Comparing environmental impacts of alien plants, insects and pathogens in protected riparian forests

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Abstract

The prioritization of alien species according to the magnitude of their environmental impacts has become increasingly important for the management of invasive alien species. In this study, we applied the Environmental Impact Classification of Alien Taxa (EICAT) to classify alien taxa from three different taxonomic groups to facilitate the prioritisation of management actions for the threatened riparian forests of the Mura-Drava-Danube Biosphere Reserve, South East Europe. With local experts we collated a list of 198 alien species (115 plants, 45 insects, and 38 fungi) with populations reported in southeast European forest ecosystems and included them in the EICAT. We found impact reports for 114 species. Eleven of these species caused local extinctions of a native species, 35 led to a population decrease, 51 to a reduction in performance in at least one native species and for 17 alien species no effects on individual fitness of native
species were detected. Fungi had significantly highest impact and were more likely to have information on their impacts reported. Competition and parasitism were the most important impact mechanisms of alien species. This study is, to our knowledge, the first application of EICAT to all known alien species of several taxonomic groups in a protected area. The impact rankings enabled to identify taxa that generally cause high impacts and to prioritize species for the management in protected areas according to their impact magnitudes. By following a standardized impact protocol, we identified several alien species causing high impacts that do not appear on any expert-based risk list, which are relevant for policymakers. Thus, we recommend that alien species be systematically screened to identify knowledge gaps and prioritize their management with respect to spatio-temporal trends in impact magnitudes.

Keywords
Alien species, biological invasions, EICAT, invasive species management, protected areas, species prioritization

Introduction

Invasive alien species are a major threat to European forest ecosystems (CBD 2001; FAO 2009; Europe and Unece 2015). Globally, they have become the second most common extinction threat to endangered species due to the increasing human-mediated transportation of species far beyond their native range (Bellard et al. 2016). Previous studies on individual or multiple alien species have revealed severe impacts of alien species on ecosystem functions, ecosystem services, and biodiversity in forest ecosystems (Seidl et al. 2018); these impacts are linked to a multitude of impact mechanisms: parasitism, competition with native species, physical changes to the environment, and pathogen transfer (Kenis and Branco 2010; Pyšek et al. 2012; Ricciardi et al. 2013; Langmaier and Lapin 2020).

As a result of the rapidly increasing impact of biological invasions, the control of invasive alien species – i.e. any species or lower taxon of animals, plants, fungi, and other microorganisms whose occurrence in a region outside its natural range that has negative impacts on an ecosystem and its services (CBD 2002) – has been implemented in international, national, and regional policies and legislations such as the EU Biodiversity Strategy or EU Regulation No. 1143/2014 on invasive alien species. Their aim is to mitigate the ecological and socioeconomic effects of alien species. The few cross-taxon assessments performed have shown that terrestrial invertebrates, and terrestrial plants in particular, are associated with ecological and economic impacts in Europe (Vilà et al. 2010; Kumschick et al. 2015).

Riparian forests are highly vulnerable to biological invasion (Marinšek and Kutnar 2017; Medvecká et al. 2018). Their high nutrient levels and frequent natural and man-made disturbances facilitate invasions, and the rivers themselves serve as effective corridors for the spread of alien species (Kowarik 1992; Pyšek and Prach 1993; Schmiedel et al. 2013; Lapin et al. 2019). Management of alien species in riparian areas is therefore essential for preserving and restoring the biodiversity and ecosystem services of these endangered ecosystems (Rivers et al. 2019). However, the resources
for conservation management in protected riparian forests are limited and require effective prioritization. A cross-taxon impact assessment, of the alien species present or likely to be present in the near future, because the species have been observed in neighboring areas, in a protected area could be useful for the prioritization of management actions and to facilitate the evaluation of management methods (Roy et al. 2019; IUCN 2020b).

Besides horizon scanning frameworks (Roy et al. 2019) and risk assessment protocols, scoring systems for impact assessments have thus gained considerable importance not only for policy makers or the scientific community, but also for conservation managers of protected areas. Several tools have been developed to quantify, compare, and prioritize the impact of alien species (Vilà et al. 2019). The generic impact scoring system (GISS), for example, focuses on the environmental and socio-economic impacts of alien species (Nentwig, et al. 2016). Here, we follow the scoring system of the Environmental Impact Classification of Alien Taxa (EICAT), which classifies alien taxa in terms of the magnitude of their highest observed environmental impacts in recipient areas, based on the level of organisation impacted of a native species and its reversibility (Blackburn et al. 2014; Hawkins et al. 2015). Recently, the International Union for Conservation of Nature adopted EICAT as a global standard similar to the IUCN Red List for extinction threat (IUCN 2020d).

In the past few years, EICAT has been widely applied and discussed (Kumschick et al. 2017; Kumschick et al. 2020). However, most impact assessments have primarily focused on EICAT classification within single taxonomic groups, such as global impact assessments of birds (Evans et al. 2016), ungulates (Volery et al. 2021), bamboos (Canavan et al. 2019), or amphibians (Kumschick et al. 2017), while only few studies have performed cross-taxon assessments. Even fewer studies have undertaken cross-taxon assessments for a specific habitat or a geographic region (Shivambu et al. 2020). This study investigates the cross-taxon impacts of alien species in order to facilitate the prioritization of management actions for the endangered riparian forests of the transboundary UNESCO Mura-Drava-Danube Biosphere Reserve in Southeast Europe. The riparian forest of the Biosphere Reserve was selected as a representative protected area for the European challenge to combat the spread of invasive alien species.

The objectives of the study are (1) to provide a cross-taxon impact assessment of alien taxa, in the Mura-Drava-Danube Biosphere Reserve, in terms of the magnitude of their highest observed environmental impacts in riparian temperate forests in Europe, (2) to determine differences in the impact severity and impact mechanisms of fungi, insects, and plants, with consideration for the time period since their introduction (residence time), (3) to identify knowledge gaps and the availability of data on alien taxa for application of the cross-taxon impact assessment. With our work we wish to support the prioritization of taxa for control and management within this vulnerable riparian ecosystem. Additionally, we quantify environmental impacts on forest ecosystems, thereby supporting forest management decisions.
Methods

Area description

The Mura-Drava-Danube Biosphere Reserve covers an area of nearly 850,000 ha in the countries of Austria, Slovenia, Hungary, Croatia and Serbia. The entire core zone of this important ecological corridor – a belt of riparian forests along the three rivers – has been designated as part of the Natura 2000 framework and contains protected areas of various categories. New parts of the Biosphere Reserve were recently nominated and now it is the largest protected river area in Europe and the only UNESCO Biosphere Reserve spanning across five countries. A share of 27% of the Biosphere Reserve is covered by forest. This portion increases to 61% within the core zone. Between the countries, there are remarkable differences regarding the ownership structure and forest management practices. The annual mean temperature ranges from 9.3 °C in the north-western part of the study area to 11.7 °C in the area between Đurđevac (Croatia) and Barcs (Hungary). The whole Biosphere Reserve shows strong variation of annual precipitation ranging from sites with nearly 1000 mm in the West to almost 500 mm in the North-Eastern Hungarian part of the Biosphere Reserve. The Biosphere Reserve is characterized by highly fertile plains along the rivers with an intense agricultural use for cereal, maize and pasture cropping on the one hand, and forestry on the other. The rivers are embedded in eutric Fluvisols (33%), surrounded by Luvisols (14%) and Cambisols (5%). Phaeozems (35%) are the dominant soil type.

