



The arthropod's guide to European vineyards: invasive pests as hitchhikers of globalization

Maria Schulze-Sylvester^{1,*}, Giovanni Benelli², Josep A. Jaques³, Philippe Louâpre⁴,
Andrea Lucchi², Valerio Mazzoni⁵, Annette Reineke¹, Marco Valerio Rossi Stacconi⁵,
Sophie Wenz¹, Lucia Zappalà⁶, Christine Becker¹

¹ Department of Crop Protection, Hochschule Geisenheim University, Von-Lade-Str. 1, 65366 Geisenheim, Germany

² Department of Agriculture, Food and Environment, University of Pisa, via del Borghetto 80, 56124 Pisa, Italy

³ Universitat Jaume I, ESTCE, Campus del Riu Sec, Av. de Vicent Sos Baynat, s/n, 12071 Castelló de la Plana, Spain

⁴ University of Burgundy, 6 Boulevard Gabriel, 21000 Dijon, France

⁵ Fondazione Edmund Mach, Research and Innovation Centre, San Michele all'Adige (Trento), Italy

⁶ Department of Agriculture, Food and Environment (Di3A), University of Catania, Via Santa Sofia 100, 95123 Catania, Italy

* Corresponding author: maria.schulzesylvester@hs-gm.de

With 3 figures

Abstract: Insects and mites are among the most widespread and economically significant invasive species worldwide due to their rapid reproduction, high dispersal ability, and capability to survive and quickly adapt to different environmental conditions and food sources. Increased globalization, i.e., increased human transportation and trade, is the main driver behind arthropod invasions. Globally, the spread of invasive arthropods represents a growing problem for agriculture, as many of these species are devastating pests, including vectors of plant pathogens. This is particularly relevant for perennial crops such as grapevine. Grapevine is a global crop that is susceptible to a range of aggressive pathogens and pests and, accordingly, one of the crops most frequently treated with pesticides in Europe. This review focuses on invasive insect and mite pests damaging European grapevine through feeding or vectoring pathogens. A comprehensive overview of present and potential future invasive arthropods threatening European viticulture is provided. Primary entry pathways of invasive grapevine pests into the EU, as well as their spread are discussed. The pest geographic origin and current distribution within the EU revealed particularly vulnerable regions. In the final section, lessons learned and future challenges are highlighted, along with sustainable monitoring and management options aimed to minimize the risk of introductions, and in turn pesticide applications.

Keywords: invasive alien species; biological invasion; viticulture; *Vitis vinifera*; European Union (EU); Coleoptera; Diptera; Hemiptera; Lepidoptera; Thysanoptera; Trombidiformes

1 Introduction

Anthropogenic changes, such as globalization and global warming, are the main drivers of insect and mite range shifts and introductions into new areas, thereby facilitating their invasiveness (Hulme 2021). “Hitchhiking” insects and mites can be moved through cargo or conveyances, such as trade with fruit and plant material via containers and ships, or through international movement of passengers and mail (Meurisse et al. 2019). Climate change, particularly increasing temperatures, facilitate the establishment and geographic expansion of invasive alien species in grapevine (van Leeuwen et al. 2024). Viticulture accounts for a major part of all plant protection products used in the EU even though

vineyards cover only about 2% of the utilized agricultural area (Eurostat 2022) and invasive pests could further exacerbate the intensity of pesticide applications. The increased frequency of biological invasions in vineyards challenges the industry, particularly in relation to the goal of reducing pesticides use outlined in the European Green Deal.

In this review, we highlight the importance of invasive grapevine arthropod pests in Europe and compile an overview of insects and mites that are currently threatening European viticulture or are expected to do so in the future. We draw attention to the main vectors and entry pathways of invasive grapevine pests into the EU as well as their means of spread. Furthermore, we outline especially vulnerable regions by investigating the species' geographic origin and

current distribution within the EU. By pointing out future challenges and possible management options we aim to reduce the risk of introductions and the associated, often massive, pesticide applications.

2 Materials and methods

A large survey of published information was conducted to build a list of invasive arthropods that threaten European viticulture by feeding on grapevine, *Vitis* spp. L., either as a main or secondary host (Table S1). As a main source of information, we used the open-access database of the European and Mediterranean Plant Protection Organization (EPPO, <https://www.eppo.int/>), which is an intergovernmental body with currently 52 member states, including all EU member states, responsible for cooperation and harmonization of plant protection within the European and Mediterranean region. EPPO information is used by the European Commission and the European Food Safety Authority (EFSA). The EPPO constantly accumulates, processes, and archives information on invasive pests gathered by the national plant protection agencies of the member states and curates several lists containing species that are recommended for regulation as quarantine pests (EPPO A1: pests that are absent in the EPPO region, EPPO A2: pests that are present but not widely distributed, Alert list: emerging pests that merit special awareness). While the established inflow of information from the national plant protection agencies of the member states brings many advantages, it may also lead to biased reporting depending on the national funding and research capacities. Additionally, we used information from the EU project DROPSA ‘Strategies to develop effective, innovative and practical approaches to protect major European fruit crops from pests and pathogens’ (Wistermann 2018), the databases of the international, inter-governmental Centre for Agriculture and Bioscience International (CABI, <https://www.cabi.org/>) and International Union for Conservation in Nature Global Invasive Species Database (IUCN GISD, <https://www.iucngisd.org/gisd/>).

Independent of the consulted database, cryptic species could be underrepresented in our analyses. Although the individual expert assessments of the co-authors regarding the importance of the respective pests might be vulnerable to bias, combining them with independently documented evidence from the databases improves their reliability (Sutherland & Burgman 2015).

The listed species have either already been introduced into Europe or are still absent. Their future arrival is considered a concrete threat (based on their damage profile in native regions). We analysed their native and current geographic distributions using the regions of the UN Geoscheme rather than individual countries. These regions are: Northern Africa, Sub-Saharan Africa, North America, Middle America, South America, Eastern Asia, South-eastern Asia, Southern Asia,

Western Asia, Central Asia, Northern Europe, Southern Europe, Western Europe, Eastern Europe, and Oceania (a detailed list of countries included in each region is provided in Table S2). For the distribution data analyses, species listed by EPPO as “transient” in a certain country or region were counted as present, while eradicated species were counted as absent. Species that do not damage plants or fruits directly or indirectly were not included in the compilation.

We surveyed the available literature of the past 100 years on high-impact species of Table S1 using Scopus (<https://www.scopus.com/search>) to identify research gaps, targeting papers that contain the species name in the title, abstract, or keywords.

Throughout the following text, Europe refers to the geographical Europe, EU refers to the member countries of the European Union in its current dimensions. In this review, we focused on the EU because these countries have a common regulatory framework when it comes to invasive species, and the free market and absence of border controls within the EU facilitate spread. Additionally, we adopted a broader perspective beyond the political borders when analysing the native and current geographic range of invasive species, and their entry and spread pathways.

3 Invasive arthropod pests in European vineyards

3.1 Invasive arthropod pests already present in European vineyards

Following the infamous invasion of grape phylloxera (*Daktulosphaira vitifoliae* Fitch 1851, Hemiptera: Phylloxeridae) in the 1850s, many more species have invaded Europe in the last 150 years. We counted 66 established invasive arthropod species that use grapevine either as a main or secondary host plant (Table S1). Among these, 19 species can have a high impact on viticulture, while 47 species are of lesser concern for the time being. Most of these established invasive arthropods belong to Hemiptera, followed by Lepidoptera and Coleoptera, Acarina, Thysanoptera, Diptera, and Hymenoptera (32, 9, 8, 5, 5, 1 species, respectively; Table S1).

These arthropods are native to different regions worldwide but the main source regions for invasive viticultural pest arthropods in Europe are North America and East Asia (Fig. 1A). Within Europe, most species are present in Southern Europe (n = 58), while Western Europe (n = 44) and Eastern Europe (n = 32) host fewer species. In Northern Europe, only 10 invasive species have been detected (Fig. 1B). This can be explained by the importance of viticulture in these regions and by the fact that most grapevine-feeding arthropods thrive in warmer regions. While there is a considerable similarity in species composition among European regions, some species can be found in one region only (Fig. 1C). For example, the hemipterans *Lopholeucaspis japonica* (Cockerell

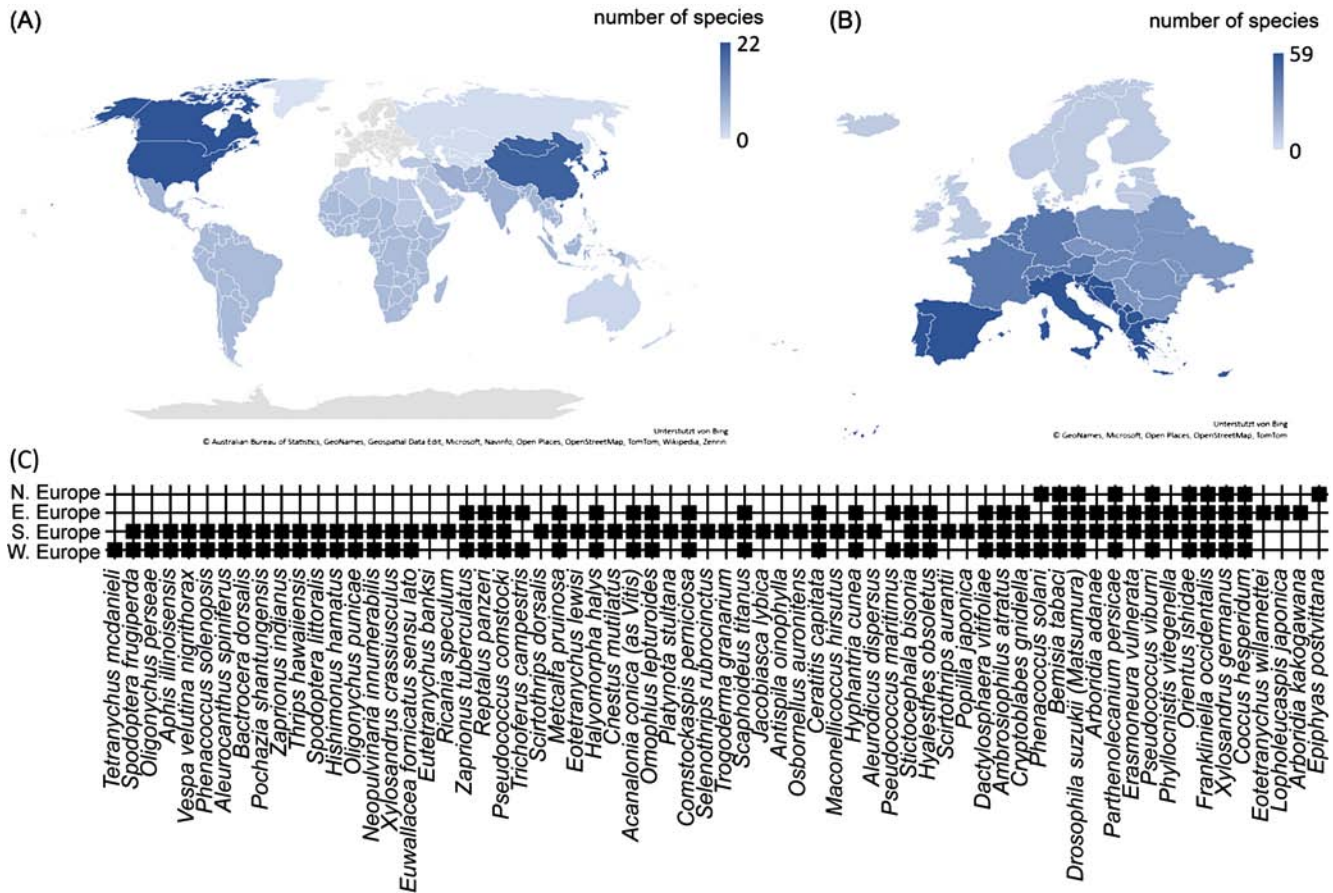


Fig. 1. The distribution of invasive arthropod species that are present in European vineyards is illustrated by heatmaps. Data was pooled for georegions. (A) native range, (B) current distribution in Europe, (C) Overview of Presence – Absence of invasive insect species in different European regions. Only species that are already present in EU countries were included (EPPO A2 list + already established pests).

1897) (Hemiptera: Diaspididae) and *Arboridia kakogawana* (Matsumura 1932) (Hemiptera: Cicadellidae) occur in Eastern Europe only. In addition, Southern Europe hosts 15 invasive pest arthropods that do not occur in the rest of the continent (Fig. 1C). These species could easily spread within Europe by human activities or through natural spread, facilitated by a warming climate, EU trading routes, tourism, and relatively soft regulations for intra-European trade of plants and fruits.

In the following section, we highlight important invasive species already present in European vineyards (a complete overview can be found in Supplementary Table S1).

3.1.1 Geographic origin: America

Aphis illinoisensis Shimer 1866 (Hemiptera: Aphididae), the vine aphid, is the second alien aphidomorpha that primarily feeds on *Vitis* to come from the Americas to Europe after grape phylloxera. While it overwinters on *Viburnum prunifolium* L. and invades vineyards in summer in their native range, anholocyclic development has been observed on *Vitis* in Eurasia (Casiraghi 2021).

Geographic range. The species is distributed on the East Coast of North America and in Central and South America. The first sighting in Europe dates back to 2002 in Turkey (Remaudière et al. 2003). Subsequently, the species was recorded in Crete in 2005 (Tsitsipis et al. 2005) and in Malta in 2009. Later, sporadic detections were done in Southern European countries, e.g. Italy, France, Spain, and Slovenia, without confirmed species' establishment (EPPO 2024a).

Means of dispersal. It is unclear how this species entered Europe. Since the vine aphid is strictly feeding on *Vitis*, an introduction via propagation material is likely. The primary local driver of expansion appears to be winged alatae transported by air currents. All countries along the Mediterranean coast provide suitable habitats for establishment (Havelka et al. 2011).

Damage. The species is a vector of *Badnavirus venavitis*, responsible for the Grapevine Vein Clearing Virus in the USA, causing vein chlorosis, stunting, and death in cultivated vines (Uhls et al. 2021), rendering it a threat to European viticulture. In Malta, *A. illinoisensis* was found

causing extensive damage to grapevine and attended by ants (*Crematogaster scutellaris* Olivier 1792 (Hymenoptera: Formicidae)) (Mifsud & Hidalgo 2011).

Erasmoneura vulnerata Fitch 1851 (Hemiptera: Cicadellidae), the grapevine leafhopper, is multivoltine with three generations per year in Italy, overwintering as adults in woody vegetation at the vineyard margins (Duso et al. 2020). The mesophyll-feeding species is strictly monophagous on *Vitis* species and is considered a pest in the Western USA.

Geographic range. This Nearctic species is widely distributed from Canada to Mexico. In Europe, it was recorded for the first time in 2004 in Northern Italy (Duso et al. 2005). Subsequently, it spread to other countries such as Switzerland, Slovenia, Serbia, Romania, and Moldova (Grozdeva & Buşmachi 2023). All European grape-growing regions offer suitable conditions for establishment.

