Testing the Australian Weed Risk Assessment with different estimates for invasiveness

Biological Invasions

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ORIGINAL PAPER

Testing the Australian Weed Risk Assessment with different estimates for invasiveness

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Abstract The Weed Risk Assessment (WRA) has become an effective tool in predicting invasiveness of exotic plant species. In studies testing the WRA, exotic plant species are usually divided into major weeds, minor weeds and non-weeds. However, these divisions are qualitative, as the categories are assigned by experts. Many studies searching for plant traits that are indicative of plant invasiveness use quantitative estimates to measure invasiveness. We compared how quantitative and qualitative estimates of invasiveness may relate to WRA scores. As quantitative estimates we used regional frequency (spread), change in regional frequency and local dominance of naturalized exotic plant species in The Netherlands. To obtain a qualitative estimate we determined if the exotic plant species occurred on a black list in neighbouring regions. We related WRA scores of the exotic plant species to these qualitative and quantitative estimates of invasiveness. Our results reveal that the WRA predicted the qualitative (black list) estimate more accurately than the quantitative (dominance and spread) ones. The black list estimate matches with the overall impact of exotic species, which is assumed to incorporate regional spread, local dominance and noxiousness. Therefore, the WRA predicts the noxiousness component, but to a lesser extent the spatial components of impact of exotic species. On the other hand, studies that use regional spread and other quantitative estimates of invasiveness tend not to include the noxiousness component of impact. We propose that our analyses may also help to further solve the recent debate on whether or not performing research on exotic species.

Keywords Risk assessment · Impact · WRA · Regional spread · Local dominance · Aliens

Introduction

The Weed Risk Assessment (WRA) has been developed in Australia (Pheloung et al. 1999) and has been suggested to be one of the most effective tools to predict which exotic plant species may become invasive. The WRA identifies specific exotic plant species that should be rejected or accepted for import, or when further evaluation is required because a species is categorized as an intermediate risk. The

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WRA is based on attributes of species that cover biogeography, life history traits and weediness. The WRA has been tested (with some minor modifications) in a number of regions outside of Australia, for example Hawaii (Daehler et al. 2004), Czech Republic (Křivánek and Pyšek 2006), Italy (Crosti et al. 2010) and Tanzania (Dawson et al. 2009b). In all these regions, the WRA has been shown to effectively predict invasiveness (Gordon et al. 2008a). Due to the costs associated with the impacts of problematic weeds, implementing the WRA appears economically prudent, even when some beneficial non-weeds might be rejected for import (Keller et al. 2007). On the other hand, a more recent review is less positive about applying weed risk assessments in general (Hulme 2012), claiming that issues with objective measures of hazards, with quantifying uncertainty and with biases in expert judgement all limit the utility of weed risk assessments.

In most studies testing WRAs, there is an a priori assignment of species to categories of major weeds, minor weeds and non-weeds (Daehler et al. 2004; Gordon et al. 2008b; McClay et al. 2010; Nishida et al. 2009; Pheloung et al. 1999). These categories are usually assigned by experts. The question remains how the WRA performs in comparison to other estimates of invasiveness or weediness. Only some studies testing the WRA have used a more quantitative approach to categorise species as major, minor and non-weeds (Křivánek and Pyšek 2006; Dawson et al. 2009b) These studies used a definition of invasiveness that is based on the concept of the invasion process (Richardson et al. 2000; Blackburn et al. 2011). This more quantitative approach is comparable to the approach mostly used in studies correlating invasion success to ecological or life history factors. A number of quantitative estimates have been used to quantify the last phase of invasiveness in these studies, for example regional frequency (Bucharova and van Kleunen 2009; Küster et al. 2008; Speek et al. 2011), rate of increase in regional frequency (Thompson et al. 1995), or local dominance (Speek et al. 2011).

The aim of the present study was to compare how qualitative versus quantitative estimates of invasiveness for exotic naturalised species in the Netherlands are predicted by WRA scores. We used three quantitative estimates, including: regional frequency, change in regional frequency over time, and local dominance. The qualitative estimate was perception of invasiveness based on perception of noxiousness in neighbour regions. We have determined these estimates for exotic plant species that have become naturalised in The Netherlands and correlated the estimates with the WRA scores according to Pheloung et al. (1999).

As the estimates may focus on different elements of invasiveness, we expected them to relate to different aspects of the WRA. For example, regional frequency likely reflects how species spread and so may relate to dispersal-related scores in the WRA, rather than to 'undesirable attributes' scores. Therefore, we analysed which of the eight categories of questions in the WRA related best to the different estimates of invasiveness.

