae* (Fitch) (Hemiptera, Phylloxeridae) (Strapazzon & Girolami, 1983). Detected in Europe in the late 19th century, it is an example of the complexity of the host-plant relationship. Within the natural range of diffusion of phylloxera and its host, *Vitis vinifera* plants show very little damage from the aphid (Gullan & Cranston, 2010). The situation was different upon its arrival in Europe, where plants had no resistance to the aphid: on *V. vinifera* European species, the insect produces nodose and tuberose galls on the subapices of young roots, causing incalculable economic damage and social consequences (Kenis & Branco, 2010). The problem was largely solved by replanting European cultivars grafted onto resistant American rootstocks. The Asian black hornet *Vespa velutina* Lepeletier (Hymenoptera, Vespidae) is an example of predator-prey coevolution. This wasp is endemic to southeast Asia, where it is a predator of social wasps and bees, including both the native *Apis cerana* F. and the introduced *Apis mellifera* L. (Hymenoptera, Apidae). While *A. cerana* colonies have evolved defense strategies against *V. velutina*, the European honeybee sustains significantly greater losses (Tan et al., 2010). Even if the insect is not yet arrived in Italy, our country is at high risk of introduction because the insect has already settled in southwestern France (Haxaire, 2006).
Sometimes the species becomes invasive only after a host shift. An example is the rice water weevil *L. oryzophilus*, which was originally confined to spontaneous gramineous and cyperaceous plants in North America. When rice was introduced in the area where the insect lived, there was a host shift to it and the insect invasion started (Chen et al., 2005; Lupi et al., 2010). However, rice is not enough for insect development as spontaneous plants are still necessary in the spring, when the adults emerge from overwintering sites and rice is not yet emerged (Lupi et al., 2009; Tindall & Stout, 2003).

2.3 Natural enemies

When an exotic pest colonizes a new habitat, the absence of natural control agents can contribute to its settlement and to the consequent damage. Sometimes research in the

country of origin can be useful in finding natural enemies as an alternative to chemical control. In fact, in many situations biological control could represent a valid and stable help to manage both autochthonous and exotic pests.

Among the recent examples of classical biological methods applied to introduced pests in Italy, we have to mention *Neodryinus typhlocybae* (Ashmead) (Hymenoptera, Dryinidae) and *Torymus sinensis* Kamijo (Hymenoptera, Torymidae). In 1987, *N. typhlocybae* was introduced in Italy into the Veneto region for the biological control of *Metcalfa pruinosa* (Say) (Hemiptera, Flatidae). First detected in Italy in 1979, this planthopper native of the United States rapidly spread because of its polyphagy and lack of natural enemies (Strauss, 2009; Zangheri & Donadini, 1980). Among the parasitoids in North America, *N. typhlocybae* was considered the most promising control agent. For this reason, a biological control project started in Italy at the end of the 1980s to import the parasitoid. Larvae develop as ectoparasitoids of *M. pruinosa* immatures, and adults also feed on the host, thus augmenting pest mortality. Over the past years, this insect has been successfully released in many urban and agricultural areas of Italy, and this has resulted in its establishment (Alma et al., 2005).

The classical biological method based on the use of the parasitoid *T. sinensis* seems to be the most effective in reducing the populations of *Dryocosmus kuriphilus* Yasumatsu (Hymenoptera, Cynipidae), a species of Chinese origin that attacks chestnut trees and that invaded Japan, Korea, Nepal, the United States, and Europe (Brussino et al., 2002; Moriya et al., 2003; Quacchia et al., 2009). Removing twigs or protecting them with nets proved to be very labor intensive and produced little results. Chemicals were also inefficient as the immature stages are protected within the gall.

New interactions among recently introduced species and endemic natural enemies are also very important. Again, *D. kuriphilus* and *H. axyridis* can be used as examples. It has been reported in many countries and apparently in Italy as well that *D. kuriphilus,* when established, rapidly recruits parasitoids attacking oak gall wasps locally (Aebi et al., 2007) and that *H. axyridis* can be parasitized by *Dinocampus coccinellae* (Shrank) (Hymenoptera, Braconidae), a general parasitoid of Coccinellidae present in Italy (Dindo et al., 2011). The relationship among alien pests and autochthonous useful species is particularly remarkable when the origin of a species is unknown or few data are available on natural enemies in the native country. We refer to the horse chestnut leaf miner *Cameraria ohridella* Deschka and Dimic (Lepidoptera, Gracillariidae), described as a new species in Macedonia and whose origin is still under debate (Deschka & Dimic, 1986; Valade et al., 2009). Detected in Italy in the 1990s, it spread rapidly and caused a great deal of aesthetic damage to the plants it attacked. Studies on this species showed that numerous native parasitoids adapted to *C. ohridella* with, sometimes, a very high parasitization percentage (Lupi, 2005; Gröbler & Lewis, 2008; Grabenweger et al., 2009). We also refer to *Anoplophora chinensis* Forster (Coleoptera, Cerambycidae), the citrus longhorned beetle, for which information on parasitoids in the native country is lacking. Studies carried out in Italy led to the detection of some polyphagous endemic parasitoids and the Asiatic egg parasitoid, *Aprostocetus anoplophorae* Delvare (Hymenoptera, Eulophidae) , probably introduced with *A. chinensis* and the efficacy of which is still under study (Delvare et al., 2004; Hérard et al., 2004). Studies concerning the presence of natural enemies of *Cacyreus marshali* Butler (Lepidoptera, Lycaenidae) in Italy gave evidence to the presence of the oophagous *Trichogramma evanescens* (Westwood) (Hymenoptera, Trichogrammatidae), already detected in other European countries, and of the larval parasitoid *Aplomya confinis* Fallen (Diptera, Tachinidae) (Vicidomini & Dindo, 2006).