Means of dispersal. The means of dispersal are unknown but propagation materials likely play a key role in medium-long range dispersal.

Damage. In Italian vineyards, high population densities resulted in severe damage such as leaf discoloration (Tirello et al. 2021). Despite the potential to become a key pest, studies on the economic impact of *E. vulnerata* on grapevine have not been conducted yet.

Neopulvinaria innumerabilis (Rathvon 1854) (Hemiptera: Coccidae), the cottony maple scale, is univoltine and able to complete its life cycle on grapevine. Although it infests numerous ornamental and wild plants in North America (DEFRA 2015), in Europe, *Vitis* is considered the main host. Oviposition begins in May, nymphs appear in June–July, and tend to concentrate on the abaxial side of leaves. Pupae appear in August and adults emerge in September. Mated females overwinter on woody plant parts and the large white ovisacs make infestations evident in the spring (Canard 1966, Dervišević & Graora 2024).

Geographic range. This Nearctic species originates in Canada and in the USA and was first recorded in Europe in 1966 in France and then Italy in 1977 from which it spread to Slovenia, Croatia (DEFRA 2015), and Serbia (Dervišević & Graora 2024).

Means of dispersal. Long-range dispersal mainly occurs through plant trade.

Damage. *Neopulvinaria innumerabilis* infestations are associated with progressive plant weakening and leaf/twig desiccation. The species is reported to be vector of ampeloviruses (GLRaV1 and GLRaV3) and the *Vitivirus alphavitis* (GVA) (Herrbach et al. 2017), control is either mechanical or chemical (Pavan et al. 1996; Seljak & Žežlina 2007).

Platynota stultana Walsingham 1884 (Lepidoptera: Tortricidae), the omnivorous leafroller, is multivoltine, larvae feed on leaves, flowers, and fruits of numerous fruit and vegetable crops (AliNiazee & Stafford 1972). They nest on foliage by weaving leaves together using silk (Bentley

& Coviello 2012) and overwinter as larvae (AliNiazee & Stafford 1972).

Geographic range. Originally from Mexico and Southwestern USA (Powell 1983), *P. stultana* is established in Spain since 2009 and was recently intercepted in Italy, England, the Netherlands, and Germany (EPPO 2017a; Trematerra & Colacci 2022). Having entered Europe several times independently, there is a severe and proven risk of establishment (Trematerra & Colacci 2022).

Means of dispersal. As every developmental stage of the omnivorous leafroller can be cryptically associated with all parts of an infested plant, introduction can occur through the import of any plant part. They mainly spread through plant trade including fruits (EPPO 2017a; Trematerra & Colacci 2022).

Damage. Larvae are primarily external feeders, causing cavities and scars that downgrade table grapes and make berries more susceptible to secondary infections (EPPO 2017a). This can result in significant economic losses of up to 80% (Trematerra & Colacci 2022).

Pseudococcus viburni (Signoret 1875), ***Phenacoccus solani*** Ferris 1918, and ***Pseudococcus maritimus*** Danzig 1971 (Hemiptera: Pseudococcidae), the obscure mealybug, the solanum mealybug, and the grape mealybug, have an ample range of host plants and are rather opportunistic in their host choice. Approximately one-third of all European scale insects are aliens and the pace of introductions is rising (Mazzeo et al. 2014; Pellizzari & Germain 2010). Mealybugs generally benefit from climate change, rising temperatures increase their densities and decrease biological control (Gutierrez et al. 2008), elevated CO₂ levels improve their fitness (Schulze-Sylvester et al. 2019). Range expansions have been predicted for Europe (Wei et al. 2024).

Geographic range. Native to South (*P. viburni*) and North America (*P. solani*, *P. maritimus*), these scale insects originally invaded Southern and/or Eastern Europe. Currently, they are expanding their territory north- and westwards and are likely to establish if given the opportunity (Michl et al. 2020; Schmutterer & Hoffmann 2016; Wei et al. 2024).

Means of dispersal. Scale insects are among the most common insects arriving in Europe with plant and fruit trade (Mazzeo et al. 2014; Pellizzari & Germain 2010). Their small size and the ability to hide in concealed plant parts promote escaping visual inspection by quarantine officers (Mazzeo et al. 2014; Pellizzari & Germain 2010). Often, their introduction pathway starts as indoor pests in greenhouses or private households, where they acclimate, survive, reproduce, and spread (Michl et al. 2020; Pellizzari & Porcelli 2014). These three species can overwinter and reproduce outdoors in Central Europe.

Damage. Apart from plant sap feeding and honeydew excretion, they damage grapevine by vectoring viral plant diseases (Fortusini et al. 1997; Zorloni et al. 2006; Blaisdell et al. 2016; Fuchs et al. 2015).

Scaphoideus titanus Ball 1932 (Hemiptera: Cicadellidae), the American grapevine leafhopper, is univoltine with nymphs appearing in May and adults occurring from late June to leaf fall. They overwinter as eggs inside the vine bark (Gonella et al. 2024a). While this species is reported to have several host plants in North America, grapevine is its main host in Europe.

Geographic range. This Nearctic species was introduced into Europe in the 1950s. First recorded in France (Bonfils & Schweser 1960), it soon invaded Northern Italy (Vidano 1964) and other European countries. Today it is widespread from the Azores to the Caucasus (EPPO 2024b). Range expansion to Central and Northern Europe is ongoing and is facilitated by climate warming and extensive trade of propagation material (Reineke & Thiery 2016).

Means of dispersal. Long distance dispersal is likely due to eggs in propagation material whereas natural dispersal is limited (Lessio et al. 2014).

Damage. *Scaphoideus titanus* represents a major threat to grapevine due to its ability to transmit the Flavescence dorée phytoplasma (*Candidatus Phytoplasma*), an epidemic disease subjected to mandatory treatments. Estimated yearly losses for EU wine and grape production are 0.5–1.0% (EFSA 2016), not including treatment costs or uprooting of infected plants. Vector containment largely depends on insecticide treatments although alternative techniques like vibrational mating disruption are under experimentation (Nieri et al. 2023; Thiery et al. 2023; Gonella et al. 2024b).

3.1.2 Geographic origin: Africa

Zaprionus indianus Gupta 1970 (Diptera: Drosophilidae), the African fig fly, is highly polyphagous, feeding on grapevine and more than 70 other plant species in 31 families.

Geographic range. Native to tropical Africa, this species has become invasive in many parts of the world, including Asia, North and South America. In Europe, the presence of the pest is restricted to specific areas in Spain, France, Portugal, and Cyprus (EPPO 2017b; Kremmer et al. 2017; Molina-Rodríguez et al. 2019).

Means of dispersal. For the EU, the most probable source of introduction is infested fruits like figs, strawberries, and guava (EFSA 2022a).

Damage. To date, damage in vineyards has only been reported in the USA (Markow et al. 2014; van Timmeren & Isaacs 2014). Considering that *Z. indianus* lacks a serrated ovipositor and likely cannot attack intact grapes, it is still unclear whether it will become a pest or can only attack damaged fruit. Its damaging potential could increase when co-occurring with *Drosophila suzukii* (Shrader et al. 2020) whose species portrait follows below.

3.1.3 Geographic origin: Oceania

Epiphyas postvittana (Walker 1863) (Lepidoptera: Tortricidae), the light brown apple moth, is a polyphagous

species whose larvae weave together leaves and fruits, altering the plant's normal development (Brockerhoff et al. 2011).

Geographic range. Native to Australia, this moth invaded New Zealand and was introduced to the UK in the 1930s, establishing in apple orchards, with a recent spread to continental Europe including grapevine cultivating regions like France, Spain, Portugal, and Italy (Trematerra 2023). Based on its distribution range in the USA, most of Western Europe offers suitable climatic conditions for this pest to establish in the coming decades (Lozier & Mills 2011).

Means of dispersal. The main entry pathway is plant trade including nursery stock.

Damage. The economic damage potential is high as *E. postvittana* is the key insect pest in Australian vineyards (Retallack et al. 2018). Larval feeding damages leaves and fruit surfaces, rendering them more susceptible to *Botrytis cinerea* infection (Bailey et al. 1997). Even without secondary infections, cosmetic damage downgrades table grapes.

3.1.4 Geographic origin: Asia

Arboridia kakogawana (Matsumura 1932) (Hemiptera: Cicadellidae), the Japanese grape leafhopper, is a multivoltine species (2–4 generations per year in Europe) infesting grapevine from late spring to autumn. Eggs are laid inside the leaf veins. They overwinter as adults, hidden under the bark of trees and shrubs.

Geographic range. *Arboridia kakogawana* originates from East Asia, with its first recorded sighting in 1999 in Krasnodar in Southern Russia (Gnezdilov 2008). Today, its range includes Eastern Europe, e.g. Serbia and Bulgaria.

Means of dispersal. Long-distance dispersal is likely due to infested woody plants (Gnezdilov 2008). Considering the original geographic range, *A. kakogawana* is likely to establish in colder, continental European areas.

Damage. Both nymphs and adults can cause significant foliar damage. Mesophyll feeding can lead to leaf surface depigmentation. Massive infestations can damage up to 99% of leaves, affecting grape maturation (EFSA 2022b).

Drosophila suzukii Matsumura 1931 (Diptera: Drosophilidae), the spotted-wing drosophila, is a pest of various fruit crops, including grapevine (Asplen et al. 2015). Female flies possess serrated ovipositors, allowing them to lay eggs inside otherwise intact berries. Larvae developing inside lead to rapid fruit rotteness.

Geographic range. Originally native to East and Southeast Asia (Ometto et al. 2013), it has successfully invaded various regions worldwide since 2008, including North America, Europe, South America, and Africa (Tait et al. 2021).

Means of dispersal. Research suggests that *D. suzukii*'s current distribution has been shaped not only by climate suitability and host availability but also by human-mediated factors, including global trade, transportation, climatic changes,

and landscape modifications (Cini et al. 2014; Little et al. 2020; Maino et al. 2021).

Damage. Although only red grapevine cultivars are considered suitable hosts for larvae of this species (Bellamy et al. 2013), *D. suzukii* has emerged as a major concern in recent years since it can significantly impact both viticultural and enological aspects. Feeding larvae cause damage to berries, facilitating bacterial and fungal infections that reduce yields. Secondary fermentation can result in alterations to wine quality and changes in flavor profiles (Rombaut et al. 2017; Ioriatti et al. 2018). Economic repercussions of *D. suzukii* vineyard infestations span from negligible to substantial, mainly depending on the susceptibility of the cultivar (Pelton et al. 2017; Weißinger et al. 2021). Many wine and table grapes, such as Yellow Muscat, Traminer, Merlot, and Barbera, are resistant or tolerant to *D. suzukii* oviposition by maintaining high penetration force thresholds from véraison to harvest (Ioriatti et al. 2015; Baser et al. 2018; Tonina et al. 2020).

Halyomorpha halys Stål 1855 (Hemiptera: Pentatomidae), the brown marmorated stink bug, is the most important non-native stink bug species for European viticulture (Daane et al. 2018). It pierces leaves, flower buds, or fruits with their proboscis to feed on the sap of their host plants (Leskey & Nielsen 2018), releasing saliva containing digestive enzymes to liquefy the tissues (Pfeiffer & Felton 2014; Liu & Bonning 2019). At latitudes where *H. halys* completes one generation per year, adult bugs aggregate in August/September for diapause (Haye et al. 2014). When aggregating in vineyards, they can be harvested and processed with the grapes, especially in outer rows (edge effect) (Basnet et al. 2015).

Geographic range. Originating from Asia (Hoebeke & Carter 2003), the first official records in Europe date back to 2007 in Switzerland (Wermelinger et al. 2008) and Liechtenstein (Arnold 2009). Subsequently, the species spread rapidly across the European continent (Cianferoni et al. 2018) including countries with important wine-growing regions such as France, Italy or Germany (EPPO 2024c). Globally, latitudes 30° to 50° provide a particularly suitable climate for *H. halys* (Zhu et al. 2012).

Means of dispersal. The main driver of expansion is the anthropogenic transport of overwintering adults that often seek refuge in non-plant objects temporarily stored outside before being transported (Hoebeke & Carter 2003).

Damage. *Halyomorpha halys* can cause both viticultural and enological damage. Their saliva can lead to discoloration, deformation, and necrosis of the plant tissue (Leskey & Nielsen 2018). Five bugs per grape cluster can cause a yield loss of 37 % (Smith et al. 2019). Their alarm and defense compound trans-2-decenal can affect the flavor, especially of fresh juice, while the taint usually diminishes during wine fermentation and ageing (Basnet et al. 2015;

Mohekar 2016). Comprehensive data on economic losses and associated damage thresholds are scarce, particularly concerning Europe.

Maconellicoccus hirsutus (Green 1806) and ***Parthenolecanium persicae*** (Fabricius 1776), (Hemiptera: Coccoidea), the hibiscus mealybug and the peach scale, have a large range of host plants including grapevine. They feed on the plant sap and excrete honeydew which attracts ants who bodyguard these scale insects against natural enemies.

Geographical range. *Parthenolecanium persicae* originates in the Far East but is already a well-established pest in European vineyards including Germany (Hoffmann & Schmutterer 1999). *Maconellicoccus hirsutus* is likely native to South Asia and has been detected in Greece and Cyprus.

Means of dispersal. Like most scale insects, they are dispersed via plant and fruit trade.

Damage. They inflict damage to grapes by plant sap feeding and honeydew excretion and plant virus transmission. *Maconellicoccus hirsutus* is of great concern for viticulture and horticulture and is therefore on the EPPO A2 list.

Popillia japonica Newman 1838 (Coleoptera: Scarabeidae), the Japanese beetle, is of particular importance to viticulture (Borner et al. 2023). It is categorized by EFSA as the second most dangerous pest in Europe (Sanchez et al. 2019) and as a priority pest¹ by the European Union (European Commission 2019). *Popillia japonica* is polyphagous, feeding on more than 300 plants, *Vitis* spp. being among their preferred hosts (Boucher & Pfeiffer 1989; Potter & Held 2002; Hammons et al. 2010). Larvae are soil-dwelling while adults feed predominantly on foliage in a pattern known as skeletonization. Adult emergence between May and July is well synchronized with the grapevine growth phase, increasing the risk for substantial damage. Aggregation for mating further exacerbates the feeding damage (Fleming 1972; Potter & Held 2002).

Geographic range. Originally from Japan (Fleming 1972), the first European record of *P. japonica* traces back to the Azores during the 1970s (Vieira 2008). In mainland Europe, it was first detected in Italy in 2014 (EPPO 2014), followed by Switzerland (EPPO 2017c) and Germany (EPPO 2022). Central European climate and landscape offer favorable conditions for the Japanese beetle's proliferation (Kistner-Thomas 2019); with climate change, this zone will probably shift northwards.

