Forestry *An International Journal of Forest Research*

Institute of Chartered Foresters

*Forestry* 2020; **93**, 519–534, doi:10.1093/forestry/cpz052
Advance Access publication 26 November 2019

# Risk is in the eye of the assessor: comparing risk assessments of four non-native tree species in Germany

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*Received 26 October 2018*

Non-native tree species (NNT) that pose risks to biodiversity are classified as 'invasive' in some European countries. However, country-specific risk assessment methods may lead to different results for the same NNT between countries of comparable growth conditions, raising doubts about the reliability of risk classifications. Here, we analysed six risk assessment tools used in Germany and adjacent countries for their practical applicability and consistency using four NNT (*Fraxinus pennsylvanica* Marsh., *Paulownia tomentosa* (Thunb. ex Murray), *Pseudotsuga menziesii* (Mirb.) Franco and *Quercus rubra* L.) as case studies. Using these tools to classify risks for the same NNT and reference area (Germany) yielded inconsistent results for all NNT. The reasons for this were (1) differences in classification and weighting of criteria, (2) a lack of data to quantify invasion risks and (3) uncertainties related to assessment methodologies. Moreover, the tools fail to distinguish between risks posed by NNT in different sites. We suggest that instead the risks should be assessed for different ecosystem types by using site-specific inventory data covering the establishment, spread and potential impact of NNT. Our recommendations provide a foundation for developing a consistent, systematic Pan-European approach to assess invasiveness while addressing both risk and forest management aspects.

## Introduction

Non-native tree species (NNT) have been introduced to Europe for a number of reasons, ranging from ornamentals in gardens, parks and forests to species with specific wood properties or high growth rates to improve forestry and diversify the portfolio of commercial species (Krumm and Vítková, 2016). The importance of certain NNT for European forestry might increase as some species are being valued for their perceived suitability for future climatic conditions (Bolte *et al*., 2009; Bauhus *et al*., 2013). Recently, awareness has increased about the potential risks of NNT that are or may become invasive in Europe and thus may have detrimental impacts on biodiversity, ecosystem functioning or socio-economy (e.g. Essl *et al*., 2011a; Felton *et al*., 2013; Kjaer *et al*., 2014). In this study, we define the risk of becoming invasive as the possibility that NNT outcompete native species, hybridize with native tree species, change ecosystem functions and introduce new pathogens (CBD COP6 Decision VI/23, 2002; FAO, 2003). In Europe, some NNT have spread from actively managed stands into nearby semi-natural habitats, where they eventually pose risks to species and habitats (e.g. Woziwoda *et al*., 2014; Drescher and Prots, 2016; Campagnaro *et al*., 2018). For this reason, some NNT have been classified as 'invasive' based on national risk assessment protocols, for example Weymouth pine (*Pinus strobus* L.) in Germany (Nehring *et al*., 2013) and black locust (*Robinia pseudoacacia* L.) in several European countries (Brus, 2016; Vítková *et al*., 2017).

Risk assessment has gained much interest as a method to provide the information basis for prioritization of risk management measures (Byers *et al*., 2002). It is common practice to develop national lists of non-native species and classify them according to the degree of their (potential) invasion risks, for example in the form of a White, Grey or Black List (Verbrugge *et al*., 2010; Roy *et al*., 2013). Risk assessment and risk management are functionally separate but interacting parts of a risk analysis framework (Andersen *et al*., 2004). Principles and methods for risk analysis are provided through the International Standards for Phytosanitary Measures (ISPMs) developed by the International Plant Protection Convention (IPPC). Risk assessment is defined as the evaluation of the probability of establishment, spread and the related (potentially) undesirable consequences of non-native species (ISPM 11, 2016, IPPC). In short, the assessment determines the level of invasion risk associated with a non-native species. Based on the risk assessment, appropriate management options are identified and implemented to reduce risks of detrimental impacts (risk management) (ISPM 11 2016, IPPC). Risk assessment is therefore essential for underpinning decision-making including prevention, early detection, rapid response and long-term control (FAO, 1995; Mehta *et al*., 2010).

Risk assessment is required to inform policy, such as the EU Regulation No 1143/2014 on invasive non-native species, and to justify restrictions on transport, breeding and planting (EU Commission, 2014). Aside from the EU Regulation, which explicitly focuses on potential future invaders (Genovesi *et al*., 2010; EU Commission, 2014), legislative requirements for European Union member states for the use of consistent risk assessment approaches are lacking. To complicate matters, 70 different original methods have been developed worldwide for this purpose (Verbrugge *et al*., 2010; Heikkilä, 2011; Leung *et al*., 2012; Roy *et al*., 2018). Only in Europe, 16 different tools have been identified in the year 2011, ranging from basic impact assessments to country-specific risk assessment methods based on a specified set of criteria, such as detrimental impacts, species' distribution and invasion history elsewhere (Essl *et al*., 2011b). The majority of tools share the aim of measuring or estimating ecological risks but vary in approach, objective and taxa covered (Verbrugge *et al*., 2010). A major challenge for risk assessments remains the provision of robust, clear and replicable evaluations for policy-making, management and scientific purposes (Shirley and Kark, 2006).

So far, detailed risk analyses have rarely been conducted on NNT in Europe (Branquart *et al*., 2016b). A careful risk–benefit analysis of the use of NNT permits identification of management strategies that mitigate risks of negative impacts (Sitzia *et al*., 2015; Brundu and Richardson, 2016). It would be desirable to improve understanding and prediction of invasion dynamics of NNT in various regions or jurisdictions in Europe based on already conducted risk assessments. Since NNT may behave similarly in European regions that are characterized by comparable growth conditions and any spread will not halt at country borders, harmonization of information collection and risk assessment could be very helpful. Yet, country-specific risk assessment methods may lead to different risk classifications for the same NNT, raising doubts about the reliability of results. Inconsistent risk classifications have already been demonstrated for aquatic species in Europe (Verbrugge *et al*., 2012; Matthews *et al*., 2017) and for vascular plant species in several states of Midwestern US (Buerger *et al*., 2016). These comparisons were based on already existing risk classifications reported from different countries or states. Therefore, inconsistencies were also related to differences in regional factors, such as habitat availability or species distribution, and in the perception of risks by diverse assessors (Verbrugge *et al*., 2012; Matthews *et al*., 2017). For example, evaluating detrimental impacts of the same species in the same risk assessment area can even lead to inconsistent answers among different assessors because they perceive invasion risks differently (Turbé *et al*., 2017; González-Moreno *et al*., 2019). Such inconsistency in the comparison of methods and risk classifications could be avoided, if the same assessor used the same dataset and the same reference area when applying different tools.

Here, we analysed and compared existing risk assessment tools that are used in several European countries for their practical applicability to NNT in Germany. We tested the tools for four presumably invasive NNT that differ in their ecological traits, history since introduction and information base, perceived invasiveness and importance for forestry: red ash (*Fraxinus pennsylvanica* Marsh.), princess tree (*Paulownia tomentosa* (Thunb. ex Murray)), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red oak (*Quercus rubra* L.). We investigated the risk classifications assigned to each species and analysed how different approaches affect the assessment and outcome. In addition, we discussed whether risk assessment tools aid in providing management approaches to reduce any negative effects of NNT. The specific objectives of this paper were to

1. evaluate consistency between risk classifications produced by a range of risk assessment tools based on the same assessor, NNT, dataset and reference area (Germany).
2. appraise the suitability of different risk assessment tools for underpinning forest management decisions.
3. suggest options to improve risk assessment for NNT in Europe.

## Data and methods

### Species selection and data

For the purpose of this study, we included NNT that had been introduced to Europe at least about 180 years ago and cover a wide range in traits. This approach increases the likelihood that any identified inconsistencies are potentially applicable to other NNT with similar traits. We picked NNT that represent different categories of (1) perceived risk, (2) economic importance and (3) available information on their potential invasiveness. The third aspect, available information, allowed us to analyse how different risk assessment tools deal with missing data and data uncertainty.

For applying tools, we selected red ash, princess tree, Douglas fir and red oak—tree species that were deliberately introduced to Europe (see Table 1 for an overview). Different perceptions of risks were obvious for Douglas fir and red oak, which have received contradictory results regarding assessment of their invasive potential (Nehring *et al*., 2013; Vor *et al*., 2015). Both publications considered different criteria for the assessment of invasiveness, which reflects different interests and motivations among stakeholders (Vor *et al*., 2016). These two species are also particularly important in terms of cultivated area (Table 1) (Hasenauer *et al*., 2017; Pötzelsberger, 2018) and thus contrast with the remaining two species regarding the second aspect, economic importance. Red ash is a facultative wetland species that has previously been cultivated in floodplain forest sites (Zacharias and Breucker, 2008) but is of limited economical relevance today (Vor, 2015). The princess tree, a species on the 'Grey List' in Germany (Nehring *et al*., 2013) (see Table 2 for definition), which indicates that its ecological effects and future development are largely unknown for Europe, contrast with the other NNT regarding the third aspect, available information. In addition, selected species differ in terms of many ecological characteristics such as seed dispersal, shade tolerance, growth rates, longevity, etc. (Vor *et al*., 2015).

The risk assessment methods used in our study (see below and Table 2) are based on criteria relating to the non-native species' (1) distribution, (2) pathways and vectors, (3) establishment, (4) spread capacity and history, (5) invasion history elsewhere, (6) impact on native biodiversity, ecosystem functioning and economy, (7) estimates for future development (e.g. in terms of climate change) and (8) available management measures to control the species. To assess these criteria, comprehensive

**Table 1** Overview of the NNT included in this study.

| Non-native tree species | *Fraxinus pennsylvanica* | *Paulownia tomentosa* | *Pseudotsuga menziesii* | *Quercus rubra* |
|---|---|---|---|---|
| Common name | Red ash | Princess tree | Douglas fir | Red oak |
| Family | Oleaceae | Scrophulariaceae | Pinaceae | Fagaceae |
| Native range (Vor *et al*., 2015) | Eastern North America | Central to Western China | Western North America | Eastern North America |
| Introduced to Europe (year) (Vor *et al*., 2015) | 1783 | 1834 | 1826 | 1691 |
| Reported forest cover in Europe (ha) (plantations or species present in a mixed forest) (Hasenauer *et al*., 2017; Pötzelsberger, 2018) | unknown | unknown | 830 707 | 345 333 |
| Environmental Agency risk classification (Nehring *et al*., 2013) | Black List | Grey List | Black List | Black List |
| DFVVA[1] risk classification (Vor *et al*., 2015) | Invasive | Limited invasiveness | Not invasive | Not invasive |

[1]DFVVA = Deutscher Verband Forstlicher Forschungsanstalten (German Union of Forest Research Institutes).

literature reviews were carried out beforehand to collect the required information on invasion biology of the four NNT in Europe with a focus on Germany. We selected Germany as the reference area for the risk assessments assuming that, owing to a comparatively good funding situation and many institutions for research on ecology, risks and management of NNT in the country (e.g. Silviculture and Forest Ecology of the Temperate Zones, University of Göttingen), we would obtain a very good information basis for one specific country. We searched the databases Web of Science (http://www.isiwebofknowledge.com/) and Google Scholar (http://scholar.google.com/) using the official Latin name of the NNT, frequently applied English name(s) of the NNT and the terms 'invasive', 'invasion', 'introduced', 'alien', 'exotic' and 'non-native'. In Google Scholar, we conducted the same search using also corresponding German terms. We also considered articles published in the CABI '**Invasive Species Compendium**' (https://www.cabi.org/isc) and through reference lists from reviews, books and (unpublished) articles obtained from colleagues (for comprehensive literature reviews see Supplementary Data).