Methods

Weed Risk Assessment (WRA)

The WRA consists of 49 questions on biogeography, naturalisation and weediness elsewhere, undesirable traits, and reproduction and dispersal mechanisms (Pheloung et al. 1999). Answers to questions receive a score from −3 to +5. Not all questions need to be answered. The outcome is the sum of all these scores, ranging from −26 to +60. The scores are used to determine whether exotic species that are being considered for introduction, should be rejected (score > 6), accepted (score < 0) or whether further evaluation is required (0–6 score). We modified a couple of questions to make them suitable for the situation of the Netherlands, as the WRA was originally developed for introduced plants in Australia (Pheloung et al. 1999). The modifications involved question 2.01 'suited to Australian climates', which was changed into 'suited to temperate climates', question 2.04 'regions with extended dry periods', which was changed into 'regions with frost periods', and question 8.05 'enemies present in Australia' was changed into 'enemies present in the Netherlands' (Appendix 1). Questions on climate and introduction history were answered as if the species had not yet been naturalised. For that, we did not use information from the Netherlands and Belgium.

The WRA was applied using a well-defined guideline (Gordon et al. 2010). Questions were answered using information from a variety of sources: online factsheets from (NOBANIS 2011), (DAISIE 2011), the Global Weed Compendium, GCW (2011) and CABI Forestry Compendium, CAB International (2010), books describing plant species, such as the Dutch flora (Van der Meijden 2005), and online databases, such as Biolflor (Klotz et al. 2002), and Kew Seed Database (Royal Botanic Gardens Kew 2008).

Species selection

The Dutch Standard list of vascular plants (Tamis et al. 2004) was used to select naturalised exotic plant species in The Netherlands that have established after 1500 AD. Also, we used only terrestrial plant species, as aquatic species are more difficult to be predicted correctly with the WRA (Gordon and Gantz 2011). From this selection, we only included plant species of which suitable data were available on both regional frequency and local dominance. Exotic plant species that have become naturalised after 1950 were excluded, because they may not have had time to occupy all suitable positions in the study region (Speek et al. 2011). The selection resulted in 111 exotic plant species (listed in Appendix 2).

Estimates of invasiveness

We used three quantitative estimates of invasiveness: regional frequency, change in regional frequency, and local dominance. For regional frequency we used data from the FLORBASE database containing approximately 8 million descriptions of occurrences of plants in specified grid cells of 1 × 1 km^2 covering almost all of the Netherlands. These data have been collected predominantly by volunteer botanists from 1975 onwards (Van der Meijden et al. 1996). Regional frequency estimates of the 111 exotic plant species were calculated by enumerating their presence in all 1 × 1 km^2 grid cells of The Netherlands (Tamis 2005; Tamis et al. 2005). Presence was expressed as the permillage (/1,000) of the total number of square kilometres of the Netherlands (c. 37,000) in which the species had been observed.

Data on change in regional frequency were based FLORBASE, supplemented with information from another database, FLORIVON. The latter contains information on plant occurrences from 1900 to 1950 (Kloosterman and Van der Meijden 1994). Change represents the increase in regional frequency from the period 1900–1950 to the last decade of the 20th century expressed as: change = log10 (regional frequency last period) − log10 (regional frequency first period). The numbers of recordings of grid cells vary considerably. For comparison in time, the most recent observations of each period have been used. The data have been corrected for temporal and geographic differences in sampling intensity (Tamis 2005; Tamis et al. 2005).

The Dutch Vegetation Database (Hennekens and Schaminée 2001) was used to collect local plant dominance data. This database comprises descriptions of approximately 500,000 local plant communities scattered across The Netherlands and is independent of the FLORBASE and FLORIVON databases. Each record in the Dutch Vegetation Database describes the abundance of all plant species in the plant community of the plot expressed as percentage cover per species. The sizes of the plots depend on the type of vegetation and ranges from 1 × 1 m^2 for grasslands to 10 × 10 m^2 for forests.

To calculate local dominance we divided the number of vegetation records with that species having >10 % ground cover by the total number of vegetation records with that plant species and multiplied this number by 100 to obtain a percentage (Speek et al. 2011). This results in frequency of local dominance, which will be named ‘local dominance’ throughout this paper. To reduce bias from non-random sampling we checked the data of all exotic plant species and modified the local dominance of some species according to expert opinion (Speek et al. 2011).

As a fourth and qualitative estimate, we used information on species from our selection that were on lists of the most invasive species in surrounding regions. We used data from EPPO, the European phytosanitairy service (EPPO 2011), the ‘100 of the Worst’ by DAISIE, the European network for invasive species (DAISIE 2011), the NOBANIS system from North and Central Europe (NOBANIS 2011) and Harmonia from Belgium (Branquart 2011). This resulted in 19 species that were identified as noxious invaders (Appendix 2). These lists are collections of exotics that are perceived as some of the worst in that region; they do not claim to be complete overviews of all noxious invaders. We termed this the ‘black list estimate, with the most noxious species as the black list species and the others the non-black list species. It is comparable to the a priori distinction between minor and major weeds. According to our data, these black list species are on average more widespread ($t_{109} = -3.54$; $p < 0.001$), spread faster ($t_{109} = -4.66$; $p < 0.001$) and have a higher local dominance ($t_{109} = -3.46$; $p < 0.001$) than selected species that are not on a black list (Fig. 1).