Data collection

A list of 390 alien species (165 fungal species – including species of pseudo-fungi, 48 insect species, and 177 plant species) with reported populations in Southeast European forest ecosystems was extracted from the Global Invasive Species Compendium database using the invasive species Horizon Scanning Tool (beta) (incorporating data up to March 2019, (CABI 2018). Additional information on alien species from the observations of Austrian, Slovenian, Croatian, Serbian, and Hungarian national experts and the alien species alert and observation list from the “Life Artemis project” (DeGroot et al. 2017; Marinšek and Kutnar 2017) was included. In total, 188 alien species were excluded by the expert panel of assessors before the beginning of the assessment process because these species do not generally occur in riparian forest ecosystems and exhibit a very low potential occurrence in the riparian forests of the Biosphere Reserve. Ultimately, 198 species (115 plants, 45 insects, and 38 fungi) were included in the list of alien species (Appendices 1, 2).

The 198 species were distributed among the assessors. All assessors and reviewers were invited to a workshop in September 2019 during which the EICAT assessment protocol was demonstrated and practiced. The assessors had different backgrounds and years of expertise, e.g. geneticists, biodiversity conservationists, forest science and also junior staff/technicians. The applied assessment protocol followed the Guidelines for
using the IUCN Environmental Impact Classification for Alien Taxa (EICAT) Categories and Criteria (IUCN 2020b, c; Volery et al. 2020). The assessors undertook a review of published literature and local reports to identify the environmental impact of the selected 198 alien species in forests. The databases Google Scholar and Scopus were used along with Google web searches to collate publications. We adapted the EICAT protocol search string in order to focus only on impacts observed in forest ecosystems using the following search terms: “forest” AND “Europe” AND (“introduced species” OR “invasive species” OR “invasive alien species” OR “IAS” OR “alien” OR “non-native” OR “non-indigenous” OR “invasive” OR “pest” OR “feral” OR “exotic”). Publications describing an environmental impact in a different ecosystem type or other climatic regions than temperate climate were not included. Each record was assessed separately. The impacts identified in the literature were classified according to their magnitude following five categories: minimal concern (MC), minor (MN), moderate (MO), major (MR) or massive (MV). Following the EICAT protocol, each alien taxon was assigned an EICAT category based on its highest observed impact across all recorded impacts. The impact mechanisms for each alien species were also identified from the assessed publications and categorized into one of 12 impact mechanism categories as defined in the EICAT guidelines (IUCN 2020b, c; Volery et al. 2020). Insect herbivory was included in the impact mechanism ‘Parasitism’, because these insects are not killing but parasitizing on the trees. All assessments were independently cross-validated for consistency by an assigned independent reviewer in three review loops. The final scores were agreed upon by consensus among all authors, which was reached in constructive discussions in several online-meetings.

Data analysis

Microsoft Excel 2010 was used for the data management, and R version 3.4.2 (R Core Team 2017), with the libraries “ordinal” (Christensen 2019), “stats” (R Core Team 2017) and “ggplot2” (Villanuev et al. 2016) for data analysis together with Python version 3.7 (Van Rossum and Drake 2009). For analysis of the respective alien species’ native region, we categorized the area of geographic origin by continents (Africa, Asia, Australia, Europe, North (including Central) America, and South America). The time of the first record in the wild in Europe was included to analyze the influence of residence time on a species’ impact. This information was obtained by reviewing scientific literature on the first records of each species.

We calculated the concurrence (Con) to analyze whether obtained EICAT impact categories vary among impact reports as well as the variance in impact magnitudes (Var) of the impact reports of each alien taxon regarding their impact categories across the impact mechanisms and taxonomic groups. For the analysis of both, the concurrence and variance, only alien species with two or more assessed impact reports were included. In total, 59 species with multiple impact reports per alien species were analyzed regarding their dissimilarity in the consensus on the impact category. For the concurrence we used the percentage of references within the most frequent category
In total, 303 references with information on 114 alien species were used, with an average of 2.7 ± 0.14 (mean ± SE) references per species. The average number of references for plants was 2.8 ± 0.06 and thus lower than the average of 3.2 ± 0.06 for insects but
higher than the average number of species references for fungi which was 1.89 ± 0.05. It is important to note that for most species only one single reference was available, as the mode for all individual taxonomic groups was equal to 1. The references used extended across a time span of 39 years, with the oldest one published in 1981 and the most recent one in 2020. The results show that, in total, 11 alien species (Plants: n = 6, Fungi: n = 5) were assessed as having caused on at least one occasion a Major impact, which led to the naturally reversible local extinction of a native taxon (i.e. change in community structure). A Major impact was the most harmful impact category of the 114 alien species assessed (Table 1); No alien species were assigned to the highest and most harmful impact category Massive (naturally irreversible local or global extinction of a native taxon). 35 alien species were assigned to the impact categories Moderate and caused population decline, 51 to Minor and caused reduction in individual performance and 17 to Minimal Concern and had no or negligible impact on other native species, across the taxonomic groups – plants, insects, and fungi, as shown in Figure 1. The full list of EICAT assessment results is provided in the Appendix 1: Table A1.

Most of the assessed alien species originate from North America (56.1%), followed by Asia (36.0%), Australia (1.3%), South America (0.69%), Africa (0.6%), and 3.0% were native in Europe, but non-native to the study area. The distribution of impact categories differed between taxonomic groups as well as in terms of years elapsed since the first introduction to Europe, i.e. residence time (Figure 1). Residence time was only different between taxonomic groups (LR Chisq = 95.52, df = 2, P < 0.001). Plants exhibited the longest residence time (years since the first recorded introduction to Europe), while fungi and insects were recorded to arrive in Europe more recently (Figure 2).

We classified nine different impact mechanisms for 114 alien species, through which environmental impacts were caused (Table 2). Overall, the most frequent impact mechanisms were Parasitism (49 alien species, or 43.0%), Competition (29 alien species, or 25.4%), and Structural impact on ecosystems (8 alien species, or 7.0%).