## Risk assessment tools

Germany was used in the literature review as a reference area. As a consequence, we were interested in the comparison of risk assessment tools currently used in Germany and neighbouring countries that are characterized by similar eco-climatic conditions (EEA, 2006). We collected information on the following methodologies of risk assessments: 'Black, Grey and Watch Lists of alien species in the Czech Republic' *(BGW Lists CZ)*, 'German–Austrian Black List Information System' *(GABLIS)*, Harmonia information system based on 'Invasive Species Environmental Impact Assessment' *(ISEIA)*, 'Classification Key for Neophytes in Black and Watch Lists in Switzerland' *(Neophyte Key)*, and 'Potentials and Risks of Non-Native Tree Species' *(PaR NNT)*, which has specifically been developed for NNT in Germany (see Table 2 for a comprehensive overview). We extended our regional scope (i.e. Germany and neighbouring countries) to include Harmonia+ because it was recently suggested for assessments of NNT by Branquart *et al*. (2016b). The different approaches were applied by assessing the tools' criteria using the information derived from the available literature for each NNT.

Several risk assessment tools were deliberately excluded from our analysis. These comprised, for example, a tool developed in Poland, since there is no final version of it available (see tentative assessment by Tokarska-Guzik, 2005), and a number of tools developed in France because of the heterogeneity in existing tools used in different French regions. Furthermore, since the four tree species in our study have already been introduced to Europe a long time ago, we did not investigate purely predictive tools such as the weed risk assessment (WRA) scheme (Křivánek and Pyšek, 2006). We also excluded tools that only assess the impacts of non-native species, such as the generic impact scoring system (GISS) (Nentwig *et al*., 2016), or the Environmental Impact Classification for Alien Taxa (EICAT) (Hawkins *et al*., 2015), which exclude important aspects of a full risk assessment. However, we did use GISS to evaluate the environmental impact of NNT in the context of applying the BGW Lists *CZ* tool as described in Pergl *et al*. (2016). In the event of uncertainties regarding risk assessment methodologies, we made direct contact with the respective corresponding authors.

The Harmonia+ tool calculates the environmental risk of NNT for different ecosystem types what has previously been done with black locust in (1) semi-natural grasslands and (2) riparian forests by Branquart *et al*. (2016b). By applying the same tool, we assessed the risk of NNT populations in two different environments for each of the study species: (1) sites with special conservation value (further referred to as 'H+ Special sites') and (2) other sites ('H+ Other sites'). Special sites can contain rare and protected semi-natural habitats and represent only a very small proportion of the total area of Germany. Since the tool requires the assessor to evaluate his/her confidence for each criterion, we provided an overall low, medium or high uncertainty for each risk classification. A direct result of this was that uncertainty was high when the assessor judged the available database as insufficient or the data quality as uncertain.

We limited the use of the GISS for the environmental impact domain in the BGW Lists *CZ*. Since the authors of GISS (Nentwig *et al*., 2016) refrained from providing thresholds of summed

**Table 2** Overview of the six risk assessment tools included in the comparison of risk classifications of NNT in Europe.

| Name of risk assessment tool (further referred to as) | Black, Grey and Watch Lists of alien species in the Czech Republic (BGW Lists CZ) | GABLIS | ISEIA | Neophyte Key | PaR NNT | Harmonia+ (Harmonia+, H+ Special sites, H+ Other sites) |
|---|---|---|---|---|---|---|
| Reference | Pergl *et al*. (2016) | Essl *et al*. (2011b); Nehring *et al*. (2015) | Branquart (2009); Vanderhoeven and Branquart (2010) | Weber *et al*. (2005) | Vor *et al*. (2015), DVFFA[1] | D'Hondt *et al*. (2015) |
| Target area (and currently used by) | Czech Republic | Central Europe (Germany) | Belgium (Luxembourg, Netherlands, Denmark) | Switzerland (Liechtenstein) | Germany | Global |
| Purpose | Identification of high risk sp[2] for setting priorities in prevention, early warning and management systems. | Identification of high risk sp for setting priorities in prevention and early warning. | Identification of high risk sp for preventative and mitigation action. Assessments are included in the Harmonia information system[3]. | Identification of high risk neophytes for setting priorities in prevention and early warning. | Evaluation of NNT[4] regarding their potential invasiveness and whether they are suitable for cultivation. | Rapid screening of the diverse risks of potentially invasive non-native sp, and prioritize them accordingly. |
| Methods | Listing by management strategy and known or estimated impacts by using GISS[5] or based on expert judgement. Further separation of the Black List in sublists based on sp distribution impacts, applicable management strategy, and population dynamics. | Listing by risks to biodiversity. Further separation of the (1) Black List in sublists based on sp distribution and availability of management techniques, (2) Grey List in sublists based on likelihood of occurring impacts. | Assessment of the environmental impact of non-native sp. A score is provided to each criterion (low, medium or high risk = 1, 2 or 3; scientific knowledge insufficient: risk likely or unlikely = 2* or 1*). Impact scores are combined with sp distribution and translated into Alert, Black and Watch Lists. | Dichotomous decision tree with each answer leading to the next question. | Risk classifications take into account simultaneously spread and reproduction capacities, site impacts, ability to outcompete native species and appropriate control measures. | A score is provided to 30 questions referring to introduction, establishment, spread and impact modules. A score is calculated for each module, which allows for numerical output on the overall risk of the species (overall risk score 0–1). |

(Continued)

**Table 2** Continued

| Name of risk assessment tool (further referred to as) | Black, Grey and Watch Lists of alien species in the Czech Republic (BGW Lists CZ) | GABLIS | ISEIA | Neophyte Key | PaR NNT | Harmonia+ (Harmonia+, H+ Special sites, H+ Other sites) |
|---|---|---|---|---|---|---|
| Risk classification | **Watch List**<br>Sp with potential high impact, but not yet present in the wild and/or classified invasive elsewhere<br>**Grey List**<br>Sp with moderate impact, some (local) management is desirable<br>**Black List**<br>(with 3 sublists) Sp with strong impact, some management (if feasible) should be applied | **White List**<br>Sp currently without risks to biodiversity<br>**Grey List** (with 2 sublists) Sp poses likely risks to biodiversity<br>**Black List** (with 3 sublists)<br>Sp poses risks to biodiversity | **Alert List (Sublist A0)**<br>Sp with moderate to high impact but not yet introduced to assessed region (score > 9)<br>**C no List** (scores 4–8)<br>sp with low impact<br>**B Watch List** (with 3 sublists) (scores 9–10)<br>sp with moderate impact<br>**A Black List** (with 3-sublists) (scores >10)<br>Sp with high impact | **Watch List**<br>Sp with likely risks to biodiversity, human health and/or economy<br>**Black List**<br>Sp quickly establishes and spreads in the wild and poses risks to biodiversity, human health and/or economy | **Not invasive**<br>Sp spread can be effectively controlled<br>**Limited invasiveness**<br>Sp spread can only be controlled in specific sites<br>**Invasive**<br>Sp is able to displace native sp, spread control is not possible or feasible | Suggested[6]<br>**Low risk**<br>score 0–0.1<br>**Medium risk**<br>score 0.1–0.3<br>**High environmental risk**<br>score > 0.3 |

[1]DFVVA = Deutscher Verband Forstlicher Forschungsanstalten (German Union of Forest Research Institutes).
[2]sp = species
[3]Harmonia: http://ias.biodiversity.be/species/all
[4]NNT = non-native tree species
[5]GISS = Generic impact scoring system (Nentwig *et al*., 2016): assessment comprising all kinds of impacts that a non-native species may exert. In each category, the intensity of impact is quantified by a six-level scale ranging from 0 (no impact detectable) to 5 (the highest impact possible)
[6]As per pers. communication with the author(s)

scores, we interpreted final GISS scores (maximum of 30 possible) as follows: scores of 1–5 for low, 6–10 for medium and 11 or more for high impact.

To increase the overall transparency of our risk assessments, we indicated for particular criteria in Table 3 when the assessor only evaluated the NNT effects on sites with special conservation values.

### Comparison of risk classifications

The focus of this study was on the comparison of different risk assessment methods to identify reasons for inconsistencies, which may be potentially applicable also to other tools. It was not our goal to provide a definitive risk classification and detailed risk analysis for the four NNT. Therefore, we evaluated the criteria of the different risk assessment tools and identified those criteria that finally led to the risk classifications of the four NNT. To ensure the validity of the comparisons of risk classifications, one assessor applied each risk assessment for the same NNT, and therefore the same dataset, based on the same reference area (Germany). The criteria were applied to the best of the assessor's knowledge and we assumed that any existing perceived risk was consistent for all risk assessments for the same NNT.

Different terminology to define risk is being used in the protocols. This hampers the comparison of risk classifications achieved with different tools for the same NNT. Therefore, we standardised the classifications based on Verbrugge *et al*. (2012) and assigned each NNT to one of three risk levels: Black List species were considered to have a 'high' risk, Grey or Watch List species to have a 'medium' risk and White List species or species considered non-invasive or those not allocated to any list were of 'low' risk. The risk classifications by Vor *et al*. (2015)—'invasive', 'limited invasiveness' and 'not invasive'—were translated into the above categories accordingly.