Statistics

We used linear regression models to analyse relationships between the WRA-score and the different estimates for invasiveness. These estimates were considered as the outcome variables and the WRA scores were considered as the predictors. Regional frequency was log-transformed to obtain a normal error structure. Outcomes for local dominance were analysed using a generalized linear model with a binomial error structure and a logit link. Binomial totals were set at 50, because 50 % was the maximum value of dominance achieved and expert opinion was used to modify the data with this maximum as a boundary. Outcomes for the black list estimate were analysed by a logistic regression.

We used the sequential Bonferroni correction procedure (Holm 1979) to account for multiple testing of each WRA-score against the variety of estimates, which is less conservative than the normal Bonferroni correction. This procedure adjusts the significance level at which hypotheses are tested. It first ranks *p* values from largest to smallest. The smallest *p* value is tested against α/c, the next at $\alpha/(c-1)$, the next at $\alpha/(c-2)$, etc., with c being the number of p values tested (4 in our study) and α being 0.05.

R-square values of different statistical models are difficult to compare. Therefore we performed additional analyses on the data. We compared how well WRA-scores predicted the different proxies for invasiveness with receiver operating characteristics (ROC) (Fawcett 2006; Delong et al. 1988), as has become custom when testing WRA outcomes (Gordon et al. 2008a, b; Dawson et al. 2009b; McClay et al. 2010). However, the method requires that a continuous predictor is tested against an outcome variable with two categories. This could be done for the black list proxy, with 19 species on a European black list and the other 92 species not. We categorised the quantitative proxies for invasiveness, based on continuous values, in a similar way, with the 19 highest values classified as invaders and the 92 lowest values classified as non-invaders in order to stay in line with the black list proxy.

ROC-curves are used to analyse the true positive rate versus the false positive rate. Each data point in the graph represents the true positive and false positive rate at different possible cut-off points. To analyse how well outcomes are predicted the area under the curve (AUC) is calculated (Fawcett 2006). If the AUC is close to 0.5 the method is not a better predictor than a random guess, if the AUC is 1.0 it is a perfect predictor. We used Sigmaplot to create graphs and perform basic analyses. We used the R package pROC (Robin et al. 2011) to compare the different AUC's and to calculate the optimal cut-off point for each

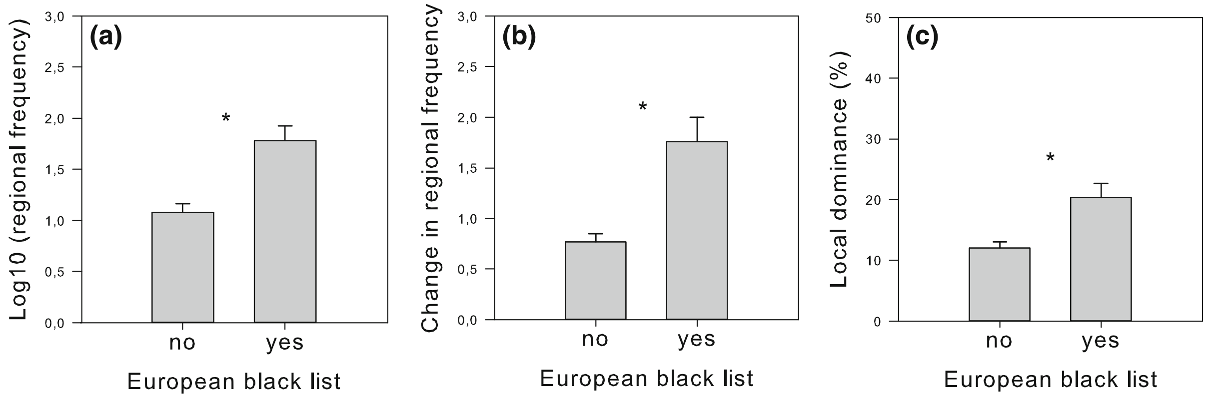


Fig. 1 Differences in regional frequency (**a**), change in regional frequency from 1900–1950 to 1990–2000 (**b**) and local dominance (**c**) for exotic plant species in The Netherlands that are on black lists in neighbouring regions or not. *Asterisks* indicate significant differences at $p < 0.05$. *Error bars* are standard errors of the mean

proxy, using Youdens' Index (Youden 1950). Again, we corrected for multiple testing with the sequential Bonferroni method.