**Table 1.** Results of the EICAT assessments indicating species that have caused on at least one occasion a local extinction of a native species and thus are listed in the most harmful impact category assessed in this study: MR (Major) (IUCN 2020b).

| Taxonomic group | Species | Impact mechanism | Origin | Years of introduction to Europe |
|-----------------|---------|------------------|--------|---------------------------------|
| Fungi           | Biscogniauxia mediterranea | (5) Parasitism | North America | 1931 |
|                 | Botryosphaeria dothidea | (5) Parasitism | Europe | – |
|                 | Cryphonectria parasitica | (5) Parasitism | Asia | 1938 |
|                 | Hymenoscyphus fraxineus | (1) Competition | Asia | 1990 |
|                 | Ophiostoma novo-ulmi | (5) Parasitism | Asia | 1990 |
| Plants          | Anorpha fruticosa | (1) Competition | North America | 1724 |
|                 | Heracleum persicum | (1) Competition | Asia | 1817 |
|                 | Humulus japonicus | (1) Competition | Asia | 1880 |
|                 | Impatiens glandulifera | (1) Competition | Asia | 1839 |
|                 | Reynoutria japonica | (9) Chemical impact on ecosystem | Asia | 1851 |
|                 | Reynoutria sachalinensis | (1) Competition | Asia | 1860 |
Figure 1. Relative frequency of EICAT impact categories (total species = 114) across the taxonomic groups of insects (n = 25), plants (n = 55) and fungi (n = 34).

Figure 2. Box plots of the residence time in Europe (years since first report) for species in different taxonomic groups and impact categories: Major (MR), Moderate (MO), Minor (MN), and Minimal Concern (MC).
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This order varied among the different taxonomic groups: For fungi the most frequent impact mechanism was found to be Parasitism (87%) followed by Competition (11%) and, lastly, Hybridisation (1%). For insects, Parasitism occurs most frequently (90%), followed by Structural impact on the ecosystem (6%) and Predation (2%). Whereas for plants Competition (50%) occurred more frequently followed by Parasitism (22%) and Structural impact on the ecosystem (9%).

The impact category with the most references found was Moderate (MO) for plants, and Minor (MN) for fungi and insects (Figure 3). Furthermore, we identified differences in the variability of impact magnitudes (concurrence) across taxonomic groups (Appendix 2: Table A2): Assessments of alien species from the taxonomic group insects varied the most (highest concurrence 87.5%, SD = 0.1), followed by fungi (concurrence = 82.2%, SD = 2.9), and plants (concurrence = 65.9%, SD = 15.2). The consensus concurrence on impact categories across impact mechanisms was the lowest for Competition (concurrence = 66.6%, SD = 4.3) and the highest for Transmission of diseases (concurrence = 100%, SD = 0.0) (Table 2).

The best model explaining the impacts of the invasive alien species included explanatory variables taxonomic group and geographic origin (Hemisphere) (Table 3).

### Table 2. Results of the concurrence and variance of the impact categories across the impact mechanisms and taxonomic groups.

| Taxonomic group | Impact mechanism                      | concurrence | Variance | Number of references |
|-----------------|---------------------------------------|-------------|----------|---------------------|
| Fungi           | Competition                           | 75.00       | 1.00     | 4                   |
|                 | Parasitism                            | 80.90       | 0.23     | 32                  |
| Insects         | Parasitism                            | 90.38       | 0.17     | 24                  |
| Plants          | Competition                           | 50.00       | 2.00     | 34                  |
|                 | Hybridisation                         | 62.50       | 1.03     | 5                   |
|                 | Parasitism                            | 76.67       | 0.53     | 14                  |
|                 | Physical impact on ecosystem          | 62.50       | 0.38     | 3                   |
|                 | Poisoning / Toxicity                  | 100.00      | 0.00     | 4                   |

### Figure 3. Distribution of the assessments by taxonomic group; the x-axis represents the impact categories: Major (MR), Moderate (MO), Minor (MN), Minimal Concern (MC); the y-axis shows the number of references in the respective category (bars).
The parameter estimates were provided by the likelihood confidence intervals. Insects had a significantly lower impact on native forests than fungi, while plants had a similar impact to fungi (Table 3). Alien species from the Southern hemisphere had a lower impact than species from the Northern hemisphere although the difference in impact was not significant (Table 3).

We were unable to conduct an EICAT impact assessment for 84 alien species due to data deficiency. For the data deficiency, the averaged model included the year of introduction, the taxonomic group and geographic origin (Table 4, Figure 4). The averaged model showed that for all taxonomic groups the impact descriptions were more likely to be found for the recently introduced species (Table 4). Furthermore, the fungi had a higher probability for an impact to be described than the insects and the plants (Table 4). There was no difference between alien species coming from both hemispheres in data deficiency.

**Discussion**

The management of harmful invasive alien species has become one of the greatest technical and financial challenges for the management of protected areas (Foxcroft et al. 2019; Mill et al. 2020). The prioritization of alien taxa is essential for setting cost-effective management goals, for high priority species, which possess a severe negative impact. This is particularly important when a large pool of alien species is present (Campagnaro et al. 2018; Fogliata et al. 2021), like in the riparian forest of the UN-
ESCO Mura-Drava-Danube Biosphere Reserve. As with many other protected areas in Europe, the Mura-Drava-Danube Biosphere Reserve also relies on transnational cooperation to face the common cross-border challenge adapting forest management to climate change, as well as for conservation of riparian forest ecosystems (Turnock 2002; Sallmannshofer et al. 2021). A prioritization of alien species is especially important to combat the spread of most harmful invasive alien species by harmonizing the management efforts of various administrations in the transboundary protected area.

