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# Environmental and economic impact of alien terrestrial arthropods in Europe

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## Abstract

In the last few decades, the abundance and importance of invasive alien species have grown continuously due to the undiminished growth of global trade. In most cases, arthropod introductions were unintended and occurred as hitchhikers or contaminants. Alien arthropods can have significant environmental impacts and can be economically costly. To measure these impacts, we expand a generic impact scoring system initially developed for mammals and birds, and applied it to terrestrial arthropods. It consists of six environmental impact categories and six economic impact categories, each with five impact levels. Information on impact was derived from an intensive analysis of published scientific literature. The scoring of the 77 most widely distributed arthropod species alien to Europe revealed the mite *Varroa destructor* as the most harmful species, followed by the Chinese longhorn beetle *Anoplophora chinensis* and the Argentine ant *Linepithema humile*. The highest environmental impact is through herbivory, disease transmission, and ecosystem impacts. The highest economic impact is on agriculture and human infrastructure and administration. The generic impact scoring system allows the impact scores of vertebrates and arthropods to be compared, thus serving as a background for the decision making processes of policy makers and stakeholders.

## Keywords

Invasive terrestrial arthropods, non-native, generic impact scoring system, prioritization

## Introduction

The number of alien species in Europe has been increasing over the last few decades (DAISIE 2009). Global trade and worldwide travel have offered many species the possibility to spread into distant biogeographic areas they would have otherwise been unable to reach (Pimentel et al. 2005; Nentwig 2007). Following an introduction event, alien species may establish, increase in number and spread (Pyšek and Richardson 2010). It is accepted that propagule pressure, i.e., the number of individuals and introductions as well as their reproductive capacity, is one of the key elements required for understanding the success of alien species establishment (Colautti et al. 2006). With increasing spread, alien species affect native species and the ecosystem (which can be analysed as environmental impact) and the economy (economic impact). Such abundant alien species with high impact are called invasive species following the definition of Blackburn et al. (2011). Along with other drivers of ecosystem degradation such as climate change, pollution and habitat change, biological invasions are seen as one of the main causes of biodiversity decline leading to reduced ecosystem services worldwide (Millennium Ecosystem Assessment 2005). Usually, the larger the population of an invasive species and the faster its spread, the higher its potential impact and the more difficult and expensive it will be to control or eradicate. Therefore, it is highly recommended to react to alien and invasive species as early as possible (e.g., Sakai et al. 2001; Wittenberg and Cock 2001; Leung et al. 2002).

The suitability of a measure or, more generally, the need for a given action in combatting alien species will depend on the circumstances (Pyšek and Richardson 2010). While it is best to prevent introductions of alien species in the first place, once they have established, decisions need to be made regarding the control measures and priorities. The UN Convention on Biological Diversity (1992) recommends to "eradicate those alien species which threaten ecosystems, habitats or species" and Genovesi (2005) even advises to eradicate alien species known to have a high environmental and economic impact, immediately after their first record in a newly invaded area. But how can the impact of an alien and invasive species be measured and comparatively quantified?

Often, the impact of an invasive species is not known for a specific invaded area, but for other invaded areas or its area of origin. Therefore, many approaches to estimate the potential impact of an alien species try to extrapolate from such data to a new situation, often including expert knowledge or expert guess. While there are many assessments of alien species available, it is not intended to provide a comprehensive overview in this paper. Examples include the Australian weed risk assessment, which evaluates the potential of a plant to become an environmental or agricultural weed prior to its introduction (Pheloung et al. 1999) and the risk assessment of alien fish species, which is a quantitative approach to categorize fish species causing high damage (Copp et al. 2005). Zaiko et al. (2011) define a "biopollution level" of invasive species and Kumschick et al. (2012) propose an evaluation system which relies, among others, on the selection and weighting of criteria by stakeholders and decision makers. Recent overviews on the development of risk assessments and their current diversity are given by Essl et al. (2011) and Kumschick and Richardson (2013).

As an alternative to assessments that are based only on expert knowledge, Nentwig et al. (2010) developed a generic impact scoring system, which relies exclusively on published information on the impact of a given species in its invaded area. Generally speaking, information on comparable impacts of a species in its native area can also be used, assuming that a species shows in principle the same behaviour in native and invaded areas (even if adaptation may lead to some flexibility as Wright et al. (2010) suggest). This system was first developed for mammals and later adapted to birds (Nentwig et al. 2010; Kumschick and Nentwig 2010). The strength of this system is its objectivity and reproducibility which allows a scale-independent assessment that can easily be adapted as new knowledge becomes available. By comparing the impact scores of different species, science-based recommendations for prioritization, eradication and other management recommendations are possible.