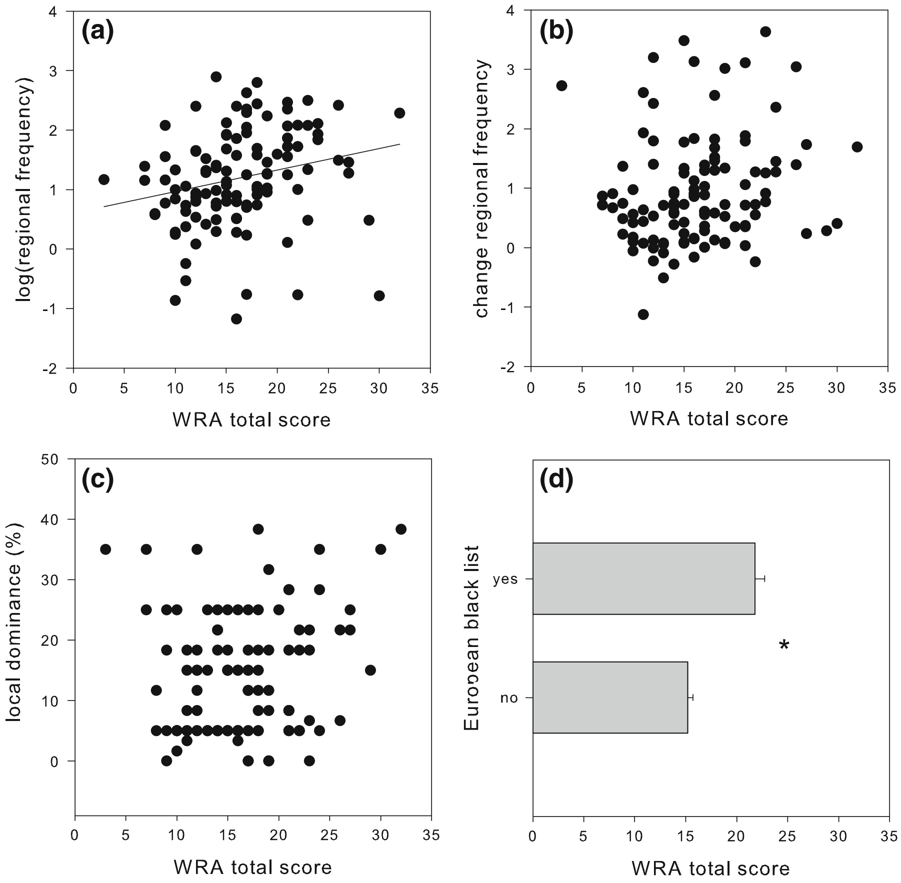
To analyse which part of the WRA relates best to each estimate for invasiveness, we have summed the WRA scores per category, resulting in eight partial scores (Appendix 1). We used model selection procedures to obtain the minimum adequate model for each estimate. To choose this model from all possible subsets, we used Schwartz Information Criterion (SIC). This criterion is more conservative and also more robust than the more often used Akaike Information Criterion (Murtaugh 2009). Scores from all eight categories of question were used as predictors in the full model. We also included residence time as a predictor, because it has been shown that measurements like regional frequency and local dominance are dynamic in time (Bucharova and van Kleunen 2009; Dawson et al. 2009a; Hamilton et al. 2005; Speek et al. 2011). This might explain why certain species with a high WRA score are not invasive yet (Gasso et al. 2010). These analyses were done in Genstat version 11.

Questions or answers in the WRA may be interpreted in different ways. We made a quality assessment of our scoring by comparing with a study from Japan (Nishida et al. 2009). Fourteen species evaluated by us also have been evaluated in Japan under similar climate conditions. We used Wilcoxon matched pair test to investigate whether the studies from Japan and the Netherlands have a different mean score.

Results

Total WRA-scores ranged from 3 to 32. Only one species (*Salix dasyclados*), was not immediately rejected (score < 6), but had a score that would require further evaluation. Number of questions answered varied from 17 to 39. Comparison with the

Fig. 2 Relationships between different estimates of invasiveness of exotic plant species in the Netherlands and WRA-scores. The estimates are regional frequency (**a**), change in regional frequency from 1900–1950 to 1990–2000 (**b**), local dominance (**c**) and being on a black list or not in a neighbouring region (**d**) of exotic plant species in the Netherlands. A *line* indicates a significant correlation. *Asterisks* indicate significant differences between categories. *Error bars* are standard errors of the mean



Japanese study showed that outcomes of the WRA for the same species were not significantly different ($t_{13} = 36.00$, $p = 0.515$).