**Figure 4.** The influence of time of the first record in the wild in Europe (x-axis) for A fungi B plants and C insects on the probability of an impact report of an alien species (y-axis). The dots show the actual presence and absence of impact reports and the line shows the prediction line of the model in Table 4.
Using the EICAT assessment, this study successfully categorized impacts on European forest ecosystems caused by 114 alien species of three taxonomic groups (plants, insects, and fungi) with reported populations in Southeast European forest ecosystems, all of which might pose a threat to the UNESCO Mura-Drava-Danube Biosphere Reserve. The information on environmental impacts was available for 90% of the fungi, 52% of the plants and 44% of the insects. The fact that more information was available for fungi is likely due to the small number of fungi included on the list of potentially occurring alien species in the assessment area (only 19% of 189 alien species were fungi). Moreover, although the tools and methods to identify fungal species have been positively influenced by advances in molecular biology, proper identification as well as invasion biology of fungi and fungal-like organisms have not yet been sufficiently explored. This is of particular importance as control measures depend on proper identification of diseases and their causal agents (Chetana et al. 2021). In addition, in this study we specifically assessed the impact of alien taxa on European forest ecosystems, which are highly affected by invasive alien species (Seidl et al. 2014). Therefore, impact reports were limited to observed impact on European forest ecosystems; well-described impacts on agriculture and horticulture (DiTommaso et al. 2016; Aneva et al. 2018) were not included in the assessment and are not covered in EICAT. This focus on impacts on forest ecosystems allowed us to provide a cross-taxon classification for the protected riparian forests of the Biosphere Reserve, as well as to identify reported impact mechanisms and knowledge gaps, and to facilitate discussions among local experts and stakeholders in the assessment area. Furthermore, our study shows that many invasive alien species are particularly affecting the riparian forest ecosystems. For instance, the fungi *Hymenoscyphus fraxineus* caused a population decline of the tree species *Fraxinus excelsior*, which is an important target tree species of the habitat type 91F0 (Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)) under the EU Habitat directive. It has been shown that *Fallopia* spp. changes the chemistry of the litter layer and outcompetes the native species, this especially affects the herb layer but also the growth of the saplings, hence the reproduction of the riparian forests (Lavoie et al. 2018).

The assessment of the current impact information showed that none of the 114 alien species were categorized with the EICAT impact category Massive (MV), because the reported impacts unlikely result in irreversible extinctions of native species populations in the context of EICAT (IUCN 2020a). However, six alien plants and five alien fungi were found at the top of the ranking list of harmful alien species – classified in the EICAT category ‘Major’ (MR) – leading to local extinctions of native species in European forest ecosystems. For example, the Himalayan balsam (*Impatiens glandulifera* Royle) has been observed to have negative impacts on herbaceous native plant species diversity due to shading, which led to local extinctions (Čuda et al. 2017; Tanner and Gange 2020). The impacts of *I. glandulifera* are recognized across Europe and therefore this species is also included on the list of invasive alien species of Union concern (Regulation (EU) 1143/2014). In total, five alien plants (Major
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13 impact: *Impatiens glandulifera, Humulus scandens; Moderate impact: Heracleum mantegazzianum, Asclepias syriaca, Ailanthus altissima* in the upper ranking of this study are considered as invasive species on the Union List and therefore subject to restrictions and measures set out in the Regulation (EU) 1143/2014. Other alien species in the top of the ranking list of harmful alien species in this paper, such as the False indigo (*Amorpha fruticosa* L.), showed severe and well-documented impacts on the native species composition of invertebrates, plant diversity, and forest regeneration in riparian areas of South-East Europe (Nagy et al. 2018; Kiss et al. 2019), which are challenging to control (Szigettvári 2002; Brigić et al. 2014). Based on the results we suggest to consider including *Amorpha fruticosa* as invasive species on the EU Union List to facilitate an effective early warning system and rapid eradication measures throughout Europe, where it mainly established in southern EU member states so far. Furthermore, only one invasive plant species causing Major impacts in this study, *Heracleum mantegazzianum* (rank 22), is ranked among the “more than 100 worst” alien species list for Europe, while two top ranked fungi, *Ophiostoma novo-ulmi* (rank 29) and *Hymenoscyphus fraxineus* (rank 18) were identified as species of the greatest concern in Europe (Nentwig et al. 2018). The other identified alien species with high impacts were missed by Nentwig et al. (2018), which indicates that the policy-relevant listing approach is lacking some of the more harmful alien species.

The invasive fungi at the top ranking of this study include globally recognized forest pathogens which parasitize on native trees, such as *Ophiostoma novo-ulmi* that causes vascular wilt disease of elms known as Dutch elm disease. The disease has resulted in a massive, destructive pandemic in which most of the native elms (*Ulmus* spp.) have died (Alford and Backhaus 2005; Brunet et al. 2013). Breeding of several resistant clones and reintroduction of resistant native elms mitigated the threat of extinction (Brasier and Webber 2019; Jürisoo et al. 2019; Martín et al. 2019). Another invasive ascomycete fungus, *Hymenoscyphus fraxineus*, of the high-ranked alien species, causes ash die-back, a lethal disease of ash trees (*Fraxinus* spp.) in Europe since the early 1990 (Cross et al. 2017; Enderle et al. 2019). The observed impacts on the forests of South-East Europe, including a riparian zone and the generalist nature of the pathogen led to a ‘Major’ classification of the regionally fast spreading invasive fungus *Botryosphaeria dothidea*, which causes disease on both native (e.g. *Populus* spp.) and introduced forest tree species (Jurc et al. 2006; Karadžić et al. 2020; Zlatković et al. 2018). Practical management options for *B. dothidea* and other members of the Botryosphaeriaceae family are limited. Biological control methods against the disease caused by these fungi are being developed, but Botryosphaeriaceae invade xylem vessels thus making the application of pesticides or biological control products difficult or even inefficient (Aćimović et al. 2019; Karličić et al. 2020).

Invasive alien insects on average showed the lowest impacts. This is similar to the only other quantitative cross taxa comparison (based on the Generic Impact Scoring System GISS) which also included non-forest animals and plant species (Kumschick et al. 2015). Most of the insect species in the study area feed on leaves at levels that do not detrimentally affect the performance of the affected trees and only few references
report damage to native trees. For example, the fruit and nut breeding Nearctic insect *Chymomyza amoena* was assigned to the lowest impact category Minor concern (MC), because no negative impact on native host species was observed despite its rapid spread since its arrival to Europe in 1975. However, the impact classification of alien insects may increase in time, if more research on other mechanisms is conducted like the competition with native species, which was recently discussed by Paulin et al. (2020) for North American oak lace bug (*Corythucha arcuata*). The feeding by *C. arcuata* can lead to a shortage of food for specialized oak-associated species and can cause larger negative impacts than previously expected (Paulin et al. 2020). Further, some invasive alien insects with a high negative environmental impact, such as the emerald ash borer (*Agrilus planipennis*), were not included for the EICAT assessment in this study, as the species was not yet found or is expected to currently occur in the Biosphere Reserve.

Alien species from the Northern hemisphere have higher environmental impacts than alien species from the Southern hemisphere. The residence time, measured as the time period that an alien species has been first recorded in Europe, was linked to the origin, especially for plants: alien plants showed an average residence time of 242 years, followed by 62 years for fungi and 60 years of residence time for insects. Alien species from the Northern hemisphere were present in Europe for a longer time period than alien species from the Southern hemisphere. They also occur more frequently, as only 2.5% of the alien species in the study area originate from the Southern hemisphere.