## Results

The different criteria employed by the risk assessment tools, their assessment and the final risk classifications of the four NNT are displayed in Table 3. No NNT was consistently assigned the same class across the different risk assessment tools (Figure 1). The princess tree ranged from low to medium risk but the other three species ranged between low and high risk. More than half of tools classified the risk of red ash as high and of princess tree as medium (Figure 1). On average, the classified risk was highest when using GABLIS and lowest when using ISEIA (and H+ Other sites). Classified risks of all NNT were lower when using H+ Other sites compared to H+ Special sites. The BGW Lists *CZ* tool consistently classified all NNT as medium risk. NNT are assigned to the three risk categories with the Neophyte Key and PaR NNT tools (Figure 2).

In the following, we will describe how and why the different risk classifications were obtained with the different tools studied.

*BGW Lists CZ*. The overall assignment to risk categories is based on estimated or known detrimental environmental impacts (criterion C). Based on the applicable risk management strategy (criterion E), species are further divided into sublists. Since Douglas fir, red oak and red ash were all assigned a moderate environmental impact by GISS (Table 3, criterion C), they were all classified as medium risk. A non-native species with unknown ecological effects, which might pose a future risk, is assigned a medium risk as well. This is the case for the princess tree in Europe (low impact based on GISS, criterion C) for which it is assumed that its spread and impact on marginal sites will likely be promoted by climate change (Essl, 2007; Stimm *et al*., 2015).

*Neophyte Key*. This tool uses a dichotomous decision tree, where responses to individual questions lead to further questions until a final risk classification is reached. Based on the available literature, red ash, Douglas fir and red oak have negative impacts on special sites (criterion 7). Specifically, red oak can outcompete native tree species (e.g. *Quercus robur*) on rocky sites in a national park in eastern Germany (Dreßel and Jäger, 2002). The spread and establishment of Douglas fir in semi-natural, open forests on rocky outcrops in Southwestern Germany change light and soil conditions (Knoerzer, 1999). Red ash causes long-term structural habitat changes of floodways in alluvial forest sites in a National Park in Eastern Germany (Schmiedel and Schmidt, 2010). Since Douglas fir and red oak do not spread rapidly and over long distances (Dick, 1955; Dreßel and Jäger, 2002; Eggert, 2014; Nagel, 2015) (criterion 8*), they are classified as medium risk. In contrast, red ash is classified as high risk because water is an important pathway for long-distance dispersal (Schmiedel and Tackenberg, 2013) (criterion 8) and it has already established several populations (criterion 9*). Princess tree was assigned a low risk because it occurs predominantly in anthropogenic habitats (Richter and Böcker, 2001; Richter, 2002) and neither threatens human health nor causes severe economic damages (criteria 3*, 4, 5).

*GABLIS*. The overall assignment to the risk categories with GABLIS is based on the level of threat to native biodiversity. Further separation in sublists is based on species distribution and feasibility of eradication measures. Douglas fir, red oak and red ash were all classified as high risk because all of them fulfilled one of the biodiversity criteria (B1-B5), as outlined for the assessment with the Neophyte Key above. Non-native species that do not fulfil one of the biodiversity criteria but four out of six biological–ecological criteria (section D) are assigned a medium risk. This was the case for the princess tree for which the capacity to reproduce and spread were both evaluated as high (Pier, 2005; Innes, 2009) (criteria D2, D3) and its populations expand at warm sites in urban areas (Richter and Böcker, 2001) (criterion D4). Any negative effects could become more relevant in the future (criterion D6), as has already been mentioned above for the princess tree under the BGW Lists CZ classification.

*PaR NNT*. The risk classification of the PaR NNT tool takes into account all criteria simultaneously. The risk of red ash was assessed to be high owing to its high spread and reproduction potential (criteria 2, 3) (Gucker, 2005) and because eradication is difficult (criterion 5) (Zacharias and Breucker, 2008). Red oak and Douglas fir were assigned a low risk. First, Douglas fir does not disperse by vegetative propagation (Spellmann *et al*., 2015b) and the vegetative regeneration of red oak is confined to stumps and does not sprout from roots (Nagel, 2015) (criteria 2, 3). Second, at the majority of forest sites, the establishment of both NNT is controlled by shade-tolerant companion tree species such as European beech (*Fagus sylvatica* L.) (Nagel, 2015, Spellmann *et al*., 2015b) and, in the case of red oak, by seed predation

**Table 3** Overview of the application of six different risk assessment tools used in Germany and neighbouring countries.

| Criteria | *Fraxinus pennsylvanica* | *Paulownia tomentosa* | *Pseudotsuga menziesii* | *Quercus rubra* |
|---|---|---|---|---|
| BGW Lists CZ (Pergl *et al.*, 2016) | | | | |
| **A Mode of current spread** | | | | |
| A1 Sp[1] highly dependent on human activities | | ✓ | | |
| A2 Mostly spontaneous | | | | |
| A3 Combination of release and spontaneous spread | ✓ | | ✓ | ✓ |
| **B Distribution** | | | | |
| B1 Regional, at large scale | ✓ | | ✓ | ✓ |
| B2 Local, isolated populations | | ✓ | | |
| **C Environmental impact** (GISS) | moderate | low | moderate | moderate |
| **D Socio-economic impact** | low | low | low | low |
| **E Management options** | | | | |
| E1 Complete eradication | | | | |
| E2 Tolerance (resignation) | | ✓ | | |
| E3 Stratified approach | ✓ | | ✓ | ✓ |
| **Final classification** | **Grey List** | **Watch List** | **Grey List** | **Grey List** |
| GABLIS (Essl *et al.*, 2011b; Nehring *et al.*, 2013) | | | | |
| **B The main criteria—risks to biodiversity** | | | | |
| B1 Interspecific competition | unknown | unknown | unknown §§ | ✓ §§ |
| B2 Predation and Herbivory | not assessed | not assessed | not assessed | Not assessed |
| B3 Hybridization | no | no | no | no |
| B4 Transfer of pathogens or organisms | no | no | no | no |
| B5 Negative effects on ecosystems | ✓ §§ | unknown | ✓ §§ | Unknown |
| **C Additional criteria** | | | | |
| C1 Current distribution | small-scale | small-scale | large-scale | large-scale |
| C2 Emergency measures | unknown | available | available | available |
| **D Biological-ecological criteria** | | | | |
| D1 Occurrence in nature value habitats | ✓ | no | ✓ | ✓ |
| D2 Reproductive capacity | high | high | low | low |
| D3 Spread capacity | high | high | low | medium |
| D4 Current spread history | (regional) expansive | (regional) expansive | (regional) expansive | stable |
| D5 Monopolization of resources | unknown | unknown | ✓ | no |
| D6 Facilitation by climate change | assumed | ✓ | no | ✓ |
| **Final classification** | **Black List** – Management List | **Grey List** -Watch List | **Black List** – Management List | **Black List** - Management List |
| ISEIA, *Harmonia* (Branquart, 2009; Vanderhoeven and Branquart, 2010) | | | | |
| 1 Dispersion potential or invasiveness | 3 | 2 | 2 | 2 |
| 2 Colonization of high conservation value habitats | 3 | 1 | 3 | 2* |
| 3 Direct or indirect adverse impacts on native species | 2* §§ | 1* | 2* §§ | 2 §§ |
| 4 Direct or indirect alteration of ecosystem functions | 2* §§ | deficient data | 2* §§ | 2* |
| Geographic distribution (invasion stage) | restricted range | restricted range | widespread | widespread |
| **Final classification** | Total score = 10 **Watch List** (B2) | Total score = 4 **Not listed** | Total score = 9 **Watch List** (B3) | Total score = 8 **Not listed** |
| Neophyte Key (Weber *et al.*, 2005) | | | | |
| 1 Neo[2] classified as invasive in Europe or climatically similar area, or invasiveness scientifically proven →3 | ✓ | ✓ | ✓ | ✓ |
| 1* Neo not classified as invasive→2 | | | | |
| 2 Neo is potentially invasive in Germany →3 | | | | |
| 2* Neo does not have potential to be invasive in Germany →Neophyte Key | | | | |
| 3 Neo threatens human health →Black List | | | | |
| 3* Neo does not threaten human health →4 | ✓ | ✓ | ✓ | ✓ |

(Continued)

**Table 3** Continued.

| Criteria | *Fraxinus pennsylvanica* | *Paulownia tomentosa* | *Pseudotsuga menziesii* | *Quercus rubra* |
|---|---|---|---|---|
| 4 Neo occurs in protected habitats or together with rare species →6 | ✓ | | ✓ | ✓ |
| 4* Neo occurs almost exclusively in anthropogenic habitats where protection is unwarranted →5 | | ✓ | | |
| 5 Neo causes economic damages →Black List | | | | |
| 5* Neo does not cause severe economic damages →not listed | | ✓ | | |
| 6 Neo competes with native sp or has negative effects on habitat conditions (or are assumed) → 7 | ✓ | | ✓ | ✓ |
| 6* Neo does not compete or has negative effects on habitat conditions →not listed | | | | |
| 7 Neo evidentially causes such damages (see 6) → 8 | ✓ §§ | | ✓ §§ | ✓§§ |
| 7* Such damages are assumed →Watch List | | | | |
| 8 Neo rapidly spreads and over long distances →9 | ✓ | | | |
| 8* Neo does not rapidly spread nor over long distances →Watch List | | | ✓ | ✓ |
| 9 Neo has established 1–5 populations →10 | | | | |
| 9* Neo has established >5 populations →Black List | ✓ | | | |
| 10 Eradication will be difficult, immediate intervention necessary →Black List | | | | |
| 10* Neo does not need to be eradicated immediately →Watch List | | | | |
| **Final classification** | **Black List** | **not listed** | **Watch List** | **Watch List** |
| | PaR NNT (Vor *et al*., 2015) | | | |
| 1 Negative site impacts | not the case | unknown | partly true | unknown§§ |
| 2 High reproduction potential | is true | is true | not the case | partly true |
| 3 High spread potential | is true | partly true | not the case | not the case |
| 4 Competition with native species | partly true | unknown | Unknown §§ | partly true |
| 5 Limited control measures | is true | partly true | not the case | not the case |
| **Final classification** | **invasive** | **limited invasive-ness** | **not invasive** | **not invasive** |

Harmonia+ (D'Hondt *et al*., 2015)

| | *Fraxinus pennsylvanica* | | *Paulownia tomentosa* | | *Pseudotsuga menziesii* | | *Quercus rubra* | |
|---|---|---|---|---|---|---|---|---|
| | Special site[3] | Other site[4] | Special site[5] | Other site[6] | Special site[7] | Other site[8] | Special site[9] | Other site[10] |
| Establishment score | 1.0 | 0.75 | 1.0 | 0.75 | 1.0 | 0.75 | 1.0 | 1.0 |
| Spread score | 0.5 | 0.5 | 0.25 | 0.125 | 0.625 | 0.625 | 0.5 | 0.5 |
| Environmental impact score | 0.5 | 0.1 | 0.45 | 0.15 | 0.5 | 0.1 | 0.4 | 0.2 |
| Overall risk score | 0.353 | 0.061 | 0.225 | 0.046 | 0.396 | 0.069 | 0.283 | 0.141 |
| **Overall assessment** | **high** | **low** | **medium** | **low** | **high** | **low** | **medium** | **low** |
| **Overall uncertainty** | high | medium | high | medium | high | medium | high | medium |

Risk assessments are based on the comprehensive literature review of the NNT red ash (*Fraxinus pennsylvanica*), princess tree (*Paulownia tomentosa*), Douglas fir (*Pseudotsuga menziesii*) and red oak (*Quercus rubra*) in the reference area Germany. *Note:* §§ was added to single criteria when the assessor only evaluated the NNT' effect on sites with special conservation values.

