Predicting invasions by woody species in a temperate zone: a test of three risk assessment schemes in the Czech Republic (Central Europe)

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ABSTRACT

To assess the validity of previously developed risk assessment schemes in the conditions of Central Europe, we tested (1) Australian weed risk assessment scheme (WRA; Pheloung et al. 1999); (2) WRA with additional analysis by Daehler et al. (2004); and (3) decision tree scheme of Reichard and Hamilton (1997) developed in North America, on a data set of 180 alien woody species commonly planted in the Czech Republic. This list included 17 invasive species, 9 naturalized but non-invasive, 31 casual aliens, and 123 species not reported to escape from cultivation. The WRA model with additional analysis provided best results, rejecting 100% of invasive species, accepting 83.8% of non-invasive, and recommending further 13.0% for additional analysis. Overall accuracy of the WRA model with additional analysis was 85.5%, higher than that of the basic WRA scheme (67.9%) and the Reichard–Hamilton model (61.6%). Only the Reichard–Hamilton scheme accepted some invaders. The probability that an accepted species will become an invader was zero for both WRA models and 3.2% for the Reichard–Hamilton model. The probability that a rejected species would have been an invader was 77.3% for both WRA models and 24.0% for the Reichard–Hamilton model. It is concluded that the WRA model, especially with additional analysis, appears to be a promising template for building a widely applicable system for screening out invasive plant introductions.

Keywords

Alien plants, biological invasions, Central Europe, forestry, invasive species, prediction, weed risk assessment.

INTRODUCTION

The search for characteristics of invasive species (Crawley et al., 1996; Rejmánek, 1996) is a central issue in invasion biology, as it determines our ability to predict the invasion success of alien plants in new regions (Richardson & Pyšek, 2006). Over the last 30 years, attempts to identify traits of successful invasive species shifted from studies focused on all vascular plants (Baker, 1974; Pyšek et al., 1995; Crawley et al., 1996) to those dealing with restricted taxonomic and/or life-form groups (Rejmánek & Richardson, 1996; Grotkopp et al., 2002; Richardson & Rejmánek, 2004; Rejmánek et al., 2005b), often in geographically and ecologically specified areas (Kowarik, 1995; Tucker & Richardson, 1995). Predicting which species will invade has been a long-standing goal of ecologists (Kolar & Lodge, 2001); this knowledge is translated into risk assessment schemes that attempt to predict the behaviour of alien species in secondary areas (Daehler & Carino, 2000). Only a small proportion of introduced alien species becomes naturalized and invasive (di Castri, 1989; Williamson, 1996). It has been proposed that about one of 10 introduced species becomes casual, one of 10 casuals naturalized, and one of 10 naturalized aliens becomes a pest (Tens Rule: Williamson & Fitter, 1996; Williamson, 1996). In the same vein, about 1% of introduced plants are estimated to invade natural vegetation (Kowarik, 1995). The risk assessment schemes attempt to identify this small fraction of species that can be potentially harmful to natural vegetation and invade large areas.

Two groups of risk assessment models can be recognized, based on the methods used and the phase of the invasion process they target. (1) Pre-introduction models predict the potential behaviour of a species prior to its introduction (Scott & Panetta, 1993; Pheloung, 1995; Tucker & Richardson, 1995; Rejmánek & Richardson, 1996; Reichard & Hamilton, 1997; Pheloung et al., 1999; Daehler & Carino, 2000; Reichard, 2001; Daehler et al., 2004; Weber & Gut, 2004). Such approaches often use statistical discrimination analysis and classification and regression trees
(CARTs). These schemes are often based on rating systems (e.g. Pheloung, 1995) or on hierarchical decision trees (e.g. Reichard & Hamilton, 1997); the only screening procedure based on biological plant attributes and some ecological interactions of woody plants is in Rejmánek & Richardson (1996; see also Richardson & Rejmánek, 2004). (2) Post-introduction models focus on predicting the future behavior of species that have already become naturalized or invasive in the new area. Such schemes typically rely on geographical information systems (Higgins et al., 1999; Sax, 2001; Windrlčchner, 2001; Windrlčchner & Iles, 2002; Rouget & Richardson, 2003; Dark, 2004; Marais et al., 2004; Rouget et al., 2004; Windrlčchner et al., 2004). In addition, empirical schemes based on investigators’ experience have been used (Hejný et al., 1973), but the predictive power of such attempts was rather limited compared to sophisticated statistical and geographical approaches (Pyšek, 2001).

