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Advancing research on alien species and biological invasions

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 (the category with the most references assigned to the species assessments). In the next step, we calculated the average percentage for a) each mechanism and b) each taxonomic group individually. The calculation of concurrence implied the division of the number of references of the most frequent impact category (n^i_{freq}) by the total number of references (n^i_{total}) within the same species i, which was performed for each species individually. We then calculated the sum of all individual species by mechanisms, respectively taxonomic groups. To arrive at concurrence, we divided the resulting sum by the number of species (N) for each mechanism respectively for each taxonomic group. In this result, a high percentage indicates high consensus whereas a low percentage indicates low consensus. The equation for concurrence is as follows:

$$\text{concurrence} = \frac{1}{N} * \sum_{i=0}^{M} \because \cdots \frac{n^i_{\text{freq}}}{n^i_{\text{total}}} * 100$$

For the variance in impact magnitudes, we investigated the statistical variance of the different EICAT impact categories, calculating the average percentage for a) each mechanism and b) each taxonomic group individually. A high variance score indicates high dissent.

We modelled the effect of the explanatory variables taxonomic group, geographic origin (southern or northern hemisphere), and years since first record in the wild in Europe on the maximum EICAT impact category per species. As the response variable of impact categories was ordinal, we used cumulative link models (CLM). For the model selection, the Akaike Information Criterion (AIC) was used in which all models within 2 AIC units from the lowest AIC were chosen as the best models (Anderson and Burnham 2002).

The residence time was analyzed for the difference with taxonomic group and impact category. An ANOVA was used between residence time compared to taxonomic group, impact category and their interaction. With the model selection, all models within 2 AIC units from the lowest AIC were chosen as the best models.

For analyzing the data deficiency of the impacts per species, we used a generalized linear model (GLM) with binomial error structure. The dependent variable was based on the presence and absence of an impact description. The independent variables were taxonomic groups, years since the first recorded introduction to Europe and geographic origin. We used a backward stepwise model selection to come to the best model on the basis of the AIC (Burnham and Anderson 2002). All models within 2 AIC units from the lowest AIC were conditional average.

Results

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

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	*Amorpha 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

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%).

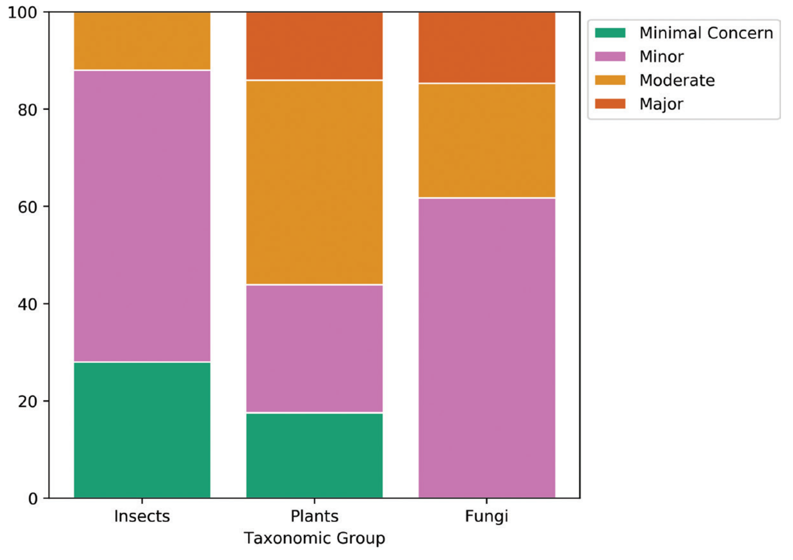

Figure 1. Relative frequency of EICAT impact categories (total species = 114) across the taxonomic groups of insects (n = 25), plants (n = 55) and fungi (n = 34).