[1]sp = species.

[2]neo = neophyte.

[3]Floodways in alluvial forest.

[4]Hard-wood alluvial forest habitats.

[5]Open habitats.

[6]Forest habitats.

[7]Warm, dry and acidic light forest habitats and treeless open rocky outcrops.

[8]Closed canopy forest habitats.

[9]Dry and acidic light oak (forest) habitats.

[10]Broad-leaved forest (e.g. beech stands).

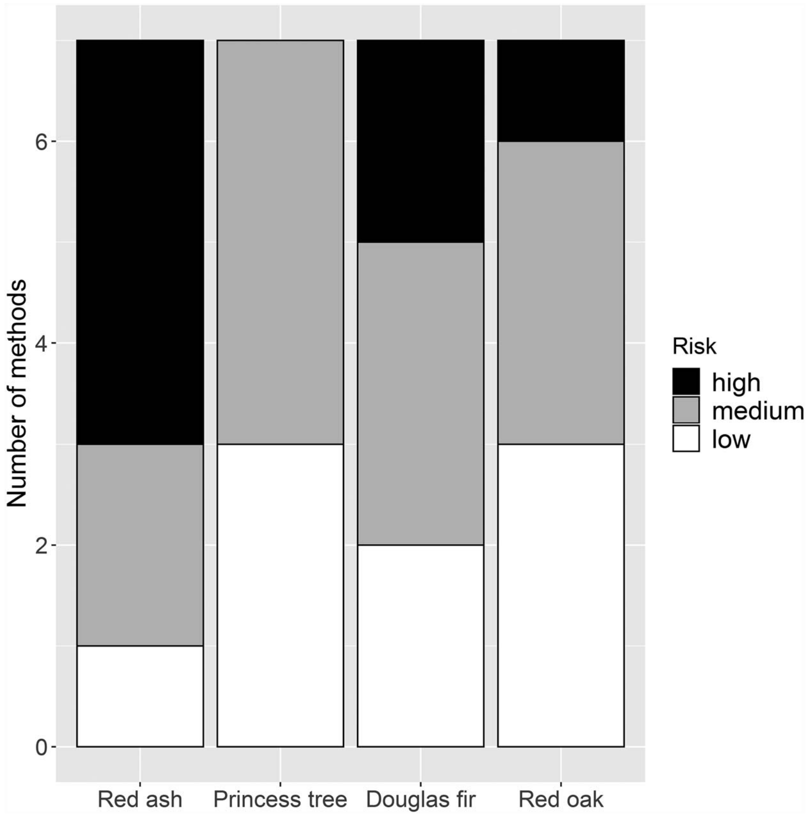


**Figure 1** Standardised risk assessment classifications (low, medium or high) derived when applying six different risk assessment tools used in Germany and adjacent countries to the NNT red ash (*Fraxinus pennsylvanica*), princess tree (*Paulownia tomentosa*), Douglas fir (*Pseudotsuga menziesii*) and red oak (*Quercus rubra*).

and browsing pressure (Nagel, 2015). Third, spread of both NNT can be controlled by specific silvicultural approaches (criterion 5). Princess tree is classified as medium risk since its potential invasiveness varies depending on ecosystem type (open *vs* forest habitats). In Germany, uncontrollable spread via root suckers is considered unlikely under forest conditions. Uncontrollable spread is considered possible in open habitats (Bork *et al*., 2015) as has been observed in the US where the NNT has already been established in disturbed sites (Lovenshimer and Madritch, 2017).

*ISEIA.* Using this tool, the assessor assigns scores for each criterion and the sum of the scores serves as indicator for the overall risk classification. Red ash and Douglas fir were both classified to have a medium risk and red oak and princess tree to have a low risk. Adverse impacts on native species and ecosystem functions were evaluated high for red ash, Douglas fir and red oak, either because they are documented (see above) or considered likely by the assessor (criteria 3, 4). The evaluation of a high dispersion potential of red ash resulted in a higher risk score than in the other tree species (criterion 1). Except for the princess tree, all NNT can colonize high conservation value habitats (criterion 2) (see above) leading to a higher score. The risk score for princess tree was lowest, since adverse impacts were either considered unlikely (criterion 3) or the knowledge was insufficient (criterion 4).

*Harmonia*+. This tool is based on 30 key questions. Scores are calculated for establishment, spread and impact modules allowing for numerical output on the overall risk. In hardwood alluvial forest habitats submitted to regular flooding events, the environmental risk score of Red ash is much higher (H+ Special sites) compared to well-established alluvial forest stands with a closed canopy, where red ash regeneration is negligible and its environmental impact is considered low (Zacharias and Breucker, 2008; Schmiedel, 2010) (H+ Other sites). The overall risk of princess tree to spread and establish in open habitats (medium risk by H+ Special sites) is higher when compared to forest habitats (H+ Other sites), where it is less competitive than other forest tree species and hence unlikely to regenerate beneath a closed canopy (Stimm *et al*., 2015). Using H+ Special sites, Douglas fir was considered to pose a high risk to dry and open (forest) sites with acidic soils (e.g. Knoerzer, 1999; Bindewald and Michiels, 2018). In closed canopy forests, risks are limited because its natural regeneration is mainly outcompeted by more shade-tolerant tree species such as European beech (Spellmann *et al*., 2015b). Red oak poses a medium risk to dry acidic sites with low browsing pressure (H+ Special sites). For the majority of other forest sites, Red oak's competitiveness decreases in competition with shade-tolerant tree species (Vor, 2005) and the overall calculated risk is therefore low (H+ Other sites). The H+ special site assessments

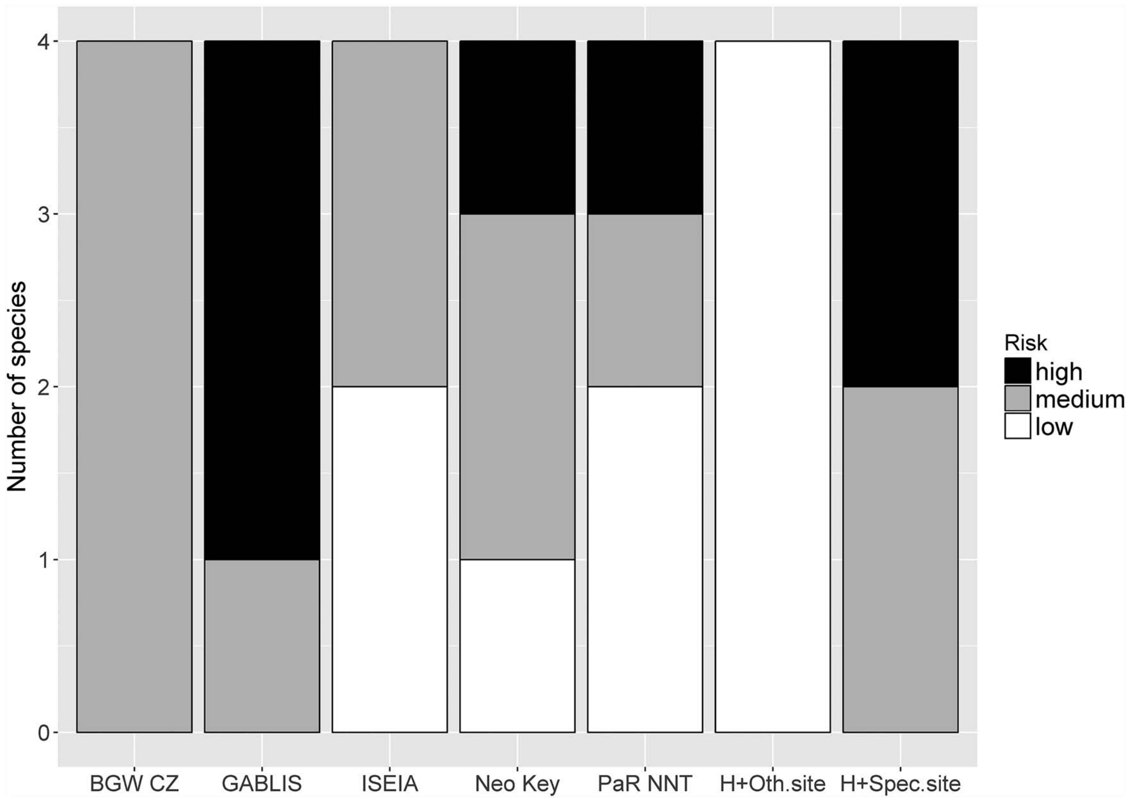


**Figure 2** Standardized risk assessment classifications (low, medium or high) derived when applying six different risk assessment tools used in Germany and adjacent countries to the NNT red ash (*Fraxinus pennsylvanica*), princess tree (*Paulownia tomentosa*), Douglas fir (*Pseudotsuga menziesii*) and red oak (*Quercus rubra*). H+Spec.site = Harmonia+ for special sites; H+Oth.site = Harmonia+ for other sites. Note: In contrast to the other tools, Harmonia+ was applied in one case only for the NNT' populations in sites with special conservation values (H+Spec.site) and in one case only for populations in other sites in Germany (H+Oth.site).

of all NNT were associated with an overall high uncertainty by the assessor.

## Discussion

The application of different risk assessment tools to four NNT for Germany produced highly inconsistent risk classifications. In the following, we will discuss the underlying reasons for these different assessments and what the practical implications are for management systems aiming at prevention and mitigation of risks posed by NNT. Finally, we suggest ways of improving the risk assessment of NNT.