Interestingly, most of the impact assessment tools for animals deal with vertebrates. Arthropods comprise the majority of all species and can have a huge environmental and economic impact, but have not been considered appropriately. Exceptions are plant pests, assessed by pest risk assessments, which are among the most comprehensive pest risk assessments for alien species (EPPO 2012). Many arthropods are frequent hitchhikers (or stowaways) carried with human transport (e.g., ship and aircraft) and contaminants of specific commodities (Hulme et al. 2008). For example, the Argentine ant *Linepithema humile*, a typical hitchhiker and native to South America, has invaded most continents and is able to displace not only native ants but also affect other arthropods, birds, lizards and mammals through predation, competition for nesting sites or by tending arthropods and plants, thus impacting pollination (Holway et al. 2002; Lach 2007; Davis et al. 2008). Other examples concern species from the whitefly *Bemisia tabaci* species complex, which entered Europe as a contaminant of potted plants. The ability to transmit plant viruses combined with a wide host range has made some of these species limiting factors in the production of food and fibre crops as well as ornamentals in many countries (Jones 2003; Naranjo et al. 1996; Oliveira et al. 2001). Many alien and invasive insects are also of medical importance for humans. The Asian tiger mosquito *Aedes albopictus*, originating from South-East Asia, has invaded Europe and many countries in the Americas, the Middle East, and Africa. It is a vector for many tropical diseases, such as dengue fever (Enserink 2008; Paupy et al. 2009; Schaffner et al. 2009).

In the last few years, the number of publications on alien and invasive insects and their ecological impact has increased continuously. However, two thirds of studies on the ecological impact of alien insects were conducted in North America, indicating that research for Europe is lagging far behind (Kenis et al. 2009). This lack of knowledge is not justified by a lack of importance, when following the analysis of Vilà et al. (2010) mentioning 2481 alien invertebrate species (342 with ecological impact and 601 with economic impact), but only 358 alien terrestrial vertebrate species (109 with ecological impact and 138 with economic impact).

Whereas terrestrial vertebrates have an influence on most aspects of the environment and economy, the main impacts of terrestrial arthropods are considered to be "only" on ecosystems and agriculture (Kenis and Branco 2010; Vilà et al. 2010). Even if the range of these fields of impact may be assumed to be narrow, the impact of terrestrial invertebrates can be comparable to vertebrates, because the importance of ecosystem services provided by insects is crucial and their disruption can produce enormous costs. To give one example, the global economic value of insect pollination was estimated to be €153 billion and €22 billion for Europe (Gallai et al. 2009).

Having one system for measuring the environmental and economic impact of vertebrates and invertebrates would be highly advantageous. This would allow the impact of alien species to be measured and analysed in a comparative manner, thus enabling management actions to be prioritized between different taxa. Therefore, in this study we modified the generic impact scoring system, initially developed for mammals and birds (Nentwig et al. 2010; Kumschick and Nentwig 2010) to arthropods.

## Methods

The generic impact scoring system was developed by Nentwig et al. (2010) for mammals and was subsequently modified for birds (Kumschick and Nentwig 2010). The principle of the generic impact scoring system is the separation of the impacts of invasive alien species into environmental and economic impacts. These two different impact groups are further subdivided into six different categories (Table 1), each with a formal description (Suppl. material 1). For each of these twelve categories, there are five levels of intensity plus a zero impact level for no impact known or detectable. The scoring points represent the intensity level and range from 1 (minor impact) to 5 (major impact), resulting in a maximum of sixty points for species with the highest impact. The description of the twelve categories and the corresponding intensity levels are summarized in the "Handbook of the generic impact scoring system" (Suppl. material 1).

Since the expansion of the scoring system to a species-rich group, arthropods, is best done with a set of species with highest impact, we performed a careful selection of those species which currently exert the highest impact in Europe. Another, more pragmatic reason for such a selection was that it was not possible to screen hundreds of species. We performed this selection in four steps. First, we selected those species which are alien to Europe (i.e., origin outside Europe), leading to the exclusion of species with unknown origin (cryptogenic species) and species alien within Europe. Second, from this list we selected the alien species with the widest distribution in Europe. Because the distribution of a given alien species is generally correlated with its invasiveness, the number of invaded countries is a powerful indicator for the impact of a particular species at a larger scale (Pyšek et al. 2008). Therefore, we compared data about the distribution of alien terrestrial arthropods from the DAISIE database (DAISIE 2012) and from Roques et al. (2010), which provides slightly more recent data. All species that were reported in more than twenty European countries in either of the sources were selected. We defined Europe in a reasonable biogeographical context: the European continent and its islands (without the Azores, Canary Islands, and Madeira), including Ukraine, Belarus and the European part of Russia in the east. Third,

**Table 1.** Impact categories with respect to environmental and economic impacts. The description of the twelve categories and the corresponding intensity levels are summarized in the "Handbook of the generic impact scoring system" (Suppl. material 1).