Relationships between the WRA score and the different estimates of invasiveness showed that the WRA correlated best with the black list estimate (Fig. 2; Table 1). Regional frequency was also significantly correlated to the WRA-score, but explained variation was relatively low ($r^2 = 0.045$). Change in regional frequency and local dominance were marginally significantly ($p = 0.081$ and $p = 0.070$ respectively) correlated to the WRA-score.

Results from ROC analyses confirmed that the WRA is significantly better at predicting the black list estimate and the regional frequency estimate than a random guess (Fig. 3; Table 2). Moreover, the black list estimate is significantly better predicted by WRA than the change in regional frequency and the local dominance (Table 2). The optimal cut-off score for the black list estimate was at WRA-score 18.

Categories of questions in the minimal adequate model varied per estimate of invasiveness (Table 3). Regional frequency correlated positively to the climate and distribution scores of the WRA. None of the other WRA categories of questions were included as predictors in the minimal adequate model. Change in regional frequency was only predicted by residence time; plant species with a shorter residence time increased more in regional frequency than species with a longer residence time. High local dominance was best predicted by a high score for weediness elsewhere. Being a black list species was best predicted by a longer residence time, a high score for weediness elsewhere and a high score on undesirable attributes.

Table 1 p Values and R^2 adjusted values of the relationships between the different estimates of invasiveness and the WRA-scores

Estimate of invasiveness	Estimate	p Value	R^2 adj
Regional frequency	**0.036**	**0.014**	**0.045**
Change of regional frequency	0.029	0.081	0.019
Local dominance	0.034	0.070	0.021
European black list	**0.271**	**0.001**	**0.240**

In bold are the results that remained significant after sequential Bonferroni correction

Discussion

Estimates of invasiveness and WRA

The qualitative estimate of invasiveness, occurrence on a black list in surrounding countries, was best predicted by the WRA-score. The WRA did not predict the quantitative estimates of invasiveness (regional spread, change in regional spread, and local dominance) very well. Interestingly, the quantitative estimates related well to the qualitative estimate, which begs the question why the WRA predicts the black listing better than regional spread or local dominance. In order to better understand the predictions of the WRA, we further examined the impact of exotic species. We assume it is this impact that the WRA strives to predict. Impact can be considered as: $I = R \times A \times E$; where I is the overall impact of a species, R is the range size (or regional frequency), A is the average abundance (comparable to local dominance) and E is the noxious impact effect per individual (Parker et al. 1999). What this ‘noxious effect per individual’ comprises, is highly variable. Studies on invasive species have shown many different types of noxious impacts. Exotics can become noxious weeds in croplands, with large economic impacts due to expensive control measures and reduced crop yields (Pimentel et al. 2005). Another example of a noxious effect is impact on human health such as the allergenic properties of *Ambrosia artemisiifolia* pollen (Taramarcaz et al. 2005). Ecosystem impacts of exotic species include altered nutrient cycling, microbial activity and community composition as exotics replace natives (Vilà et al. 2011). All these factors can contribute to the noxiousness of exotic plants.

Black list species in our study appear to have all the impact elements; they have greater regional frequency (R) and an increase in regional frequency, they have greater local dominance (A) and are also perceived as noxious invaders (E). The black list proxy, therefore, seems an appropriate proxy for the impact, which may explain why it is so well predicted by the WRA.

’Weed elsewhere and undesirable traits’ are the categories of questions that relate strongest to the species placement on the black list. This is quite different from the results for the quantitative estimates, which appeared unrelated to ‘undesirable traits’, except that local dominance was related to ‘weed elsewhere’.