### Underlying reasons for inconsistencies caused by different assessment methods

Owing to the large number of variables included in the different risk assessments, it is not possible to name a single factor for the detected inconsistencies.

The risk assessment methodologies differ substantially and can roughly be divided into two types: (1) systems that weigh the different criteria, for example by scoring, and (2) systems that use decision trees to arrive at a risk classification. ISEIA, *Harmonia+* and PaR NNT belong to the first type while the Neophyte Key, GABLIS and BGW List CZ can be assigned to the second type of methodologies. There is some overlap among the six risk assessment tools regarding the criteria related to spread and reproductive capacities of NNT and their impacts on native species and habitats. However, there were fundamental differences between the tools regarding the number, classification and weighting of these criteria. As a consequence, risk classifications produce different results for the same NNT.

The assessment of detrimental impacts is part of each tool, but the criterion is treated differently. The overall assignment of risk categories in GABLIS and BGW Lists CZ is based on the 'level of threat to native biodiversity'. Thus, both tools classify NNT as high risk based solely on documented or perceived detrimental impacts on native biodiversity. For example, red oak and Douglas fir are assigned as high risk by GABLIS because they meet one of the criteria related to risks to biodiversity, regardless of the spatial extent of this impact (see Table 3 criteria B1- B5). Although the BGW Lists CZ tool uses a similar method, the same two NNT were assigned as medium risks. This difference is attributable to the calculation of impact in GISS, where a score is provided for each impact type ranging from minor local to major large-scale effects. Since the potentially detrimental impacts of these NNT are limited to special sites, the calculated impact is lower. In PaR NNT, Harmonia+ and ISEIA, there is no one absolute criterion that assigns a high risk to a species solely based on detrimental ecological impacts. Instead, all criteria are evaluated equally.

The criteria spread and reproduction potential are included in several methods but are not always taken into account (see high risk species classification by GABLIS and BGW Lists CZ tool above). Douglas fir and red oak were assigned a medium risk by the Neophyte Key, because they neither spread rapidly nor over long distances. The capacity of non-native species to reach high population densities through high reproduction rates is considered only in ISEIA, Harmonia+ and PaR NNT.

The assessment of available management options to control populations of undesired NNT is only considered in the PaR NNT risk classification. This tool explicitly includes forest management options to prevent or control spread of NNT. Therefore, the PaR NNT classified the same two NNT species as low risk because it was deemed feasible to regulate undesired occurrences of Douglas fir and red oak. GABLIS and BGW Lists CZ consider management options only for further separation of the risk classifications into sublists. The other tools do not consider management as a way to mitigate risk in the assessment.

Another important source for inconsistencies is the different consideration of the actual area affected or potentially affected by NNT species in the tools. For example, based on the methodology used in PaR NNT, Douglas fir and red oak are classified as low risk because they are not considered to pose an overall threat to native biodiversity in Germany. This evaluation is attributable to the fact that the spatial extent of sites at which natural regeneration of the species is undesirable are small and their unintended spread into these sites can be controlled through management. Except for Harmonia+, it was not possible to assess invasiveness for different ecosystem types. In contrast, the methodology behind GABLIS, Neophyte Key *or* ISEIA is based on negative impacts on native biodiversity, irrespective of whether these impacts occur only at one site or in a very small area or across large regions of the country. For example, the competition exerted by red oak on native vegetation is assessed to be high in several tools. However, this assessment is mostly based on a single study on south-exposed rocky sites with little browsing pressure by Dreßel and Jäger (2002). Similarly, the overall threat of Douglas fir was assessed to be high because the species is establishing in rare semi-natural forest associations in southwestern Germany (~0.01 per cent of total forest area) (Knoerzer, 1999; Bindewald and Michiels, 2018).

Overall, the GABLIS approach yielded consistently the highest risk scores for all NNT. The tool was commissioned by the German Agency for Nature Conservation and developed to serve as a basis for nature conservation regulations and as an early warning system. In particular the latter purpose, which explicitly employed the precautionary principle (Essl *et al*., 2011b) following the saying 'guilty until proven innocent' (Mack *et al*., 2000), strongly affects the design of the assessment process through a purpose-driven low risk threshold. Interestingly, the time since introduction of NNT is not considered despite the 'early warning' focus of GABLIS.

Apart from H+ Other sites, for which we excluded areas of high conservation value, the lowest risk classifications were obtained with ISEIA. Here, the final classification is equally based on four criteria that are combined into a final score. In addition, scores for each criterion depend on scientific evidence. When negative impacts are considered likely but are not yet scientifically proven, the score is lower than if there was robust evidence. Owing to a general lack of robust scientific information on (long-term) impacts of NNT species, particularly for semi-natural ecosystems, risks assessed with ISEIA are more moderate than with GABLIS. Since evidence typically accumulates gradually, the time since introduction of NNT species is considered indirectly in ISEIA.

Most risk assessment tools classified red ash as high risk and princess tree as medium risk species. For red ash, undisputed characteristics such as high reproduction and spread potential were recognized by the tools to increase the risk of being or becoming invasive. Also, red ash might be able to permanently establish in semi-natural hardwood forest sites (Schmiedel, 2010; Schmiedel and Schmidt, 2010), where eradication proves to be difficult (Zacharias and Breucker, 2008). In case of the princess tree, the majority of tools classified the species as low or medium risk because it predominantly grows in anthropogenic or disturbed habitats, where an adverse impact on native species is considered unlikely (Stimm, 2013; Stimm *et al*., 2015).

## Additional uncertainties related to methodologies and missing data

In this study, differences in risk classifications may be also caused by uncertainties related to assessment methodologies (see also Matthews *et al*., 2017) and a lack of data and models to quantify invasiveness of NNT. First, uncertainty over terminology occurred because some wording was open to interpretation. For example, criterion 8 'the neophyte rapidly spreads and over long distances' of the Neophyte Key protocol leaves room for assessors to interpret 'rapidly' and 'long'. Risk perceptions of assessors can particularly influence the outcome of risk classifications when studies have yielded equivocal results, when there is little available information and the data quality is uncertain. In these cases, it is up to assessors to decide how to address these problems and how strong the influence of necessary assumptions will be on the outcome of the assessment. For the four NNT species assessed in this study, we identified gaps in the literature particularly related to (a) species spread and establishment in various (forest) ecosystems across Germany and (b) their (long-term) impacts on native biodiversity, particularly in semi-natural ecosystems. For example, we only found a few, limited case studies on red oak establishment, mainly in managed forests (e.g. Vor 2005; Major *et al*., 2013) and only one case study in a protected area (Dreßel and Jäger, 2002) in Germany. However, the latter study is based on observations and expert opinion and did not collect quantitative data on the competition of the different tree species. Several studies that we screened for the NNT were not based on quantitative data, which again contributes to assessors' uncertainty. This raises the question, how assessors should weigh the available literature from different case studies for the risk assessments, when there has been no systematic review to develop a solid evidence base. An evidence ranking for ecological studies such as the one proposed by Binkley and Menyailo (2005) could provide guidance and transparency. The authors developed a scheme with five different levels to evaluate the strength of evidence associated with different types of forest ecological studies. However, such an approach is not yet considered in most risk assessment tools.

## Consequences of assessments for risk management of NNT

European forestry has substantial experience with responses of NNT to management. Therefore, the implementation of appropriate forest management and planning activities can noticeably help to reduce or prevent undesired effects of NNT (Sitzia *et al.*, 2015). Moreover, in some European countries, the management of forests also covers semi-natural habitats (Cullotta *et al.*, 2015), which also host habitats and species protected under the Federal Forest Acts or the Flora-Fauna-Habitat Directive (e.g. ForstBW, 2014). Consequently, it is important to involve foresters and their know-how in risk management approaches (van Wilgen and Richardson, 2014), which include the following measures: (1) preventing unwanted dispersal of NNT, (2) controlling or removing NNT in areas where they pose problems, (3) controlling and containing impacts of NNT that are already widespread and (4) sharing knowledge on risks and opportunities with other stakeholders (Forestry Commission Scotland, 2015; Sitzia *et al.*, 2015; Brundu and Richardson, 2016). Yet, the main purpose of several tools assessed here is to prioritize high risk species for preventative and mitigation action (see e.g. 'Purpose' of the tools in Table 2) and only few include elements of risk management. For example, GABLIS and BGW Lists CZ provide only a rough indication what is generally advisable to mitigate detrimental impacts in protected areas. The outcome of several risk assessment approaches is one single risk classification without detailed information on risks posed by the NNT in different ecosystem types. The assessments, which apply to politically rather than ecologically defined areas (Shirley and Kark, 2006), are thus less suitable for practitioners managing risks of NNT. To effectively reduce undesired ecological effects of NNT, management strategies must consider spatial planning (Hulme, 2006; Sádlo *et al.*, 2017) since their establishment, spread and impact are strongly determined by habitat characteristics and also by humans cultivating the NNT and influencing local site conditions (e.g. through harvesting) (Pyšek *et al.*, 2009; Dodet and Collet, 2012). In addition, approaches that follow the precautionary principle are less suited to tree species such as Douglas fir or red oak that are already widely cultivated. In these cases, control of spread on a national scale is no longer feasible and management, where necessary, should focus on demarcated areas for priority actions such as eradication or prevention of further spread into areas most sensitive to invasion (Rouget *et al.*, 2002). At the same time, cultivation is unproblematic in areas where stands do not present a threat to native biodiversity but should be restricted in and near susceptible nature conservation areas, for example by appropriate buffer zones (ForstBW, 2014; Ammer *et al.*, 2016). Sádlo *et al.* (2017) proposed comprehensive risk management guidelines for major NNT in Europe based on rigorous cost-benefit analysis associated with NNT cultivation (as suggested by Naidoo *et al.* (2006) and Gaertner *et al.* (2016)). Their approach represents one important step towards responsible management of widely used NNT in Europe. Its purpose is the identification of potential conflicts with the presence of NNT, for example conservation values of adjacent habitats, to support context-dependent management decisions. Such spatially differentiated approaches that consider positive and negative effects of NNT can also help to avoid conflicts between different stakeholders (Dickie *et al.*, 2014; Pergl *et al.*, 2016; Vor *et al.*, 2016; Sádlo *et al.*, 2017; Vítková *et al.*, 2017). To reconcile diverging views, different stakeholder groups, such as those representing forestry and nature conservation interests, should best be engaged in the management process (Stokes *et al.*, 2006).