Means of dispersal. Anthropogenic activities, particularly the transportation of infested plant materials and soil containing eggs or larvae, are the primary drivers for long-distance dispersal (Ranney & Walgenbach 1992; Mori et al. 2022). Additionally, the adults' remarkable flight capabilities facilitate local dispersal (Potter & Held 2002).

¹ According to article 6(2) of Regulation (EU) 2016/2031.

Damage. Severe defoliation can cause viticultural and enological damage (Pfeiffer 2012, Ebbenga et al. 2022). Straubinger et al. (2023) reported an average net income loss of 2,727 €/ha among affected Italian winegrowers, primarily attributed to increased labor costs. At high-density *P. japonica* infestations, the authors project future potential damage of 68 million € per year for grapes in Italy and the USDA (2015) reports a damage of 460 million US Dollar per year in the USA.

Ricania speculum (Walker 1851) (Hemiptera: Ricaniidae), is a polyphagous planthopper univoltine in Europe. Eggs are laid in twigs and leaves of grapevine and many other plants.

Geographic range. *Ricania speculum* is present in various areas of China, Japan, India, and Southeastern Asia. It was first detected in 2014 in Northern Italy and is now quickly spreading into other regions (Mazza et al. 2018). Almost all the grape-growing European countries offer suitable climatic conditions for establishment.

Means of dispersal. Likely, eggs laid in plants for planting including artificially dwarfed plants.

Damage. Grapevine being an important host, this planthopper can inflict direct damage because eggs are laid into small twigs and leaf midribs and indirect damage through honeydew production which can promote the growth of sooty mold on grapes (Rossi & Lucchi 2015). This planthopper is not a vector of grapevine Flavescence dorée phytoplasma (Galetto et al. 2019).

Pochazia shantungensis (Chou & Lu 1977) (Hemiptera: Ricaniidae), the Asian planthopper, is univoltine and feeds on more than 200 plant species from 81 families including economically important hosts like *Vitis* spp., apple, peach, persimmon, forest and ornamental trees.

Geographic range. Originally from China, it entered the Republic of Korea in 2010 and later Japan. Within the EU, it is present in Italy, France, and the Netherlands (EFSA 2023).

Means of dispersal. Though adults are efficient fliers, the main carrier over long distances is plant tissue into which eggs are laid.

Damage. This planthopper can cause direct damage to *Vitis* spp. by sucking plant sap and inserting eggs into young shoots. Indirectly, honeydew production can promote the growth of sooty mold on grapes.

3.2 Future invasive insect pests that threaten European viticulture

Among the 62 invasive viticultural arthropod pests still absent from Europe, 24 are expected to have a high impact and 40 species to have a minor impact on viticulture (Table S1). Lepidoptera are the most prominent order among the absent invaders, followed by Hemiptera, Coleoptera, Thysanoptera, Diptera, and Trombidiformes (21, 19, 14, 6, 5, and 2 species, respectively). Most of these species currently occur in

North, Central, and South America (n = 34, n = 22, n = 20 respectively), followed by Southern Asia, Sub-Saharan Africa, Eastern Asia, Oceania, and Western Asia (Fig. 2A). Notably, species from Northern Africa and Central Asia pose little threat to European viticulture: Northern Africa is home to only three species while Central Asia does not host any (Fig. 2A). Hence, human-mediated long-distance dispersal from overseas is of greater concern for future invasions than introductions from neighboring non-European regions. This agrees with findings on marine biological invasions where close-by regions were posing little threat (Seebens et al. 2013). Nonetheless, cargo of ships and airplanes has fewer entry points and is easier to control than railway and street-bound trade. In the following section, we highlight important invasive species that have not yet arrived in Europe but are considered future threats to viticulture. For an exhaustive overview of these species please refer to Supplemental Table S1.

3.2.1 Geographic origin: America

Anastrepha fraterculus (Wiedemann 1830) (Diptera: Tephritidae), the South American fruit fly, exhibits a broad host range and can be met with the same apprehensions as *D. suzukii*.

Geographic range. Currently, *A. fraterculus* is present in subtropical Central and South America where it occurs as a complex of several cryptic species (Hernandez-Ortiz et al. 2015). Establishment in Europe is expected to be limited to Southern regions due to cold winters in the North and Center.

Means of dispersal. For the EU, the most probable source of introduction is infested fruits like guava citrus, apple, *Prunus*, and mangos but puparia might also be transported in soil or packaging (EPPO 2024d).

Damage. The phytosanitary risk has not specifically been assessed for grapes. However, laboratory studies showed that oviposition punctures on table grapes can lead to infection by *Botrytis cinerea* and *Glomerella cingulata* as well as by microorganisms causing acid rot (Machota et al. 2016).

Homalodisca vitripennis (Germar 1821) (Hemiptera: Cicadellidae), the glassy-winged sharpshooter, is another potential threat to European viticulture.

Geographic range. This species is native to the USA and the Gulf of Mexico coast region (Triapitsyn & Phillips 2000) but has become a primary problem for grapes in California (CDFA 2021). Europe offers suitable habitats along Mediterranean coasts, especially in Cyprus, Italy, Greece, Malta, Portugal, and Spain.

Means of dispersal. The main means of dispersal is the trade of live ornamental plants containing egg masses (Hoddle & Morgan 2022).

Damage. As a vector of the bacterium *Xylella fastidiosa*, *H. vitripennis* can contribute to the spread of Pierce's Disease (Almeyda & Purcell 2003). A few years after the invasion, the economic damage in California amounted to

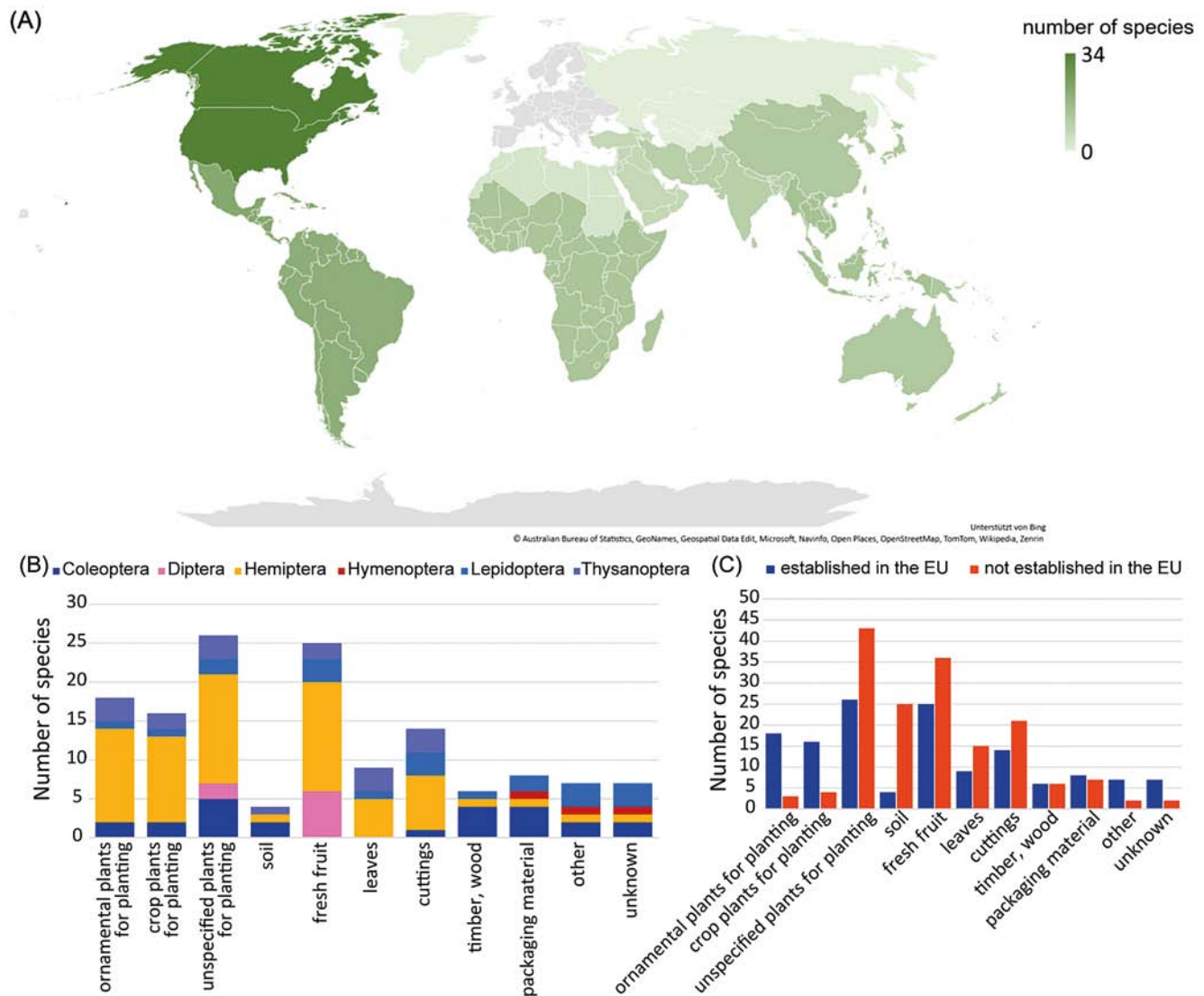


Fig. 2. (A) Heatmap of the current distribution of invasive arthropod species that are not yet present in European vineyards. Data were pooled for georegions. Only species that are not yet present in EU countries were included (EPPO A1 list). (B) Main vectors of vineyard invasive arthropod pest species already established in the EU, displayed by order. (C) Comparison of main vectors of established (blue bars) and not established (orange bars) invasive vineyard arthropod pests.

almost 60 million US Dollar (CDFA 2021). Eradication attempts using biological control through parasitoids have led to significant reductions of up to 95 % in the total population without achieving eradication (Hoddle & Morgan 2022). The presence of *X. fastidiosa* in suitable habitats in Europe fundamentally affects this species' potential as an economically relevant pest.

Lasiothyris luminosa (Razowski & Becker 1983) (Lepidoptera: Tortricidae), the American grapevine moth, feeds inside grapevine inflorescences or berries (Costa-Lima et al. 2016).

Geographic range. First reported in Northeastern Brazil in 2015 (Costa-Lima et al. 2016), the species was included

in the European and Mediterranean Plant Protection Organization alert list in 2017 (EPPO 2017d). As for other grapevine moths, climate change and globalization seriously increase the risk of *L. luminosa* invasion in Europe.

Means of dispersal. Although poorly known, it could resemble other tortricid species, i.e. via the transport of infested plant materials such as berries, leaves, or tender stems.

Damage. Larval feeding reduces vine production and increases susceptibility to fungal infections. The potential impact on European vineyards is likely to be very high because, following the invasion of Brazilian vineyards, infested areas have shown a dramatic reduction in harvest, estimated at 5,150 US \$/ha (Costa-Lima et al. 2016).

Margarodidae Guiling, 1829 (Hemiptera), commonly known as ground pearls, are a family of subterranean scale insects that can be serious grapevine root pests. They have a complex life cycle with several nymphal stages, including a cyst stage that can remain dormant in the soil for several years. Larvae feed on the plant sap of grapevine roots, adult males lack mouthparts.

Geographic range. While they are frequently found in vineyards in the Americas and southern Africa, none of the grapevine-damaging species have been recorded in Europe (De Klerk 2017; EPPO 2024e). The species *Margarodes vredendalensis* De Klerk 1983, *M. prieskaensis* (Jakubski 1965), and *M. vitis* (Philippi 1884) are currently on the EPPO Alert list, other *Margarodes* spp. have been on and off this list in the past years.

Means of dispersal. While natural dispersal is limited due to their subterranean nature, *Margarodes* spp. are easily spread within and between vineyards by soil cultivation machines and tools including tractor tires (De Klerk 2017). They may also be transported over long distances via human-assisted spread on grapevines and other plants for planting when moved with roots and soil attached (EPPO 2024e).

Damage. The first sign of a *Margarodes* infestation is poor growth, typically appearing in patches. Shoots become shorter and thinner, and the leaves, smaller than average, point downwards. Over time, one or more branches of the vine die, eventually leading to the death of the entire plant. Infested areas expand gradually, likely due to natural dispersal of the pest in the vineyard. There are no resistant rootstock cultivars available (De Klerk 2017).

Paralobesia viteana (Clemens 1860) (Lepidoptera: Tortricidae) larvae feed on flower buds or berries woven together. Their preferred host is *V. vinifera* but their host range includes Fabaceae, Lauraceae, and Rosaceae.

Geographic range. Originally from Eastern North America, they expanded their range to the Western coast (Gilligan & Epstein 2014). While *P. viteana* has not established in European vineyards yet, the warming climate could create suitable habitats in Europe, with subsequent expansion similar to that observed in America (Zumbado-Ulate et al. 2023).

Means of dispersal. As for other Tortricidae, dispersal mostly happens through the transport of infested plant materials such as berries, leaves, or tender stems.

Damage. In vineyards, external damage to grapes may result in significant economic losses (EPPO 2016a). Additionally, secondary infections with fungi can cause bunch rot, substantially degrading wine quality (Bostanian & Isaac 2012). In North America, this species is considered one of the worst insect pests on grape berries and the damage potential in newly invaded areas is just as high.

Tetranychus mexicanus (McGregor 1950) (Trombidiformes: Tetranychidae), the Mexican spider mite, is a highly polyph-

agous species, with more than 100 hosts in 44 families, including many of agricultural importance such as avocados, bananas, beans, citrus, cotton, sugarcane, or grapevine (Migeon & Dorkeld 2024).

Geographic range. This species was originally described in Mexico (McGregor 1950) and is known to occur in the Americas, from Texas and Florida in the USA to Argentina, including the Caribbean. In the EU, it was found in the Netherlands in 2018 but was eradicated in 2019 (EPPO 2023a; Migeon & Dorkeld 2024).

Means of dispersal. Their small size allows spider mites to easily disperse through air and wind currents. However, long range dispersal occurs with trade of infested plant material, mostly plants for planting.

Damage. With their stylet-like mouthparts, spider mites puncture their host plants (mostly on the abaxial leaf surface) and suck plant fluids. They are often considered induced/secondary pests of grapes as their densities increase when non-selective pesticides reduce the abundance of their natural enemies (mostly phytoseid mites). Healthy grapevines usually tolerate moderate densities of Tetranychidae. Heavy infestation can cause leaf browning and premature leaf fall, reducing the plant photosynthetic activity and vine vigor, and can delay fruit ripening.

Tetranychus pacificus (McGregor 1919) (Trombidiformes: Tetranychidae), the pacific spider mite, is highly polyphagous with more than 50 hosts in 25 families. In addition to grapevines, it can feed on important crops including almonds, apples, beans, brassicas, citrus, cotton, maize, pears, roses, and sunflower (EPPO 2024f; Migeon & Dorkeld 2024).

Geographic range. Originally from the Western USA (McGregor 1920), it currently also occurs in Canada, Mexico, and Chile (Migeon & Dorkeld 2024).

Means of dispersal and damage. See *T. mexicanus* above.