The EICAT classification revealed the impact mechanisms of 85% of the assessed alien species. Two impact mechanisms accounted for 68% of impacts across taxonomic groups: Parasitism for fungi and insects, and Competition for plants. This may partly be due to the different focus of the assessed studies; most references on insects and fungi studied the impact of insects and fungi on the health of their host trees. The assessed impact reports for this study on fungi and insects were mostly published by experts in forest protection, and for plants by experts in invasion biology. This may explain the different focus on the studied impact and impact mechanism of alien species, which impact tree species of economic interests (insects and fungi), and alien species, which impact the species richness (plants). However, the indirect impact mechanisms are more difficult to analyse, therefore impact reports usually focus on studying the direct impact mechanisms, rather than the indirect ones. Especially for insects, the indirect impacts are chronically underestimated, because the research direction is mainly focussed on the effects of insects on individual trees.

The EICAT classification identified knowledge gaps for 84 alien species, which were assigned to the category ‘Data deficiency’ (DD). We had to assign species to the category DD for three reasons: Firstly, no references were found on the species; second, references were found, but no impact was described or observed that can be assigned under EICAT; third, references describing impacts were found, but these impacts were not reported from European forest ecosystems. We suggest prioritizing research efforts on alien species with a commonly known impact outside of forests to investigate their potential impact on European forest ecosystems. For example, the invasive alien cicada
Stictocephala bisonia caused plant damage and crop losses in Europe, but the impact on forest ecosystems has not been studied, although the species has been spreading in European forests (Walczak et al. 2018; Hörren et al. 2019). Furthermore, the risk of hybridization and competition of Asian weeping willow (Salix babylonica L.) with native species has been reported for forest ecosystems outside Europe, but the impacts were not yet investigated for European forest ecosystems (Amy and Robertson 2001; Richardson and Rejmánek 2011; Thomas and Leyer 2014). For some alien species, valuable references for forests on other continents, which are similar to European temperate forests in ecological conditions, were not included in this study, but could provide interesting results for the prioritization of alien species in forest ecosystems.

Paap et al. (2020) encourages the collaboration of the two disciplines, invasion biology and plant pathology, to increase the success and efficiency for global biosecurity (Hulme 2021). In this study we experienced that interdisciplinary knowledge of the team of assessors is beneficial for cross-taxa EICAT assessments, which increased the understanding of the magnitude of environmental impacts of alien species of different taxonomic groups. The classification of alien species into harmful impact categories is needed for both forest health and invasive species management, as harmful alien species can cause great socio-economic impacts caused by decrease of timber production as well as the increase of management expenses (Hauer et al. 2020). It is therefore highly suggested to do a socio-economic impact assessment with SEICAT (Bacher et al. 2018) in order to include it in further management considerations.

This study has several implications for forests and forestry. Traditionally, forest management in the context of invasive alien species was focused on pests and diseases (Liebhold 2012). Many of them are also invasive alien species with a huge impact on the forest and the potentially harmful ones are listed in the EU regulations as quarantine species (Schrader and Unger 2003). Our study shows that fungi do have a very high environmental impact in forests, but plants are also represented among the highest impacting invasive alien species in the riparian forests of the transboundary Mura-Drava-Danube Biosphere Reserve in Southeast Europe. Therefore, more attention should be paid to invasive plants and the ground layer vegetation.

Conclusions

We see the classification of alien species according to the magnitude of their environmental impact as an important tool for prioritizing the species on which conservationists and forest managers should focus their immediate attention and for policy makers to ensure funding for protecting our forests from invasions. Especially in respect to the high level of biodiversity and heritage value provided in riparian forest ecosystems (Richardson et al. 2007; Ellison et al. 2017) as well as their numerous abiotic and biotic threats, the ranking approach is to be considered complementary to a site-led management approach, where prioritization is driven by urgency of control relative to the extinction of the native species (Downey et al. 2010).
We demonstrated that EICAT assessments were useful to prioritize alien species in the local assessment area and to refocus research efforts on recent knowledge gaps. More research on the impacts and impact mechanisms of more recently introduced alien species, especially insects and fungi, is needed to implement effective management measures in the early stage of the invasion. Additionally, analysis of available control methods is another prerequisite for planning conservation activities.

We join the recommendation that EICAT assessments should be performed as transparently as possible, which allows an open discussion of the results (Kumschick et al. 2020). This study is only the second study after Volery et al. (2021) that publishes the original impact data that led to the EICAT classifications. The EICAT assessment can also be repeated after some time, as updated impact evidence can be found or new alien species occur in the region of the assessment area (IUCN 2020a). In conclusion, we recommend applying the EICAT protocol when planning conservation activities, because it decreases the danger of overlooking potential high-risk alien species. Although we are aware that the assessments reported here are a snapshot in time and space and impact magnitudes might change over time, a repeated application of EICAT will be very useful to study spatio-temporal trends in impact magnitudes.

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## Appendix 1

### Table A1

List of the 189 alien species included in the EICAT assessment by the maximum EICAT impact category (EICAT), impact mechanism native range (Origin), and information on the year of introduction in Europe (Years).