## Recommendations for risk assessment approaches

Efforts towards consistent risk assessment frameworks across Europe have already been implemented (Brunel *et al.*, 2010; Roy *et al.*, 2018). For example, the checklist developed by Roy *et al.*, (2018) provides useful minimum standards to design risk assessments. However, from a practical point of view, essential information is still lacking on how exactly the criteria should be assessed and which data should be used to underpin the assessment.

Considering the above issues, a range of criteria are important for assessing invasiveness of NNT. These include biodiversity risks, reproduction potentials, dispersal and establishment at different sites. First, tree-specific characteristics that influence the spread and reproduction potential have to be taken into account. NNT that regenerate vegetatively by root suckers, stump or basal shoot, carry a higher risk to expand and to establish permanent populations, and thus control options are limited. For example, in the US, princess tree has already established in disturbed, open sites based on a single introduction (Lovenshimer and Madritch, 2017) by forming colonies from prolific root sprouts (Langdon and Johnson 1994). These characteristics are also one of the considerations for deciding whether population control is feasible or not (Vor *et al.*, 2015). The effectiveness of different management strategies against NNT substantially differ between species, like black cherry (*Prunus serotina* Ehrh.), which can grow shoots from the stump after disturbances (Annighöfer *et al.*, 2012), or, for example, grand fir (*Abies grandis* Dougl. ex D. Don Lindl.), which is not able to coppice and thus can be controlled by stem removal (Spellmann *et al.*, 2015a). Pathways of introduction and spread potential need to be considered on site to mitigate future risks of invasiveness. Therefore, climatic and site-specific requirements of the NNT must also be taken into consideration to assess the risks of spread and establishment of new populations. We further need data on dispersal distances for establishing buffer zones around areas that are sensitive to invasion. Competition with other trees can substantially influence the establishment potential. The four NNT of our study posed lower risks in closed canopy forests because their natural regeneration is mainly outcompeted by more shade-tolerant tree species in a later stage of succession. However, risks increased when these NNT are cultivated in or nearby more open habitats where they are less affected by other tree species. In this regard, browsing pressure on-site, shade tolerance and growth rates of the NNT in relation to different life stages must also be taken into account. Specific forest management practices can thus hamper (potential) invasion of these NNT, for example, by favouring competitive native species and avoiding intensive disturbances such as clear-cuts (for other examples see Sitzia *et al.* (2015)).

Assessing detrimental impacts on native species and habitats is a fundamental part of risk assessments. For example, NNT that significantly promote soil acidification or accumulate nitrogen in the ecosystem apparently pose high risks to ecosystem functioning (Rejmánek and Richardson, 2013). Yet, available impact studies, for example on the displacement of native species, often lack a solid evidence base and/or have been conducted under very specific conditions and thus cannot be easily transferred to other settings. In the absence of better information, the ability to establish large, dense and persistent populations is being regarded as an indication of the potential to cause detrimental impacts in different ecosystem types, as has been proposed by Branquart *et al*. (2016a) and Kenis *et al*. (2012). This information is also necessary to distinguish between ecosystem types of different invasibility.

Data on the natural regeneration as a measure of establishment success in various forest types can be used to evaluate the levels of NNT invasions in woodlands (e.g. Verheyen *et al*., 2007; Merceron, 2016; Wagner *et al*., 2017). Since forests are regularly monitored in most European countries (Tomppo *et al*., 2010), there could be potential in using national, regional or enterprise-based forest inventory data in risk assessments of widespread NNT. The suitability of inventories will depend on the grid size and the probability with which NNT are sampled. For example, forest inventory data have already been used to analyse occurrence and spread of invasive plants in private and state forests across the US (Oswalt *et al*., 2015). Similarly, typical enterprise-based inventories can be used to assess the forest type-specific regeneration potential of more common NNT and their temporal development (Steinmetz and Bauhus, 2016). If widespread NNT are systematically recorded in European forests, these data could be incorporated in the proposed site-specific approach to assess the establishment, spread and the NNT' potential to cause detrimental impacts.

## Conclusions

The main finding of this study is that risk assessments of NNT are challenging due to the complexity of ecological risks, benefits and uncertainties associated with them (Felton *et al*., 2013).

The outcome of our comparison of risk assessments for NNT highlights three issues in particular. First, country-specific tools that do not provide consistent risk classifications cannot be used as reliable decision-making support across country borders. Second, risk assessment is substantially influenced by risk perception, which constrains 'repeatability' (two or more people repeating the analysis and arriving at the same result) and likely exacerbates conflicts of interest (Hulme, 2006). Third, the assessment methods in most tools are not suited to support (forest) management decisions since a single, undifferentiated risk classification is unlikely to provide meaningful guidance for a wide range of different regions and ecosystems.

To improve the robustness of risk assessment of NNT in Europe, we suggest the development of a protocol that can be applied consistently across country borders and is Pan-European in scope. To address both risk and forest management aspects, we consider the assessment of varying risks posed by NNT at different sites more useful than providing one single risk classification. Hence, different types of sites, independent of their size, should be included in a comprehensive risk assessment framework. Such an approach will be a combination of criteria: (1) that are commonly accepted and undisputed (Brunel *et al*., 2010; Roy *et al*., 2018), for example documented detrimental impacts or uncertainties surrounding the assessment (confidence); (2) that are specifically related to NNT traits and characteristics, like vegetative reproduction capacities which influence control options and (3) that need to be quantified in different ecosystems types, primarily for assessing the establishment and the magnitude of potential impacts.

We are aware that there will always be an intrinsic subjectivity to the evaluation of NNT risks (Felton *et al*., 2013); however, the use of site-specific data will improve evidence-based decision-making and facilitate a move towards a reliable and robust Pan-European invasiveness assessment.

## Supplementary material

Supplementary data are available at Forestry online.

## Acknowledgements

We would like to thank Peter Antkowiak for his help with the literature review and Lena Carlson for language editing. We appreciate the opportunity to discuss our study within the scope of the European Cost Action FP1403 'Non-native tree species for European forest: experiences, risks and opportunities' (NNEXT). The authors also acknowledge suggestions from the editor and reviewers which helped us to improve this article.

## Conflict of interest statement

None declared.

## References

Ammer, C., Bolte, A., Herberg, A., Höltermann, A., Krüß, A., Krug, A. *et al*. 2016 *Vertreter von Forstwissenschaft und Naturschutz legen gemeinsame Empfehlungen für den Anbau eingeführter Waldbaumarten vor—Gemeinsames Papier des DVFFA und des BfN*. Nordwestdeutsche Forstliche Versuchsanstalt—NW-FVA.

Andersen, M.C., Adams, H., Hope, B. and Powell, M. 2004 Risk assessment for invasive species. *Risk Anal.* **24**, 787–793.

Annighöfer, P., Schall, P., Kawaletz, H., Mölder, I., Terwei, A., Zerbe, S. *et al*. 2012 Vegetative growth response of black cherry (Prunus serotina) to different mechanical control methods in a biosphere reserve. *Can. J. For. Res.* **42**, 2037–2051.

Bauhus, J., Puettmann, K.J. and Kuehne, C. 2013 Close-to-nature forest management in Europe: does it support complexity and adaptability of forest ecosystems? In *Managing Forests as Complex Adaptive Systems: Building Resilience to the Challenge of Global Change*. C., Messier, K.J., Puettmann, K.D., Coates (eds.). The Earthscan Forest Library Ed, pp. 187–213.

Bindewald, A. and Michiels, H.-G. 2018 Invasivität der Douglasie in Südwestdeutschland: Waldinventurdaten erlauben eine Einschätzung. *Schweiz. Z. Forstwes.* **169**, 86–92.

Binkley, D. and Menyailo, O. 2005 Gaining insights on the effects of tree species on soils. In *Tree Species Effects on Soils: Implications for Global Change*. D., Binkley, O., Menyailo (eds.). Kluwer Academic Publishers, pp. 1–16.

Bolte, A., Ammer, C., Löf, M., Madsen, P., Nabuurs, G.-J., Schall, P. *et al.* 2009 Adaptive forest management in Central Europe: climate change impacts, strategies and integrative concept. *Scand. J. For. Res.* **24**, 473–482.

Bork, J., Walter, E., Mosandl, R. and Stimm, B. 2015 Paulownia—vorläufige Ergebnisse zu Möglichkeiten und Grenzen des Anbaus im Wald. *Forstarchiv* **86**, 102–106.

Branquart, E. 2009 Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium—ISEIA guidelines Version 2.6. Biodiversity.be, pp. 1–16.

Branquart, E., Brundu, G., Buholzer, S., Chapman, D., Ehret, P., Fried, G. *et al.* 2016a A prioritization process for invasive alien plant species incorporating the requirements of EU Regulation no. 1143/2014. *EPPO Bulletin* **46**, 603–617.

Branquart, E., D'Hondt, B., Vanderhoeven, S. and Kumschick, S. 2016b From impact studies to management actions: practicing risk analysis of introduced trees In *Introduced Tree Species to European Forests.* F. Krumm and L. Vitcova (eds). European Forest Institute, pp. 114–135.

Brundu, G. and Richardson, D.M. 2016 Planted forests and invasive alien trees in Europe: a code for managing existing and future plantings to mitigate the risk of negative impacts from invasions. *NeoBiota* **30**, 5–47.

Brunel, S., Branquart, E., Fried, G., Van Valkenburg, J., Brundu, G., Starfinger, U. *et al.* 2010 The EPPO prioritization process for invasive alien plants. *EPPO Bulletin* **40**, 407–422.

Brus, R. 2016 Current occurrence of non-native tree species in European forest. Presentation to the 827 Joint WG Meeting of COST Action Non-native tree species for European forests—experiences, 828 risks and opportunities (NNEXT). Lisbon, 4th of October 2016.

Buerger, A., Howe, K., Jacquart, E., Chandler, M., Culley, T., Evans, C. *et al.* 2016 Risk assessments for invasive plants: a Midwestern US comparison. *Invas. Plant. Sci. Man.* **9**, 41–54.

Byers, J.E., Reichard, S., Randall, J.M., Parker, I.M., Smith, C.S., Lonsdale, W.M. *et al.* 2002 Directing research to reduce the impacts of nonindigenous species. *Conserv. Biol.* **16**, 630–640.

Campagnaro, T., Brundu, G. and Sitzia, T. 2018 Five major invasive alien tree species in European Union forest habitat types of the Alpine and Continental biogeographical regions. *J. Nat. Conserv.* **43**, 227–238.