Rapid development of computing facilities and increasing availability of databases allowed for increasing generality of recently developed screening models (Daehler & Carino, 2000). The Weed Risk Assessment (WRA) scheme developed for Australia and New Zealand (Pheloung, 1995; Pheloung et al., 1999) and successfully tested in Hawaii and other Pacific islands (Daehler & Carino, 2000; Daehler et al., 2004) is a promising tool for assessing the risks from plant invasions. This study explores predictive potential of WRA in a biogeographical zone that has not been subject to testing so far and compares it with other schemes. We used alien woody species commonly planted in the Czech Republic, Central Europe, a country prone to invasions by alien species (Pyšek et al., 2002; Mandák et al., 2004; Chytry et al., 2005). Invasions by woody species often alter the functioning of invaded ecosystems (Williamson, 1999; Richardson et al., 2000). On the other hand, there is a strong requirement for finding non-harmful woody species for commercial use (Richardson, 1998; Richardson et al., 2004a). These two contradicting aspects make the need for reliable weed risk assessment schemes for woody plants particularly urgent. Moreover, woody plants are a frequently used test group (Rejmánek & Richardson, 1996; Reichard & Hamilton, 1997; Reichard, 2001; Windrlčchner, 2001; Windrlčchner & Iles, 2002; Windrlčchner et al., 2004; Rejmánek et al., 2005a) because of detailed records of introduction history and plentiful data on biology, ecology, and adaptation to climate of target areas (Richardson et al., 2004b). This study aims at exploring the extent to which risk assessment schemes developed in other parts of the world and for different ecological and climatic conditions are useful under the temperate conditions of Central Europe.

METHODS

Risk assessment schemes tested

Three models were chosen for testing: (1) weed risk assessment scheme (WRA) (Pheloung, 1995; Pheloung et al., 1999); (2) WRA with additional decision tree analysis of species recommended for further evaluation (Daehler et al., 2004; fact sheets available at http://www.botany.hawaii.edu/faculty/daeveloper/ WRA); and (3) Reichard and Hamilton’s decision tree (Reichard & Hamilton, 1997; Reichard, 2001). The former two models were selected because they have already been tested in a number of regions around the world (Pheloung et al., 1999; Daehler & Carino, 2000; Daehler et al., 2004). Proving them successful under temperate conditions of Central Europe would be a further step to their wider applicability. Reichard and Hamilton’s scheme was used because it was primarily designed for woody species in the temperate zone (i.e. for conditions applicable to our study region).

(1) The WRA model (Pheloung et al., 1999) was developed for Australian and New Zealand alien plants. It consists of 49 questions divided into sections on biogeography, biology/ecology, and traits potentially contributing to the invasiveness. Answers are scored from −3 to +5 and the species is accepted for introduction (score < 1), rejected (> 6), or recommended for further analysis (1–6). A minimum of 10 answers are needed for a species to be evaluated: at least two in the biogeography section, two in traits section and six in biology/ecology. However, for proper evaluation it is recommended that at least one-third of questions are answered.

(2) WRA with additional decision tree analysis (further referred to as ‘WRA+Daehler’) resulted from testing the WRA in Hawaii (Daehler & Carino, 2000) and other Pacific islands (Daehler et al., 2004). Species qualified by the WRA for further analysis are subjected to an additional questionnaire, built as a binary decision tree and resulting in the same classification as the WRA scheme, i.e. accept, reject or recommended for further analysis.

(3) Reichard and Hamilton’s decision tree was built for woody species in North America (Reichard & Hamilton, 1997) and Hawaii (Reichard, 2001). It consists of seven questions in a binary (yes/no) tree. Similarly to the WRA analysis, a species is recommended for acceptance, rejection, or further analysis and monitoring.

In our study, questions related to geography and climate were modified to reflect the conditions of the target area. In WRA, suitability of species to Australian climate was changed to suitability to Central European climate (question 2.01) and origin or naturalization in regions with extended dry periods was changed to origin or naturalization in regions with temperate climate (question 2.04). In the Czech Republic, the mean annual temperature is 7.3 °C (min. 0.4 °C, max. 10.1 °C), and the mean annual precipitation is 672.6 mm (min. 384.6, max. 1497.8) (Czech Hydrometeorological Institute, http://www.chmu.cz). The presence of effective natural enemies in Australia was changed to the presence of effective natural enemies in the Central Europe (question 8.05). In the Reichard–Hamilton scheme, North America was changed to Central Europe in questions related to invasiveness of the species outside the target region and to its membership in a genus or family with another strongly invasive representative. The question about origin in parts of North America other than the region of the proposed introduction was changed to origin of the species in other parts of Europe.