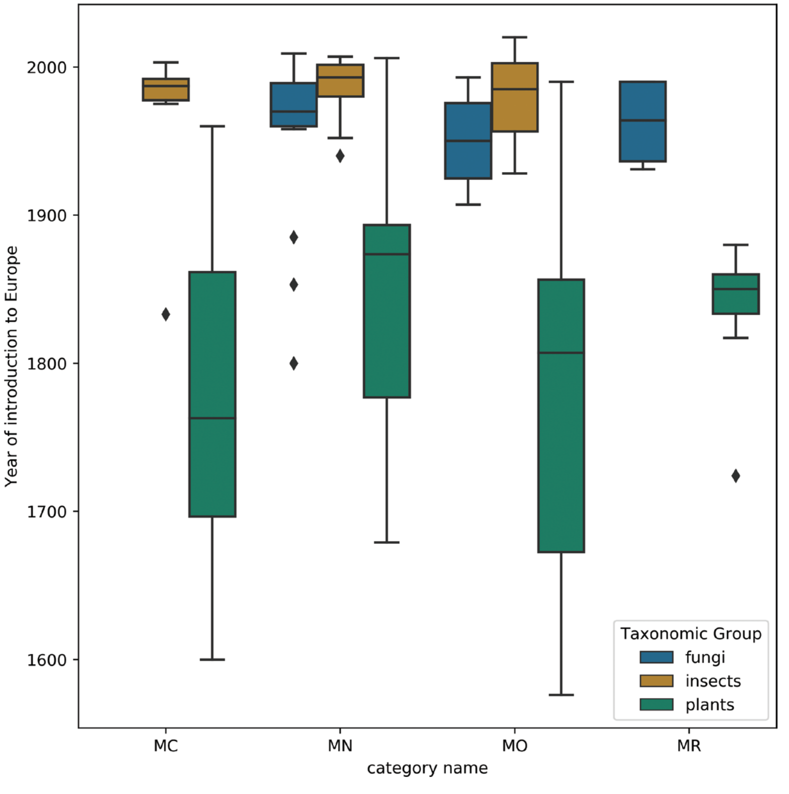

Figure 2. Box plots of the residence time in Europe (years since first report) for species in different taxonomic groups and impact categories: Major (MR), Moderate (MO), Minor (MN), and Minimal Concern (MC).

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	Chemical impact on ecosystem	83.33	0.67	4
	Competition	66.28	0.42	34
	Hybridization	50.00	2.00	2
	Indirect impacts	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

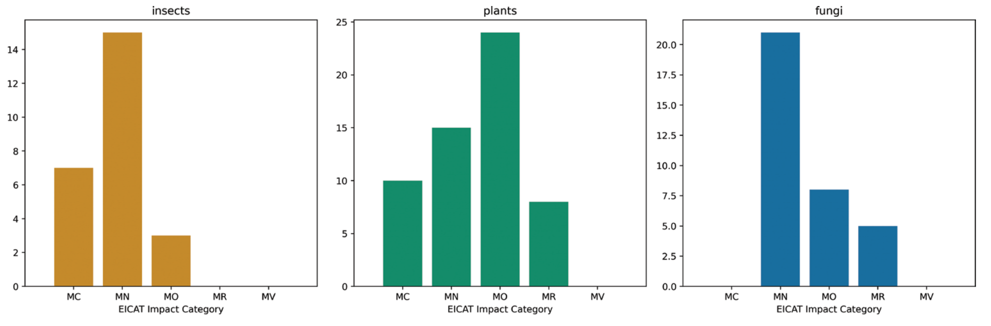

Figure 3. Distribution of the assessments by taxonomic group; the x-axis represents the impact categories: Major (MR), Moderate (MO), Minor (MN), Minimal Concern (MC); the y-axis shows the number of references in the respective category (bars).

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 3. Results from the cumulative link model (CLM) demonstrating the relationship between the impact category of the EICAT impact assessments and explanatory variables: taxonomic groups and native geographic origin, showing the parameter estimates for the minimum adequate CLM; * P < 0.05, ** P < 0.01. The taxonomic groups were compared to plants and the southern hemisphere is compared to the northern hemisphere. The estimate shows the slope or the estimated difference from the reference level.

Variables	Estimate	Std. error	z value	Pr(>|z|)	
Taxonomic group-insect	-1.773	0.547	-3.244	0.001	**
Taxonomic group-plant	0.048	0.448	0.107	0.914	
Hemisphere-South	-1.663	0.917	-1.813	0.07	

Table 4. Model statistics of the averaged model within 2 AIC units from the best model, explaining the influence of factors on the data deficiency of invasive alien species impact in the forests. * P < 0.05, ** P < 0.01. Estimate shows the slope or the estimated difference from the reference level.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-5.113	3.608	1.406	0.160	
Taxonomic group-insect	-2.369	0.798	2.945	0.003	**
Taxonomic group-plant	-1.699	0.827	2.038	0.042	*
Years since Introduction	0.004	0.002	2.160	0.031	*
Southern Hemisphere	-0.771	0.835	0.916	0.360	