CBD 2002 *Alien Species That Threaten Ecosystems, Habitats or Species. COP VI/23.* https://www.cbd.int/decision/cop/default.shtml?id=7197 (accessed on 25 April, 2016.

Cullotta, S., Bončina, A., Carvalho-Ribeiro, S.M., Chauvin, C., Farcy, C., Kurttila, M. *et al.* 2015 Forest planning across Europe: the spatial scale, tools, andinter-sectoral integration in land-use planning. *J. Environ. Plan. Manag.* **58**, 1384–1411.

D'Hondt, B., Vanderhoeven, S., Roelandt, S., Mayer, F., Versteirt, V., Adriaens, T. *et al.* 2015 Harmonia (+) and Pandora (+): risk screening tools for potentially invasive plants, animals and their pathogens. *Biol. Invasions* **17**, 1869–1883.

Dick, J.T.A. 1955 *Studies of Douglas Fir Seed Flight in South Western Washington*. Weyerhaeuser Timber Company, p. 4.

Dickie, I.A., Bennett, B.M., Burrows, L.E., Nunez, M.A., Peltzer, D.A., Porte, A. *et al.* 2014 Conflicting values: ecosystem services and invasive tree management. *Biol. Invasions* **16**, 705–719.

Dodet, M. and Collet, C. 2012 When should exotic forest plantation tree species be considered as an invasive threat and how should we treat them? *Biol. Invasions* **14**, 1765–1778.

Drescher, A. and Prots, B. 2016 Fraxinus Pennsylvanica–an invasive tree species in middle Europe: case studies from the Danube basin. *Contrib. Bot.* **51**, 55–69.

Dreßel, R. and Jäger, E.J. 2002 Beiträge zur Biologie der Gefäßpflanzen des herzynischen Raumes. 5. Quercus rubra L. (Roteiche): Lebensgeschichte und agriophytische Ausbreitung im Nationalpark Sächsische Schweiz. *Hercynia-Ökologie und Umwelt in Mitteleuropa* **35**, 37–64.

EEA 2006 *The Indicative Map of European Biogeographical Regions: Methodology and Development*, Muséum National d'Histoire Naturelle, p. 13.

Eggert, M. 2014 Die Douglasie in Bayern (1. Teil): Wie verjüngt sich die Douglasie? *AFZ-Der Wald* **11**, 27–29.

Essl, F. 2007 From ornamental to detrimental? The incipient invasion of Central Europe by Paulownia tomentosa. *Preslia* **79**, 377–389.

Essl, F., Milasowszky, N. and Dirnböck, T. 2011a Plant invasions in temperate forests: Resistance or ephemeral phenomenon? *Basic Appl. Ecol.* **12**, 1–9.

Essl, F., Nehring, S., Klingenstein, F., Milasowszky, N., Nowack, C. and Rabitsch, W. 2011b Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). *J. Nat. Conserv.* **19**, 339–350.

EU Commission 2014 Regulation (EU) No 1143/2014 of the European Parliament and of the Council No. 25.04.2016. European Commission, Brussels.

FAO 1995 Guidelines for pest risk analysis. International Standards for Phytosanitary Measures (ISPM). No. 2. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO 2003 The status of invasiveness of forest tree species outside their natural habitat: a global review and discussion paper. ftp://ftp.fao.org/docrep/fao/006/J1583E/J1583E00.pdf

Felton, A., Boberg, J., Bjorkman, C. and Widenfalk, O. 2013 Identifying and managing the ecological risks of using introduced tree species in Swedens production forestry. *For. Ecol. Manag.* **307**, 165–177.

Forestry Commission Scotland 2015 *Guidance for Forest Owners and Managers—Managing Invasive and Non-native Forestry Species*. Crown, p. 35.

ForstBW 2014 Richlinie Landesweiter Waldentwicklungstypen. Landesbetrieb Forst Baden-Württemberg. Stuttgart, Germany, 118 pp.

Gaertner, M., Larson, B.M.H., Irlich, U.M., Holmes, P.M., Stafford, L., van Wilgen, B.W. *et al.* 2016 Managing invasive species in cities: a framework from Cape Town, South Africa. *Landsc. Urban Plan.* **151**, 1–9.

Genovesi, P., Scalera, R., Brunel, S., Roy, D. and Solarz, W. 2010 Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe—Technical report No 5/2010, 52 pp.

González-Moreno, P., Lazzaro, L., Vilà, M., Preda, C., Adriaens, T., Bacher, S. *et al.* 2019 Consistency of impact assessment protocols for non-native species. *NeoBiota* **44**, 1–25.

Gucker, C.L. 2005 *Fire Effects Information System—Fraxinus pennsylvanica.* http://www.fs.fed.us/database/feis/plants/tree/frapen/all.html (accessed on 12 March, 2018).

Hasenauer, H., Konnert, M., Lapin, K., Mohren, G., Spiecker, H., van Loo, M. *et al.* 2017 *Non-Native Tree Species for European Forests: Experiences, Risks and Opportunities. COST Action FP1403 NNEXT Country Reports, Joint Volume*. University of Natural Resources and Life Sciences Vienna, 427 pp.

Hawkins, C.L., Bacher, S., Essl, F., Hulme, P.E., Jeschke, J.M., Kühn, I. *et al.* 2015 Framework and guidelines for implementing the proposed IUCN

Environmental Impact Classification for Alien Taxa (EICAT). *Divers. Distrib.* **21**, 1360–1363.

Heikkilä, J. 2011 A review of risk prioritisation schemes of pathogens, pests and weeds: principles and pratices. *Agric. Food Sci.* **20**, 15–28.

Hulme, P.E. 2006 Beyond control: wider implications for the management of biological invasions. *J. Appl. Ecol.* **43**, 835–847.

Innes, R.J. 2009 *Fire Effects Information System—Paulownia tomentosa*. https://www.fs.fed.us/database/feis/plants/tree/pautom/all.html (accessed on 15 January, 2018).

ISPM 11 2016 *Pest Risk Analysis for Quarantine Pests*. IPPC, FAO, Rome, 20 pp.

Kenis, M., Bacher, S., Baker, R., Branquart, E., Brunel, S., Holt, J. *et al.* 2012 New protocols to assess the environmental impact of pests in the EPPO decision-support scheme for pest risk analysis. *Bulletin OEPP/EPPO Bulletin* **42**, 21–27.

Kjaer, E.D., Lobo, A. and Myking, T. 2014 The role of exotic tree species in Nordic forestry. *Scand. J. For. Res.* **29**, 323–332.

Knoerzer, D. 1999 *Zur Naturverjüngung der Douglasie im Schwarzwald—Invenur und Analyse von Umwelt- und Konkurrenzfaktoren sowie eine naturschutzfachliche Bewertung*. Gebrüder Borntraeger Verlagsbuchhandlung, p. 283.

Křivánek, M. and Pyšek, P. 2006 Predicting invasions by woody species in a temperate zone: a test of three risk assessment schemes in the Czech Republic (Central Europe). *Divers. Distrib.* **12**, 319–327.

Krumm, F. and Vítková, L. 2016 *Introduced Tree Species in European Forests: Opportunities and Challenges*. European Forest Institute, p. 423.

Langdon, K.R. and Johnson, K.D. 1994 *Additional notes on invasiveness of Paulownia tomentosa in natural areas*. Natural Areas Journal, **14**, 139–140.

Leung, B., Roura-Pascual, N., Bacher, S., Heikkilä, J., Brotons, L., Burgman, M.A. *et al.* 2012 TEASIng apart alien species risk assessments: a framework for best practices. *Ecol. Lett.* **15**, 1475–1493.

Lovenshimer, J.B. and Madritch, M.D. 2017 Plant community effects and genetic diversity of post-fire princess tree (Paulownia tomentosa) invasions. *Invas. Plant Sci. Mana.* **10**, 125–135.

Mack, R., Simberloff, D., Mark Lonsdale, W., Evans, H., Clout, M. and Bazzaz, F. 2000 Biotic invasions: causes, epidemiology, global consequences, and control. *Ecol. Appl.* **10**, 689–710.

Major, K.C., Nosko, P., Kuehne, C., Campbell, D. and Bauhus, J. 2013 Regeneration dynamics of non-native northern red oak (Quercus rubra L.) populations as influenced by environmental factors: a case study in managed hardwood forests of southwestern Germany. *For. Ecol. Manag.* **291**, 144–153.

Matthews, J., van der Velde, G., Collas, F.P.L., de Hoop, L., Koopman, K.R., Hendriks, A.J. *et al.* 2017 Inconsistencies in the risk classification of alien species and implications for risk assessment in the European Union. *Ecosphere* **8**, 1–17.

Mehta, S.V., Haight, R.G. and Homans, F.R. 2010 Decisionmaking under risk in invasive species management: risk management theory and applications, Gen. Tech. Rep. PNW-GTR-802. In *Advances in Threat Assessment and Their Application to Forest and Rangeland Management*. J.M., Pye, H.M., Rauscher, Y., Sands, D.C., Lee, J.S., Beatty (eds.). US Department of Agriculture, Forest Service, Northwest and Southern Research Stations Pacific, pp. 445–468.

Merceron, N. 2016 *Processus écologiques et évolutifs impliqués dans le succès de l'introduction de Quercus rubra L. en Europe*. PhD, Université de Liège, Liège, Belgique.

Nagel, R.-V. 2015 Roteiche (*Quercus rubra* L.). In *Potenziale und Risiken eingeführter Baumarten—Baumartenportraits mit naturschutzfachlicher Bewertung*. T., Vor, H., Spellmann, A., Bolte, C., Ammer (eds.). Universitätsverlag Göttingen, pp. 219–267.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H. and Rouget, M. 2006 Integrating economic costs into conservation planning. *Trends Ecol. Evol.* **21**, 681–687.

Nehring, S., Essl, F. and Rabitsch, W. 2015 *Methodik der naturschutzfachlichen Invasivitätsbewertung für gebietsfremde Arten Version 1.3*. Bundesamt für Naturschutz (BfN), Bonn, Germany.

Nehring, S., Kowarik, I., Rabitsch, W. and Essl, F. 2013 *Naturschutzfachliche Invasivitätsbewertungen für in Deutschland wild lebende gebietsfremde Gefäßpflanzen*. BfN, Bonn, Germany, 204 pp.

Nentwig, W., Bacher, S., Pyšek, P., Vilà, M. and Kumschick, S. 2016 The generic impact scoring system (GISS): a standardized tool to quantify the impacts of alien species. *Environ. Monit. Assess.* **188**, 315.