Following present trends in taxonomy and nomenclature, a taxonomic concept of broader genera was adopted, i.e. Prunus s.l. (including Cerasus, Padus, and Laurocerasus), Acer (Acer, 2006 The Authors

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Negundo), and Cornus (Cornus, Swida). This approach allows for better reflection of evolutionary relationships than concept of narrow genera, when evaluating invasiveness of closely related taxa. Status of hybrids followed the approach of Pyšek et al. (2004), i.e. they were considered native to Europe only if both parent species originated from this continent.

Species tested
The data set comprised 180 alien woody species frequently planted and acclimatized in the Czech Republic: all 28 species that are at present widely planted for timber in forests (Křivánek et al., 2006), and 152 species commonly planted in parks and gardens. The latter group was selected from the total of 1691 park and garden woody species on the basis of their residence time, frequency of planting, and horticultural importance. Only species planted in the Czech Republic for at least 60 years and well adapted to the conditions of target region were considered (a similar time criterion as applied by Reichard & Hamilton, 1997).

Species only planted in specialized collections, not offered in garden catalogues, or planted in parks in the Czech Republic were excluded. The selection was based on summarizing literature sources (Koblížek, 2000), on 121 garden catalogues, covering the period since year 1852 up to present, and on the occurrence of woody species in 823 chateau parks in the countryside (Heike, 1984, 1985) and in 13 large parks of Prague (B. Gregorová et al., unpublished). An effort was made to include species with comparable intensity of planting in the country, implying comparable propagule pressure. Under such assumption, the potential invasiveness of species does not depend on the frequency of planting but on their geographical and ecological traits.

Concerning the invasion status, 17 species on the list were invasive, 9 naturalized but non-invasive, 31 casual aliens, and 123 were never reported to escape from cultivation (see Appendix S1 in Supplementary Material; status taken from Pyšek et al., 2002). Classification of the invasion status follows Richardson et al. (2000) and Pyšek et al. (2004). Casual species do not form self-replacing populations outside cultivation and rely on repeated introductions for their persistence. Naturalized species reproduce consistently and sustain populations over many life cycles without direct intervention by humans. Invasive species are a subset of naturalized, that have the potential to spread over a considerable area. Environmental weeds (pests) are alien species that invade natural vegetation, usually adversely affecting native biodiversity and/or ecosystem functioning (Pyšek et al., 2004).

Taxonomic nomenclature follows Koblížek (2000).

Accuracy and reliability of tested schemes
For each scheme, accuracy and reliability for Central Europe were calculated following Smith et al. (1999). Accuracy indicates the probability of correct classification, i.e. the proportion of known invasive species that would be correctly assessed as invasive \[A_i = (I/I) \times 100;\] where \(I\) is the number of invaders that were rejected by the system, and \(I\) was the total number of invaders assessed], and that of known non-invasive species that would be correctly identified as non-invasive \[A_o = (N_o/N_t) \times 100;\] where \(N_o\) was the number of non-invasive species accepted and \(N_t\) the total number of non-invaders assessed]. Overall accuracy \[A = (N_r + I)/(N_r + I)\], including both components, was used to compare the suitability of the schemes tested.

To set up the bottom level for the acceptance of each scheme for Central Europe, we followed overall accuracy \(A\), in the prime region of its development as calculated by Smith et al. (1999). These values were 76% for Reichard–Hamilton and 85% for the WRA scheme based on the figures from Australia and New Zealand; the latter was taken as the acceptable level of overall accuracy for our data.

Reliability takes into account that any sample of species rejected by a screening system will include a proportion of non-invasive species wrongly classified as invaders. It has two components: the probability that an accepted species will become invader, \(P_a = I/(N_r + I)\), and the probability that a rejected species would have been an invader, \(P_r = I/(N_r + I)\). When assessing the reliability of prediction schemes, the base-rate effect must be taken into account. This effect refers to the fact that it is much harder to predict rare events. The overall base-rate probability for a species to become invasive is a product of three probabilities, i.e. the rate at which it escapes from cultivation and becomes casual, the rate of naturalization, and the rate of the naturalized species becoming a pest (Smith et al., 1999). The base-rate for alien woody plants in the Czech Republic was calculated following Smith et al. (1999) with the only difference of using the category invasive instead of pest for the latter probability. Nonetheless, as 11 of the 17 invasive species in the data set are environmental weeds with serious impact (Křivánek et al., 2004), the figure obtained can be compared with those given in Smith et al. (1999).