2.4 Reproduction strategies

Among the traits that promote successful invasion after initial colonization, there is the establishment of a self-sustaining population. Reproduction strategies that feature the ability to reproduce asexually or to shift between r- and K-selected strategies seem to play a really important role in this process (Sakai et al., 2001). Among insects reproducing sexually at low densities in the founder population, the efficiency in mate finding can influence insect settlement. The ability to reproduce asexually overcomes this difficulty and facilitates the settlement. Because the founding population of an invading species often suffers from a lack of genetic diversity, organisms that reproduce sexually could be more prone to extinction because of inbreeding (Liebhold & Tobin, 2008). Hoffmann et al. (2011), evaluating two databases from North America and Italy, found that parthenogenetic species cover 45% (North America) or 48% (Italy) of pest species derived from genera where parthenogenesis occurred. They concluded that several factors may contribute to the high incidence of parthenogenesis among pests. The most likely factor is a stable and uniform agricultural environment with an abundance of resources. In such a habitat, the same genotype may be continuously favored by selection, leading to a selective advantage of some parthenogenetic lineages over a sexual population. Among the successful parthenogenetic species in Italy we have to mention many Hemiptera. Moreover, *Lissorhoptrus oryzophilus* is a parthenogenetic species in nearly all colonized areas and in Italy (Lupi et al., 2007).

The lack of genetic diversity has a notable exception in the Argentine ant *Linepithema humile* (Mayr) (Hymenoptera, Formicidae), for which reduced genetic variability likely enhanced the invasion success (Suarez et al., 2008). Native to South America, it is now a cosmopolitan pest. In its area of origin the species has a social system with multicoloniality and systematic aggression between workers from different nests, while in invaded countries, it exhibits an extraordinary social organization, called unicoloniality, in which individuals mix freely among physically separated nests because of a loss of aggression between colonies having the same recognition alleles. From 33 Argentine ant populations collected along the Mediterranean and Atlantic coasts from Portugal to Italy, it was established that in this area there are only two supercolonies and that aggression never occurred between individuals from the same supercolony, even when taken from very distant nests (Giraud et al., 2002).

2.5 Habitat fragmentation

Both long-distance dispersal and stratified diffusion can greatly increase invasion rates: short-range expansion is mainly due to insect adult active dispersal flying, crawling, and swimming, whereas long-range expansion is due to accidental movements caused by human transportation. The alteration of land-use patterns has resulted in the fragmentation of habitats, ecosystems, and landscapes in most parts of the world, and several theoretical explorations indicate that spread rates are affected by habitat fragmentation (Hoffmeister et al., 2005; Perrings et al., 2010). In fragmented habitats very specialized species or those species with poor dispersal ability may suffer more than generalistic and invasive species. The Italian outbreaks of *Cameraria ohridella*, *Diabrotica virgifera virgifera*, and *Lissorhoptrus oryzophilus* have expanded by stratified dispersal, involving both continuous diffusion and discontinuous long-distance dispersal (Ciosi et al., 2011; Gilbert et al., 2004; Lupi et al., 2010).

3. Secondary effects of alien species introduction

Many alien species are dangerous not only for the direct damage they can cause, but also for their secondary effects. Invasive species can act as vectors for pathogens both to plants and

to humans. The impact of invasives on native species, communities, and ecosystems has been widely recognized for decades. Ecological interactions between native and invasive species may be direct (predation, herbivory, parasitism, competition, mutualism) or indirect (habitat alteration, apparent predation, cascading trophic interactions) and result in changes in the population biology of the native species.

3.1 Pathogen transmission

Alien species can behave as vectors of pathogens (e.g., nematodes, fungi, viruses, bacteria) to both plants and animals.

Hemiptera are known for their aptitude to transmit pathogens. Among them we have whiteflies, aphids, psyllid, and leafhoppers. *Scaphoideus titanus* Ball (Hemiptera, Cicadellidae), a leafhopper introduced in Europe from North America and currently spread in vineyards, is the vector of Flavescence Dorée, a quarantine grapevine disease caused by the bacterium '*Candidatus Phytoplasma vitis*' (Angelini et al., 2001).

Among thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera, Thripidae), a North American invasive species introduced in Europe in 1983 and currently widespread, is the main vector of the tomato spotted wilt virus, a serious disease in several economically important crops worldwide and in many wild plants that can behave as reservoirs for the virus in the environment. This disease was first described in Australia in 1915 (Brittlebank, 1919). In Europe the virus was present before the Second World War, but the malady was noticeable only when *F. occidentalis* arrived as the preexisting vector, *Thrips tabaci* (Thysanoptera, Thripidae), has a low transmission rate (Inoue & Sakurai, 2006).

Coleoptera are important as they can be vectors of wood nematodes. The presence of the pinewood nematode *Bursaphelenchus xylophilus* Steiner & Buhrer, a major threat to pine forests in Japan, is remarkable. This quarantine disease, whose vector is the cerambycid *Monochamus alternatus* (Coleoptera, Cermabycidae) Hope, has been found in Europe, particularly in Portugal (Mota et al., 1999). In Italy neither the insect nor the nematode has been detected so far.

Many insects can bite and transmit disease, at least potentially. An Asian mosquito species, *Stegomyia albopicta* (Skuse) (*sensu* Reinert et al., 2004) (Diptera, Culicidae), often referred to as the "tiger mosquito", is the vector of major human diseases such as dengue, yellow fever, the West Nile virus, and chikungunya (Eritja, 2005). This species began to spread worldwide in the 1970s thanks to the marine transport of tires and other goods, leading to colonization of many areas of the world. European concern rose when the species was detected in Italy, first in Genoa and one year later near Padua (Dalla Pozza & Majori, 1992). Fortunately the species has invaded many countries without carrying human pathogens. However, we cannot ignore the unexpected outbreaks of chikungunya fever in northern Italy (Angelini et al., 2007), the sudden appearance of West Nile virus in North America, and the increasing frequency of Rift Valley fever epidemics in the Arabian Peninsula.