| |
|---|
| **1 Environmental impacts** |
| 1.1 Impacts on plants or vegetation through herbivory |
| 1.2 Impacts on animals through predation or parasitism |
| 1.3 Impacts on other species through competition |
| 1.4 Impacts through transmission of diseases or parasites to native species |
| 1.5 Impacts through hybridization |
| 1.6 Impacts on ecosystems |
| **2. Economic impacts** |
| 2.1 Impacts on agricultural production |
| 2.2 Impacts on animal production |
| 2.3 Impacts on forestry production |
| 2.4 Impacts on human infrastructure and administration |
| 2.5 Impacts on human health |
| 2.6 Impacts on human social life |

we ensured that all terrestrial arthropods that appear on the list of the "hundred of the worst alien invasive species" presented on the DAISIE (2012) website were included. Because the spread of a species needs time, our list was completed in a fourth step by adding species first recorded in Europe after the year 2000 and now occur in eight or more countries, according to Roques et al. (2010). This fourth step was undertaken to compensate for a potential data bias concerning the more recently introduced and rapidly spreading species. This resulted in a list of 77 terrestrial arthropod species alien to Europe and invasive in many countries.

The scoring of these 77 arthropod species was carried out using published information from the scientific literature. The literature search was conducted using the ISI Web of Knowledge. As a search string, the scientific species names combined with the following terms of the descriptions of the impact categories were used: herbivory, predation, parasitism, competition, transmission of disease, hybridization, ecosystem, agriculture, livestock, aquaculture, forestry, host, pesticide and human health. Additionally, information on the biology of a species was obtained using the following terms along with the scientific species names: biodiversity, economic impact, yield loss, crop pest, Europe, allergens, economic importance and economic loss.

From these publications (Suppl. material 2), the information relevant to species impact was translated to the particular impact level of the scoring system, ranging from 0 to 5 (Suppl. material 1). For completeness, we also cross-checked the information obtained from the literature search with general overview articles available in databases on alien and invasive species. These included the Invasive Species Compendium (CABI 2012), the Global Invasive Species Database (GISD 2012), the European Network on Invasive Alien Species (NOBANIS 2012), the European and Mediterranean Plant Protection Organization (EPPO 2012) and DAISIE (2012).

It was necessary to modify the definitions used in the vertebrate version of the "Handbook of the generic impact scoring system" to adapt this method to arthropods (Suppl. material 1). In general, this led to broader impact definitions or descriptions per impact category. These modified descriptions made it possible to assign all published impact reports to an appropriate impact category and impact level. Since we consider the repeatability of the results of this scoring process to be very important, the second author tested this by independently scoring a number of randomly chosen species. The test showed a very good match of the final scores, which differed by no more than one or two impact points per species.

## Results

The 77 invasive alien arthropod species we selected belong to 13 orders and 38 families of insects, myriapods and mites (Table 2). Hemiptera and Coleoptera comprise most species (64%) whereas many orders are represented by only one or a few species, such as Acari, Blattodea and Chilopoda (Figure 1a). These 77 species have a combined total impact of 449.5 impact points, which is distributed among the higher taxa more or less according to the number of species. Only Hemiptera and Hymenoptera seem to produce an overall lower impact (42% of species have 28% of impact points), whereas Acari (4% of species, *Varroa destructor*, *Panonychus citri* and *Brevipalpus obovatus*) have 11% of total impact (Figure 1b).

Overall, 183.5 impact points (41%) originated from environmental impacts and 266 impact points (59%) originated from economic impacts. Among environmental categories, invasive alien arthropods had the largest impact on the ecosystem (20% of total impact), followed by impact through herbivory (10%). Impact through hybridization was not reported. From an economic point of view, the main impacts of invasive alien arthropods were on agriculture (29%) and on human infrastructure and administration (18%). Only *Varroa destructor* showed an impact on animal production resulting in 1% of the total impact (Figure 2).

The five most harmful invasive alien species are the mite *Varroa destructor*, the Argentine ant *Linepithema humile*, the Chinese longhorn beetles *Anoplophora glabripennis* and *A. chinensis*, and the harlequin ladybird *Harmonia axyridis*. In the categories of environmental impact *Varroa destructor*, *Linepithema humile* and *Harmonia axyridis* are the most harmful species, whereas in the categories of economic impact, the highest scoring species are *Varroa destructor*, the citrus red mite *Panonychus citri* and both *Anoplophora* species (Table 2).

Using the impact data for mammals and birds from the studies by Nentwig et al. (2010) and Kumschick and Nentwig (2010), it is possible to compare the impacts of these three taxa. Figure 3 illustrates the mean environmental and economic impacts of the 20 highest scoring mammals, birds and arthropods. It shows that the impact increases from birds, with the lowest (average environmental impact 4.4; economic impact 2.4) to arthropods with a medium impact (environmental impact 6.4; eco-

**Table 2.** Environmental, economic and total impact scores of all selected 77 invasive alien arthropod species. Impact categories 1.1 to 1.6 refer to environmental impact (1.1 on plants or vegetation through herbivory, 1.2 on animals through predation or parasitism, 1.3 on other species through competition, 1.4 through transmission of disease or parasites to native species, 1.5 through hybridization, 1.6 on ecosystems) and impact categories 2.1 to 2.6 refer to economic impact categories (2.1 on agricultural production, 2.2 on animal production, 2.3 on forestry, 2.4 on human infrastructure and administration, 2.5 on human health, and 2.6 on human social life).