RESULTS
The WRA+Daehler model provided the best results. The basic WRA model rejected all invasive species but also 3.5% (5 species) of non-invasive taxa. Sixty-four percent (91 species) of non-invaders were accepted and 32.5% (46) were suggested for further analysis. Using the WRA+Daehler model led to the final acceptance of 83.8% (119) of non-invaders; further evaluation was still needed for 13.0% (18) of species (Fig. 1, see Appendix S1 in Supplementary Material). On average, the data allowed to answer 37 questions of 49 posed by the scheme.

The Reichard and Hamilton’s decision tree model was least successful. It rejected only 35.0% (6) of invasive species and 47.0% (8) were suggested for further evaluation. This model was the only one that accepted some invaders (3 species, 18.0%). One of the accepted species (Quercus rubra) is considered a pest in the Czech Republic (Křivánek et al., 2004). The Reichard–Hamilton model accepted 65.0% (92) of non-invasive species and recommended 22.0% (31) for further evaluation. The number of non-invasive species rejected (19, i.e. 13.0%) was also highest of the three models tested (Table 1, Fig. 1).

Overall accuracy was highest for the WRA+Daehler model (85.5%); the additional analysis of species recommended for
further evaluation increased the accuracy of the basic WRA scheme by 17.6%. The accuracy of the basic WRA scheme (67.9%) was still higher than that of the Reichard–Hamilton model (61.6%) (Table 1).

Both WRA-based schemes rejected all invasive species, so the probability that an accepted species would become an invader was null. On the other hand, the probability that a rejected species would have been an invader was 77.3%. A low number of
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Table 1 Accuracy and reliability of tested models evaluated according to Smith et al. (1999)

<table>
<thead>
<tr>
<th>Model</th>
<th>Species number</th>
<th>Accuracy (%)</th>
<th>Reliability (%)</th>
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<td>$I_i$</td>
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<tr>
<td>WRA</td>
<td>17</td>
<td>0</td>
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<tr>
<td>WRA+Daehler</td>
<td>17</td>
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<td>17</td>
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<td>Reichard &amp; Hamilton</td>
<td>6</td>
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<td>17</td>
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$I_i$, number of invasive species; $N$, number of non-invasive species; $r$, accepted; $o$, total; $A_i$, accuracy of correctly identifying invasives; $A_o$, overall accuracy; $P_{ai}$, the probability that a species accepted will become an invader; $P_{ar}$, the probability that a rejected species would have been an invader. See text for details on particular screening models.

rejected invasive species in the Reichard–Hamilton’s model yielded a 3.2% probability that an accepted species would invade but that only 24.0% of rejected species would invade (Table 1).

Of casual aliens, 6% (WRA and WRA+Daehler) and 23% (Reichard–Hamilton) were rejected. The number of casual species recommended for further evaluation was reduced from 29% (WRA) to 13% (WRA+Daehler), and 65% and 81% of casualties were accepted by WRA and WRA+Daehler, respectively. Reichard–Hamilton’s model accepted 48% of casualties and 29% were recommended for further analysis. Both WRA schemes rejected 22% of naturalized species. Percentage of naturalized species recommended for acceptance by the WRA scheme (11%) increased to 45% in the WRA+Daehler model, as the number of species recommended for further evaluation decreased from 67% to 23%. Reichard–Hamilton’s scheme rejected 33% of naturalized species, 45% were accepted, and 22% required further evaluation (Fig. 1).