3.2 Autochthonous species competitiveness

Many studies have documented invaders that show a superior ability to exploit local resources as compared with native residents (Bazzocchi et al., 2004; Burgio et al., 2008; Holway, 1998) or as compared with non-invading introduced species. The Argentine ant (*Linepithema humile*) is not only an agricultural and house pest but is also competitively superior to the native ant species in both interference and exploitative competition in the

riparian woodlands of northern California and in the alteration of plant community structure (Holway, 1998; Suarez et al., 2008).
The intentional introduction of natural enemies for biological control has raised some criticism (Michaud, 2002) on the potentially negative effects induced by exotic species on indigenous natural ones and, in general, on non-target native taxa (Howarth, 1991; Pearson & Callaway, 2003; Van Lenteren et al., 2003). We must consider that the more a natural control agent is specific, the less negative the impact is on the environment. Predators have a generally wide range of hosts whereas parasitoids are usually more specific and so potentially less invasive. The coccinellid *H. axyridis*, a voracious predator native to southern Siberia, China, Taiwan, Korea, and Japan, is a major example of this impact. This coccinellid has been introduced in North America and Europe to control aphid and scale populations, and has settled (Pervez & Omkar, 2006). *H. axyridis* has been used in greenhouses since the 1990s, and its negative impact was already reported in 1995 in America. Nowadays this species is considered the most invasive ladybeetle in the world: it reduces the biodiversity of the new colonized areas, directly affecting useful insects, replacing the native ladybeetles, and altering the ecosystem equilibrium (Alyokhin & Sewell, 2004).

3.3 Landscape alteration

Alien species invasion can contribute to landscape alteration. This effect can be due directly to insect feeding or indirectly to the necessity of altering the environment because of eradication programs. The devastating impact of the introduction of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera, Curculionidae) on landscape palms is well known (Jucker et al., 2007; Longo & Tamburino, 2005; Sacchetti et al., 2005). In many coastal areas in Italy the urban landscape is principally based on palm, and many of such palms represent a patrimony of high value. The settlement of this weevil in our country represents a serious environmental problem liable to have significant repercussions both on the landscape and on tourism. Eradication programs that consist in the removal of trees infested with *Anoplophora chinensis,* detected in northern Italy (Colombo & Limonta, 2001a), are altering the landscape of many areas, especially urban and suburban (Maspero et al., 2007).
Another example of habitat alteration is correlated to the voluntary introduction of the Ailanthus silkmoth (*Samia cynthia*), a saturniid moth, used to produce silk and introduced in Italy at the end of the 19th century as a possible alternative to *Bombyx mori*. The impact of this insect on biodiversity has been indirect because the insect itself cannot be considered an invasive insect as it does not threaten any other species, nor does it invade the niche of others. Its introduction, however, was associated with that of its preferred host, *Ailanthus altissima*, a deciduous tree indigenous to China, which is a serious threat to ecosystems in introduced areas, as the plant is very competitive and it contains allelopathic chemicals that may inhibit the growth of surrounding native plants (Heisey, 1990).

3.4 Human nuisance

Sometimes the insects do not transmit pathogens but annoy humans and cattle. Examples are *Leptoglossus occidentalis* and *Harmonia axyridis*, which do not bite, sting, feed on people and pets, or reproduce inside the house, but disturb because of their large number in houses, buildings, and food industries, and because they can give off a pungent odor when touched. The habit of *H. axyridis* to aggregate on grapes in vineyards before harvest also results in great consequences for the grape industry (Linder et al., 2009). Further cases are reported of *H. axyridis* leading to patient complaints and symptoms of rhinitis, wheezing, and urticaria after exposure to the beetles (Albright et al., 2006; Yarbrough et al., 1999). A

problem, encountered in crowded parks in cities, is represented by the presence of species of the genus *Corythucha* (Hemyptera, Tingidae). The species usually feed on ornamental plants, but if they fall on people, during probing, they can bite. A historical example for Italy is the abundant presence on *Platanus* spp. of *Corythucha ciliata* Say.

4. Italian situation on invasive species

Within the Research Project of European Commission DAISIE (www.europe-aliens.org), an inventory of alien species in Europe was taken. Among introduced organisms, terrestrial invertebrates, mostly insects, represent the major cases of exotic introductions (Roques et al., 2009). Concerning Italy, 425 species of insects and 22 mites were recorded from 1492 to 2006 (Jucker et al., 2007, 2009; Pellizzari & Dalla Montà, 1997; Pellizzari & Faccoli, 2007). In our analysis we considered the species detected in Italy as exotic pests introduced by human activities or by passive transport from other countries, starting from 1945. We did not count insects that are naturally spreading in different Italian regions (e.g. as a result of the global warming process). The list was made after an examination of different material, mostly published in scientific journals and the EPPO website. We considered the species as being of agricultural, forest, or human importance for their different impact. Species introduced as biological control or species of stored products were not counted. The year of publication was considered as the same of that of detection; we have to point out, however, that in many cases the arrival could have happened some years before the official report, because most introductions occur unintentionally. A total of 291 exotic insects have been listed.

4.1 Country of origin

The native area of each species was taken from the publication of the interception. For our purposes, the world area was divided as follows: Africa (excluding Mediterranean Basin countries), Asia, Australia, North America, Central and South America, Mediterranean Basin, Europe (excluding Mediterranean Basin countries), and Pacific Islands (Australia not included). When the origin was not sure, as the case of many cosmopolitan species, we reported it as unknown (Fig. 1).