3.2.2 Geographic origin: Africa

Thaumatotibia leucotreta (Meyrick 1913) (Lepidoptera: Tortricidae), the false codling moth, is categorized as an EU priority pest (European Commission 2019). Their larvae feed on berries but grapevine is only a marginal host.

Geographic range. Originally from Sub-Saharan Africa, it successfully invaded Israel. The species was intercepted in Italy in 2014 and 2022. Notably, the European Mediterranean region offers potentially suitable habitats including major grape-growing regions. Expansion further north is not likely due to cold winters.

Means of dispersal. The species is mainly dispersed via trade with infested fruits, notably *Capsicum* spp. and *Citrus* spp. (Loomans et al 2020).

Damage. Since grapevine is only a marginal host, the impact on European viticulture and enology is not expected to be high. Even in South Africa, where the pest is established, it is not a major threat to viticulture. The citrus indus-

try, however, might be more at risk since citrus is more attractive to the pest than grapevine.

3.2.3 Geographic origin: Asia

Euwallacea fornicatus sensu stricto (*s.s.*) (Eichhoff 1868) (Coleoptera: Curculionidae), the polyphagous shot-hole borer, is part of a species complex (*E. fornicatus sensu lato*, *s.l.*) including three additional species (Smith et al. 2019). *Euwallacea fornicatus s.s.*, feeds on *Vitis* spp. and almost 500 other plant species from more than 75 families (EPPO 2024g) but cannot establish on *Vitis* spp., which is considered a non-reproductive host (FABI 2023). Members of the complex cause substantial damage to avocado and tea, two reproductive hosts (Stouthammer et al. 2017; Smith et al. 2019; FABI 2023).

Geographic range. The *E. fornicatus* species complex is native to southeast Asia but has spread worldwide (Argentina, Australia, Brazil, Costa Rica, Madagascar, Mexico, Panama, South Africa, and USA), including Israel since 2019. *Euwallacea fornicatus s.l.* was detected in 2021 in Germany and in 2024 in Spain and was under eradication in both countries by the end of 2024 (Smith et al. 2019; EPPO 2024g).

Means of dispersal. Active flight is one of the main means of dispersal locally while the movement of timber and wood packaging material as well as trade of infested plants for planting is the main long-distance pathway for *E. fornicatus* (EPPO 2024g).

Damage. Although important economic damage, leading to tree death in less than two years since infestation, has been reported for reproductive hosts (EPPO 2024g), *Vitis* spp.?, as a non-reproductive host, doesn't allow beetles to establish breeding galleries and therefore are not expected to die from attack (FABI 2023).

Lycorma delicatula (White 1845) (Hemiptera: Fulgoridae), the spotted lanternfly, is a species whose arrival in Europe is anticipated with great concern. Grapevine is their primary host. Females lay eggs under a pink wax layer, stacked onto the bark and inert materials including construction materials.

Geographic range. Originally from East Asia, *L. delicatula* invaded the Eastern coast of the USA in 2014 from where it is still spreading despite numerous eradication attempts. In case of invasion, the species could establish in all grape-growing European countries (Wakie et al. 2020).

Means of dispersal. Likely, the species travels worldwide through trading routes on shipments and landscaping material (EPPO 2016b; Urban & Leach 2023).

Damage. Since the species arrived in the USA, it has caused significant damage to viticulture due to sap feeding and honeydew production, becoming a key pest for viticul-

ture. Massive infestations were followed by a decline in grape yield and quality.

4 Challenges for invasive pest control in vineyards

4.1 Identifying and regulating the main introduction pathways and commodities

Although the main European entry points for invasive arthropod species have yet to be investigated (Rosace et al. 2023), same as for invasive plants, these are most probably container ports (Schneider et al. 2021), where they could be imported as stowaways or with plant trade (Fig. 2B). To protect the EU territory against such arrivals, the Regulation (EU) 2016/2031 (so called “Plant Health Law”) and the Commission Implementing Regulation (EU) 2019/2072 entered into force in December 2019. Different annexes of (EU) 2019/2072 are relevant for the import of grapevines and grapes into the EU.

On the one hand, Annexes II A and B list the Union Quarantine Pests that are either absent or present in EU territories, respectively. These pests pose the highest risk for plant health and include several pests of grapes (e.g., non-EU cicadellid vectors of Pierce’s Disease, non-EU Tephritidae). The list is based on EFSA Plant Health Panel recommendations. New threats are identified through different EFSA activities, including Commodity Risk Assessments for High-Risk-Plants and Horizon Scanning in combination with an assessment of their potential impact through PeMoScoring and, if necessary, a categorization and, eventually, a full risk assessment (EFSA 2021; Antoniou et al. 2024). On the other hand, Annex VI (point 10.), prohibits the introduction of *Vitis* plants², other than fruits, from third countries other than Switzerland, and Annex XI (Part A, point 5.) requires a Phytosanitary Certificate for *Vitis* fruits when imported from third countries other than Switzerland. Moreover, as Cyprus is a Protected Zone for grape phylloxera, before import into Cyprus, an official statement from the corresponding National Plant Protection Organization confirming their absence on *Vitis* plants (other than fruits and seeds) is mandatory (Annex X, point 10.) as well as the absence of leaves on imported *Vitis* fruits (Annex X, point 38.). These regulations ensure that the grapevine plants for planting-entry pathway is closed and that of fruits should be safe. However, potential gaps exist as many *Vitis* pests are polyphagous (e.g., *L. delicatula*, ground pearls, mealybugs, spider mites) and therefore, could still enter on other commodities (e.g., ornamental plants, soil attached to plants for planting) for which regulated open pathways exist. These species could also enter as stowaways in containers, on ships, trucks, cars,

² According to EU 2016/2031, “plants” includes living plants but also living plant parts such as fruits, shoots, stems, branches, leaves, foliage, tissue cultures, pollen, buds, cuttings, scions, and grafts.

and planes. Indeed, there are reports of *Spodoptera frugiperda* (Smith 1797) (Lepidoptera: Noctuidae) egg masses on airplanes in international flights (EPPO 2023b), while *L. delicatula* was even found on imported stones for landscaping (EPPO 2016b; Burne 2020). Actually, the main drivers behind the (accidental) import of invasive pests, i.e. the associated human activities motivating the import, are agriculture, consumption of (exotic) fruits, and trade with ornamental or horticultural plants for planting (Table S1), which constitute the dominant entry pathway for these invasive species (Fig. 2B).

Import rules in EU 2019/2072 are complemented with additional regulations for the internal movement of grapevines within the EU. Annex VIII (point 19) requires an official statement that plants are free from *Flavescence dorée* phytoplasma for *Vitis* plants for planting, other than seeds. Annex XIII requires a plant passport for the movement of *Vitis* plants other than fruit and seeds. Finally, Annex XIV requires a plant passport for *Vitis* plants other than seeds with the designation for introduction into, and movement within the protected zone of Cyprus. In spite of these rules, the non-indigenous arthropod pests already present in the EU (Annex II B (EU) 2019/2072) have spread within the EU territory with the trade of fresh fruits and plants for planting.

Comparing the most important commodities for the movement of the different orders in Table S1 shows that, among the established pests, Hemiptera were mostly imported via ornamental and crop plants for planting as well as fresh fruit, while Diptera were mainly imported with fresh fruits, followed by unspecified plants for planting. Thysanoptera also show a strong relationship with plants for planting, leaves, and cuttings. Lepidopterans were most often vectored by cuttings, followed by “other” means which include stowaway in trucks and airplanes or finished wood products, and by unspecified plants for planting. Coleopterans were mainly introduced on unspecified plants for planting but also on packaging material. The only invasive hymenopteran species, *Vespa velutina* Lepeletier 1836 (Hymenoptera: Vespidae), was not imported with plant material but with packaging material and as a stowaway.

While fresh fruit and plants for planting were the most common entry pathways among pests already established in the EU, plants for planting, soil, and fresh fruit are the most prominent among those not yet established (Fig. 2C). This highlights the pivotal role of phytosanitary regulations in plant trade. It may be surprising that soil imported as such or attached to plants, e.g. turf rolls for lawns, was a comparably uncommon pathway among established pests but carries a higher potential among not-yet established pests. This is probably related to the strict prohibition in (EU) 2019/2072 Annex VI for the introduction of soil (point 19.) and growing medium (point 20.) from third countries other than Switzerland, as well as the special requirements in Annex VII for growing medium associated to plants to sustain their vitality (point 1.), for machinery and vehicles which have

been operated for agricultural or forestry purposes (point 2.), and for other commodities (e.g., roots, tubercles bulbs) for which a threshold soil content (1% weight) is set (points 12., 13., and 14.). These efficient measures should definitely continue to receive special attention to avoid future invasions (Fig. 2C). On the contrary, fresh fruits have provided a prominent pathway for established arthropod pests and could provide a frequent pathway for those expected in the future. This implies that controls in the fresh fruit trade may not be efficient enough and should receive special focus to avoid future invasions. A similar situation applies to plants for planting, including the trade of plant parts like cuttings and leaves.

Once a species arrives in a new territory, seasonal and geographical “stepping stones” can be of pivotal importance, aiding its establishment (Saura et al. 2013). Such refuges in time and space can serve as intermediate habitats from which they can disperse and expand their range, facilitated by adaptation and climate change. Greenhouses and warmer regions can serve as such stepping stones. Mealybugs, for instance, often establish in greenhouses first and then escape to reach outdoor plants in the surrounding areas while *P. japonica* established in warmer regions first, where it could exploit warm seasons, to expand its range into cooler regions or to the next stepping stone. Human activities such as trade and travel as well as global warming facilitate their spread to Northern Europe (Banks et al. 2015).

4.2 Research gaps

Research efforts and potential damage of pest species are not necessarily congruent. Considering the number of Scopus-listed, peer-reviewed publications in the last decades, *D. suzukii* and *H. halys* received the most scientific attention by far (Fig. 3). This research effort is congruent with their large damage potential on a wide range of economically important crops. Publications on the beetle *P. japonica*, the fruit fly *A. fraterculus*, the moth *E. postvittana*, and the grape phylloxera *D. vitifoliae* have been less numerous but in steady supply (Fig. 3). Given the immense damage potential of *P. japonica*, however, more research would be warranted. Research interest in *L. delicatula* has risen considerably in the last five years coinciding with its range expansion and the increasing risk of invasion of previously non-infested habitats (Fig. 3). Similarly, the two leafhoppers *S. titanus* and *H. vitripennis* have received increasing scientific attention in the last 10–15 years (Fig. 3). Among the already established pests, more research should especially be directed towards the lepidopteran *P. stultana*, the beetle *P. japonica*, and the hemipterans *A. kakogawana*, *E. vulnerata*, and *N. innumerabilis* (Fig. 3). Although *P. maritimus* and *P. viburni* received some research efforts so far, it is disproportionate to their impact potential and should be increased (Fig. 3). Overall, there are more publications concerning invasive vineyard insect pest species that are already established in the EU compared to those that are not. This research gap

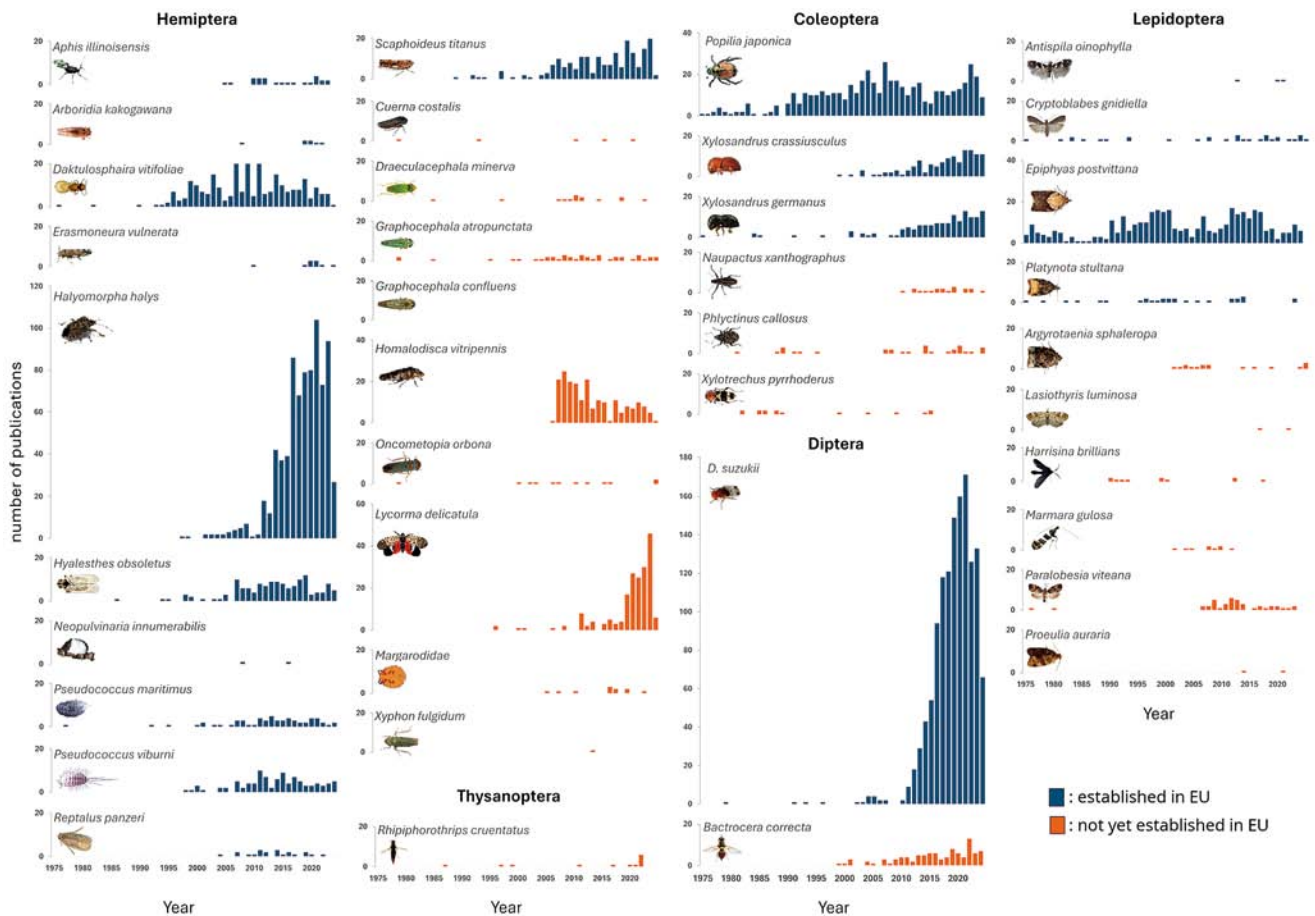


Fig. 3. Research directed towards invasive vineyard arthropod pests with current or expected high impact on EU-viticulture and/or enology, illustrated as the number of publications over time. Displayed are species that are already established (blue bars) or not yet established (orange bars) in the EU, arranged by order.

should be closed by future studies aimed at better preparing for their arrival in the EU. This applies especially to six lepidopteran species (*P. viteana*, *L. luminosa*, *Marmara gulosa* Guillén & Davis 2001, *Argyrotaenia spheropera* (Meyrick 1909), *Proeulia auraria* (Clarke 1949), and *Harrisina brillians* Barnes & McDunnough 1910) and three coleopteran species (*Xylotrechus pyrrhoderus* Bates 1873, *Naupactus xanthographus* (Germar 1824), and *Phlyctinus callosus* (Schönherr 1826); Fig. 3). The Margarodidae are a special case: they are dramatically understudied and their impact can be huge but their introduction potential into the EU is low due to their subterranean nature and the soil-related EU regulations.