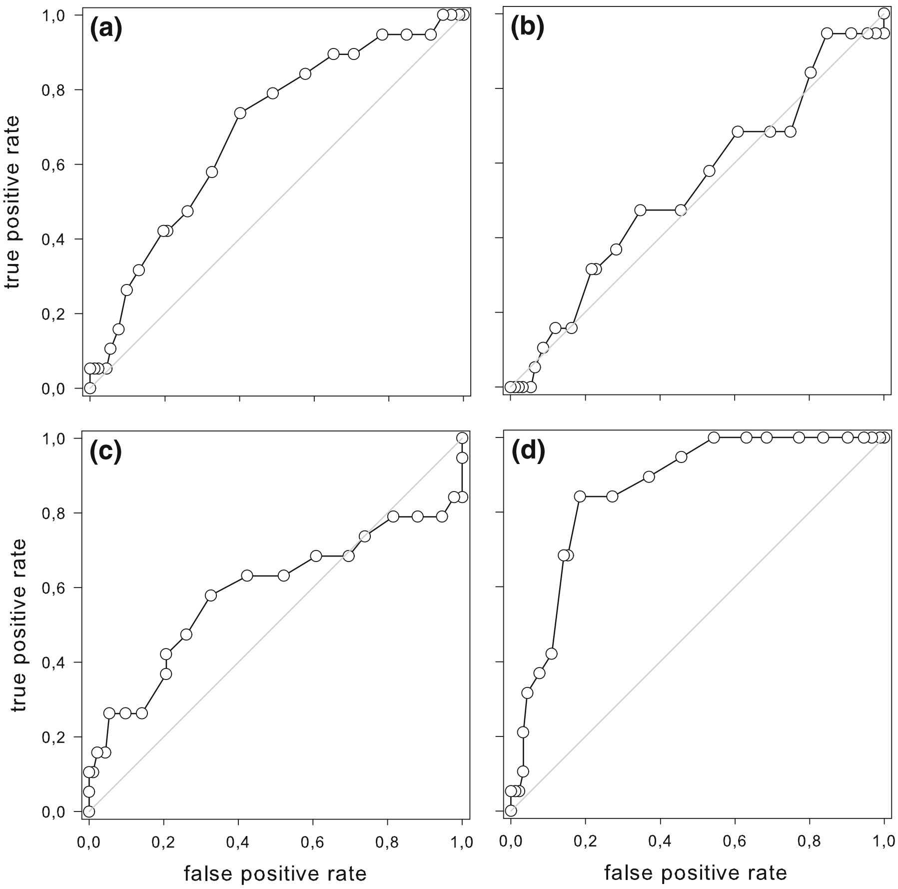


Fig. 3 ROC graphs of the performance of the WRA to predict whether species are defined as invasive or non-invasive, for the estimates of invasiveness regional frequency (**a**), change in regional frequency (**b**), local dominance (**c**) and being on a black list or not (**d**). We categorised the continuous proxies for invasiveness into dichotomous factors, with the top 19 species as invasive and the others as non-invasive (in line with the 19 species that are European black list species). Each data point in the graph represents a different cut-off point for the WRA score that defines species as invasive or non-invasive. False positive rate is the proportion of species that are incorrectly classified as invasive at each cut-off score. True positive is the proportion of species that is correctly classified as invasive at each cut-off score

Table 2 Test-values for ROC-curves using WRA scores to test different estimates of invasiveness

Estimate	AUC	SE	CI	*p* Values	Compare AUC's
Regional frequency	0.6891	0.0641	0.563–0.815	0.0097	ab
Change in regional frequency	0.5363	0.0738	0.392–0.681	0.6191	a
Local dominance	0.5850	0.0871	0.414–0.756	0.2450	a
European black list	0.8587	0.0392	0.782–0.936	<0.0001	b

Letters in the last column show which AUC values were significantly different from each other after sequential Bonferroni correction

Regional frequency related to WRA climate and distribution questions, whereas change in regional frequency related most to residence time. Clearly, these factors are not typical indicators of noxious effects. Therefore, our results suggest that black list species are so well predicted by the WRA, because it includes their individual noxious effects.

Our results seem to indicate that although the quantitative estimates include an important part of the impact of invasive species, they exclude the noxious impact per individual, which can be important as well. For example, *Matricaria discoidea* is one of the most widespread exotic plant species in the Netherlands and in Europe more generally (Lambdon et al. 2008). It has a higher than average local dominance, but has not been considered to have noxious impacts.

Recently, proponents have argued that decisions to implement species control measures should be based on impact and not origin (Thompson and Davis 2011; Davis et al. 2011). Our study indicates that the WRA already focuses strongly on the noxiousness of exotic species, which is an important aspect of their impact.

Table 3 Results of minimal adequate model after model selection for four different estimates of invasiveness of exotic plant species in the Netherlands

Estimate of invasiveness	WRA predictors	Estimate	p Value	R^2 adj
Regional frequency	Climate and distribution	0.561	<0.001	0.112
Change of regional frequency	Residence time	−0.004	<0.001	0.127
Local dominance	Weed elsewhere	0.085	0.022	0.039
Black list[a]	Residence time	−0.014	<0.001	0.082
	Weed elsewhere	0.372	<0.001	0.075
	Undesirable traits	0.499	<0.001	0.081

Predictors are partial scores of the WRA, per category of questions and residence time

[a] Total R^2 adjusted for this model is 34.5 %

Thus, the WRA does not promote combatting exotic species because of their origin, but for their impacts. This has been shown as well in a study on native weeds, which have a WRA score similar to exotic weeds (Nishida et al. 2009). Our study also shows that quantitative estimates of invasiveness miss out on the noxious part of impact.