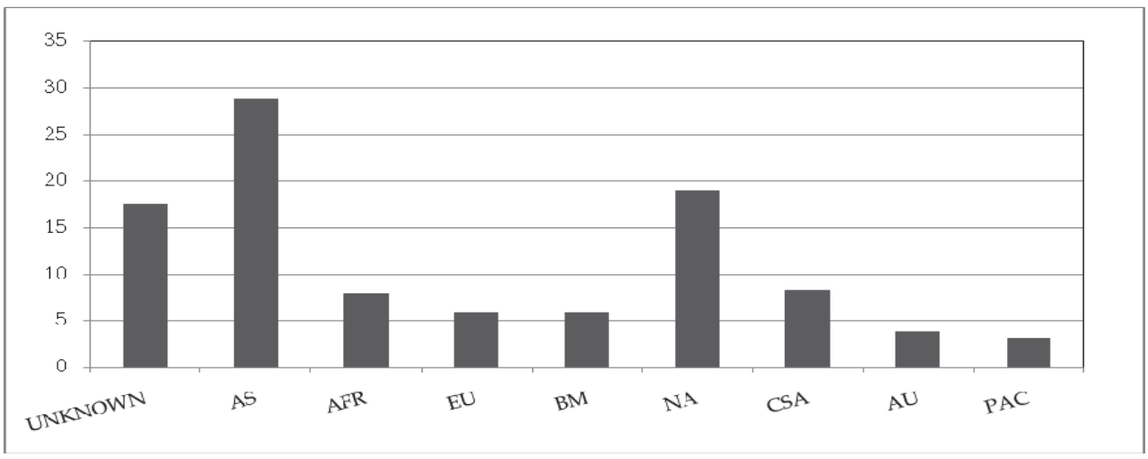


Fig. 1. Original country of the alien species in Italy. AS, Asia; AFR, Africa (excluding Mediterranean Basin countries); EU, Europe; BM, Mediterranean Basin countries; NA, North America; CSA, Central-South America; AU, Australia; PAC, Pacific Islands.

Asia accounts for the largest proportion of Italian alien species (28.9%), followed by North America (19.0%). In many cases (17.5%) the country of origin is unknown. Next, in order of decreasing importance, come the Central-South American countries (8.2%), Africa (7.9%), and European countries, in particular from the East (5.8%) and Mediterranean Basin countries (5.8%). Australia and other Pacific islands together represent 6.9%. In addition, the proportion of the species coming from Asia and North America over the last 30 years represents 47.9% of the total.

Figure 2 illustrates the temporal evolutions of the detections of non-indigenous arthropods, with the data organized in decades (apart the first 15 years 1945-1960). The findings of alien species starts to increase significantly from 1980, and the highest number of new records was in the decade 1991-2000, with 111 species. In the last 10 years the number of new introductions has only slightly decreased. Considering our data, the rate of introduction increased from an average of 2.3 species/year until 1990 to an average of 9.9 species/year in the last 20 years.

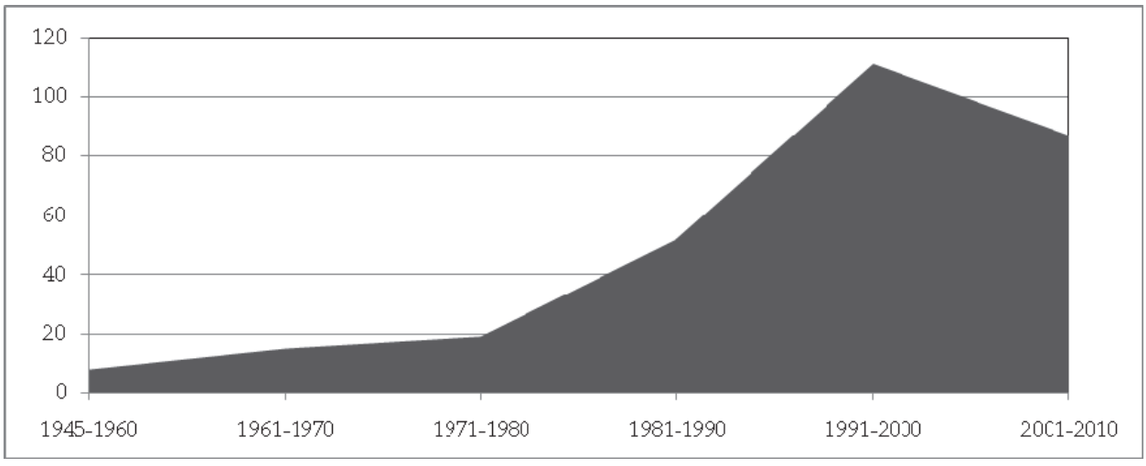


Fig. 2. Trend of non-indigenous species recorded in Italy in the recent decades.

4.2 Taxonomy

In the Figure 3 the taxonomic groups of the exotic insects in Italy are represented. Detailed descriptions of exotic species in the different orders follow.

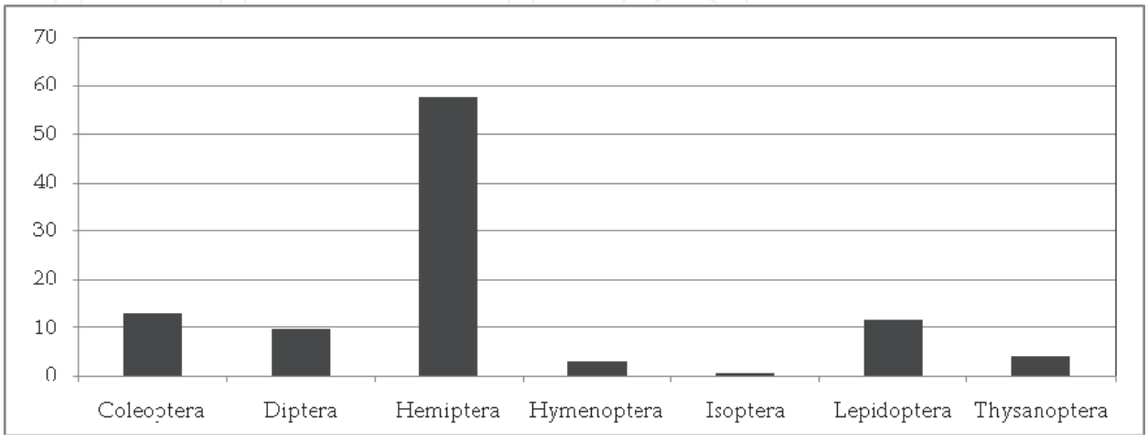


Fig. 3. Percentage of the orders introduced in Italy from 1945.