Hemiptera dominate the list of already present invasive species with (current or expected) high impact on European viticulture, followed by Lepidoptera, Coleoptera, and Diptera (11, 4, 3, 1 species, respectively; Table S1). Despite this dominance and the additional threat through transmitted pathogens such as Grapevine Leafroll associated Viruses as *Ampelovirus univitis*, *Ampelovirus trivitis*, *Vitivirus alpha-*

vitis (Grapevine Virus A), *Grapevine flavescence dorée phytoplasma*, and *X. fastidiosa*, there are many understudied species, notably among scale insects and leafhoppers (Fig. 3). Furthermore, there are research gaps regarding *A. illinoisensis* and the thysanopteran *Rhipiphorotherips cruentatus* (Hood 1919) (Thysanoptera: Thripidae). Studies on these pests are very scarce despite their potential high impact on viticulture.

4.3 Measures to prevent the establishment of invasive insect pests in vineyards

Upon a new introduction into vineyards, a pivotal factor restricting the establishment and growth of an invasive insect is the vine growers' capacity to detect the invasion and promptly implement effective control methods. As a prerequisite, sufficient information for growers on characteristics and symptoms of putative invasive species ahead of potential establishment is important. Recent technological advances in smart pest detection can provide a head start. Early detection systems harnessing data collected by high-quality sen-

sors can detect specific traits of target species such as odors, sounds, and vibrations (Lima et al. 2020; Hall et al. 2023). Sniffer dogs, electronic noses, sentinel trees, and genetic identification tools complement traditional visual inspections in the toolbox of biosecurity measures (EPPO 2021; Poland & Rassati 2019). Other promising techniques include remote sensing, x-rays, camera traps, and even citizen science programs (Larson et al. 2020; Bjerger et al. 2023). A multidisciplinary approach would certainly enhance the chances to intercept an invasive species at the early stages of infestations using robust, reliable, and accurate detection techniques combined with sufficient and early information of winegrowers as well as extension services.

In case early detection of an invasive insect species is not achieved, the optimal course of action is to leverage already existing methods against taxonomically related species, including pesticides, semiochemicals, and biological control agents (Daane et al. 2018). Control methods applied in the native regions of the invasive pests should also be examined for their potential transferability, taking into account the legal and ecological requirements of the EU (Santos et al. 2020). If the active substance of synthetic pesticides that are effective in the native region is already registered in the EU for other indications, against closely related species for instance, an authorization to use them against the respective invasive species in the EU may be eased. In the long run, however, more sustainable and environmentally friendly approaches should be favored over conventional pesticides, also in the case of invasive species.

Once detected, rapid control of invasive insect species with suitable synthetic or organic insecticides is the most promising approach (Bostanian et al. 2012; Pfeiffer et al. 2012). Against some invasive species, organic insecticides are known, e.g. botanicals and mineral dusts against *S. titanus* (Prazaru et al. 2023) and the attract-and-kill combination of the yeast *Hanseniaspora uvarum* and spinosad against *D. suzukii* (Spitaler et al. 2021). Semiochemicals such as pheromone-based mating disruption represent another promising tool to control invasive species (Benelli et al. 2023b; Thiery et al. 2023). A major example is represented by the recent *Lobesia botrana* Denis & Schiffermüller 1775 (Lepidoptera: Tortricidae) eradication program in the USA (Cooper et al. 2014). The so-gathered experience could be used to design mating disruption protocols for the invasive moth *Cryptoblabes gnidiella* (Millière 1867) (Lepidoptera: Pyralidae) (Lucchi et al. 2019). Of course, the pheromones have to be adjusted to account for the high species-specificity of insect sexual communication (Tabata 2018).

Biocontrol mediated by natural enemies, such as parasitoid insects and predators, can also contribute to combating invasive species in European vineyards. For instance, the dryinid predator *Neodryinus typhlocybae* (Ashmead 1893) (Hymenoptera: Dryinidae) was introduced from North America and successfully controls the citrus flatid planthopper *Metcalfa pruinosa* (Say 1830) (Hemiptera: Flatidae)

which also invaded Europe (Tohamy et al. 2007; Véték et al. 2019). Parasitic wasps of the genus *Trichogramma*, which are egg parasitoids of native Lepidoptera like the pest tortricids *L. botrana* and *Eupoecilia ambiguella* Hübner 1796 (Lepidoptera: Tortricidae) may be able to also parasitize related species like *C. gnidiella* and *P. viteana* (Tohamy et al. 2007; Lucchi et al. 2016; Thiery et al. 2018; Becker et al. 2023).

5 Lessons learned and future challenges

While the eradication of an invasive alien species is considered a paramount objective, achieving it is extremely difficult. In most cases, it is not even attempted because the target species was not detected early enough, allowing its population to spread over a wide territory. Lack of early detection is likely the primary reason for the failure of eradication programs, together with a lack of effective monitoring and control methods and excessively high cost of measures to be undertaken. Nonetheless, these costs should be compared with the economic impact of the invasion. Failure or incorrect risk analysis leading to an underestimation of the economic and social costs associated with the invasion can effectively prevent eradication attempts. Additionally, the biology of the target species must be considered; polyphagous species are more difficult to counteract than mono- or oligophagous ones. Species phenology and fecundity, the number of female matings, behavior, and communication systems, as well as habitat and its fragmentation, should also be considered, especially when defining the “Allee effect” (i.e., the population growth rate decreases as the population density decreases) associated with a certain species. In some cases, misinformed public opinion can be a major obstacle, e.g. preventing treatments or removals in urban or suburban areas (Liebhold et al. 2016).

In summary, previous failures and successes, e.g. in the management of *L. botrana* (Benelli et al. 2023a, b) and *S. titanus* (Gonella et al. 2024a, b), emphasize that early detection and swift response are crucial for effective eradication. Applying multiple eradication tactics is a key feature for success (Lampert et al. 2021), together with outreach efforts aimed primarily at growers but also reaching common citizens. Identifying potential new invasive species before their arrival is a crucial tool to prevent their establishment in non-invaded areas, especially from regions where they already threaten viticulture, harnessing pre-existing pest control experience.

6 Conclusions

Many invasive pest insects are already established and threaten European viticulture, but as many are still absent from Europe. Several factors enhance or hinder the arrival

and establishment of these invasive insect species. Poland & Rassati (2019) describe the three types of biosecurity measures available to importing countries and carried out by the EU member states: (i) at the primary points-of-entry: border surveillance to prevent the arrival of invasive species; thereafter: (ii) post-border surveillance on a large spatial scale and (iii) containment activities in and around infested areas to prevent their establishment.

While the EU regulation is rather rigorous for non-EU imports, inner European traffic is less controlled which makes within-EU insect dispersal difficult to stop. Upon introduction, early detection, including smart techniques, as well as well-informed growers are a prerequisite to successfully avoid the establishment of invasive species. National monitoring networks are in place to detect new pests early. Their results allow the EPPO to collect and communicate detailed information, pest alerts are published, quarantine lists are updated and communication campaigns are launched. Despite all efforts, global trade and climate change fuel the spread of invasive insects, and pest pressure on European viticulture will increase. Above all other vectors, table grapes and other fresh fruit are a continuous introduction pathway for “hitchhiking” insects. EU regulation forbids the entry of grapevine plants, but many insects have a broad host plant spectrum and can be imported via ornamental plants. Although, in this review, we only focus on arthropod pest invasions, one should not forget the associated threat of new arthropod species vectoring newly introduced and/or already established pathogens. Hemipterans are especially known to vector viruses, phytoplasmas, and bacteria and establish easily in greenhouses, private gardens, or balconies. From these stepping stones secondary dispersal is often only a matter of time.

Acknowledgements: We thank Francisco Sylvester for his valuable input and advice. Publication costs were partly funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project number 531285960.

References

- Aliniaze, M. T., & Stafford, E. M. (1972). Notes on the biology, ecology, and damage of *Platynota stultana* on grapes. *Journal of Economic Entomology*, 65(4), 1042–1044. <https://doi.org/10.1093/jee/65.4.1042>
- Antoniou, A., Abergel, M., Akrivou, A., Beale, T., Day, R., Fielder, H., & Tramontini, S. (2024). Horizon scanning: Tools to identify emerging threats to plant health in a changing world. *Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation*, 54(1), 73–88. <https://doi.org/10.1111/epb.12988>
- Arnold, K. (2009). *Halyomorpha halys* (Stal, 1855), a stink bug species newly detected among the European fauna (Insecta: Heteroptera, Pentatomidae, Pentatominae, Cappaeini). *Mitteilungen des Thüringer Entomologenverbandes e.*, 16, 10.
- Asplen, M. K., Anfora, G., Biondi, A., Choi, D. S., Chu, D., Daane, K. M., & Desneux, N. (2015). Invasion biology of spotted wing *Drosophila (Drosophila suzukii)*: A global perspective and future priorities. *Journal of Pest Science*, 88(3), 469–494. <https://doi.org/10.1007/s10340-015-0681-z>
- Bailey, P. T., Ferguson, K. L., McMahon, R., & Wicks, T. J. (1997). Transmission of *Botrytis cinerea* by lightbrown apple moth larvae on grapes. *Australian Journal of Grape and Wine Research*, 3(2), 90–94. <https://doi.org/10.1111/j.1755-0238.1997.tb00120.x>
- Banks, N. C., Paini, D. R., Bayliss, K. L., & Hodda, M. (2015). The role of global trade and transport network topology in the human-mediated dispersal of alien species. *Ecology Letters*, 18(2), 188–199. <https://doi.org/10.1111/ele.12397>
- Baser, N., Broutou, O., Verrastro, V., Porcelli, F., Ioriatti, C., Anfora, G., & Rossi Stacconi, M. V. (2018). Susceptibility of table grape varieties grown in south-eastern Italy to *Drosophila suzukii*. *Journal of Applied Entomology*, 142(5), 465–472. <https://doi.org/10.1111/jen.12490>
- Basnet, S., Kuhar, T. P., Laub, C. A., & Pfeiffer, D. G. (2015). Seasonality and distribution pattern of brown marmorated stink bug (Hemiptera: Pentatomidae) in Virginia vineyards. *Journal of Economic Entomology*, 108(4), 1902–1909. <https://doi.org/10.1093/jee/108.4.tov124>
- Becker, C., Herrmann, K., & Reineke, A. (2023). Biological control in a changing climate: Plant-mediated impact of elevated CO₂ concentration on *Lobesia botrana* eggs and egg parasitism by *Trichogramma cacoeciae*. *Journal of Pest Science*, 96(2), 683–693. <https://doi.org/10.1007/s10340-022-01545-w>
- Bellamy, D. E., Sisterson, M. S., & Walse, S. S. (2013). Quantifying host potentials: Indexing postharvest fresh fruits for spotted wing drosophila, *Drosophila suzukii*. *PLoS One*, 8(4), e61227. <https://doi.org/10.1371/journal.pone.0061227>
- Benelli, G., Lucchi, A., Anfora, G., Bagnoli, B., Botton, M., Campos-Herrera, R., & Thiéry, D. (2023a). European grapevine moth, *Lobesia botrana* Part I: Biology and ecology. *Entomologia Generalis*, 43(2), 261–280. <https://doi.org/10.1127/entomologia/2023/1837>
- Benelli, G., Lucchi, A., Anfora, G., Bagnoli, B., Botton, M., Campos-Herrera, R., & Thiéry, D. (2023b). European grapevine moth, *Lobesia botrana* Part II: Prevention and management methods. *Entomologia Generalis*, 43(2), 281–304. <https://doi.org/10.1127/entomologia/2023/1947>
- Bentley, W. J., & Coviello, R. L. (2012). Leaf-Eating Lepidoptera in North American Vineyards. In N. J. Bostanian, C. Vincent, & R. Isaacs (Eds.), *Arthropod Management in Vineyards: Pests, Approaches, and Future Directions* (pp. 309–338). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-4032-7_13
- Bjerge, K., Alison, J., Dyrmann, M., Frigaard, C. E., Mann, H. M., & Høye, T. T. (2023). Accurate detection and identification of insects from camera trap images with deep learning. *PLoS Sustainability and Transformation*, 2(3), e0000051. <https://doi.org/10.1371/journal.pstr.0000051>
- Blaisdell, G. K., Cooper, M. L., Kuhn, E. J., Taylor, K. A., Daane, K. M., & Almeida, R. P. P. (2016). Disease progression of vector-mediated *Grapevine leafroll-associated virus 3* infection of mature plants under commercial vineyard conditions. *European Journal of Plant Pathology*, 146(1), 105–116. <https://doi.org/10.1007/s10658-016-0896-8>