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-

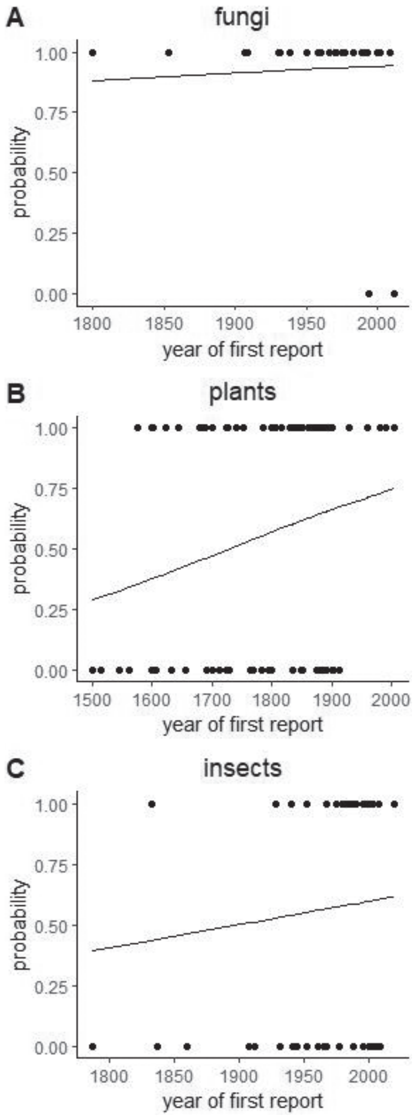

Figure 4. The influence of time of the first record in the wild in Europe (x-axis) for **A** fungi **B** plants and **C** insects on the probability of an impact report of an alien species(y-axis). The dots show the actual presence and absence of impact reports and the line shows the prediction line of the model in Table 4.

ESCO Mura-Drava-Danube Biosphere Reserve. As with many other protected areas in Europe, a 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.