Oswalt, C.M., Fei, S., Guo, Q., Iannone, B.V. III, Oswalt, S.N., Pijanowski, B.C. *et al.* 2015 A subcontinental view of forest plant invasions. *NeoBiota* **24**, 49–54.

Pergl, J., Sádlo, J., Petrusek, A., Laštůvka, Z., Musil, J., Perglová, I. *et al.* 2016 Black, Grey and watch lists of alien species in the Czech Republic based on environmental impacts and management strategy. *NeoBiota* **28**, 1–37.

Pier 2005 *Pacific Island Ecosystems at Risk (PIER)—Paulownia tomentosa risk assessment*. http://www.hear.org/pier/wra/pacific/paulownia_tomentosa_htmlwra.htm (accessed on 21 December, 2017).

Pötzelsberger, E. 2018 *Should we be Afraid of Non-native Trees in our Forests? Stories About Sucesses and Failures with Versatile Tree Species with Migration Background*. University of Natural Resources and Life Sciences, p. 35.

Pyšek, P., Křivánek, M. and Jarosik, V. 2009 Planting intensity, residence time, and species traits determine invasion success of alien woody species. *Ecology* **90**, 2734–2744.

Rejmánek, M. and Richardson, D.M. 2013 Trees and shrubs as invasive alien species-2013 update of the global database. *Divers. Distrib.* **19**, 1093–1094.

Richter, M. 2002 *Die Bedeutung städtischer Gliederungsmuster für das Vorkommen von Pflanzenarten unter besonderer Berücksichtigung von Paulownia tomentosa (Thunb.) Steud. – dargestellt am Beispiel Stuttgart*. Ph.D. dissertation, Universität Hohenheim.

Richter, M. and Böcker, R. 2001 Städtisches Vorkommen und Verbreitungstendenzen des Blauglockenbaumes. *Mitt. Dtsch. Dendrolog. Ges.* **86**, 125–132.

Rouget, M., Richardson, D.M., Nel, J.L. and Van Wilgen, B.W. 2002 Commercially important trees as invasive aliens: towards spatially explicit risk assessment at a national scale. *Biol. Invasions* **4**, 397–412.

Roy, H., Schonrogge, K., Dean, H., Peyton, J., Branquart, E., Vanderhoeven, S. *et al* . 2013 Invasive alien species—framework for the identification of invasive alien species of EU concern ENV.B.2/ETU/2013/0026. Natural Environment Research Council, 298 pp.

Roy, H.E., Rabitsch, W., Scalera, R., Stewart, A., Gallardo, B., Genovesi, P. *et al.* 2018 Developing a framework of minimum standards for the risk assessment of alien species. *J. Appl. Ecol.* **55**, 526–538.

Sádlo, J., Vítková, M., Pergl, J. and Pyšek, P. 2017 Towards site-specific management of invasive alien trees based on the assessment of their impacts: the case of Robinia pseudoacacia. *NeoBiota* **35**, 1–34.

Schmiedel, D. 2010 *Invasionsbiologie und ökologisches Verhalten der gebietsfremden Baumart Fraxinus pennsylvanica MARSH. in den Auenwäldern der Mittelelbe im naturschutzfachlichen Kontext*. Ph.D. dissertation, Technische Universität Dresden.

Schmiedel, D. and Schmidt, P.A. 2010 *Fraxinus pennsylvanica*. https://neobiota.bfn.de/handbuch/gefaesspflanzen/fraxinus-pennsylvanica.html (accessed on 3rd April, 2018).

Schmiedel, D. and Tackenberg, O. 2013 Hydrochory and water induced germination enhance invasion of Fraxinus pennsylvanica. *For. Ecol. Manag.* **304**, 437–443.

Shirley, S.M. and Kark, S. 2006 Amassing efforts against alien invasive species in Europe. *PLoS Biol.* **4**, 1311–1313.

Sitzia, T., Campagnaro, T., Kowarik, I. and Trentanovi, G. 2015 Using forest management to control invasive alien species: helping implement the new European regulation on invasive alien species. *Biol. Invasions* **18**, 1–7.

Spellmann, H., Brang, P., Hein, S. and Geb, M. 2015a Große Küstentanne (Abies grandis Dougl. ex D. Don Lindl.). In *Potenziale und Risiken eingeführter Baumarten—Baumartenportraits mit naturschutzfachlicher Bewertung*. T., Vor, H., Spellmann, A., Bolte, C., Ammer (eds.). Universitätsverlag Göttingen, pp. 29–46.

Spellmann, H., Weller, A., Brang, P., Michiels, H.-G. and Bolte, A. 2015b Douglasie (Pseudotsuga menziesii (Mirb.) Franco). In *Potenziale und Risiken eingeführter Baumarten—Baumartenportraits mit naturschutzfachlicher Bewertung*. T., Vor, H., Spellmann, A., Bolte, C., Ammer (eds.). Universitätsverlag Göttingen, pp. 187–217.

Steinmetz, A. and Bauhus, J. 2016 Naturverjüngung der Douglasie im Stadtwald Freiburg–Invasiv? *AFZ-Der Wald*, **08**, 2016, 25–28.

Stimm, B. 2013 Paulownia—Hoffnungsträger aus Fernost. *LWF aktuell* **96**, 18–21.

Stimm, B., Heinrichs, S. and Mosandl, R. 2015 Paulownie (Paulownia tomentosa (Thunb. ex Murray) Steud.). In *Potenziale und Risiken eingeführter Baumarten—Baumartenportraits mit naturschutzfachlicher Bewertung*. T., Vor, H., Spellmann, A., Bolte, C., Ammer (eds.). Universitätsverlag Göttingen, pp. 111–125.

Stokes, K.E., O FNeill, K.P., Montgomery, W.I., Dick, J.T.A., Maggs, C.A. and McDonald, R.A. 2006 The importance of stakeholder engagement in invasive species management: a cross-jurisdictional perspective in Ireland. *Biodivers. Conserv.* **15**, 2829–2852.

Tokarska-Guzik, B. 2005 Invasive ability of kenophytes occurring in Poland: a tentative assessment. *In Biological Invasions - From Ecology to Control*. W. Nentwig, S. Bacher, M.J.W. Cock, H. Dietz, A. Gigon and R. Wittenberg (eds.), Institute of Ecology of the TU Berlin, Berlin, Germany, pp. 47–65.

Tomppo, E., Gschwantner, T., Lawrence, M. and McRoberts, R.E. 2010 *National Forest Inventories*. Springer Science+Business Media B. V, p. 594.

Turbé, A., Strubbe, D., Mori, E., Carrete, M., Chiron, F., Clergeau, P. *et al.* 2017 Assessing the assessments: Evaluation of four impact assessment protocols for invasive alien species. *Divers. Distrib.* **23**, 297–307.

van Wilgen, B.W. and Richardson, D.M. 2014 Challenges and trade-offs in the management of invasive alien trees. *Biol. Invasions* **16**, 721–734.

Vanderhoeven, S. and Branquart, E. 2010 *The Harmonia Information System And The Iseia Protocol—Explanatory document for the Life + Project AlterIAS*. Belgian Biodiversity Platform, p. 4.

Verbrugge, L.N.H., Leuven, R.S.E.W. and van der Velde, G. 2010 *Evaluation of International Risk Assessment Protocols For Exotic Species*. Radboud University Nijmegen, 54 pp.

Verbrugge, L.N.H., van der Velde, G., Hendriks, A.J., Verreycken, H. and Leuven, R. 2012 Risk classifications of aquatic non-native species: application of contemporary European assessment protocols in different biogeographical settings. *Aquat. Invasions* **7**, 49–58.

Verheyen, K., Vanhellemont, M., Stock, T. and Hermy, M. 2007 Predicting patterns of invasion by black cherry (Prunus serotina Ehrh.) in Flanders (Belgium) and its impact on the forest understorey community. *Divers. Distrib.* **13**, 487–497.

Vítková, M., Müllerová, J., Sádlo, J., Pergl, J. and Pyšek, P. 2017 Black locust (Robinia pseudoacacia) beloved and despised: A story of an invasive tree in Central Europe. *For. Ecol. Manag.* **384**, 287–302.

Vor, T. 2005 Natural regeneration of Quercus rubra L. (Red Oak) in Germany. In *Biological Invasions—From Ecology to Control*. W., Nentwig, S., Bacher, M.J.W., Cock, H., Dietz, A., Gigon, R., Wittenberg (eds.). NEOBIOTA, pp. 111–123.

Vor, T. 2015 Rotesche (Fraxinus pennsylvanica Marsh.). In *Potenziale und Risiken eingeführter Baumarten Baumartenportaits mit naturschutzfachlicher Bewertung*. T., Vor, H., Spellmann, A., Bolte, C., Ammer (eds.). Universitätsverlag, pp. 73–83.

Vor, T., Nehring, S., Bolte, A. and Höltermann, A. 2016 Assessment of invasive tree species in nature conservation and forestry—contradictions and coherence. In *Introduced Tree Species in European Forests: Opportunities and Challenges*. F., Krumm, L., Vitcova (eds.). European Forest Institute, pp. 148–156.

Vor, T., Spellmann, H., Bolte, A. and Ammer, C. 2015 *Potenziale und Risiken eingeführter Baumarten Baumartenportaits mit naturschutzfachlicher Bewertung*. Universitätsverlag, p. 296.

Wagner, V., Chytrý, M., Jiménez-Alfaro, B., Pergl, J., Hennekens, S., Biurrun, I. *et al.* 2017 Alien plant invasions in European woodlands. *Divers. Distrib.* **23**, 969–981.

Weber, E., Köhler, B., Gelpke, G., Perrenoud, A. and Gigon, A. 2005 Schlüssel zur Einteilung von Neophyten in der Schweiz in die Schwarze Liste oder die watch-Liste. *Bot. Helv.* **115**, 169–194.

Woziwoda, B., Potocki, M., Sagan, J., Zasada, M., Tomusiak, R. and Wilczyński, S. 2014 Commercial forestry as a vector of alien tree species—the case of Quercus rubra L. Introduction in Poland. *Balt. For.* **20**, 131–141.

Zacharias, D. and Breucker, A. 2008 Die nordamerikanische rot-Esche (Fraxinus pennsylvanica MARSH.)–zur Biologie eines in den Auenwäldern der Mittelelbe eingebürgerten Neophyten. *Braunschweiger Geobotanische Arbeiten* **9**, 499–529.