- Bonfils, J., & Schwester, D. (1960). Les cicadelles (Homoptera: Auchenorrhyncha) dans leurs rapports avec le vignes dans le sud-ouest de la France. *Annales des Epiphyties*, *11*, 325–336.
- Borner, L., Martinetti, D., & Poggi, S. (2023). A new chapter of the Japanese beetle invasion saga: Predicting suitability from long-infested areas to inform surveillance strategies in Europe. *Entomologia Generalis*, *43*(5), 951–960. <https://doi.org/10.1127/entomologia/2023/2073>
- Bostanian, N. J., Wise, J. C., & Isaacs, R. (2012). Pesticides for arthropod control in vineyards. *Arthropod Management in Vineyards: Pests, Approaches, and Future Directions*, 53–90. https://doi.org/10.1007/978-94-007-4032-7_4
- Boucher, J. T., & Pfeiffer, D. G. (1989). Influence of Japanese beetle (Coleoptera: Scarabaeidae) foliar feeding on ‘Seyval Blanc’ grapevines in Virginia. *Journal of Economic Entomology*, *82*(1), 220–225. <https://doi.org/10.1093/jee/82.1.220>
- Brockerhoff, E. G., Suckling, D. M., Ecroyd, C. E., Wagstaff, S. J., Raabe, M. C., Dowell, R. V., & Wearing, C. H. (2011). Worldwide Host Plants of the Highly Polyphagous, Invasive *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Journal of Economic Entomology*, *104*(5), 1514–1524. <https://doi.org/10.1603/EC11160>
- Burne, A. R. (2020). *Pest Risk Assessment: Lycorma delicatula (spotted lanternfly). Version 1.0, November 2019*. New Zealand: Ministry for Primary Industries.
- Canard, M. (1966). Une Pulvinaire de la vigne nouvelle pour la France – *Neopulvinaria imeretina* (Coccoidea Coccidae). *Annales de la Société Entomologique de France*, *2*, 189.
- Casiraghi, A. (2021). First record of the invasive grapevine aphid *Aphis illinoisensis* Shimer, 1866 (Hemiptera: Aphididae) in mainland Italy. *Bonn Zoological Bulletin*, *70*, 373–375.
- CDFA California Department of Food and Agriculture. (2021). *Pierce’s disease control program annual report to the legislature*. Sacramento, CA: CDFA.
- Cianferoni, F., Graziani, F., Dioli, P., & Ceccolini, F. (2018). Review of the occurrence of *Halymorpha halyis* (Hemiptera: Heteroptera: Pentatomidae) in Italy, with an update of its European and World distribution. *Biologia*, *73*(6), 599–607. <https://doi.org/10.2478/s11756-018-0067-9>
- Cini, A., Anfora, G., Escudero-Colomar, L. A., Grassi, A., Santosuosso, U., Seljak, G., & Papini, G. (2014). Tracking the invasion of the alien fruit pest *Drosophila suzukii* in Europe. *Journal of Pest Science*, *87*(4), 559–566. <https://doi.org/10.1007/s10340-014-0617-z>
- Cooper, M., Varela, L. G., Smith, R. J., Whitmer, D., Simmons, G., Lucchi, A., & Steinhauer, R. (2014). Growers, scientists and regulators collaborate on European grapevine moth program. *California Agriculture*, *68*(4), 125–133. <https://doi.org/10.3733/ca.v068n04p125>
- Costa-Lima, T. C., Moreira, G. R. P., Goncalves, G. L., & Specht, A. (2016). *Lasiothyris luminosa* (Razowski & Becker) (Lepidoptera: Tortricidae): a new grapevine pest in northeastern Brazil. *Neotropical Entomology*, *45*(3), 336–339. <https://doi.org/10.1007/s13744-016-0379-9>
- Daane, K. M., Vincent, C., Isaacs, R., & Ioriatti, C. (2018). Entomological opportunities and challenges for sustainable viticulture in a global market. *Annual Review of Entomology*, *63*(1), 193–214. <https://doi.org/10.1146/annurev-ento-010715-023547>
- DEFRA (2015). Rapid pest risk analysis (PRA) for: *Neopulvinaria innumerabilis*. <https://pra.eppo.int/praf/0df1106e-5a62-4ef2-9464-b2ccb24b516>
- De Klerk, C. A. (2017). Identification, control and management of grapevine *margarodes*. *Winetech Technical*, <https://www.wineland.co.za/identification-control-management-grapevine-margarodes/> (accessed 2023-11-01).
- Dervišević, M., & Graora, D. (2024). *Neopulvinaria innumerabilis* (Rathvon, 1854), a new species of Coccidae in Serbia. *Pesticides and Phytomedicine*, *39*, 43–50. <https://doi.org/10.2298/PIF2402043D>
- Duso, C., Bressan, A., Mazzon, L., & Girolami, V. (2005). First record of the grape leafhopper *Erythroneura vulnerata* Fitch (Hom., Cicadellidae) in Europe. *Journal of Applied Entomology*, *129*(3), 170–172. <https://doi.org/10.1111/j.1439-0418.2005.00944.x>
- Duso, C., Zanettin, G., Gherardo, P., Pasqualotto, G., Raniero, D., Rossetto, F., ... Pozzebon, A. (2020). Colonization patterns, phenology and seasonal abundance of the Nearctic leafhopper *Erasmoneura vulnerata* (Fitch), a new pest in European vineyards. *Insects*, *11*(11), 731. <https://doi.org/10.3390/insects11110731>
- Ebbenga, D. N., Burkness, E. C., Clark, M. D., & Hutchison, W. D. (2022). Impact of adult *Popillia japonica* (Coleoptera: Scarabaeidae) foliar feeding injury on fruit yield and quality of a temperate, cold-hardy wine grape, ‘Frontenac’. *Frontiers in Insect Science*, *2*, 887659. <https://doi.org/10.3389/finsc.2022.887659>
- EFSA Panel on Plant Health (PLH), Jeger, M., Bragard, C., Caffier, D., Candresse, T., Chatzivassiliou, E., & Grégoire, J. C. (2016). Risk to plant health of Flavescence dorée for the EU territory. *EFSA Journal*, *14*, e04603. <https://doi.org/10.2903/j.efsa.2016.4603>
- EFSA Panel on Plant Health (PLH), Bragard, C., Baptista, P., Chatzivassiliou, E., Di Serio, F., Gonthier, P., Jaques Miret, J. A., Justesen, A. F., Magnusson, C. S., Milonas, P., Navas-Cortes, J. A., Parnell, S., Potting, R., Reignault, P. L., Stefani, E., Thulke, H.-H., Van der Werf, W., Vicent Civera, A., Yuen, J., Zappala, L., Gregoire, J.-C., Malumphy, C., Kertesz, V., Maiorano, A., & MacLeod, A. (2023). Pest categorisation of *Pochazia shantungensis*. *EFSA Journal*, *21*, e08320. <https://doi.org/10.2903/j.efsa.2023.8320>
- EFSA (European Food Safety Authority), Mannino, M. R., Larenaudie, M., Linge, J. P., Candresse, T., Jaques Miret, J. A., Jeger, M. J., Gachet, E., Maiorano, A., Muñoz Guajardo, I., & Stancanelli, G. (2021). Horizon Scanning for Plant Health: report on 2017–2020 activities. *EFSA Supporting Publication 2021:EN-2010*. 113 pp. <https://doi.org/10.2903/sp.efsa.2021.EN-2010>
- EFSA PLH Panel (EFSA Panel on Plant Health), Bragard, C., Baptista, P., Chatzivassiliou, E., Di Serio, F., Gonthier, P., Jaques Miret, J. A., Justesen, A. F., Magnusson, C. S., Milonas, P., Navas-Cortes, J. A., Parnell, S., Potting, R., Reignault, P. L., Stefani, E., Thulke, H.-H., Van der Werf, W., Vicent Civera, A., Yuen, J., Zappala, L., Gregoire, J.-C., Malumphy, C., Kertesz, V., Maiorano, A., & MacLeod, A. (2022a). Pest categorisation of *Zaprionus indianus*. *EFSA Journal*, *20*, e07144. <https://doi.org/10.2903/j.efsa.2022.7144>
- EFSA PLH Panel (EFSA Panel on Plant Health), Bragard, C., Baptista, P., Chatzivassiliou, E., Di Serio, F., Gonthier, P., Jaques Miret, J. A., Justesen, A. F., Magnusson, C. S., Milonas, P., Navas-Cortes, J. A., Parnell, S., Potting, R., Reignault, P. L., Stefani, E., Thulke, H.-H., Van der Werf, W., Vicent Civera, A., Yuen, J., Zappala, L., Gregoire, J.-C., Malumphy, C., Kertesz, V., Maiorano, A., & MacLeod, A. (2022b). Pest categorisation

- of *Arboridia kakogawana*. *EFSA Journal*, 20, e07023. <https://doi.org/10.2903/j.efsa.2022.7023>
- European Commission (2019). Commission Delegated Regulation (EU) 2019/1702 of 1 August 2019 supplementing regulation (EU) 2016/2031 of the European parliament and of the council by establishing the list of priority pests. *Official Journal of the European Communities*. http://data.europa.eu/eli/reg_del/2019/1702/oj
- EPPO (2014). First report of *Popillia japonica* in Italy. EPPO Reporting Service, No. 10, 2014/179. <https://gd.eppo.int/reporting/article-3272>
- EPPO (2016a). Mini data sheet on *Paralobesia viteana*. https://gd.eppo.int/download/doc/1210_minids_PAROVI.pdf
- EPPO (2016b). Pest risk analysis for *Lycorma delicatula*. EPPO, Paris. http://www.eppo.int/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm
- EPPO (2017a). Mini data sheet on *Platynota stultana*. <https://gd.eppo.int/taxon/PLAAST/documents>
- EPPO (2017b). First reports of *Drosophila suzukii* and *Zaprionus indianus* in Cyprus, and confirmation of the presence of *Z. tuberculatus*. EPPO Reporting Service, No. 04, 2017/081. <https://gd.eppo.int/reporting/article-6049>
- EPPO (2017c). First report of *Popillia japonica* in Switzerland. EPPO Reporting Service, No. 09, 2017/160. <https://gd.eppo.int/reporting/article-6128>
- EPPO (2017d). New data on quarantine pests and pests of the EPPO Alert List, EPPO Reporting Service no. 08-2017 Num. article: 2017/145, <https://gd.eppo.int/reporting/article-6113>
- EPPO (2021) PM3/92 (1) Consignment inspection of fresh fruit and vegetables for fruit flies. EPPO Bulletin 51, 406–417. <https://doi.org/10.1111/epp.12775>
- EPPO (2022). First report of *Popillia japonica* in Germany. EPPO Reporting Service, No. 08, 2022/165. <https://gd.eppo.int/reporting/article-7397>
- EPPO (2023a). Distribution of *Tetranychus mexicanus*. <https://gd.eppo.int/taxon/TETRME/distribution> (accessed 2024-02-11)
- EPPO (2023b). First report of *Spodoptera frugiperda* in Cyprus. EPPO Reporting Service, No. 02, 2023/034. <https://gd.eppo.int/reporting/article-7516>
- EPPO (2024a). Distribution of *Aphis illinoisensis*. <https://gd.eppo.int/taxon/APHIIL/distribution> (accessed 2024-27-06)
- EPPO (2024b). Distribution of *Scaphoideus titanus*. <https://gd.eppo.int/taxon/SCAPLI/distribution> (accessed 2024-27-06)
- EPPO (2024c). Taxon *Halyomorpha halys*. EPPO Global Database. <https://gd.eppo.int/taxon/HALYHA/distribution>
- EPPO (2024d). *Anastrepha fraterculus*. EPPO datasheets on pests recommended for regulation. <https://gd.eppo.int/taxon/ANSTFR/datasheet> (accessed 2024-06-06)
- EPPO (2024e). *Margarodes prieskaensis*. EPPO datasheets on pests recommended for regulation. <https://gd.eppo.int/taxon/MARGPR/datasheet> (accessed 2024-05-23)
- EPPO (2024f). Hosts of *Tetranychus pacificus*. <https://gd.eppo.int/taxon/TETRPA/hosts> (accessed 2024-12-11)
- EPPO (2024g). *Euwallacea fornicatus sensu stricto*. <https://gd.eppo.int/taxon/EUWAWH> (accessed 2024-12-11)
- Eurostat (2022) Vineyards in the EU – statistics. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Vineyards_in_the_EU_-_statistics#:~:text=The%20total%20area%20under%20vines,utilised%20agricultural%20area%20\(UAA\).](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Vineyards_in_the_EU_-_statistics#:~:text=The%20total%20area%20under%20vines,utilised%20agricultural%20area%20(UAA).) (accessed 2024-12-23)
- FABI (Forestry and Agricultural Biotechnology Institute) (2023) PSHB South African host list | Version 6: 17 April 2023. https://www.fabinet.up.ac.za/images/PSHB/PSHB_host_list_v6_20230417.pdf
- Fleming, W. E. (1972). *Biology of the Japanese beetle. Technical Bulletin, 1449*. Washington, DC: US Department of Agriculture.
- Fortusini, A., Scattini, G., Prati, S., Cinquanta, S., & Belli, G. (1997). Transmission of grapevine leafroll virus 1 (GLRaV-1) and grapevine virus A (GVA) by scale insects. In *Proceedings 12th Meeting of ICVG*, Lisbon, Portugal (pp. 121–122).
- Fuchs, M., Marsella-Herrick, P., Hesler, S., Martinson, T., & Loeb, G. M. (2015). Seasonal pattern of virus acquisition by the grape mealybug, *Pseudococcus maritimus*, in a leafroll-diseased vineyard. *Journal of Plant Pathology*, 97, 503–510.
- Galetto, L., Pegoraro, M., Marzachi, C., Rossi, E., Lucchi, A., & Bosco, D. (2019). Potential role of the alien planthopper *Ricania speculum* as vector of Flavescence dorée phytoplasma. *European Journal of Plant Pathology*, 154(4), 1103–1110. <https://doi.org/10.1007/s10658-019-01731-0>
- Gonella, E., Benelli, G., Arricau-Bouvery, N., Bosco, D., Duso, C., Dietrich, C. H., ... Alma, A. (2024a). *Scaphoideus titanus* up-to-the-minute: Biology, ecology, and role as a vector. *Entomologia Generalis*, 44(3), 481–496. <https://doi.org/10.1127/entomologia/2023/2597>
- Gonella, E., Benelli, G., Arricau-Bouvery, N., Bosco, D., Duso, C., Dietrich, C. H., ... Alma, A. (2024b). *Scaphoideus titanus* forecasting and management: Quo vadis? *Entomologia Generalis*, 44(3), 497–510. <https://doi.org/10.1127/entomologia/2023/2598>
- Gnezdilov, V. M., Sugonyaev, E. S., & Artokhin, K. S. (2008). *Arboridia kakogawana* (Matsumura) (Hemiptera Cicadellidae Typhlocybinae) – a new pest of grapevine in Southern Russia. *Redia (Firenze)*, 91, 51–54.
- Gilligan T. M., & Epstein, M. (2014). Tortricids of Agricultural Importance. Interactive Keys developed in Lucid 3.5. Last updated August 2014. <http://idtools.org/id/leps/tortai/index.html>
- Grozdeva, S., & Buşmachi, G. (2023). First record of the nearctic leafhopper *Erasmoneura vulnerata* (Fitch, 1851) (Hemiptera: Cicadellidae) in the republic of Moldova. *Studii și comunicări. Științele Naturii*, 39, 142–146.
- Gutierrez, A. P., Daane, K. M., Ponti, L., Walton, V. M., & Ellis, C. K. (2008). Prospective evaluation of the biological control of vine mealybug: Refuge effects and climate. *Journal of Applied Ecology*, 45(2), 524–536. <https://doi.org/10.1111/j.1365-2664.2007.01356.x>
- Hall, H., Bencsik, M., & Newton, M. (2023). Automated, non-invasive Varroa mite detection by vibrational measurements of gait combined with machine learning. *Scientific Reports*, 13(1), 10202. <https://doi.org/10.1038/s41598-023-36810-0>
- Hammons, D. L., Kurtural, S. K., & Potter, D. A. (2010). Japanese beetle defoliation reduces primary bud cold hardiness during vineyard establishment. *American Journal of Enology and Viticulture*, 61(1), 130–134. <https://doi.org/10.5344/ajev.2010.61.1.130>
- Havelka, J., Shukshuk, A. H., Ghaliow, M. E., Laamari, M., Kavallieratos, N. G., Tomanović, Ž., ... Starý, P. (2011). Review of invasive grapevine aphid, *Aphis illinoisensis* Shimer, and native parasitoids in the Mediterranean (Hemiptera, Aphididae; Hymenoptera, Braconidae, Aphidiinae). *Archives of Biological Sciences*, 63(1), 269–274. <https://doi.org/10.2298/ABS1101269H>