| EICAT category | Species                  | Taxonomic group | Impact mechanism | Origin   | Years |
|----------------|--------------------------|-----------------|------------------|----------|-------|
| MR Biscogniauxia mediterranea | fungi | (5) Parasitism | North America  | 1931     |
| MR Botryosphaeria dothidea | fungi | (5) Parasitism | Europe |          |
| MR Cryphonectria parasitica | fungi | (5) Parasitism | Asia | 1938     |
| MR Hymenoscyphus fraxineus | fungi | (1) Parasitism | Asia | 1990     |
| MR Ophiostoma novo-ulmi | fungi | (5) Parasitism | Asia | 1990     |
| MR Amorpha fruticosa | plants | (1) Competition | North America | 1724     |
| MR Heracleum persicum | plants | (1) Competition | Asia | 1817     |
| MR Humulus scandens | plants | (1) Competition | Asia | 1880     |
| MR Impatiens glandulifera | plants | (1) Competition | Asia | 1839     |
| MR Reynoutria japonica | plants | (9) Chemical impact on ecosystem | Asia | 1851     |
| MR Reynoutria sachalinensis | plants | (1) Competition | Asia | 1860     |
| MO Cucurbitaria piceae | fungi | (5) Parasitism | North America | 1909     |
| MO Eutelena mammata | fungi | (5) Parasitism | North America | 1975     |
| MO Erysiphe alphitoides | fungi | (5) Parasitism | tropical Asia | 1907     |
| MO Eutypella parasitica | fungi | (5) Parasitism | North America | 1950     |
| MO Guignardia aesculi | fungi | (1) Competition | North America | 1950     |
| MO Nothofagus cryptopus garumnannii | fungi | (5) Parasitism | North America | 1930     |
| MO Phytophthora alni | fungi | (5) Parasitism | Europe | 1993     |
| MO Sclerencoelia pruinosa | fungi | (5) Parasitism | North America | 1977     |
| MO Aphytis mytilaspidis | insects | (5) Parasitism | Asia | 1928     |
| MO Encarsia berlesii | insects | (11) Structural impact on ecosystem | Asia | 2020     |
| MO Phyllonorycter riskii | insects | no information | Asia | 1985     |
| MO Ailanthus altissima | plants | (1) Competition | Asia | 1740     |
| MO Ambrosia artemisiifolia | plants | (1) Competition | North America | 1863     |
| MO Artemisia verlotiorum | plants | (1) Competition | Asia | 1873     |
| MO Asclepias syriaca | plants | (11) Structural impact on ecosystem | North America | 1930     |
| MO Conyza canadensis | plants | (1) Competition | North America | 1600     |
| MO Heracleum mantegazzianum | plants | (1) Competition | Asia | 1849     |
| MO Impatiens parviflora | plants | (1) Competition | Asia | 1831     |
| MO Iva xanthifolia | plants | (1) Competition | North America | 1842     |
| MO Lupinus polyphyllus | plants | (11) Structural impact on ecosystem | North America | 1807     |
| MO Panicum acuminatum | plants | (11) Structural impact on ecosystem | North America | 1990     |
| MO Panicum capillare | plants | (11) Structural impact on ecosystem | North America | 1800     |
| MO Paulownia tomentosa | plants | no information | Asia | 1834     |
| MO Physiota americana | plants | (1) Competition | North America | 1600     |
| MO Pinus strobus | plants | (11) Structural impact on ecosystem | North America | 1800     |
| MO Prunus laurocerasus | plants | no information | Asia | 1576     |
| MO Prunus serotina | plants | no information | North America | 1623     |
| MO Quercus rubra | plants | (1) Competition | North America | 1700     |
| MO Reynoutria bohemica | plants | (1) Competition | Europe | 1982     |
| MO Robinia pseudacacia | plants | (1) Competition | North America | 1601     |
| MO Solidago canadensis | plants | (1) Competition | North America | 1645     |
| MO Solidago gigantea | plants | no information | North America | 1700     |
| MO Spiraea tomentosa | plants | no information | Asia | 1850     |
| MO Symphyotrichum novi-belgii | plants | (1) Competition | North America | 1865     |
| MO Ulmus pumila | plants | (3) Hybridisation | Asia |          |
| EICAT category | Species | Taxonomic group | Impact mechanism | Origin | Years |
|----------------|---------|-----------------|------------------|--------|-------|
| MN             | Apiognomonia veneta | fungi          | (5) Parasitism   | no information | |
| MN             | Blumeriella jaapii  | fungi          | (5) Parasitism   | no information | 1885 |
| MN             | Cronartium ribicola | fungi          | (5) Parasitism   | Asia    | 1983 |
| MN             | Doutistroma septosporum | fungi | (5) Parasitism | North America | 1960 |
| MN             | Dreypanopeziza punctiformis | fungi | (5) Parasitism | North America | 1958 |
| MN             | Erysiphe arcuata     | fungi          | (5) Parasitism   | North America | 2009 |
| MN             | Erysiphe elevata     | fungi          | (5) Parasitism   | North America | 2002 |
| MN             | Erysiphe flexuosa    | fungi          | (5) Parasitism   | North America | 2000 |
| MN             | Erysiphe platani     | fungi          | (5) Parasitism   | North America | 1960 |
| MN             | Glomerella acutata   | fungi          | (5) Parasitism   | Australia | 1990 |
| MN             | Guignardia philoprina| fungi          | (5) Parasitism   | no information | 1970 |
| MN             | Lachnellula willkommii | fungi | (5) Parasitism | Asia    | 1800 |
| MN             | Melampsoridium biratsukenum | fungi | (5) Parasitism | Asia    | |
| MN             | Montilinia fructicola | fungi | (1) Competition | Africa  | 1970 |
| MN             | Mycosphaerella pini  | fungi          | (5) Parasitism   | North America | 1989 |
| MN             | Neonecctria coccinea | fungi          | (5) Parasitism   | Europe   | |
| MN             | Petriaea echinata    | fungi          | (5) Parasitism   | Europe   | 1966 |
| MN             | Phleospora robiniae  | fungi          | (5) Parasitism   | North America | 1853 |
| MN             | Plectobomella concentrica | fungi | (4) Transmission of disease to native species | no information | 1981 |
| MN             | Pseudomicrostoma juglandis | fungi | (5) Parasitism | no information | |
| MN             | Rhodolecine pseudotrigae | fungi | (5) Parasitism | North America | 1971 |
| MN             | Adelencyrtus aslacaspidis | insects | (5) Parasitism | North America | |
| MN             | Aprocerus leucopoda  | insects        | (5) Parasitism   | Asia     | 2003 |
| MN             | Ceroplastes japonicus| insects        | (5) Parasitism   | Asia     | 1983 |
| MN             | Corythucha arcuata   | insects        | (5) Parasitism   | North America | 2000 |
| MN             | Dryocosmus kuriphilus | insects | (12) Indirect impacts through interactions with other species | Asia | 2002 |
| MN             | Halosma gala       | insects        | (5) Parasitism   | Asia     | 2007 |
| MN             | Hypanthria cunea    | insects        | (5) Parasitism   | North America | 1940 |
| MN             | Impatiensnthus asiaticum | insects | (5) Parasitism | Asia | 1967 |
| MN             | Metallula prunosa   | insects        | (5) Parasitism   | North America | 1979 |
| MN             | Orientus ibidiae    | insects        | (4) Transmission of disease to native species | Asia | 1998 |
| MN             | Parectopa robinella | insects        | (5) Parasitism   | North America | 1983 |
| MN             | Phyllocoesty robiniae | insects | (5) Parasitism | North America | 1996 |
| MN             | Prociphilus fraxiniolii | insects | (5) Parasitism | North America | 2003 |
| MN             | Rhagoletis completa | insects        | (5) Parasitism   | North America | 1990 |
| MN             | Xyloxyaninus germanus | insects | (5) Parasitism | Asia | 1952 |
| MN             | Acer negundo       | plants         | (1) Competition  | North America | 1688 |
| MN             | Berberis aquifolium | plants         | (1) Competition  | North America | 1860 |
| MN             | Bidens frondosa    | plants         | no information  | North America | 1891 |
| MN             | Buddleja davidii   | plants         | no information  | Asia     | 1890 |
| MN             | Celtis occidentalis | plants         | no information  | North America | 1785 |
| MN             | Hemerocallis fulva  | plants         | (1) Competition  | Asia     | 1753 |
| MN             | Lonicera japonica  | plants         | no information  | Asia     | 1900 |
| MN             | Panicum dichotomiflorum | plants | (1) Competition | North America | |
| MN             | Parthenocissus inserta | plants | no information | North America | 1887 |
| MN             | Parthenocissus quinquefolia | plants | (10) Physical impact on ecosystem | North America | 1679 |
| MN             | Physocarpus opulifolius | plants | (1) Competition | North America | |
| MN             | Physiolarcia acicoma | plants         | (1) Competition  | South America | 2006 |
| MN             | Rhus typhina       | plants         | (1) Competition  | North America | 1959 |
| MN             | Sporobolus neglectus | plants       | no information  | North America | |
| EICAT category | Species | Taxonomic group | Impact mechanism | Origin | Years |
|----------------|---------|-----------------|------------------|--------|-------|
| MN             | Symphyotrichum lanceolatum | plants | (6) Poisoning / Toxicity | North America | 1800 |
| MC             | Chlynomysa amoena | insects | (5) Parasitism | North America | 1975 |
| MC             | Deraeosoris flavilinea | insects | (11) Structural impact on ecosystem | Asia | 1996 |