| | | | Impact categories | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class / Order** | **Family** | **Species** | **1.1** | **1.2** | **1.3** | **1.4** | **1.5** | **1.6** | **2.1** | **2.2** | **2.3** | **2.4** | **2.5** | **2.6** | **Total** |
| Acari | Trombidiiformes | *Brevipalpus obovatus* | 1.5 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | **6.5** |
| | | *Panonychus citri* | 0.5 | 0 | 0 | 0 | 0 | 3 | 5 | 0 | 0 | 3 | 2.5 | 0 | **14** |
| | Varroidae | *Varroa destructor* | 0 | 5 | 0 | 5 | 0 | 5 | 5 | 5 | 0 | 3.5 | 1 | 1 | **30.5** |
| Chilopoda | Henicopidae | *Lamyctes emarginatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Diplopoda | Paradoxosomatidae | *Oxidus gracilis* | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | **4** |
| Blattodea | Blattidae | *Periplaneta americana* | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 3 | 0 | **5.5** |
| Coleoptera | Anobiidae | *Ptinus tectus* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | **6** |
| | Anthicidae | *Omonadus floralis* | 0 | 0 | 0 | 0 | 0 | 0 | 1.5 | 0 | 0 | 0 | 0 | 0 | **1.5** |
| | | *Stricticomus tobias* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Bostrichidae | *Rhyzopertha dominica* | 0 | 0 | 0 | 0 | 0 | 2 | 3.5 | 0 | 1 | 3 | 0 | 0 | **9.5** |
| | Carabidae | *Trechicus nigriceps* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Cerambycidae | *Anoplophora chinensis* | 3.5 | 0 | 0 | 0 | 0 | 4 | 3.5 | 0 | 4 | 3 | 0 | 3 | **21** |
| | | *Anoplophora glabripennis* | 3 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 3 | 0 | 3 | **17** |
| | Chrysomelidae | *Acanthoscelides obtectus* | 2 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 2 | 0 | 0 | **10** |
| | | *Bruchus pisorum* | 1 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 2 | 0 | 0 | **10** |
| | | *Bruchus rufimanus* | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **2** |
| | | *Callosobruchus chinensis* | 1 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 2.5 | 1 | 0 | **11.5** |
| | | *Diabrotica virgifera* | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 3 | 0 | 0 | **10** |
| | | *Leptinotarsa decemlineata* | 1 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 3.5 | 0 | 0 | **10.5** |
| | Coccinellidae | *Harmonia axyridis* | 0 | 4 | 2 | 0 | 0 | 3 | 2 | 0 | 0 | 2.5 | 2 | 1 | **16.5** |
| | Cryptophagidae | *Caenoscelis subdeplanata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Dryophthoridae | *Sitophilus oryzae* | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 3 | 0 | 0 | **10** |
| | Latridiidae | *Cartodere nodifer* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Nitidulidae | *Carpophilus marginellus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |

| Class / Order | Family | Species | Impact categories 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Carpophilus bifenestratus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | | *Carpophilus nepos* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | | *Glischrochilus quadrisignatus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Urophorus humeralis* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | Staphylinidae | *Philonthus rectangulus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Diptera | Agromyzidae | *Liriomyza huidobrensis* | 2 | 0 | 0 | 0 | 0 | 3 | 2.5 | 0 | 0 | 2 | 0 | 0 | **9.5** |
| | Cecidomyiidae | *Obolodiplosis robiniae* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | **3** |
| | Culicidae | *Aedes albopictus* | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 3 | 3 | **12** |
| | Phoridae | *Megaselia gregaria* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Tephritidae | *Ceratitis capitata* | 0 | 0 | 0 | 1 | 0 | 3 | 3 | 0 | 0 | 2 | 2 | 0 | **11** |
| Hemiptera | Aleyrodidae | *Bemisia tabaci* | 2 | 0 | 0 | 3 | 0 | 3 | 4 | 0 | 0 | 3 | 0 | 0 | **15** |
| | Aphididae | *Acyrthosiphon caraganae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | | *Aphis gossypii* | 2 | 0 | 0 | 3 | 0 | 3 | 3 | 0 | 0 | 3 | 0 | 0 | **14** |
| | | *Aphis spiraephaga* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Chaetosiphon fragaefolii* | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **4** |
| | | *Chromaphis juglandicola* | 1 | 0 | 0 | 0 | 0 | 0 | 2 | | 0 | 0 | 0 | 0 | **3** |
| | | *Eriosoma lanigerum* | 1 | 0 | 0 | 0 | 0 | 3 | 3.5 | 0 | 0 | 2 | 0 | 0 | **9.5** |
| | | *Macrosiphoniella sanborni* | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **2** |
| | | *Macrosiphum euphorbiae* | 1 | 0 | 0 | 3 | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | **11** |
| | | *Myzus ornatus* | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **2** |
| | | *Myzus varians* | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **2** |
| | | *Myzus ascalonicus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Neomyzus circumflexus* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | **2** |
| | | *Panaphis juglandis* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Rhodobium porosum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Rhopalosiphum maidis* | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **3** |
| | | *Rhopalosiphum insertum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Uroleucon erigeronense* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Coccidae | *Coccus hesperidum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Pulvinaria hydrangeae* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | **2** |