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 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 (Szigetvári 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; Karadzic 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	*Entoleuca 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	*Nothophaeocryptopus gaeumannii*	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 berlesei*	insects	(11) Structural impact on ecosystem	Asia	2020
MO	*Phyllonorycter issikii*	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 xanthiifolia*	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	*Phytolacca 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	*Dothistroma septosporum* [as '*septospora*']	fungi	(5) Parasitism	North America	1960
MN	*Drepanopeziza 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 hiratsukanum*	fungi	(5) Parasitism	Asia	
MN	*Monilinia fructicola*	fungi	(1) Competition	Africa	1970
MN	*Mycosphaerella pini*	fungi	(5) Parasitism	North America	1989
MN	*Neonectria coccinea*	fungi	(5) Parasitism	Europe	
MN	*Petrakia echinata*	fungi	(5) Parasitism	Europe	1966
MN	*Phloeospora robiniae*	fungi	(5) Parasitism	North America	1853
MN	*Plectophomella concentrica*	fungi	(4) Transmission of disease to native species	no information	1981
MN	*Pseudomicrostroma juglandis*	fungi	(5) Parasitism	no information	
MN	*Rhabdocline pseudotsugae*	fungi	(5) Parasitism	North America	1971
MN	*Adelencyrtus aulacaspidis*	insects	(5) Parasitism	North America	
MN	*Aproceros 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	*Halyomorpha halys*	insects	(5) Parasitism	Asia	2007
MN	*Hyphantria cunea*	insects	(5) Parasitism	North America	1940
MN	*Impatientinum asiaticum*	insects	(5) Parasitism	Asia	1967
MN	*Metcalfa pruinosa*	insects	(5) Parasitism	North America	1979
MN	*Orientus ishidae*	insects	(4) Transmission of disease to native species	Asia	1998
MN	*Parectopa robiniella*	insects	(5) Parasitism	North America	1983
MN	*Phyllonorycter robiniella*	insects	(5) Parasitism	North America	1996
MN	*Prociphilus fraxinifolii*	insects	(5) Parasitism	North America	2003
MN	*Rhagoletis completa*	insects	(5) Parasitism	North America	1990
MN	*Xylosandrus 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	*Phytolacca acinosa*	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	*Chymomyza amoena*	insects	(5) Parasitism	North America	1975
MC	*Deraeocoris flavilinea*	insects	(11) Structural impact on ecosystem	Asia	1996
MC	*Heliothrips haemorrhoidalis*	insects	(5) Parasitism	South America	1833
MC	*Myzocallis walshii*	insects	(5) Parasitism	North America	1988
MC	*Neodryinus typhlocybae*	insects	(11) Structural impact on ecosystem	North America	1987
MC	*Obolodiplosis robiniae*	insects	(5) Parasitism	North America	2003
MC	*Oegoconia 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	
MC	*Catalpa bignonioides*	plants	no information	North America	1726
MC	*Gleditsia triacanthos*	plants	no information	North America	1700
MC	*Juglans nigra*	plants	(9) Chemical impact on ecosystem	North America	1686
MC	*Lonicera maackii*	plants	no information	North America	1896
MC	*Oenothera biennis*	plants	no information	North America	1600
MC	*Oenothera glazioviana*	plants	(3) Hybridisation	North America	1850
MC	*Oxalis dillenii*	plants	(12) Indirect impacts through interactions with other species	North America	1960
MC	*Spiraea japonica*	plants	(1) Competition	Asia	
DD	*Ganoderma pfeifferi*	fungi	no information	Europe	1994
DD	*Phaeocryptopus nudus*	fungi	no information	Asia	
DD	*Sawadaea tulasnei*	fungi	no information	North America	2012
DD	*Volutella buxi*	fungi	no information	no information	1997
DD	*Adelges viridula*	insects	(5) Parasitism	Asia	
DD	*Antheraea yamamai*	insects	(5) Parasitism	Asia	1860
DD	*Caenoscelis subdeplanata*	insects	no information	North America	2000
DD	*Chaetosiphon fragaefolii*	insects	no information	South America	1941
DD	*Coccus pseudomagnoliarum*	insects	no information	Asia	2003
DD	*Diaspidiotus perniciosus*	insects	no information	Asia	1988
DD	*Drosophila suzukii*	insects	(5) Parasitism	Asia	2009
DD	*Eriosoma lanigerum*	insects	no information	North America	1787
DD	*Glischrochilus quadrisignatus*	insects	no information	North America	1945
DD	*Japananus hyalinus*	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	*Neoclytus acuminatus*	insects	no information	North America	1908
DD	*Neopulvinaria innumerabilis*	insects	no information	North America	1996
DD	*Pseudaulacaspis pentagona*	insects	no information	Asia	2005
DD	*Pulvinaria hydrangeae*	insects	(5) Parasitism	North America	1965
DD	*Saissetia coffeae*	insects	no information	Africa	1977
DD	*Stictocephala bisonia*	insects	(5) Parasitism	North America	1912
DD	*Trichoferus campestris*	insects	(5) Parasitism	Asia	1967
DD	*Xylotrechus stebbingi*	insects	no information	Asia	1952
DD	*Abutilon abutiloides*	plants	no information	North America	
DD	*Aesculus hippocastanum*	plants	no information	Europe	1561
DD	*Amaranthus powellii*	plants	no information	South America	
DD	*Amaranthus retroflexus*	plants	no information	North America	1700
DD	*Armoracia rusticana*	plants	no information	Asia	1514
DD	*Broussonetia papyrifera*	plants	no information	Asia	
DD	*Commelina communis*	plants	no information	Asia	1880
DD	*Consolida ajacis*	plants	no information	Asia	
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	Asia	
DD	*Epilobium ciliatum*	plants	no information	North America	1891
DD	*Erechtites hieraciifolia*	plants	no information	South America	1876
DD	*Erigeron annuus*	plants	no information	North America	1700
DD	*Erucastrum gallicum*	plants	no information	Europe	
DD	*Euphorbia humifusa*	plants	no information	Asia	
DD	*Euphorbia maculata*	plants	no information	North America	1600
DD	*Euphorbia nutans*	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 parviflora*	plants	no information	North America	1800
DD	*Galinsoga quadriradiata*	plants	no information	North America	1892
DD	*Glyceria striata*	plants	no information	North America	1849
DD	*Helianthus × laetiflorus*	plants	no information	North America	
DD	*Helianthus pauciflorus*	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 virginicum*	plants	no information	North America	1713
DD	*Lindernia dubia*	plants	no information	North America	
DD	*Lonicera 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 miliaceum*	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 aubertii*	plants	no information	Asia	1900
DD	*Reynoutria baldschuanica*	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	*Veronica persica*	plants	no information	Asia	
DD	*Vitis vulpina*	plants	no information	North America	
DD	*Xanthium albinum*	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 mytilaspidis	66.67	1.33
Aproceros leucopoda	83.33	0.17
Asclepias syriaca	100.00	0.00
Bidens frondosa	100.00	0.00
Blumeriella jaapii	100.00	0.00
Buddleja davidii	66.67	0.33
Celtis occidentalis	66.67	0.33
Ceroplastes japonicus	100.00	0.00
Chymomyza amoena	100.00	0.00
Conyza canadensis	100.00	0.00
Corythucha arcuata	100.00	0.00
Cronartium ribicola	100.00	0.00
Cryphonectria parasitica	66.67	0.33
Dryocosmus kuriphilus	100.00	0.00
Erysiphe alphitoides	50.00	0.50
Glomerella acutata	100.00	0.00
Halyomorpha halys	100.00	0.00
Humulus scandens	50.00	0.50
Hymenoscyphus fraxineus	75.00	1.00
Impatiens glandulifera	66.67	0.33
Impatiens parviflora	100.00	0.00
Lupinus polyphyllus	33.33	0.80
Metcalfa pruinosa	75.00	0.21
Neodryinus typhlocybae	100.00	0.00
Neonectria coccinea	100.00	0.00
Nothophaeocryptopus gaeumannii	50.00	0.50
Obolodiplosis 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
Phloeospora robiniae	100.00	0.00
Phyllonorycter issikii	50.00	0.50
Physocarpus opulifolius	66.67	0.33
Phytolacca acinosa	50.00	0.50
Phytolacca americana	50.00	0.67
Phytophthora alni	50.00	0.50
Pinus strobus	100.00	0.00
Prociphilus fraxinifolii	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