4.2.1 Hemiptera

In our list of phytophagous insects, Hemiptera alone represent more than 57.7% of the total of the recorded species: 97% are Homoptera, while only 3% belong to Heteroptera. Members of this order (particularly psyllids, scales, aphids, and whiteflies) can easily escape during the phytosanitary controls because of their small size and their position, often hidden under the foliage, inside the flowers, or on the plant roots. They mostly come from Asia and North America, and many of them are of worldwide distribution, with the country of origin unclear. Considering the host, more than 50% attack woody plants, while 34% are phytophagous of various herbaceous plants. Only in a small number of cases the pathway of introduction well known. Because a lot of species are host-plant specific, in many cases they are introduced with the trade of their host plant. The major vector of the species in the new habitat is represented by ornamental woody plants. The psyllid *Acizzia jamatonica* (Kuwayama), native to Asia, was first recorded in Europe, in Italy, in 2002 (Alma et al., 2002). It was introduced in our country with its host plant, *Albizia julibrissin*, a plant species used in streets and in parking areas. Belonging to the same genus are *A. acaciaebaileyanae* (Froggatt) and *A. uncatoides* (Ferris & Klyver), native to Australia and host of *Acacia* spp. and *Albizia* spp. Other examples of phytophagous insects on ornamental plants that are now widespread in our country are the two tyngids, *Stephanitis takeyai* Drake & Maa from Japan, and *S. pyrioides* Scott from North America, both pests of *Rhododendron* spp. (Colombo & Limonta, 2001b; Del Bene & Pluot-Sigwalt, 2005). The same plant species can host the aphid *Illinoia azaleae* (Mason) and the whitefly *Pealius azaleae* (Baker & Moles) (Del Bene et al.; 1991 Süss, 1973). The aphid *Illinoia liriodendri* (Monell) was found in Italy in 2001 (Limonta, 2001) on *Liriodendron tulipifera*, an exotic ornamental tree largely used for the color of its foliage and, in the past, for the absence of pests. Among scales affecting various ornamental woody plants mainly in gardens and urban parks, we refer to *Ceroplastes japonicus* Green (Kozar et al., 1984) and *C. ceriferus* (Fabricius) (Mori et al., 2001), both originating from Asia. *Pulvinaria hydrangeae* (Steinweden) is native to North America and its host is *Tilia* (Pellizzari, 1976). Recently, the red gum lerp psyllid *Glycaspis brimblecombei* Moore, attacking *Eucalyptus camaldulensis* in urban and rural landscapes, was reported (Laudonia & Garonna, 2010). *Corythucha ciliata* and *C. arcuata* are two Heteroptera introduced to Italy from North America and living respectively on *Platanus* spp. and on *Quercus* spp. (Bernardinelli & Zandigiacomo, 2000; Servadei, 1966). Two species with a high poliphagy are the well-known *Metcalfa pruinosa* and *Acanalonia conica* (Say) (D'Urso & Uliana, 2004). They both live on wild and cultivated trees, shrubs, and grasses belonging to different families, some of which have an economic importance (Alma et al., 2005; Wilson & McPherson, 1980).

Some Homoptera that damage forest plants are the scales *Matsucoccus feytaudi* Ducasse on *Pinus pinaster* and *Marchalina hellenica* Gennadius on pines (Arzone & Vidano, 1981; Kozar et al., 1984). We can also add *Gilletteella coweni* (Gillette) on Douglas fir and *Cinara cedri* and *C. laportei* on *Cedrus* (Covassi, 1971; Covassi & Binazzi, 1974, 1981). The western conifer seed bug *Leptoglossus occidentalis* is a serious pest of conifer seed production throughout western North America; economic damage consists in a reduction of the quantity and quality of seeds because of the trophic activity of adults and young instars sucking the seeds' endosperm. In Italy at the end of the 1990s the total weight of pine cones for pine nut production for food was about 40,000 tonnes per year. Since the introduction of the pest, production of pine nuts has rapidly decreased and in 2009 cone harvests from Italian stone pine forests declined by as much as 95% (Roversi et al., 2011).

Herbaceous plants that host Hemiptera include graminaceae and various flowers; *Tryonimus* spp. and *Antonina graminis* Maskell are just some examples (Pellizzari, 1994).
Among fruits plants, *Vitis vinifera* had been seriously attacked since the 1960s by *Scaphoideus titanus*, and more recently by the leafhopper *Erythroneura vulnerata* Fitch (Duso et al., 2005). The latter pest is widespread in the United States and Canada where it has been reported as a pest of wild and cultivated grapes, and of other host plants. Up to now its occurrence in commercial vineyards is relatively unimportant, probably because of insecticide applications carried out during summer to control other pests. Many hemipteran pests of *Citrus* cultivation are found in Italy: *Aonidiella citrina* (Coquillett), *Bemisia citricola* Gomez Menor, *Dialeurodes citri* Ashmead, *Aphis spiraecola* Patch, *Aleurothrixus floccosus* Maskell, *Chrysomphalus aonidum* L., *Unaspis yanonensis* (Kuwana), and *Aleurocanthus spiniferus* Quaintance. The last one is a quarantine species, representing a serious risk to Italy.