- Haye, T., Abdallah, S., Garipey, T., & Wyniger, D. (2014). Phenology, life table analysis and temperature requirements of the invasive brown marmorated stink bug, *Halyomorpha halys*, in Europe. *Journal of Pest Science*, 87(3), 407–418. <https://doi.org/10.1007/s10340-014-0560-z>
- Herrbach, E., Alliaume, A., Prator, C. A., Daane, K. M., Cooper, M. L., & Almeida, R. P. P. (2017). Vector transmission of Grapevine Leafroll-Associated Viruses. In B. Meng, G. Martelli, D. Golino, & M. Fuchs (Eds.), *Grapevine viruses: Molecular biology, diagnostics and management* (pp. 483–503). New York, Heidelberg: Springer; https://doi.org/10.1007/978-3-319-57706-7_24
- Hernandez-Ortiz, V., Canal, N. A., Tigrero Salas, J. O., Ruiz-Hurtado, F. M., & Dzul-Cauich, J. F. (2015). Taxonomy and phenotypic relationships of the *Anastrepha fraterculus* complex in the Mesoamerican and Pacific Neotropical dominions (Diptera, Tephritidae). *ZooKeys*, 540, 95–124. <https://doi.org/10.3897/zookeys.540.6027>
- Hoddle, M. S., & Morgan, D. J. (2022). Successful biological control of glassy-winged sharpshooter, *Homalodisca vitripennis*, in invaded regions. In R. G. Van Driesche, R. L. Winston, T. M. Perring, & V. M. Lopez (Eds.), *Contributions of classical biological control to the US food security, forestry, and biodiversity* (pp. 92–103). Morgantown, West Virginia: USDA Forest Service; FHAAS-2019-05.
- Hoebeke, E. R., & Carter, M. E. (2003). *Halyomorpha halys* (Stal) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. *Proceedings of the Entomological Society*, 105, 225–237.
- Hoffmann, C., & Schmutterer, H. (1999). Die Pfirsichschildlaus *Parthenolecanium persicae* (F.) ein für Deutschland neuer Schädling der Weinrebe *Vitis vinifera*. *Anzeiger für Schädlingskunde*, 72(2), 52–54. <https://doi.org/10.1007/BF02771097>
- Hulme, P. E. (2021). Unwelcome exchange: International trade as a direct and indirect driver of biological invasions worldwide. *One Earth*, 4(5), 666–679. <https://doi.org/10.1016/j.oneear.2021.04.015>
- Ioriatti, C., Walton, V., Dalton, D., Anfora, G., Grassi, A., Maistri, S., & Mazzoni, V. (2015). *Drosophila suzukii* (Diptera: Drosophilidae) and its potential impact to wine grapes during harvest in two cool climate wine grape production regions. *Journal of Economic Entomology*, 108(3), 1148–1155. <https://doi.org/10.1093/jee/tov042>
- Ioriatti, C., Guzzon, R., Anfora, G., Ghidoni, F., Mazzoni, V., Villegas, T. R., ... Walton, V. M. (2018). *Drosophila suzukii* (Diptera: Drosophilidae) contributes to the development of sour rot in grape. *Journal of Economic Entomology*, 111(1), 283–292. <https://doi.org/10.1093/jee/tox292>
- Ioriatti, C., Krawczyk, G., & Lucchi, A. (2019). *Lycorma delicatula*, cicalina di temuta introduzione. *L'Informatore Agrario*, 45, 56–59.
- Kistner-Thomas, E. J. (2019). The potential global distribution and voltinism of the Japanese beetle (Coleoptera: Scarabaeidae) under current and future climates. *Journal of Insect Science*, 19(2), 16. <https://doi.org/10.1093/jisesa/iez023>
- Kremmer, L., David, J., Borowiec, N., Thaon, M., Ris, N., Poirie, M., & Gatti, J. L. (2017). The African fig fly *Zaprionus indianus*: A new invasive pest in France? *Bulletin of Insectology*, 70, 57–62.
- Lampert, A., & Liebhold, A. M. (2021). Combining multiple tactics over time for cost-effective eradication of invading insect populations. *Ecology Letters*, 24(2), 279–287. <https://doi.org/10.1111/ele.13640>
- Larson, E. R., Graham, B. M., Achury, R., Coon, J. J., Daniels, M. K., Gambrell, D. K., & Suarez, A. V. (2020). From eDNA to citizen science: Emerging tools for the early detection of invasive species. *Frontiers in Ecology and the Environment*, 18(4), 194–202. <https://doi.org/10.1002/fee.2162>
- Leskey, T. C., & Nielsen, A. L. (2018). Impact of the invasive brown marmorated stink bug in North America and Europe: History, biology, ecology, and management. *Annual Review of Entomology*, 63(1), 599–618. <https://doi.org/10.1146/annurev-ento-020117-043226>
- Lessio, F., Tota, F., & Alma, A. (2014). Tracking the dispersion of *Scaphoideus titanus* Ball (Hemiptera: Cicadellidae) from wild to cultivated grapevine: use of a novel mark-capture technique. *Bulletin of Entomological Research*, 104(4), 432–443. <https://doi.org/10.1017/S0007485314000030>
- Liebhold, A. M., Berec, L., Brockerhoff, E. G., Epanchin-Niell, R. S., Hastings, A., Herms, D. A., & Yamanaka, T. (2016). Eradication of invading insect populations: From concepts to applications. *Annual Review of Entomology*, 61(1), 335–352. <https://doi.org/10.1146/annurev-ento-010715-023809>
- Lima, M. C. F., de Almeida Leandro, M. E. D., Valero, C., Coronel, L. C. P., & Bazzo, C. O. G. (2020). Automatic detection and monitoring of insect pests –. *Revista de Agricultura (Piracicaba)*, 10, 161.
- Lima, C. G., Sofia Vaz, A., Honrado, J. P., Aranha, J., Crespo, N., & Vicente, J. R. (2022). The invasion by the Yellow-legged hornet: A systematic review. *Journal for Nature Conservation*, 67, 126173. <https://doi.org/10.1016/j.jnc.2022.126173>
- Little, C. M., Chapman, T. W., & Hillier, N. K. (2020). Plasticity is key to success of *Drosophila suzukii* (Diptera: Drosophilidae) invasion. *Journal of Insect Science*, 20(3), 1–8. <https://doi.org/10.1093/jisesa/ieaa034>
- Liu, S., & Bonning, B. C. (2019). The principal salivary gland is the primary source of digestive enzymes in the saliva of the brown marmorated stink bug, *Halyomorpha halys*. *Frontiers in Physiology*, 10, 1255. <https://doi.org/10.3389/fphys.2019.01255>
- Loomans, A., van Noort, T., Schenk, M., Delbianco, A., & Vos, S. (2020). Pest survey card on *Thaumatotibia leucotreta*. *EFSA Supporting Publications*, 17, 1916E.
- Lozier, J. D., & Mills, N. J. (2011). Predicting the potential invasive range of light brown apple moth (*Epiphyas postvittana*) using biologically informed and correlative species distribution models. *Biological Invasions*, 13(10), 2409–2421. <https://doi.org/10.1007/s10530-011-0052-5>
- Lucchi, A., Scaramozzino, P. L., Michl, G., Loni, A., & Hoffmann, C. (2016). The first record in Italy of *Trichogramma cordubense* Vargas & Cabello 1985 (Hymenoptera Trichogrammatidae) emerging from the eggs of *Lobesia botrana* (Denis & Schiffmüller, 1775) (Lepidoptera Tortricidae). *Vitis*, 55, 161–164.
- Lucchi, A., Ricciardi, R., Benelli, G., & Bagnoli, B. (2019). What do we really know on the harmfulness of *Cryptoblabes gni-diella* (Millière) to grapevine? From ecology to pest management. *Phytoparasitica*, 47(1), 1–15. <https://doi.org/10.1007/s12600-018-0705-3>
- Machota, R., Jr., Bortoli, L. C., Cavalcanti, F. R., Botton, M., & Grützmacher, A. D. (2016). Assessment of injuries caused by *Anastrepha fraterculus* (Wied.) (Diptera: Tephritidae) on the incidence of bunch rot diseases in table grape. *Neotropical*

- Entomology*, 45(4), 361–368. <https://doi.org/10.1007/s13744-016-0377-y>
- Maino, J. L., Schouten, R., & Umina, P. (2021). Predicting the global invasion of *Drosophila suzukii* to improve Australian biosecurity preparedness. *Journal of Applied Ecology*, 58(4), 789–800. <https://doi.org/10.1111/1365-2664.13812>
- Markow, T. A., Hanna, G., Riesgo-Escovar, J. R., Tellez-Garcia, A. A., Richmond, M. P., Nazario-Yepiz, N. O., & Pfeiler, E. (2014). Population genetics and recent colonization history of the invasive drosophilid *Zaprionus indianus* in Mexico and Central America. *Biological Invasions*, 16(11), 2427–2434. <https://doi.org/10.1007/s10530-014-0674-5>
- Mazza, G., Marraccini, D., Lucchi, A., Marianelli, L., Peverieri, G. S., Bosio, G., & Gargani, E. (2018). First record of *Ricania speculum* (Walker, 1851) (Hemiptera Ricaniidae) from Veneto, Piedmont and Latium regions and new host plants. *Giornale di Zoologia*, 101.
- Mazzeo, G., Longo, S., Pellizzari, G., Porcelli, F., Suma, P., & Russo, A. (2014). Exotic scale insects (Coccoidea) on ornamental plants in Italy. a never-ending story. *Acta Zoologica Bulgarica*, 6, 55–61.
- McGregor, E. A. (1920). The red spiders of America, a few European species likely to be introduced. *Proceedings of the United States National Museum*, 56(2303), 641–679. <https://doi.org/10.5479/si.00963801.56-2303.641>
- McGregor, E. A. (1950). Mites of the family Tetranychidae. *American Midland Naturalist*, 44(2), 257–420. <https://doi.org/10.2307/2421963>
- Meurisse, N., Rassati, D., Hurley, B. P., Brockerhoff, E. G., & Haack, R. A. (2019). Common pathways by which non-native forest insects move internationally and domestically. *Journal of Pest Science*, 92(1), 13–27. <https://doi.org/10.1007/s10340-018-0990-0>
- Michl, G., Fischer, M., & Hoffmann, C. (2020). Solanum mealy-bug *Phenacoccus solani* Ferris, 1918: New in germany! *Journal für Kulturpflanzen*, 72, 479–482. <https://doi.org/10.5073/JfK.2020.09.04>
- Mifsud, D., & Perez Hidalgo, N. (2011). The grapevine aphid *Aphis illinoisensis*: A good example of recent invasion and rapid colonization by aphids. *Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation*, 41(2), 183–184. <https://doi.org/10.1111/j.1365-2338.2011.02462.x>
- Migeon, A., & Dorkeld, F. (2024). Spider Mites Web: a comprehensive database for the Tetranychidae. <https://www1.montpellier.inrae.fr/CBGP/spmweb> (Accessed 02/11/2024)
- Mohekar, P. (2016). *Brown Marmorated Stink Bug (BMSB), Halyomorpha halys taint in wine: impact on wine sensory, effect of wine-processing and management techniques*. PhD Thesis, Oregon State University in Corvallis.
- Molina-Rodríguez, J. M., & Pérez-Guerrero, S. (2019). New records on the occurrence of *Zaprionus indianus* (Diptera: Drosophilidae), a potential fig pest, in southwestern Spain. *Entomological News*, 128(4), 333–335. <https://doi.org/10.3157/021.128.0403>
- Mori, N., Santoiemma, G., Glazer, I., Gilioli, G., Ciampitti, M., Cavagna, B., & Battisti, A. (2022). Management of *Popillia japonica* in container-grown nursery stock in Italy. *Phytoparasitica*, 50(1), 83–89. <https://doi.org/10.1007/s12600-021-00948-2>
- Nieri, R., Berardo, A., Akassou, I., Anfora, G., Pugno, N. M., & Mazzoni, V. (2023). Vibrational mating disruption against insect pests: five years of experimentation in the vineyard. *Proceedings of the International Congress on Sound and Vibration*, Prague, 9–13.
- Ometto, L., Cestaro, A., Ramasamy, S., Grassi, A., Revadi, S., Siozios, S., ... Rota-Stabelli, O. (2013). Linking genomics and ecology to investigate the complex evolution of an invasive *Drosophila* pest. *Genome Biology and Evolution*, 5(4), 745–757. <https://doi.org/10.1093/gbe/evt034>
- Pavan, F., Antoniazzi, P., & Del Cont, B. D. (1996). Danni da *Neopulvinaria innumerabilis* (Rathvon) nei vigneti e strategie di controllo. *Informatore Fitopatologico*, 46, 50–58.
- Pellizzari, G., & Germain, J.-F. (2010). Scales (Hemiptera, Superfamily Coccoidea). Chapter 9.3. *BioRisk*, 4, 475–510. <https://doi.org/10.3897/biorisk.4.45>
- Pellizzari, G., & Porcelli, F. (2014). Alien scale insects (Hemiptera Coccoidea) in European and Mediterranean countries: The fate of new and old introductions. *Phytoparasitica*, 42(5), 713–721. <https://doi.org/10.1007/s12600-014-0414-5>
- Pelton, E., Gratton, C., & Guedot, C. (2017). Susceptibility of cold hardy grapes to *Drosophila suzukii* (Diptera: Drosophilidae.). *Journal of Applied Entomology*, 141(8), 644–652. <https://doi.org/10.1111/jen.12384>
- Pfeiffer, D. G. (2012). Japanese beetle and other Coleoptera feeding on grapevines in eastern North America. In N. J. Bostanian, C. Vincent, & R. Isaacs (Eds.), *Arthropod Management in Vineyards: Pests, Approaches, and Future Directions* (pp. 403–429). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-4032-7_17
- Pfeiffer, M., & Felton, G. W. (2014). Insights into the saliva of the brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae). *PLoS One*, 9(2), e88483. <https://doi.org/10.1371/journal.pone.0088483>
- Pfeiffer, D. G., Leskey, T. C., & Burrack, H. J. (2012). Threatening the harvest: The threat from three invasive insects in late season vineyards. In N. J. Bostanian, C. Vincent, & R. Isaacs (Eds.), *Arthropod Management in Vineyards: Pests, Approaches, and Future Directions* (pp. 449–474). Dordrecht: Springer Netherlands; https://doi.org/10.1007/978-94-007-4032-7_19
- Prazaru, S. C., D'Ambrogio, L., Dal Cero, M., Rasera, M., Cenedese, G., Guerrieri, E., ... Duso, C. (2023). Efficacy of Conventional and Organic Insecticides against *Scaphoideus titanus*: Field and Semi-Field Trials. *Insects*, 14(2), 101. <https://doi.org/10.3390/insects14020101>
- Poland, T. M., & Rassati, D. (2019). Improved biosecurity surveillance of non-native forest insects: A review of current methods. *Journal of Pest Science*, 92(1), 37–49. <https://doi.org/10.1007/s10340-018-1004-y>
- Potter, D. A., & Held, D. W. (2002). Biology and management of the Japanese beetle. *Annual Review of Entomology*, 47(1), 175–205. <https://doi.org/10.1146/annurev.ento.47.091201.145153>
- Powell, J. A. (1983). Expanding geographical and ecological range of *Platynota stultana* in California. *The Pan-Pacific Entomologist*, 59, 233–239.
- Ranney, T. G., & Walgenbach, J. F. (1992). Feeding preference of Japanese beetles for taxa of birch, cherry and crabapple. *Journal of Environmental Horticulture*, 10(3), 177–180. <https://doi.org/10.24266/0738-2898-10.3.177>
- Reineke, A., & Thiéry, D. (2016). Grapevine insect pests and their natural enemies in the age of global warming. *Journal of Pest Science*, 89(2), 313–328. <https://doi.org/10.1007/s10340-016-0761-8>

