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ORIGINAL PAPER

Trans-national horizon scanning for invasive non-native species: a case study in western Europe

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Abstract Horizon scanning for high-risk invasive non-native species (INNS) is crucial in preparing and implementing measures to prevent introductions, as well as to focus efforts in the control of species already present. We initiated a trans-national horizon-scanning exercise focused on four countries in western Europe: Great Britain, France, Belgium and The Netherlands, which share similar environmental and socio-economic characteristics. We followed a structured four-step approach combining existing knowledge about INNS, with a collaborative identification of priorities for research and management: (1) systematic review of potential INNS of concern, (2) discrimination of INNS into an Alert and Black List depending on their absence or presence in the study area respectively, (3) risk analysis of the Alert List, and (4) expert ranking of species in the Black List. Amongst species not yet present in the four countries (i.e. Alert List), assessors reliably pointed to the Emerald ash-borer (*Agrilus planipennis*) and Sosnowski's hogweed (*Heracleum sosnowskyi*) as those INNS with the highest risk of invasion and impact. The Japanese knotweed (*Fallopia japonica*), Himalayan balsam (*Impatiens glandulifera*), zebra mussel

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B. Gallardo · A. Zieritz · D. C. Aldridge
Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK

Present Address:
B. Gallardo (✉)
Department of Biodiversity Conservation and Ecological Restoration, Pyrenean Institute of Ecology (IPE-CSIC), Avda. Montañana 1005, Campus de Aula Dei, 50059 Saragossa, Spain
e-mail: belinda@ipe.csic.es; galla82@hotmail.com

A. Zieritz
School of Geography, University of Nottingham Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia

T. Adriaens
Research Institute for Nature and Forest (INBO), Kliniekstraat 25, 1070 Brussels, Belgium

C. Bellard
Department of Genetics, Evolution and Environment, Centre for Biodiversity and Environment Research, Darwin Building, UCL, Gower Street, London WC1E 6BT, UK

C. Bellard
Ecology, Systematic and Evolution, UMR CNRS 8079, Université Paris Sud, 91405 Orsay, France

P. Boets
Laboratory of Environmental Toxicology and Aquatic Ecology, Ghent University, J. Plateaustraat 22, 9000 Ghent, Belgium

P. Boets
Provincial Centre of Environmental Research, Godshuizenlaan 95, 9000 Ghent, Belgium

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(*Dreissena polymorpha*) and killer shrimp (*Dikerogammarus villosus*) were consistently highlighted as some of the most problematic INNS already present in the study area (i.e. Black List). The advantages of our combined approach include that it is inclusive of all-taxa, prioritizes both established and emerging biological threats across trans-national scales, and considers not only the ecological impact, but also potential direct economic consequences as well as the manageability of invasive species.

Keywords Collaborative risk assessment · Ecological impact · Invasive potential · Economic impact · Management · Invasive species · Alert List · Black List · Prioritization

Introduction

The introduction and spread of invasive non-native species (INNS) today constitutes one of the most important drivers of global change in biodiversity and ecosystem services (Sala et al. 2000). Impacts associated to INNS are numerous and include widespread alteration of habitats, replacement of native species through predation and competition, transmission of diseases, and hybridisation, and adverse impacts on human health and the economy (DAISIE 2009; Pimentel et al. 2000). As a consequence, biological invasions have been implicated in 54 % of animal extinctions (Clavero and García-Berthou 2005), and their costs to the European economy are estimated as €12.5–20 billion annually (Kettunen et al. 2008). For this reason, the European Union recently adopted Regulation No. 1143/2014 on the prevention and management of the introduction and spread of INNS (European Commission 2014; Genovesi et al. 2015). The successful prevention of future introductions and effective control of species that are already present, first and foremost requires the systematic examination of potential high-risk INNS to support decision making (Caffrey et al. 2014). In fact, such proactive horizon scanning policies and approaches have already demonstrated net economic and ecological benefits (Keller et al. 2007).