On the other hand, our results suggest that the WRA has a stronger focus on the noxiousness component of impact than on spread and dominance components of impact. This is evidenced by our results showing that the black list estimate relates strongly to the WRA, but the quantitative estimates do not, even though they relate strongly to the black list. This is further supported by our analyses of which categories of questions are most related to the black list, including the presence of undesirable traits and weediness elsewhere, which are questions about noxiousness. Further, species that are weedy elsewhere are perceived as noxious or weedy in one region and therefore are likely to be perceived as noxious or weedy in another region.

Species selection bias

Data on regional frequency and local dominance are only available for naturalised species. This causes a bias in our species selection. Usually the WRA is tested with species from the entire range of the invasion process, including casuals and even non-escaping exotic plant species (Dawson et al. 2009b; Gordon et al. 2008b; Křivánek and Pyšek 2006; McClay et al. 2010), but our analysis includes only exotic species at the last phase of the invasion process, and therefore only species at the high end of the WRA scores. Our species selection does not enable us to compare the WRA between non-naturalised versus naturalised exotic species. It needs to be confirmed if our conclusions may be extrapolated to species with lower WRA scores as well.

Performance of WRA in the Netherlands

Applying the WRA to data from naturalized exotic plant species in the Netherlands resulted in quite high scores and all species but one were categorized as ‘rejected’, which means that they should be prevented from entering this region. Our results showed no higher average scores than the same species in a Japanese study, so the relatively high WRA scores do not seem to be caused by a tendency of us to answer questions differently (Nishida et al. 2009). Our WRA scores might be explained partially by our species selection of only naturalised species. However, studies testing naturalised non-invasive species (Dawson et al. 2009b; Křivánek and Pyšek 2006) found scores low enough to have these non-invaders accepted, that is having scores below zero. Possibly, the increased availability of data on exotic species increases the WRA scores. Availability of factsheets on weedy species is increasing. Moreover, factsheets on weedy species typically describe species in relation to the most severe impact (Hulme 2012), and so the increased availability of these data should result in higher WRA scores. Other studies also resulted in a relatively high scores and a higher a cut-off point for the ‘reject’ category, for example a score of 10 (Nishida et al. 2009) or even a score of 14 (McClay et al. 2010) compared to a score of 6 as used in the Australian WRA. For our study, a cut-off score of 18 is calculated to give the best result for black list species. This cut-off score, therefore, might be more appropriate when using the WRA to predict which new exotic plant species could become invasive in the Netherlands.

Conclusion

In our study, the WRA predicted quantitative estimates of invasiveness, like regional spread and local dominance, less well than the more qualitative proxy of occurring on a blacklist in the surrounding region. Quantitative estimates of invasiveness apparently do not include the noxiousness of species, which is generally believed to be an important component of invasiveness. Whereas the WRA is heavily weighted by the noxious aspects of invasive species, it only weakly predicts the dominance and spread of these species. This shows an important gap between studies testing the WRA, using more qualitative proxies of invasiveness and studies searching for traits related to invasiveness, mostly using quantitative estimates like spread and dominance. We conclude that it may be valuable in future studies to use different estimates of invasiveness for both type of studies, in order to bridge this gap. This may also help to further research and management priorities.

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Appendix 1

See Table 4.

Table 4 Questions in the WRA

History/biogeography		
Domestication/ cultivation	1.01	Is the species highly domesticated. If answer is 'no' got to question 2.01
	1.02	Has the species become naturalised where grown
	1.03	Does the species have weedy races
Climate and distribution	2.01	Species suited to **temperate** climates
	2.02	Quality of climate match data
	2.03	Broad climate suitability (environmental versatility)
	2.04	Native or naturalised in regions with **frost** periods
	2.05	Does the species have a history of repeated introductions outside its natural range
Weed elsewhere	3.01	Naturalised beyond native range
	3.02	Garden/amenity/disturbance weed
	3.03	Weed of agriculture/horticulture/ forestry
	3.04	Environmental weed
	3.05	Congeneric weed
Biology/ecology		
Undesirable traits	4.01	Produces spines, thorns or burrs
	4.02	Allelopathic
	4.03	Parasitic
	4.04	Unpalatable to grazing animals
	4.05	Toxic to animals
	4.06	Host for recognised pests and pathogens
	4.07	Causes allergies or is otherwise toxic to humans
	4.08	Creates a fire hazard in natural ecosystems
	4.09	Is a shade tolerant plant at some stage of its life cycle
	4.10	Grows on infertile soils
	4.11	Climbing or smothering growth habit
	4.12	Forms dense thickets
Plant type	5.01	Aquatic
	5.02	Grass
	5.03	Nitrogen fixing woody plant
	5.04	Geophyte
Reproduction	6.01	Evidence of substantial reproductive failure in native habitat
	6.02	Produces viable seed
	6.03	Hybridises naturally
	6.04	Self-fertilisation
	6.05	Requires specialist pollinators
	6.06	Reproduction by vegetative propagation
	6.07	Minimum generative time (years)
Dispersal mechanisms	7.01	Propagules likely to be dispersed unintentionally
	7.02	Propagules dispersed intentionally by people
	7.03	Propagules likely to disperse as a produce contaminant
	7.04	Propagules adapted to wind dispersal
	7.05	Propagules buoyant
	7.06	Propagules bird dispersed
	7.07	Propagules dispersed by other animals (externally)