| Class / Order | Family | Species | Impact categories 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Saissetia oleae* | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | **7** |
| | Diaspididae | *Aspidiotus nerii* | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | **3** |
| | | *Diaspidiotus perniciosus* | 1 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 3 | 0 | 0 | **11** |
| | Membracidae | *Stictocephala bisonia* | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **2** |
| | Pseudococcidae | *Pseudococcus viburni* | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | **6** |
| Hymenoptera | Aphelinidae | *Aphytis mytilaspidis* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | | *Encarsia formosa* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | Encyrtidae | *Copidosoma floridanum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | | *Leptomastix dactylopii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Formicidae | *Hypoponera punctatissima* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| | | *Linepithema humile* | 2 | 2 | 4 | 0 | 0 | 4 | 2 | 0 | 0 | 3 | 0 | 0 | **17** |
| | | *Monomorium pharaonis* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 2 | **6** |
| | Torymidae | *Megastigmus spermotrophus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | **2** |
| Lepidoptera | Arctiidae | *Hyphantria cunea* | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 0 | 1 | **8** |
| | Gelechiidae | *Sitotroga cerealella* | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | **7** |
| | | *Tuta absoluta* | 2 | 0 | 0 | 0 | 0 | 3 | 5 | 0 | 0 | 3.5 | 0 | 0 | **13.5** |
| | Noctuidae | *Spodoptera littoralis* | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 2.5 | 0 | 0 | **8.5** |
| | Tineidae | *Tinea translucens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Tortricidae | *Grapholita molesta* | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 2 | 1 | 0 | **11** |
| Siphonaptera | Ceratophyllidae | *Nosopsyllus fasciatus* | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **4** |
| Thysanoptera | Thripidae | *Frankliniella occidentalis* | 2 | 0 | 0 | 3 | 0 | 3 | 4 | 0 | 0 | 3 | 1 | 0 | **16** |
| | | *Heliothrips haemorrhoidalis* | 2 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 1 | 2 | 0 | 0 | **10** |
| | | *Parthenothrips dracaenae* | 2 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 0 | **4.5** |
| | | **Total** | 43.5 | 13 | 6 | 30 | 0 | 91 | 132.5 | 5 | 14 | 79 | 20.5 | 15 | **449.5** |

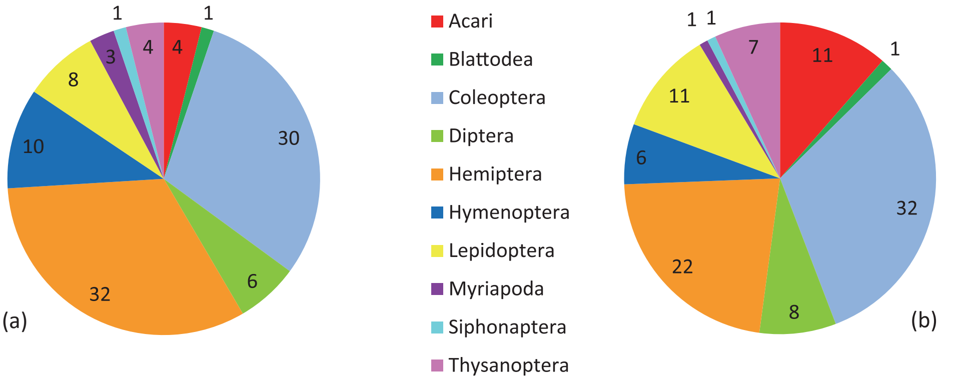


**Figure 1.** (**a**) Percentage of species representing a particular higher taxon of terrestrial invasive alien arthropods and (**b**) percentage of the impact points of these taxa of the total impact points produced by terrestrial arthropods (77 species). This comparison indicates that the impact of some taxa is higher than estimated from their frequency.