4.2.2 Coleoptera

Non-indigenous Coleoptera (13.1%) are mostly Cerambycidae, Chrysomelidae, Curculionidae, and Scolytidae. Asia and America have contributed the most non-indigenous Coleoptera, with more than 65% together, followed by Australia and the Pacific islands. Africa and Europe are of secondary importance.
Some alien beetles settled easily in our country, becoming agricultural pests. Omitting the well-acclimatized *Leptinotarsa decemlineata* Say, found in Italy in 1945, we want to focus on *Diabrotica virgifera virgifera* (LeConte), the northern corn rootworm from Central America, detected in 1992 near the Belgrade International Airport (Bača, 1994). The species, considered the major pest of maize in North America, settled in the new colonized area and now is present in 19 European countries. The chrysomelid arrived in Italy in 1998 and now occupies all the maize area in northern and central Italy. Its arrival in new countries can be attributed to aircraft; Miller et al. (2005) demonstrated that the pest has been introduced in Europe at least three times. Economic damage in Italy was observed in 2001 on only a few maize hectares (Boriani et al., 2002). More recently, the rice water weevil *Lissorhoptrus oryzophilus* was recorded in northern Italy (Caldara et al., 2004), but because this finding accidentally occurred during faunistic studies in the litter in Ticino Park (Lombardy), it was impossible to acquire information on the pathway of introduction of the insect (Lupi et al., 2010). Besides, until the rice water weevil detection, there were only a few arthropod species related to rice cultivation in Italy, with few outbreaks and little damage (Süss et al., 2008).
Among the exotic beetles that damage ornamental plants, some are extremely harmful and are listed as quarantine species. Among the most dangerous species of wooden plants worldwide we have to report *Anoplophora chinensis* and *A. glabripennis* (Motschulski), native to the Far East and detected in Italy in 2000 and in 2007, respectively (Colombo & Limonta, 2001a; Maspero et al., 2007). The first one has acclimatized in our country and is spreading to the north despite the eradication program. A single infestation has also been present in Rome from 2008. *A. glabripennis* seemed to be eradicated in the first area but in 2009 a new report was made in Veneto Region (EPPO, 2011). *A. chinensis* was introduced with living trees, while *A. glabripennis* was found in the backyard of a private company that imports valves, and other metallic parts in wood packaging material from China. They are both xylophagous species that damage many broad-leaf plants. The high rate of polyphagy of these species increases the possibility of the pest spreading, making eradication more difficult. Up to now in Italy for the eradication of *A. chinensis* more than 18,000 plants have been removed and the cost of the

eradication program has amounted to about 12 million euros. Originating from Asia, the red palm weevil, *Rhynchophorus ferrugineus*, is now threatening palms in public and private villas, historical gardens, roads and squares with inestimable environmental and cultural value (in particular *Phoenix canariensis*, *P. dactylifera* and *Washingtonia robusta*), spreading in all Italian regions where palms are grown (Sacchetti et al., 2005). Because of the low efficacy of control methods, all infested plants are cut and removed. *Megaplatypus mutatus* Chapuis, polyphagous on broad-leaf species, can compromise the stability of plants. Coming from South America, it is considered a quarantine species. In Italy serious damage has been recorded on *Populus* sp. (Tremblay et al., 2000).

Not included among quarantine pests but considered by EPPO as a potential threat and thus included in the Alert List is the Asiatic xylophagous *Psacothea hilaris* (Pascoe), a pest of fig and mulberry trees. Detected in 2005, it has shown how dangerous it can be by killing infested plants in the area where it has settled (Jucker et al., 2006). Its bio-ethology in the new habitat is still under study. Another Asiatic exotic insect threatening *Ficus carica* is *Aclees* spp., found in 2005 in a nursery. Larvae bore tunnels at the base of the trunk and in the roots, compromising the health of the plants (Ciampolini et al., 2005). Some other xylophagous pests of ornamental and forest plants introduced into Italy are the cerambycid *Xylotrechus stebbingi* Gahan from North America, the two Scolytidae *Xylosandrus crassiusculus* (Motsculsky) from the Pacific islands and *Phloeotribus liminaris* (Harris) from North America (Dioli & Viganò, 1990; Pennacchio et al., 2003, 2004). *Phoracantha semipunctata* Fabricius, *Phoracantha recurva* (Newman), and *Gonipterus scutellatus* Gyllenhal are three pests of *Eucalyptus* native to Australia, introduced with infested wooden material (Arzone, 1976; Sama & Bocchini, 2003; Tassi, 1970). All these species, which affect different plants, have not shown a particular impact on our environment yet, but they represent further records among the numerous introductions in our country.

4.2.3 Lepidoptera

Lepidoptera represent 11.7% of the alien species in Italy; 30% come from Asia, 23% are native to America (North and Central-South), and 20% are of unknown origin. Others are European or African species.

In this order some species that cause serious economic damage are accounted. We refer, for example, to the Geranium Bronze *Cacyreus marshalli* (Butler), one of the most harmful insect pests of cultivated *Geranium* and *Pelargonium*. Native to South Africa, it was recorded in 1996 in central Italy and is now widespread (Trematerra et al., 1997; Lupi & Jucker, 2004). In 2002 *Paysandisia archon* (Burmeister), a palm tree pest native to South America, was found in southern Italy and easily settled in our country (Espinosa et al., 2003). This is the only exotic castniid known in Europe, and it is present in almost all Mediterranean coasts. In Europe the species has been found on several palms. Originally feeding on *Trithrinax campestris*, the species in Europe has switched from the host plants to *Phoenix canariensis, Latania* sp. and on the only native European palm, *Chamaerops humilis* (Montagud, 2004). In Italy *Chamaerops humilis, Trachycarpus fortunei, Phoenix canariensis*, and *Washingtonia* represent the hosts. The tomato leaf borer *Tuta absoluta* (Meyrick), counted in the EPPO A2 list of quarantine pests, was found in Italy in 2008 and has shown itself to be very aggressive on different Solanaceae, especially tomatoes (Viggiani et al., 2009).