| MC             | Heliotris haemorrhoidalis | insects | (5) Parasitism | South America | 1833 |
| MC             | Myocallis odobii | insects | (5) Parasitism | North America | 1988 |
| MC             | Neodyrynus typhlocybae | insects | (11) Structural impact on ecosystem | North America | 1987 |
| MC             | Obolodiphia robini | insects | (5) Parasitism | North America | 2003 |
| MC             | Oenoconia novimundi | insects | (5) Parasitism | North America | 1980 |
| MC             | Abutilon theophrasti | plants | (4) Transmission of disease to native species | Asia | 1800 |
| MC             | Artemisia annua | plants | no information | Asia | 1726 |
| MC             | Catalpa bipinnatis | plants | no information | North America | 1700 |
| MC             | Gleditsia triacanthos | plants | no information | North America | 1700 |
| MC             | juglans nigra | plants | (9) Chemical impact on ecosystem | North America | 1686 |
| MC             | Lonicer maackii | plants | no information | North America | 1896 |
| MC             | Oenothera biennis | plants | no information | North America | 1850 |
| MC             | Neolotliella plants | plants | (12) Indirect impacts through interactions with other species | North America | 1960 |
| DD             | Ganoderma pfeifferi | fungi | no information | Europe | 1994 |
| DD             | Phaeocytopthus nudus | fungi | no information | Asia | 2012 |
| DD             | Sauadaea tulaneti | fungi | no information | North America | 1978 |
| DD             | Volouella buxi | fungi | no information | no information | 1997 |
| DD             | Adelges viridula | insects | (5) Parasitism | Asia | |
| DD             | Antheraea yamamai | insects | (5) Parasitism | Asia | 1860 |
| DD             | Caenoucleis subdeplanata | plants | no information | North America | 2000 |
| DD             | Chaetoisphon fragaeolii | insects | no information | South America | 1941 |
| DD             | Coccus pseudomagnoliarum | insects | no information | Asia | 2003 |
| DD             | Diapidsis perniciosus | insects | no information | Asia | 1988 |
| DD             | Droopilaha suzuki | insects | (5) Parasitism | Asia | 2009 |
| DD             | Eriosophus enigerum | insects | no information | North America | 1787 |
| DD             | Glicrichiulus quadririvignatus | insects | no information | North America | 1945 |
| DD             | Japananos hylaeus | insects | (4) Transmission of disease to native species | Asia | 1961 |
| DD             | Myzus ornatus | insects | (5) Parasitism | North America | 1932 |
| DD             | Nematus tibialis | insects | (5) Parasitism | North America | 1837 |
| DD             | Nercythus acuminatus | insects | no information | North America | 1908 |
| DD             | Neopulicinaria innumerabilis | insects | no information | North America | 1996 |
| DD             | Pseudalacapis pentagona | insects | no information | Asia | 2005 |
| DD             | Pulicinaria tyliporitor | insects | (5) Parasitism | North America | 1965 |
| DD             | Saissetia coffeae | insects | no information | Africa | 1977 |
| DD             | Sticteophila bisonia | insects | (5) Parasitism | North America | 1912 |
| DD             | Trichoferus canestravi | insects | (5) Parasitism | Asia | 1967 |
| DD             | Xyletrechus stebbingi | insects | no information | Asia | 1952 |
| DD             | Abutilon abutiloides | plants | no information | North America | 1952 |
| DD             | Aesculus hippocastanum | plants | no information | Europe | 1561 |
| DD             | Amarathus powellii | plants | no information | South America | 1700 |
| DD             | Amaranthus retroflexus | plants | no information | North America | 1514 |
| DD             | Broussauetia pappriforma | plants | no information | Asia | |
| DD             | Commelina communis | plants | no information | Asia | 1880 |
| DD             | Crambidaca ajacis | plants | no information | Asia | 1880 |
| DD             | Cotoneaster horizontalis | plants | no information | Asia | 1889 |
| EICAT category | Species              | Taxonomic group | Impact mechanism | Origin         | Years |
|----------------|----------------------|-----------------|------------------|----------------|-------|
| DD             | Cuscuta campestris   | plants          | no information   | North America  | 1800  |
| DD             | Duchesnea indica     | plants          | no information   | Asia           | 1800  |
| DD             | Echinocystis lobata  | plants          | no information   | North America  | 1904  |
| DD             | Elaeagnus angustifolia| plants         | no information   | Asia           | 1633  |
| DD             | Eleusine indica      | plants          | no information   | North America  | 1891  |
| DD             | Epilobium ciliatum   | plants          | no information   | South America  | 1876  |
| DD             | Erigeron annuus      | plants          | no information   | North America  | 1700  |
| DD             | Erucastrum gallicum  | plants          | no information   | Europe         |       |
| DD             | Euphorbia numifera   | plants          | no information   | Asia           |       |
| DD             | Euphorbia maculata   | plants          | no information   | North America  | 1600  |
| DD             | Euphorbia suaveana   | plants          | no information   | North America  |       |
| DD             | Fraxinus americana   | plants          | no information   | North America  | 1724  |
| DD             | Fraxinus pennsylvanica| plants       | no information   | North America  | 1783  |
| DD             | Galinsoga parvisflora| plants         | no information   | North America  | 1800  |
| DD             | Galinsoga quadriradiata| plants     | no information   | North America  | 1892  |
| DD             | Glycera striata      | plants          | no information   | North America  | 1849  |
| DD             | Helianthus × laetiflorus| plants       | no information   | North America  |       |
| DD             | Helianthus patensflora| plants        | no information   | North America  | 1500  |
| DD             | Helianthus tuberosus  | plants          | no information   | North America  | 1607  |
| DD             | Juncus tenuis        | plants          | (1) Competition  | North America  | 1795  |
| DD             | Koelreuteria paniculata | plants       | (1) Competition  | Asia           | 1765  |
| DD             | Lepidium virgincum   | plants          | no information   | North America  | 1713  |
| DD             | Lindernia dubia      | plants          | no information   | North America  |       |
| DD             | Loniceran tatarica   | plants          | no information   | Asia           | 1770  |
| DD             | Lycium barbarum     | plants          | no information   | Asia           | 1800  |
| DD             | Matricaria discoidea | plants          | no information   | North America  | 1852  |
| DD             | Morus alba           | plants          | no information   | Asia           | 1600  |
| DD             | Oxalis corniculata   | plants          | no information   | North America  | 1656  |
| DD             | Oxalis stricta       | plants          | no information   | North America  | 1800  |
| DD             | Panicum miliaecum    | plants          | no information   | Asia           | 1700  |
| DD             | Platanus × hispanica | plants          | no information   | no information | 1600  |
| DD             | Platycladus orientalis| plants        | no information   | Asia           | 1690  |
| DD             | Potentilla indica    | plants          | no information   | Asia           | 1800  |
| DD             | Reynoutria laevigata | plants          | no information   | Asia           | 1900  |
| DD             | Reynoutria hagedahuanica| plants       | no information   | Asia           | 1900  |
| DD             | Reynoutria multiflora| plants          | no information   | Asia           |       |
| DD             | Rosa rugosa          | plants          | no information   | Asia           | 1796  |
| DD             | Rubus armeniacus     | plants          | no information   | Asia           | 1835  |
| DD             | Rudbeckia laciniata  | plants          | no information   | North America  | 1886  |
| DD             | Salix babylonica     | plants          | no information   | Asia           | 1730  |
| DD             | Solanum lycopersicum | plants          | no information   | South America  | 1544  |
| DD             | Solidago gigantea    | plants          | no information   | North America  | 1700  |
| DD             | Sorghum halepense    | plants          | no information   | Asia           | 1914  |
| DD             | Symphoricarpus albus | plants          | no information   | North America  | 1800  |
| DD             | Tanacetum parthenium | plants          | no information   | Asia           |       |
| DD             | Véronica persica     | plants          | no information   | Asia           |       |
| DD             | Vitis vulpina        | plants          | no information   | North America  |       |
| DD             | Xanthium albinscum   | plants          | no information   | Asia           |       |
| DD             | Xanthium orientale   | plants          | no information   | North America  |       |
| DD             | Xanthium saccharatum | plants          | no information   | Asia           |       |
### Appendix 2