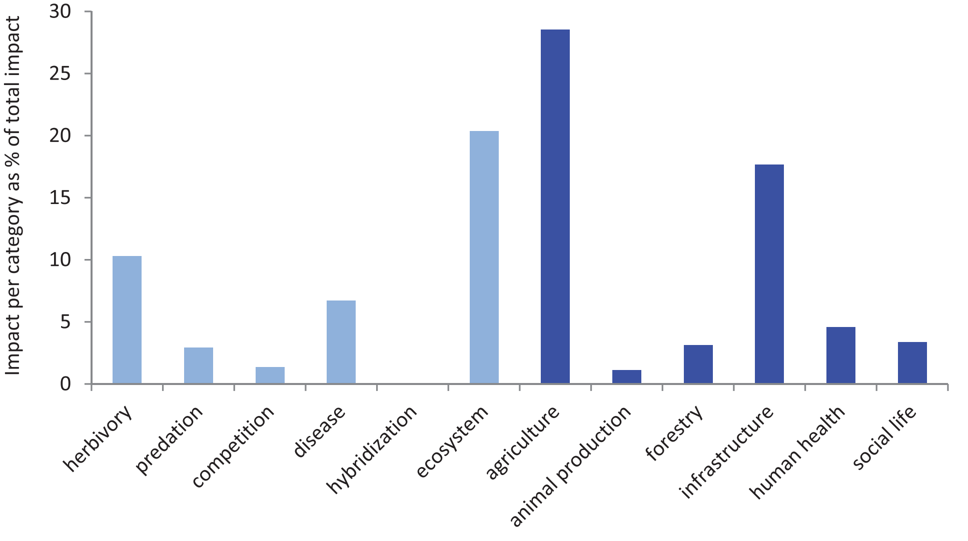


**Figure 2.** Distribution of the impacts (%) of 77 species of invasive alien arthropods among six impact categories each in the field of environmental (light blue) and economic impact (dark blue).

nomic impact 7.9) to mammals with the highest overall impact (environmental impact 11.4; economic impact 10.7). For the environmental categories, arthropods reach the highest scores by influencing ecosystems (mean 3.2), while mammals score highest due to their impact on herbivory and the transmission of diseases (means of 3). The highest impact of birds is through hybridization with native species (mean 2.2) (Figure 4). Among all categories of economic impact, arthropods score the highest for their impact on agriculture (mean of 3.2) and human infrastructure and administration (mean

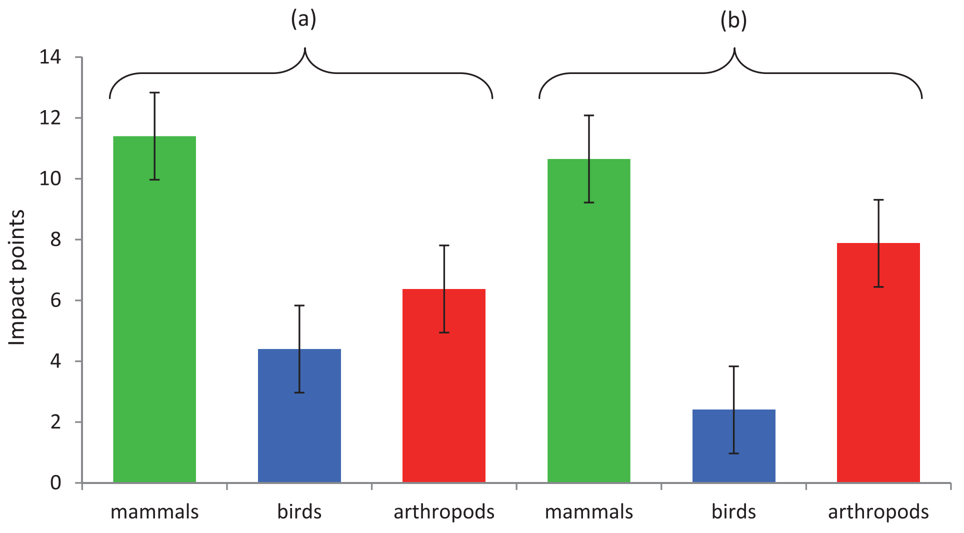


**Figure 3.** The mean impact and standard deviation of the 20 highest scoring species of mammals, birds and arthropods for environmental impact (**a**) and economic impact (**b**). Bird and mammal data from Kumschick and Nentwig (2010).