Cameraria ohridella Deschka & Dimic, *Phillonorycter robiniellus* Clemens, *Parectopa robiniella* Clemens, *Phyllocnistis citrella* Stainton, and *P. vitegenella* Clemens are exotic leaf miners

belonging to the family Gracillariidae, attacking woody plants. In particular, *C. ohridella* (Butin & Fuhrer, 1994) causes aesthetic damage through larval trophic activity. Host trees (*Aesculus hippocastanum*) rarely die, but can be completely defoliated in the middle of summer. Moreover, recent studies suggest that *C. ohridella* could have a potential negative impact on native leaf miners via apparent competition and could also represent a risk for *Acer pseudoplatanus* in some areas (Péré et al., 2010).

4.2.4 Diptera

Diptera are 9.6% of all the arthropods introduced in Italy, and species in the family Agromyzidae and Cecydomyiidae predominate. Horticultural and ornamental trade represents the most important pathway of introduction. Most of the species are of unknown origin (53.5%); others come essentially from North America, followed by Asia and Central-South America. Although they represent less than 10% of the introduced exotic insects, they include pest of economic importance.

The quarantine leafminers Agromizydae *Liriomyza trifolii* L. and *L. huidobrensis* Blanchard, coming respectively from North America and from Central-South America, caused much economic damage in the greenhouse cultivation of flowers and in general horticultural crops (Arzone, 1979; Süss, 1992).

Some species affect ornamental plants. The honeylocust gall midge *Obolodiplosis robiniae* (Haldeman) is strictly specific to *Robinia pseudacacia.* Detected in northern Italy in 2002, it is now present throughout the country (Bella, 2007). *Cecydomia gleditchiae* (Osten Sacken) cause galls on leaflets of *Gleditsia triacanthos,* while *Phytoliriomyza jacarandae* Steyskal & Spencer is the leafminer of *Jacaranda mimosifolia* (Bella et al., 2007; Bolchi & Volontè, 1984). Because of the species they attack and their monophagy, the importance of these pests is minimized to aesthetic damage, particularly in the area where these tree species are planted.

Rhagoletis completa Cresson represents an economically important pest of *Juglans regia* in the United States, especially in California. The species was recorded in Italy in 1991 (Duso, 1991) on some plants in the west of the country and could represent a serious threat to this tree and eventually to peach, known to be another host plant.

A species with economic importance is the newly introduced Drosophilidae *Drosophila suzukii* (Matsumura). Coming from the Far East, the species was recently recorded in North America and in Europe as noxious on strawberries, raspberries and other *Rubus*, blueberries, sweet cherries, plums, and many others fruit crops (EPPO, 2011). The dissemination of the pest over long distances is assured both by plants for planting and fruits. In Italy the species was detected in 2009 in the province of Trento (Grassi et al., 2009) and today represents a serious risk for many fruit crops with possible economic damage; *D. suzukii* was added to the Alert list in 2010 (EPPO, 2011).

Among diptera affecting humans we have to remember the mentioned *Stegomyia albopicta.*

4.2.5 Thysanoptera

Alien thrips (4.1%) are native to Asia, North and Central-South America, Australia, and the Pacific islands. Because of their size and the part of plants infested, they are mostly transferred through trade in ornamental greenhouse plants; in fact, this tropical species can easily establish inside greenhouses.

Frankliniella occidentalis (Perg.) is considered one of the major worldwide crop pests, listed within the quarantine species producing high economic damage to different crops. Detected

in Italy in 1987, it has represented a serious problem in glasshouses, both for direct and indirect damage, since the 1990s (Arzone et al., 1989). In 1998 a massive infestation of *Echinothrips americanus* Morgan (Scarpelli & Bosio, 1999) was found in a heated greenhouse. This is a polyphagous species that can affect plants in glasshouses. Coming from America, it was probably introduced with ornamentals plants for planting. Another thrips on ornamentals in glasshouses is *Bradinothrips musae* (Hood), detected in 1999 in Lombardy on *Spatiphyllum* sp. and *Musa* sp. (Colombo et al., 1999). *Pezothrips kellyanus* (Bagnall), originally from Australia (Conti, 2001), was found on Citrus in 1998. This thrips can also attack *Jasmimum fruticans*, *Pittosporum tobira*, and *Lonicera* spp.
Thrips palmi Karny is a quarantine polyphagous pest, especially of Cucurbitaceae and Solanaceae, and represents a serious threat to numerous crops worldwide. Native to Asia, several interceptions have been reported, especially on cut flowers (mainly orchids) imported from Thailand, but up to now no settlement is known in Europe (Marullo, 1997).

4.2.6 Hymenoptera

Hymenoptera exotic species in Italy are mostly beneficials used as biological control agents. Pests in this order are few, representing 3.1% of the alien species. Belonging to the Eulophidae family and associated with *Eucalyptus* spp. are the species *Lectocybe invasa* Fisher & La Salle, *Ophelimus maskelli* Ashmead, and *Leprosa milga* Kim & La Salle; they are native to Australia and the Pacific islands and probably have been introduced with the host plant.
In 2002, the Hymenoptera Cinipidae *Dryocosmus kuriphilus* Yasumatzu, considered to be the most important pest of chestnut worldwide, was detected for the first time in Europe (in Piedmont, Italy) (Melika et al., 2002). From its first detection the pest rapidly expanded its colonization and now is present in quite the entire country, threatening chestnut production and *Castanea* trees, largely cultivated in some Italian regions. This quarantine species arrived with material for grafting.
Moreover, some exotic ants, mostly of tropical or subtropical origin, were recorded as new for the Italian fauna (Jucker et al., 2008). Because of their small size and their ability to nest in different materials, ants can easily be transferred by humans. Many species are found in glasshouses (e.g., *Pheidole megacephala* (Fabricius), *P. nodus* Smith, and *Tetramorium bicarinatum*) (Limonta & Colombo, 2003) or indoors in heated buildings. Among exotic ants, we include the well-known Argentine ant *Linepithema humile* (Mayr) and the pharaoh ant *Monomorium pharaonis* (Linnaeus). Considered as anthropic pests, they are mostly present in buildings. At present, if we exclude the Argentine ant, most of these non-indigenous ants seem harmless to environments and humans.