- Remaudière, G., Sertkaya, E., & Özdemir, I. (2003). Alert! Discovery in Turkey of the American aphid, *Aphis illinoisensis*, a grapevine pest (Hemiptera, Aphididae). *Revue Française d'Entomologie*, 25.
- Retallack, M. J., Mackay, D., Thomson, L. J., & Keller, M. A. (2018). Which species of Tortricidae leafrollers are key insect pests in South Australian vineyards? *Transactions of the Royal Society of South Australia*, 142(2), 130–142. <https://doi.org/10.1080/03721426.2018.1510656>
- Rombaut, A., Guilhot, R., Xuéreb, A., Benoit, L., Chapuis, M. P., Gibert, P., & Fellous, S. (2017). Invasive *Drosophila suzukii* facilitates *Drosophila melanogaster* infestation and sour rot outbreaks in the vineyards. *Royal Society Open Science*, 4(3), 170117. <https://doi.org/10.1098/rsos.170117>
- Rosace, M. C., Cendoya, M., Mattion, G., Vicent, A., Battisti, A., Cavaletto, G., ... Rossi, V. (2023). A spatio-temporal dataset of plant pests' first introductions across the EU and potential entry pathways. *Scientific Data*, 10(1), 731. <https://doi.org/10.1038/s41597-023-02643-9>
- Rossi, E., & Lucchi, A. (2015). The Asian planthopper *Ricania speculum* (Walker) (Homoptera: Ricaniidae) on several crops in Italy: a potential threat to the EPPO region? *Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation*, 45(1), 119–122. <https://doi.org/10.1111/epp.12175>
- Sánchez, B., Barreiro-Hurle, J., Soto Embodas, I., & Rodríguez-Cerezo, E. (2019). *The Impact Indicator for Priority Pests (I2P2): a tool for ranking pests according to Regulation (EU) 2016/2031. EUR29793 EN*. Publications Office of the European Union; <https://doi.org/10.2760/585182>
- Santos, J. A., Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Dinis, L. T., Correia, C., ... Schultz, H. R. (2020). A review of the potential climate change impacts and adaptation options for European viticulture. *Applied Sciences (Basel, Switzerland)*, 10(9), 3092. <https://doi.org/10.3390/app10093092>
- Saura, S., Bodin, Ö., & Fortin, M.-J. (2014). EDITOR'S CHOICE: Stepping stones are crucial for species' long-distance dispersal and range expansion through habitat networks. *Journal of Applied Ecology*, 51(1), 171–182. <https://doi.org/10.1111/1365-2664.12179>
- Schmutterer, H., & Hoffmann, C. (2016). Die wildlebenden Schildläuse Deutschlands (Sternorhyncha, Coccina). *Entomologische Nachrichten und Berichte*, 20, 1–104.
- Schneider, K., Makowski, D., & van der Werf, W. (2021). Predicting hotspots for invasive species introduction in Europe. *Environmental Research Letters*, 16(11), 114026. <https://doi.org/10.1088/1748-9326/ac2f19>
- Schulze-Sylvester, M., & Reineke, A. (2019). Elevated CO₂ levels impact fitness traits of vine mealybug *Planococcus ficus* Signoret, but not its parasitoid *Leptomastix dactylopii* Howard. *Agronomy (Basel)*, 9(6), 326. <https://doi.org/10.3390/agronomy9060326>
- Seljak, G., & Žežlina, I. (2007). Kaparji vinske trte: Možnosti in težave pri njihovem obvladovanju. *Zbornik Predavanj in Referatov*, 8, 233–237.
- Seebens, H., Gastner, M. T., & Blasius, B. (2013). The risk of marine bioinvasion caused by global shipping. *Ecology Letters*, 16(6), 782–790. <https://doi.org/10.1111/ele.12111>
- Shrader, M. E., Burrack, H. J., & Pfeiffer, D. G. (2020). Effects of interspecific larval competition on developmental parameters in nutrient sources between *Drosophila suzukii* (Diptera: Drosophilidae) and *Zaprionus indianus*. *Journal of Economic Entomology*, 113(1), 230–238. <https://doi.org/10.1093/jee/toz297>
- Smith, S. M., Gomez, D. F., Beaver, R. A., Hulcr, J., & Cognato, A. I. (2019). Reassessment of the species in the *Euwallacea fornicatus* (Coleoptera: Curculionidae: Scolytinae) complex after the rediscovery of the “lost” type specimen. *Insects*, 10, 261. <https://doi.org/10.3390/insects10090261>
- Spitaler, U., Cossu, C. S., Delle Donne, L., Bianchi, F., Rehmann, G., Eisenstecken, D., ... Schmidt, S. (2022). Field and greenhouse application of an attract-and-kill formulation based on the yeast *Hanseniaspora uvarum* and the insecticide spinosad to control *Drosophila suzukii* in grapes. *Pest Management Science*, 78(3), 1287–1295. <https://doi.org/10.1002/ps.6748>
- Stouthamer, R., Rugman-Jones, P. F., Thu, P. Q., Eskalen, A., Thibault, T., Hulcr, J., ... Zong, S. X. (2017). Tracing the origin of a cryptic invader: phylogeography of the *Euwallacea fornicatus* (Coleoptera: Curculionidae: scolytinae) species complex. *Agricultural and Forest Entomology*, 19(4), 366–375. <https://doi.org/10.1111/afe.12215>
- Straubinger, F. B., Venus, T. E., Benjamin, E. O., & Sauer, J. (2023). Private management costs of *Popillia japonica*: A study of viticulture in Italy. *Frontiers in Insect Science*, 3, 1176405. <https://doi.org/10.3389/finsc.2023.1176405>
- Sutherland, W. J., & Burgman, M. (2015). Policy advice: Use experts wisely. *Nature*, 526(7573), 317–318. <https://doi.org/10.1038/526317a>
- Tabata, J. (2018). Mating Disruption: Concepts and Keys for Effective Application. *Chemical Ecology of Insects*, 197–233. <https://doi.org/10.1201/9781351228398-9>
- Tait, G., Mermer, S., Stockton, D., Lee, J., Avosani, S., Abrieux, A., ... Walton, V. M. (2021). *Drosophila suzukii* (Diptera: Drosophilidae): A decade of research towards a sustainable integrated pest management program. *Journal of Economic Entomology*, 114(5), 1950–1974. <https://doi.org/10.1093/jee/toab158>
- Thiéry, D., Louâpre, P., Muneret, L., Rusch, A., Sentenac, G., Vogelweith, F., ... Moreau, J. (2018). Biological protection against grape berry moths. A review. *Agronomy for Sustainable Development*, 38(2), 15. <https://doi.org/10.1007/s13593-018-0493-7>
- Thiéry, D., Mazzoni, V., & Nieri, R. (2023). Disrupting pest reproduction techniques can replace pesticides in vineyards. A review. *Agronomy for Sustainable Development*, 43(5), 69. <https://doi.org/10.1007/s13593-023-00915-7>
- Tirello, P., Marchesini, E., Gherardo, P., Raniero, D., Rossetto, F., Pozzebon, A., & Duso, C. (2021). The control of the American leafhopper *Erasmoneura vulnerata* (Fitch) in European vineyards: Impact of synthetic and natural insecticides. *Insects*, 12(2), 85. <https://doi.org/10.3390/insects12020085>
- Tohamy, T. H., A. Abd El- Raheem, A., & El Khoully, M. (. (2007). Biological control of the honeydew moth, *Cryptoblabes gnidella* MILL. In grape orchards using the local egg parasitoid, *Trichogramma evanescens* WEST. and Agerin (*Bacillus thuringiensis*) as compared with recommended insecticides in Middle Egypt. *Assiut Journal of Agricultural Sciences*, 38, 93–111. <https://doi.org/10.21608/ajas.2007.270997>
- Triapitsyn, S. V., & Phillips, P. A. (2000). First record of *Gonatocerus triguttatus* (Hymenoptera: Mymaridae) from eggs of *Homalodisca coagulata* (Homoptera: Cicadellidae) with

- notes on the distribution of the host. *The Florida Entomologist*, 83(2), 200–200. <https://doi.org/10.2307/3496158>
- Tsitsipis, J. A., Angelakis, E., Margaritopoulos, J. T., Tsamandani, K., & Zarpas, K. D. (2005). First record of the grapevine aphid *Aphis illinoisensis* in the island of Kriti, Greece. *Bulletin OEPP/EPPO Bulletin. European and Mediterranean Plant Protection Organisation*, 35(3), 541–542. <https://doi.org/10.1111/j.1365-2338.2005.00898.x>
- Tonina, L., Giomi, F., Sancassani, M., Ajelli, M., Mori, N., & Giongo, L. (2020). Texture features explain the susceptibility of grapevine cultivars to *Drosophila suzukii* (Diptera: Drosophilidae) infestation in ripening and drying grapes. *Scientific Reports*, 10(1), 10245. <https://doi.org/10.1038/s41598-020-66567-9>
- Trematerra, P., & Colacci, M. (2022). *Platynota stultana* WALSINGHAM, 1884 (Lepidoptera: Tortricidae) found in Italy, invasive pest in Europe. *Giornale di Zoologia*, 105.
- Trematerra, P. (2023). *Thaumatotibia leucotreta* and *Epiphyas postvittana* found in Italy, invasive pests in Europe (Lepidoptera Tortricidae). *Bulletin of Insectology*, 76, 203–207.
- Uhls, A., Petersen, S., Keith, C., Howard, S., Bao, X., & Qiu, W. (2021). Grapevine vein clearing virus is prevalent and genetically variable in grape Aphid (*Aphis illinoisensis* Shimer) populations. *Plant Disease*, 105(5), 1531–1538. <https://doi.org/10.1094/PDIS-10-20-2176-RE>
- Urban, J. M., & Leach, H. (2023). Biology and management of the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae), in the United States. *Annual Review of Entomology*, 68(1), 151–167. <https://doi.org/10.1146/annurev-ento-120220-111140>
- USDA (2015). *Managing the Japanese Beetle: A Homeowner's Handbook*. United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), 559 16 pp.
- van Leeuwen, C., Sgubin, G., Bois, B., Ollat, N., Swingedouw, D., Zito, S., & Gambetta, G. A. (2024). Climate change impacts and adaptations of wine production. *Nature Reviews. Earth & Environment*, 5(4), 258–275. <https://doi.org/10.1038/s43017-024-00521-5>
- van Timmeren, S., & Isaacs, R. (2014). *Drosophila suzukii* in Michigan vineyards, and the first report of *Zaprionus indianus* from this region. *Journal of Applied Entomology*, 138(7), 519–527. <https://doi.org/10.1111/jen.12113>
- Vétek, G., Korányi, D., Mezőfi, L., Bodor, J., Péntzes, B., & Olmi, M. (2019). *Neodryinus typhlocybae*, a biological control agent of *Metcalfa pruinosa*, spreading in Hungary and reaching Slovakia. *Bulletin of Insectology*, 72, 1–11.
- Vidano, C. (1964). Scoperta in Italia dello *Scaphoideus littoralis* Ball cicalina americana collegata alla flavescence dorée della vite. *L'Italia Agricola*, 101, 1031–1049.
- Vieira, V. (2008). The Japanese beetle *Popillia japonica* Newman, 1838 (Coleoptera: Scarabaeidae) in the Azores islands. *Boletim de la SEA*, 43, 450–451.
- Wakie, T. T., Neven, L. G., Yee, W. L., & Lu, Z. (2020). The establishment risk of *Lycorma delicatula* (Hemiptera: Fulgoridae) in the United States and globally. *Journal of Economic Entomology*, 113, 306–314.
- Wei, J., Niu, M., Zhang, H., Cai, B., & Ji, W. (2024). Global potential distribution of invasive species *Pseudococcus viburni* (Hemiptera: Pseudococcidae) under climate change. *Insects*, 15(3), 195. <https://doi.org/10.3390/insects15030195>
- Weißinger, L., Arand, K., Bieler, E., Kassemeyer, H. H., Breuer, M., & Müller, C. (2021). Physical and chemical traits of grape varieties influence *Drosophila suzukii* preferences and performance. *Frontiers in Plant Science*, 12, 664636. <https://doi.org/10.3389/fpls.2021.664636>
- Wermelinger, B., Wyniger, D., & Forster, B. (2008). First records of an invasive bug in Europe: *Halyomorpha halys* Stal (Heteroptera: Pentatomidae), a new pest on woody ornamentals and fruit trees? *Mitteilungen der Schweizerische Entomologische Gesellschaft*, 81, 1–8.
- Wistermann, A., Grousset, F., Petter, F., Schrader, G., & Suffert, M. (2016). DROPSA Deliverable 1.3 Report for Table grapes – Fruit pathway and Alert List. <https://doi.org/10.1111/epp.12462> (accessed 2024-11-10)
- Zorloni, A., Prati, S., Chiesa, S., & Bianco, P. A. (2006). Transmission of grapevine leafroll associated virus 3 by the soft scale insect *Neopulvinaria innumerabilis*. *Journal of Plant Pathology*, 88, S61.
- Zhu, G., Bu, W., Gao, Y., & Liu, G. (2012). Potential geographic distribution of brown marmorated stink bug invasion (*Halyomorpha halys*). *PLoS One*, 7(2), e31246. <https://doi.org/10.1371/journal.pone.0031246>
- Zumbado-Ulate, H., Scharfel, T. E., Simmons, G. S., & Daugherty, M. P. (2023). Assessing the risk of invasion by a vineyard moth pest guild. *NeoBiota*, 86, 169–191. <https://doi.org/10.3897/neobiota.86.100579>

Manuscript received: July 1, 2024

Revisions requested: September 19, 2024

Revised version received: January 10, 2025

Manuscript accepted: January 27, 2025

The pdf version (Adobe JavaScript must be enabled) of this paper includes an electronic supplement:

Supplementary Table S1, S2