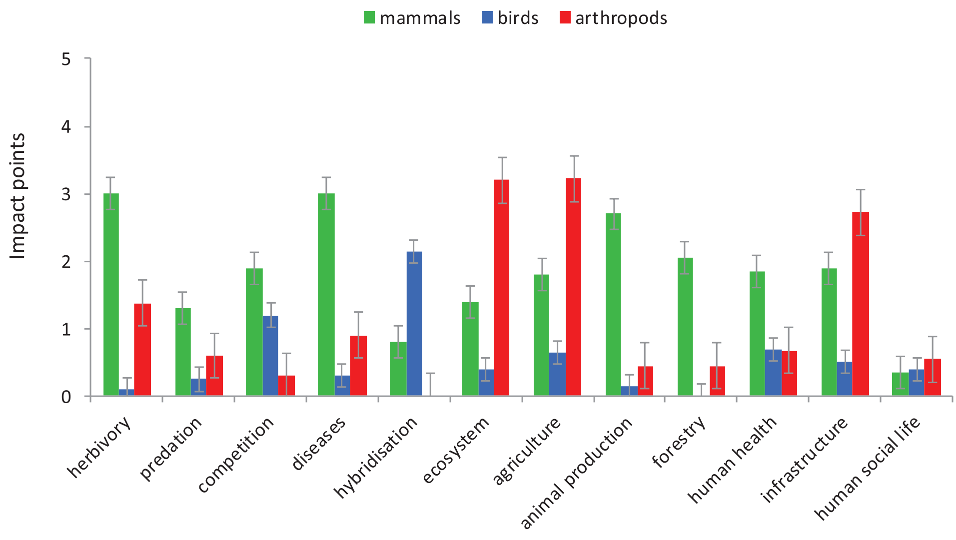


**Figure 4.** The mean impact and standard deviation of the 20 highest scoring species of mammals, birds and arthropods for the different categories of environmental and economic impact. Bird and mammal data from Kumschick and Nentwig (2010).

of 2.7), and mammals reach similarly high values of 2.7 by their impact on animal production. The scores of birds were also very low in these categories (means of 0–0.7) (Figure 4).

## Discussion

In this study, we modified the generic impact scoring system developed by Nentwig et al. (2010) for vertebrates, in such a way that it can also be applied to arthropods. By adapting the definitions of the twelve categories of environmental and economic impact to apply to arthropods, we were able to express the impact of the most invasive alien arthropod species in a comparative manner as impact points. In order to end up with robust results guaranteeing reproducibility and broad acceptability, only published information from scientific journals was used. By summing up the corresponding scoring points of each category, a ranked list of the analysed arthropod species was created, ranging from highest to lowest impacts. These values reflect the current state of knowledge and can therefore be easily adapted over time as new knowledge becomes available. If no information is available (neither from other invaded areas nor from its native area), the generic impact scoring system cannot be applied, but this would also be the case with any other assessment approach. The great advantage of the system presented here is its broad applicability and the possibility to compare vertebrates and arthropods. This prioritisation list can serve as a background for decision makers and can facilitate the creation of policies and decision processes. With further enhancement of this system, it should even be possible to translate the environmental and economic impacts of every invasive alien species into general scoring points, regardless of the taxonomic group.

### Environmental and economic impact categories

The comparison of the overall impact of invasive alien arthropods on the environment and economy shows a large impact on the economic categories, mainly agriculture and human infrastructure and administration. Since the 1960s, the importance and value of merchandise trade has accelerated enormously, but this has also lead to an increase in the introduction of alien species (Hulme 2009). The degree of trade is a significant indicator of the number of alien species present and the rate of new introductions into a region (Levine and D'Antonio 2003; Westphal et al. 2007; Roques et al. 2010). Most invasive alien arthropods have been introduced as contaminants or as stowaways (Hulme et al. 2008) and many of them benefit from cultivation and husbandry, or escape from their natural enemies (Mack et al. 2000). As a consequence, invasive alien arthropods have a major impact on agriculture (Roques et al. 2010), which results in economic losses and requires the application of pesticides to reduce these losses. Since pesticides have to be developed, produced and regulated, this explains why agricultural pests also have a strong impact in the category "human infrastructure and administration". The use of (nonspecific) pesticides also leads to the loss of many non-target organisms, some of which play important roles in ecosystem functions. Therefore, the impact of alien agricultural pests usually also causes an impact on ecosystem level.

During this study it became obvious that our overall knowledge of the impact of invasive alien arthropods on the environment is insufficiently documented in the scientific literature (compare also Kenis et al. 2009). Therefore, we assume that the current impact in environmental categories is probably underestimated. Information about predation on or parasitism of native species was available in the literature for *Varroa destructor*, *Linepithema humile* and *Harmonia axyridis*. However, for ten of the other eleven predacious or parasitic species, no information could be found, indicating that more research is needed in this field. The same is true for impact through hybridization: in all species analysed here, we had to state "no impact known", but we believe that this is mainly a knowledge gap. Allopatric speciation is common in arthropods and when human-assisted dispersal overcomes the natural separation of species, this can lead to hybridization (Sanchez-Guillen et al. 2013). Previous analyses showed that alien mammals have some impact on native mammals through hybridization (Nentwig et al. 2010) and alien birds exert an even higher impact (Kumschick and Nentwig 2010). Schierenbeck and Ellstrand (2009) found that hybridization in plants can be an evolutionary stimulus for invasiveness and that hybridization could be an explanation for the time lag between the first introduction of a species and the beginning of an invasion. Hybridization with native species and/or multiple introductions of an alien species produces a genetic advantage in favour of the invasive species, finally leading to the exclusion of native species (Rhymer and Simberloff 1996; Vilà et al. 2000; Largiadèr 2007). This is supported by the findings of Colautti et al. (2006) that propagule pressure is a significant predictor of invasiveness. Even if alien arthropods may encounter fewer closely related species in invaded areas than alien vertebrates, the genetic impact of invasive alien arthropods is largely unexplored. Following studies on hybridization of native and introduced bees and bumblebees (Labrador et al. 1999; Jensen et al. 2005), we may assume that in the near future there will be more examples demonstrating the impact of hybridization of alien arthropods with native species.