DISCUSSION

For the reasons outlined above, our study focused on risk assessment schemes applicable to woody plants in Central Europe. Nevertheless, there are other screening systems and some of them yielded promising results: the model developed for South African fynbos vegetation (Tucker & Richardson, 1995), EPPO Pest Risk Assessment (http://www.eppo.org/QUARANTINE/quarantine.htm), or risk assessment of new environmental weeds in Central Europe (Weber & Gut, 2004). The fynbos model was designed for application to very specific conditions — fire-prone, nutrient-poor shrublands — that do not occur in Central Europe. The EPPO screening procedure was primarily developed for plant and insect pests of agricultural habitats and cannot be used to predict invasions to natural vegetation. The risk assessment scheme developed for environmental weeds in Switzerland was not used here because it is very similar to the WRA scheme and its overall accuracy, calculated for 47 plants invasive in temperate Europe and 193 aliens that have failed to naturalize in Switzerland, was as low as 63% (Weber & Gut, 2004). The present study therefore focused on testing the two models developed for Australian vegetation (Pheloung, 1995; Pheloung et al., 1999) and alien woody species in North America and Hawaii (Reichard & Hamilton, 1997; Reichard, 2001).

Reichard and Hamilton’s decision tree is relatively easy to use. Only seven questions need to be answered, using the binary mode. In North America, 90% of 235 tested woody species were correctly assessed with this scheme, 97.1% of invasive species were rejected, and 70.8% of non-invasive were accepted; the overall accuracy was 76% (Reichard & Hamilton, 1997; Smith et al., 1999; but see Rejmánek et al., 2005a; pp. 110–111 for some problems with the categorization of species as ‘non-invasive’ in this scheme). The scheme is now being used in botanical gardens and horticultural practice in the USA (S. Reichard, pers. comm.). However, when applied to Central Europe, this scheme rejected only 35% of invasive species and accepted 65% of non-invasive. The overall accuracy was 14% lower than in the region for which it was developed. Primary reason for this failure could be that the model ignores climatic factors in native distribution area of tested species. Many species rejected as potentially invasive in our test of this model are not suited to the Central European climate because of severe winter seasons and frost. This, in combination with a strong emphasis on whether or not a species is invasive elsewhere, leads to misclassification of some non-invasive species as pests (see Appendix S1 in Supplementary Material). For example, Buddleja davidii is a serious invader in Australia, Mediterranean basin, and European regions with oceanic climate (Weber, 2003). In the Czech Republic, however, it was only reported as casual for the first time recently (Pyšek et al., 2002) because it is limited by frost. Other incorrectly classified harmful species are Paulownia tomentosa (invasive in North America; planted in the Czech Republic since 1844), Gleditschia triacanthos (South Africa and Australia, 1785), Morus alba (South Africa, 1835), and Wisteria sinensis (North America, 1913). All these species have been planted in the Czech Republic for a sufficiently long period to have become adapted to the local climate.

In our data set, the criterion of being invasive elsewhere appeared less important than suggested in the Reichard–Hamilton scheme; this criterion is also included in the WRA screening procedure. In our tested group, 38 species are reported as invasive elsewhere (Reichard, 1997; Bingelli et al., 1998; Haysom & Murphy, 2003; Weber, 2003). All seven species reported as invasive both elsewhere and in the Czech Republic were rejected by both WRA schemes, and six of them by the Reichard–Hamilton scheme, too. On the other hand, the Reichard–Hamilton scheme rejected also 13 of 17 species not escaped from cultivation in the
Czech Republic. WRA rejected 11 not escaped species and the WRA+Daehler provided best results, rejecting only one such species. The invasive-elsewhere criterion is generally considered very important for the assessment of potentially invasive species and sometimes it is even taken as the only permanent predictor of invasion (Williamson, 1999).

Taxonomic classification is another source of bias when transferring screening system of Reichard and Hamilton from one area to another. Stressing the invasiveness of other species within the genus/family and using it as an important decision attribute makes the results rather sensitive to the differences in generic concept used in different areas. Although many invasive species belong to genera containing a single invasive species, membership to a large genus becomes a sort of ‘the mark of Cain’ for all its representatives. The probability that a large genus includes an invasive species is higher than for small genera and the simple system of answering yes or no does not take into account how large a proportion of species within the genus are invasive. Because of the invasion of Acer negundo (Negundo aceroides) in the Czech Republic, decision on other casually occurring or even non-escaping maples was postponed to further analysis (see Appendix S1 in Supplementary Material). A pest species Quercus rubra is an example of the one most seriously misclassified; it was accepted while two other non-escaping oaks were recommended for further screening. The results within genera Prunus and Robinia were also biased by the ‘genus invasiveness’ concept. Finally, absence of vegetative growth is an attribute of non-invasiveness in the North American system. Although vegetative growth is considered as an important attribute of successful invader (Kolar & Lodge, 2001; Weber & Gut, 2004), some successful invaders in Central Europe do not reproduce vegetatively. From the tested list, this holds for Mahonia aquifolium, Lycium halimifolium, Pinus strobus, and Quercus rubra, but only the first species was rejected (see Appendix S1 in Supplementary Material). To conclude, it appears that the low number of questions on which the Reichard and Hamilton’s system is based makes the scheme easy to use in situations for which it was developed, but limits its applicability elsewhere.