4.2.7 Isoptera

Among Isoptera (0.7%), the presence of *Cryptotermis brevis* (Walker), native to Central America, was recorded in 1994 (Tremblay & Priore, 1997). The species was first found in the South of Italy, but afterwards other findings were made in Palermo and in northern Italy (Raineri et al., 2001). Further interception was made in 2003, when an infestation of adults belonging to the *Coptotermes* genus was found on a boat in Naples harbor. These termites add to the other species of Isoptera still present in our country (*Kalotermes flavicollis* F. and *Reticulitermis lucifugus* (Rossi) (Savoldelli & Lupi, 2008).

4.3 Pathways

Beyond the natural spreading of species, most alien insects are accidentally transferred across countries through passive transport arising from commercial activities and human

movement. Many interceptions occur on live wooden plants, mostly ornamental plants, considering the entire plant or just part of it. The import of bonsais has recently been receiving more and more attention for the introduction of alien insects, such as *Anoplophora chinensis* and numerous Homoptera (e.g. *Neophyllaphis podocarpi* Takahashi, *Lopholeucaspis japonica* (Cockerell), *Rhizoecus hibisci* Kawai & Takagi, and *Tinocallis ulmiparvifoliae* Matsumura). Wood packaging material and timber in general are associated with Coleoptera, in particular xylophagous, and Isoptera. Recently, some harmful cerambycids were imported on those goods, e.g. *Anoplophora glabripennis, Psacothea hilaris*, and *Megaplatypus mutatus*. *Anoplophora chinensis* is also known to be transported on pallets.

Notwithstanding phytosanitary regulations, these cryptic species can easily escape control because they live most of their biological cycle hidden inside the wood. Moreover, up to now effective detection methods do not exist, even though researchers are studying various techniques (e.g. acoustic methods, ultrasound, x-rays, tomography, infrared thermo imaging, detection dogs). Species are often transported inside living plants or wooden material without any observable symptoms outside. Only when the pests are in the new area and the environmental conditions are suitable do they emerge, causing much damage. Where living plants are concerned, horticultural and ornamental trade is probably the most significant pathway. Larvae of leaf miners can easily hide inside leaves or fruits (e.g. *Liriomyza* spp., *Rhagoletis completa*), as for the gall midge. Cut flowers, plant materials for propagation, and seeds are also known to carry pests (*Liriomyza trifolii*, *Dryocosmus kuriphilus*, *Frankliniella occidentalis*, etc.).

Means of transport also represent a possible pathway of entrance of exotic insects. The introduction of *Aedes albopictus* in Italy from the United States is ascribed to the trade of secondhand tires, where females lay eggs; moreover, larvae of *A. albopictus* were found inside bags watering "lucky bamboos" (*Dracaena senderiana*). Diffusion over short distances can be attributed to cars or trucks. The spreading of *Cameraria ohridella* inside Europe can also be ascribed to land transport. The arrival of *D. virgifera virgifera* in Europe, near the Belgrade airport, can be attributed to transfer by plane. Afterwards, many other new findings in different European countries were made close to airport areas by plane, as well the introduction of *Metcalfa pruinosa*.

Intentional introductions represent a high percentage of the species in some orders, like Hymenoptera and some Diptera, due to the large number of species introduced as biological control agents, which is not considered in our work.

5. Conclusion

The introduction of exotic arthropods is a dynamic non-stop process with new species reported each year. Insects probably represent the taxon with the most numerous exotic species in Italy. The history of new introductions in our country is similar to that in other parts of the world. The increasing globalization of trade and people can raise this trend with new interceptions every day, especially in industrialized countries with a high level of commercial exchanges. Moreover, the global warming phenomenon can enhance the risk of some species—particularly of tropical or subtropical origin—settling in the Mediterranean area, allowing them to spread in the new colonized area. Moreover, many Italian exotic species are listed among the 100 most invasive species in Europe (e.g. *Anoplophora chinensis*, *A. glabripennis*, *Stegomyia albopicta*, *Diabrotica virgifera virgifera*, *Harmonia axyridis*), and in many cases they have been recorded in our country for the first time in Europe, confirming that Italy is at high risk of introduction.

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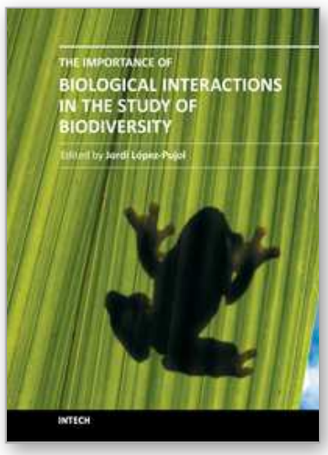
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The Importance of Biological Interactions in the Study of Biodiversity

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The term biodiversity defines not only all the variety of life in the Earth but also their complex interactions. Under the current scenario of biodiversity loss, and in order to preserve it, it is essential to achieve a deep understanding on all the aspects related to the biological interactions, including their functioning and significance. This volume contains several contributions (nineteen in total) that illustrate the state of the art of the academic research in the field of biological interactions in its widest sense; that is, not only the interactions between living organisms are considered, but also those between living organisms and abiotic elements of the environment as well as those between living organisms and the humans.

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