**Table A2.** List of concurrence and variance results for each alien species.

| Alien species                  | Concurrence | Variance |
|-------------------------------|-------------|----------|
| Acer negundo                  | 66.67       | 0.27     |
| Ailanthus altissima           | 60.00       | 0.80     |
| Ambrosia artemisiifolia       | 33.33       | 1.00     |
| Amorpha fruticosa             | 77.78       | 0.25     |
| Aphytis mytilapidis           | 66.67       | 1.33     |
| Aprocerus leucopoda           | 83.33       | 0.17     |
| Asclepias syriaca             | 100.00      | 0.00     |
| Bidens frondosa               | 100.00      | 0.00     |
| Blomeriella jaapii            | 100.00      | 0.00     |
| Buddleja davidii              | 66.67       | 0.33     |
| Celtis occidentalis           | 66.67       | 0.33     |
| Ceroplastes japonicus         | 100.00      | 0.00     |
| Chrysomyza amoena             | 100.00      | 0.00     |
| Coryza canadensis             | 100.00      | 0.00     |
| Corythucha arcuata            | 100.00      | 0.00     |
| Cronartium ribicola           | 100.00      | 0.00     |
| Cryptonectria parasitica      | 66.67       | 0.33     |
| Dryocosmus kuriphilus         | 100.00      | 0.00     |
| Erysiphe alphitoides          | 50.00       | 0.50     |
| Glomerella acuata             | 100.00      | 0.00     |
| Halyomorpha halys             | 100.00      | 0.00     |
| Hamulus scandens              | 50.00       | 0.50     |
| Hymenocapsus fraxineus        | 75.00       | 1.00     |
| Impatiens glandulifera        | 66.67       | 0.33     |
| Impatiens parviflora          | 100.00      | 0.00     |
| Lupinus polyphyllus           | 33.33       | 0.80     |
| Metcalpha pruinosa            | 75.00       | 0.21     |
| Neodyrmina lepidocybae        | 100.00      | 0.00     |
| Neonecrosis coccinea          | 100.00      | 0.00     |
| Nothobacryptopus gaumannii    | 50.00       | 0.50     |
| Obolodiplois robiniae         | 100.00      | 0.00     |
| Ophiostoma novo-ulmi          | 60.00       | 0.21     |
| Panicum acuminatum            | 66.67       | 1.33     |
| Panicum capillare             | 50.00       | 2.00     |
| Panicum dichotomiflorum       | 50.00       | 0.50     |
| Parthenocissus quinquefolia   | 75.00       | 0.25     |
| Paulownia tomentosa           | 50.00       | 0.50     |
| Phloeopora robiniae           | 100.00      | 0.00     |
| Phylloxyrtyct tiskii          | 50.00       | 0.50     |
| Physocarpus opalifolius       | 66.67       | 0.33     |
| Phyllotaxa acinova            | 50.00       | 0.50     |
| Phyllotaxa americana          | 50.00       | 0.67     |
| Phytophthora alni             | 50.00       | 0.50     |
| Pinus strobus                 | 100.00      | 0.00     |
| Prociphsis fraxinfolii        | 100.00      | 0.00     |
| Prunus laurocerasus           | 50.00       | 2.00     |
| Prunus serotina               | 100.00      | 0.00     |
| Quercus rubra                 | 66.67       | 0.33     |
| Reynoutria bohemica           | 66.67       | 0.33     |
| Reynoutria sachalinensis      | 75.00       | 0.21     |
| Alien species                  | Concurrence | Variance |
|-------------------------------|-------------|----------|
| Reynoutria japonica           | 50.00       | 0.92     |
| Rhabdocline pseudotsugae      | 100.00      | 0.00     |
| Rhagoletis completa           | 100.00      | 0.00     |
| Robinia pseudacacia           | 66.67       | 1.33     |
| Sclerencoelia pruinosa        | 100.00      | 0.00     |
| Solidago canadensis           | 66.67       | 0.24     |
| Solidago gigantea             | 45.45       | 0.56     |
| Sporobolus neglectus          | 50.00       | 0.50     |
| Ulmus pumila                  | 50.00       | 2.00     |