## Mammals, birds and arthropods

The comparison between these three different taxonomic groups showed mammals to have the highest overall impact on the environment and economy (Figure 3). The impact scores of alien arthropods, however, may be underestimated due to a bias towards arthropod species with relevance for the economy and human health (Kenis et al. 2009). This resulted in a knowledge gap regarding the other impact categories of alien arthropods. Arthropods reach the highest impact in three connected categories (agriculture, ecosystem and human infrastructure and administration, Figure 4), with mean scores higher than 3, which is not reached by mammals in any category. Our list of the top 20 arthropods may change towards a higher impact score once some of the important pest species recently imported into Europe and currently rapidly spreading (e.g., *Vespa velutina* and *Drosophila suzukii*) are included.

## Necessity and opportunities of the generic impact scoring system

Creating a prioritization list for the three taxonomic groups analysed so far (mammals, Nentwig et al. 2010; birds, Kumschick and Nentwig 2010; arthropods, this study), the Canada goose *Branta canadensis* scores the highest, followed by the muskrat *Ondatra zibethicus*, the sika deer *Cervus nippon* and the Varroa mite *Varroa destructor.* All these species score higher than 30 points, indicating a very serious impact on the environment and economy in Europe. The fact that the four highest scoring species belong to different taxonomic groups (one bird, two mammals and one arthropod) demonstrates the need for a prioritization tool that allows the impacts of different taxonomic groups to be compared. Decision making processes about the management of invasive alien species are usually not restricted to taxonomic borders and therefore need to include all groups that occur in a given area. We are convinced that a generalized approach in combination with our simple "currency" of impact points as a general unit for environmental and economic impacts is a broadly applicable method for prioritizing alien species.

The generic impact scoring system is characterized by relying on already available and published scientific information (not expert opinion). The impact point system implies that all impact categories are (at least initially) of equal importance. Definitions of impact categories and impact intensities as provided in the Handbook (Supplementary material) make the results reproducible and transparent. In a second approach, the results can be weighted, restricted to given areas, or modified according to expert opinion. This is the major difference compared to other prioritization systems, such as those of Smallwood and Salmon (1992) and Bomford (2003). These systems weight the categories differently and place more weight on agricultural impacts. Kumschick et al. (2012) proposed a system to prioritize invasive alien species that largely depends on expert opinions and management opinions, while also allowing selected categories to be weighted.

Another important point in the engagement against invasive alien species is the coordination of measures undertaken by different European countries (Hulme et al. 2009). The impact scoring system is basically scale-independent, which means that it can be conducted for a country in which a given species is not yet present but has the potential to invade. This allows early reactions and in combination with knowledge about the pathways of introduction, the invasion of such a species can be prevented (Hulme 2006). Prevention measures are much less costly than combatting an invasive alien species once it has established (Hulme 2009). Up to now, successful eradications were mostly restricted to alien vertebrates on islands. In Europe, only a small number of successful eradications have taken place and no invertebrates were included (Genovesi 2005; 2007). A cautionary example is the initial lack of pathway analyses and coordinated measures against *Varroa destructor*. The situation might have developed differently with today's prioritization information available at that time.

A current example concerns the repeated introductions of the Chinese longhorn beetle *Anoplophora glabripennis* to Europe (Carter et al. 2009). It has a total of 21 impact points and exerts a very high impact on forestry and forest ecosystems. In many European countries, the general public is informed by newspaper articles in the daily press reporting on the enormous impact of these beetles and the cost of local eradication campaigns. Mentioning the relatively high impact score of the species and drawing attention to a comparison with other high-impact invasive alien species could help to justify such means and to increase the acceptance of eradication activities in the public opinion.

## Conclusion

A sound knowledge is needed for policy and decision makers to control invasive alien species. The introduction of species known to have a high impact should be avoided or, if already introduced they should be eradicated as soon as possible. The core challenge is the limited possibility to know about the invasiveness of a given species in advance. The generic impact scoring system can help to translate scientific knowledge regarding environmental and economic impacts into easily comparable impact scoring points, leading to a prioritization list across different taxonomic groups. In this study, the generic impact scoring system was applied to terrestrial arthropods in order to enhance and broaden the applications of the system, which was developed for vertebrate groups. Further applications to other taxonomic groups will result in an enhancement of the generic impact scoring system approach and a broader usage of science-based tools in invasion management.

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## Supplementary material 1

**Handbook of the scoring system for the impacts of alien species**

Authors: Sibylle Vaes-Petignat, Wolfgang Nentwig

Data type: other



Link: doi: 10.3897/neobiota.22.6620.app1

## Supplementary material 2

**Literature used to score 77 terrestrial arthropod species**

Authors: Sibylle Vaes-Petignat, Wolfgang Nentwig

Data type: other



Link: doi: 10.3897/neobiota.22.6620.app2