WRA was developed for Australia and New Zealand (Phe- loung, 1995; Pheloung et al., 1999) and successfully tested in Hawaii and other Pacific islands (Daehler & Carino, 2000; Daehler et al., 2004). Pheloung et al. (1999) tested 370 plant species alien to Australia, representing both weeds and useful taxa from agriculture, the environment, and other sectors. All serious pests and 84% non-harmful but invasive species were rejected and only 7% of non-invasive species were rejected or recommended for further analysis. When applied to Hawaii, WRA rejected 99% of invasive species (Daehler & Carino, 2000). In other Pacific islands, 95% of invasive species were rejected and 85% of non-invasive species were accepted. By using additional decision tree, Daehler et al. (2004) were able to cut down the portion of species recommended for further analysis from 24% to 8%. The results yielded by the WRA model with additional decision tree in the Czech Republic were even better than in Australia and Pacific region. All invasive species were rejected and 83.8% of non-invasive were accepted. This implies that the WRA screening procedure, as modified by Daehler et al. (2004), might be potentially suitable for a wider range of geographical regions.

Of the 127 woody species reported as escaping from cultivation in the Czech Republic, 54 are naturalized (42.5%) and there are 11 (20.3%) pests among the latter. These values are much higher than predicted by the Tens Rule (Williamson, 1996) and compare to those found in vertebrates (Jeschke & Strayer, 2005). It implies that woody plants are very successful as invaders, compared to other plant groups. All three schemes reflected a clear trend of increasing proportion of rejected species as naturalization process progressed from casual to naturalized to invasive stage. In general, results obtained for casual and naturalized but non-invasive species are not too encouraging regardless of the scheme used. Not surprisingly, it is more difficult to predict the behaviour of species that escaped from cultivation but are not yet invasive. Many woody species have long lag-phases to invasions and the number of invasive aliens will increase in the future even if introductions ceased instantly (Kowarik, 1995). In our study, we attempted to reduce this bias by testing only those species that are planted for sufficiently long period in the Czech Republic, but it is clear that species yet to become invasive increase the variation in possible outcome of invasion, hence affecting the accuracy of the risk assessment schemes.

The overall accuracy of the best fit model (WRA+Daehler) achieved in conditions of Central Europe was 86% (compared to 68% for WRA and 62% for Reichard–Hamilton). Nevertheless, the predictive power of risk assessment schemes is higher for identifying invasive and harmful species than for finding safe non-invasive species. The level of misclassifications tends to be higher for species that will probably never become invasive than for harmful invaders; the number of potentially rejected non-invasive aliens is relatively high because of low base-rate effect of occurrence of invasive species (Smith et al., 1999). Data are available for the Czech Republic that allow to quantify successful transition from one step of invasion process to the next and demonstrate that predicting invasions is indeed about predicting rare events. The potential pool of woody aliens introduced to the Czech Republic includes 4360 taxa (M. Křivánek, unpublished data). Of these, only 2.9% are known to have escaped from cultivation, 1.7% persist as casuals, and 0.8% are naturalized. Only 0.4% (one in 257 species) are invasive and 0.25% (one in 396) are harmful pests. These numbers can be related to the accuracy of the three tested schemes. Of the total source pool of 4360 taxa, 4343 are currently not invasive. If the percentage of false predictions obtained by the tested schemes (Fig. 1) is approximated to these 4343 species, 608 (WRA+Daehler), 1390 (WRA), and 1650 (Reichard–Hamilton) species that are probably safe in terms of potential invasion would be rejected.