Table 4 continued

	7.08	Propagules dispersed by other animals (internally)
Persistence attributes	8.01	Prolific seed production
	8.02	Evidence that a persistent propagule bank is formed (>1year)
	8.03	Well controlled by herbicides
	8.04	Tolerates or benefits from mutilation, cultivation
	8.05	Effective natural enemies present in **the Netherlands**

Parts of the questions that are in bold, are the parts where the questions have been adapted to the Dutch situation

Appendix 2

See Table 5.

Table 5 Species in bold are species that were identified as being on a black list in a neighboring region

Species	WRA-score	Species	WRA-score
Allium carinatum	17	*Leucojum vernum*	17
Allium paradoxum	11	***Lupinus polyphyllus***	16
Alnus incana	16	*Lycium barbarum*	18
Amaranthus blitoides	16	***Mahonia aquifolium***	26
Amaranthus retroflexus	21	*Matricaria discoidea*	14
Amelanchier lamarckii	18	*Medicago sativa*	15
Angelica archangelica	18	*Mibora minima*	10
Anthemis tinctoria	8	*Muscari botryoides*	9
Anthoxanthum aristatum	13	*Muscari comosum*	13
Arabis arenosa	10	*Oenothera parviflora*	14
Aronia prunifolia (*x*)	11	*Ornithogalum nutans*	17
Aster lanceolatus	19	*Oxalis corniculata*	19
Berteroa incana	9	*Oxalis fontana*	16
Bidens connata	12	*Oxycoccus macrocarpos*	12
Bidens frondosa	21	*Parentucellia viscosa*	14
Buddleja davidii	21	*Pentaglottis sempervirens*	12
Bunias orientalis	21	*Persicaria wallichii*	11
Ceratochloa carinata	18	*Poa chaixii*	22
Chenopodium foliosum	14	*Potentilla intermedia*	10
Claytonia perfoliata	17	*Potentilla norvegica*	19
Claytonia sibirica	12	*Potentilla recta*	22
Coincya monensis subsp. *recurvata*	9	***Prunus serotina***	17
Conyza canadensis	18	*Pseudofumaria lutea*	7
Corispermum intermedium	7	*Rapistrum rugosum*	10
Coronopus didymus	15	***Rhododendron ponticum***	19
Cotula coronopifolia	16	*Ribes alpinum*	16
Crambe maritima	12	***Robinia pseudoacacia***	19
Crepis tectorum	13	*Rorippa austriaca*	17
Crocus vernus	8	***Rosa rugosa***	24
Cuscuta lupuliformis	15	*Rubus spectabilis*	18
Cymbalaria muralis	20	*Salix dasyclados*	3
Cynodon dactylon	21	*Salvia verticillata*	11
Datura stramonium	21	*Scilla bifolia*	23
Diplotaxis muralis	15	*Scilla siberica*	15
Eragrostis minor	12	*Scrophularia vernalis*	10
Eragrostis pilosa	15	***Senecio inaequidens***	23
Eranthis hyemalis	17	*Setaria pumila*	19
Erigeron annuus	18	*Setaria verticillata*	18
Erucastrum gallicum	13	*Sisymbrium altissimum*	17
Fallopia japonica	24	*Sisymbrium austriacum* subsp. *chrysanthum*	16
Fallopia sachalinensis	27	*Sisymbrium loeselii*	14
Galanthus nivalis	15	*Sisymbrium orientale*	16
Galinsoga parviflora	23	*Solanum triflorum*	14
Galinsoga quadriradiata	21	***Solidago canadensis***	22
Geranium phaeum	11	***Solidago gigantea***	32
Geranium pyrenaicum	14	***Spartina anglica***	15
Heracleum mantegazzianum	26	*Symphoricarpos albus*	24
Hieracium amplexicaule	30	*Tragopogon porrifolius*	11

Table 5 continued

Species	WRA-score	Species	WRA-score
Hieracium praealtum	29	*Trifolium hybridum*	12
Hordeum jubatum	12	*Tulipa sylvestris*	10
Hypericum canadense	16	*Veronica filiformis*	9
Impatiens glandulifera	21	*Veronica peregrina*	14
Impatiens parviflora	22	*Veronica persica*	17
Juncus tenuis	17	*Vicia villosa*	13
Lepidium draba	27	*Xanthium strumarium*	23
Lepidium virginicum	15		

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