Smith et al. (1999) also document that a scheme can be ignored if the economic loss caused by introduction of a harmful species is not eight times higher than a loss caused by its rejection. This approach, however, does not take the identity of species in question and habitat invaded into account. The damage to natural ecosystems is in most cases irreversible, hence difficult to compare to an economic loss resulting from unrealized opportunity. The rejection of a potentially harmless species can be in many
cases compensated by an introduction of another harmless spe-
cies, alien or native. It is possible that continuing commercial use
of some harmful species reflects the inertia of forestry authorities
rather than economic reasons. For example, Pinus strobus has
been planted in the Czech Republic for more than two centuries;
it invades unique natural sandstone habitats. The invasion of this
species has been one of the most dramatic by woody species in
this country (Hadinčová et al., 1997). It does not produce a good
quality timber and could be replaced in many cases by aliens that
are not invasive in the Czech Republic, such as Pseudotsuga
menziesii or Abies grandis (Forest Management Institute 1994);
yet new plantations of P. strobus are being established (Czech
Statistical Office, 2002). This example indicates that a decision
whether to introduce a prediction scheme or to discard it cannot
be based solely on the value of accuracy and reliability it
provides. Schemes achieving high levels of accuracy in different
geographical and ecological situations, such as the WRA model
elaborated by Daehler et al. (2004), represent a valuable tool with
capacity to diminish the risk of invasion by newly introduced
species.

Our study was performed on woody species commonly
planted in the Czech Republic but all the species tested are
planted in a wider area of Central Europe; most of them were
introduced to other parts of Europe prior to their introduction to
the Czech Republic (Svoboda, 1976, 1981). This makes the
results of the present study applicable to the temperate climate of
Central Europe in general.

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REFERENCES

invasive woody plants in the tropics. School of Agricultural
and Forest Sciences Publication 13. University of Wales, Bangor,
83 p.
di Castri, F. (1989) History of biological invasions with special
emphasis on the Old World. Biological Invasions: a global perspective
Invasions by alien plants in the Czech Republic: a quantitative
Crawley, M.J., Harvey, P.H. & Purvis, A. (1996) Comparative
ecology of the native and alien floras of the British Isles. Philo-
sophical Transactions of the Royal Society of London Series B,
Biological Sciences, 351, 1251–1259.
Czech Statistical Office (2002) Forestry in the Czech Republic:
statistical review for year 2002. [URL: http://www.czso.cz/]
(Last accessed April 2004).
prospects for general screening system based on current
regional models. Biological Invasions, 2, 93–102.
risk assessment system for screening out invasive pest plants
from Hawai‘i and other Pacific Islands. Conservation Biology,
18, 360–368.
California: an application of GIS and spatial regression analysis.
Diversity and Distributions, 10, 1–9.
Forest Management Institute (1994) Possible use of introduced
alien woody species in forestry in the Czech Republic. Ústav pro
hospodářskou úpravu lesů — Forest Management Institute,
Brandýs nad Labem (In Czech).
explanation of plant invasiveness: seedling growth and life-
history strategies of 29 pine (Pinus) species. The American
Naturalist, 159, 396–419.
Hadinčová, V., Dobrý, J., Halželová, D., Härkel, H., Herben, T.,
Krahulec, F., Kyndl, J., Moravcová, L., Šmilauer, P. & Šmilauerová,
M. (1997) Invasive species Pinus strobus in protected area
Labské Pískovce. Invasive alien plants in the Czech flora. (ed. by
Společnosti Praha 32, Materiály 14 (In Czech).
of forest tree species outside their natural habitat: a global
review and discussion paper. Forest Health and Biosecurity
Hejný, S., Jehlík, V., Kopecký, K., Kropáč, Z. & Lhotská, M.
(1973) Quarantine weeds of the Czechoslovakia. A Study of the
SZN Praha, Praha (In Czech).
SZN Praha, Praha (In Czech).
Higgins, S.I., Richardson, D.M., Cowling, R.M. & Trinder-Smith,
T. (1999) Predicting the landscape-scale distribution of alien
plants and their threat to plant diversity. Conservation Biology,
13, 303–313.
brates in Europe and North America. Proceedings of the
National Academy of Sciences USA, 102 (20), 7198–7202.
Koblížek, J. (2000) Conifers and hardwoods in our gardens and
parks. Freedom DTP Studio and SURSUM, Tůšnov (In Czech).
propagate pressure as predictors of invasion by woody species
plant species. Management of Natura 2000 habitats (ed. by
Praha (In Czech).


**SUPPLEMENTARY MATERIAL**

The following material is available online at http://www.blackwell-synergy.com/loi/ddi

Appendix S1 List of species used in the present study and results of their evaluation using the three tested prediction schemes.