According to the Convention on Biological Diversity (http://www.cbd.intinvasive/terms.shtml), horizon scanning of INNS ideally involves a systematic risk assessment of the likelihood and consequences of the introduction, establishment, spread, and impact of a wide range of non-native species using the best available scientific information, and often involves expert consultation. According to these guidelines, various national risk assessment protocols have been developed for a number of European countries including, amongst others, Belgium (e.g. ISEIA, Branquart et al. 2009; D'hondt et al. 2015), Great Britain (e.g. GB-NNRA, Baker et al. 2008; FISK, Copp et al. 2009), Norway (Sandvik et al. 2013), and Ireland (Kelly et al. 2013). Issues relating to INNS are, however, rarely specific to single countries but instead transcend national borders. Moreover, the invasion history of a species in one region can inform on its likely impacts in another country, especially where the regions are bioclimatically similar (Ricciardi 2003). To guarantee that knowledge on INNS gained in one country informs decisions on preventive actions, management and control options for INNS in other vulnerable countries, a trans-national approach to horizon-scan invasive species is required (Caffrey et al. 2014).

As well as being restricted to single countries, INNS horizon-scan protocols are typically taxon-specific, which can limit their general utility to scientists and practitioners. Examples include the protocols of the European and Mediterranean Plant Protection Organization (EPPO) (Brunel et al. 2010), the European Food Safety Agency (EFSA) for plant pests (Gilioli et al. 2014), or the Freshwater Fish Invasiveness Screening Kit (Copp et al. 2009). The comparatively narrow scope of these and many other protocols greatly reduces the possibility for comparing the risks of non-native species across different habitats, economic sectors and types of organisms.

J. R. Britton
Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset BH12 5BB, UK

J. R. Newman
Centre for Ecology and Hydrobiology (CEH Wallingford), Crowmarsh Gifford, Wallingford, Oxon OX10 8BB, UK

J. L. C. H. van Valkenburg
Netherlands Food and Consumer Product Safety Authority, National Reference Centre, P.O. Box 9102, 6700 HC Wageningen, The Netherlands

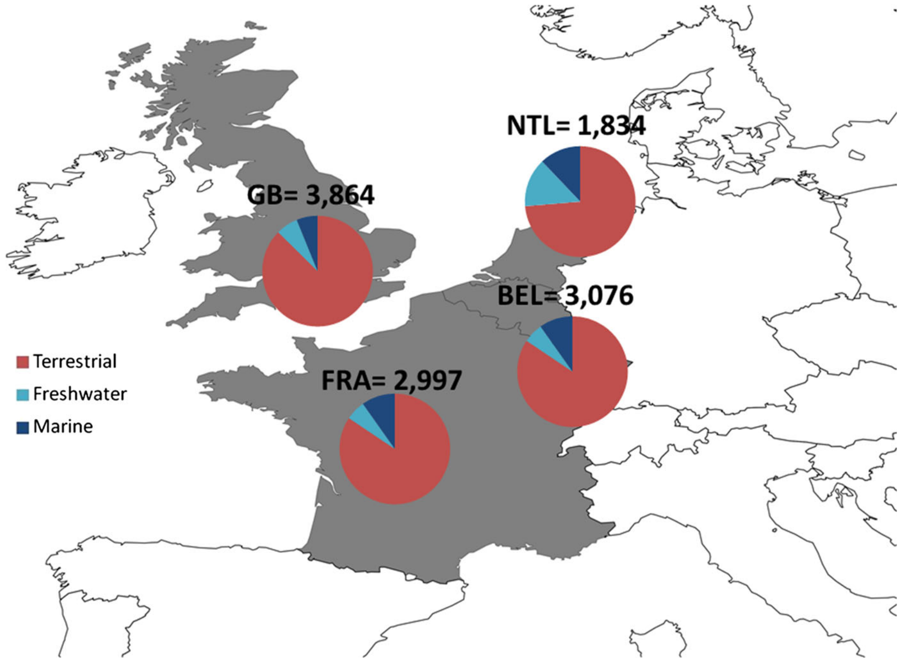

Fig. 1 The focus area of the present horizon-scanning exercise comprises four countries in western Europe: Great Britain (GB), France (FRA), Belgium (BEL) and The Netherlands (NTL), highlighted in *grey*. Numbers indicate total number of non-native species known to be present in each country according to Zieritz et al. (2014). *Pie charts* represent the proportion of terrestrial, freshwater and marine non-native species

Finally, whilst ecological impacts of species are almost always considered in INNS horizon scans, potential economic, human health and safety effects have often been ignored in horizon-scan exercises carried out to date (e.g. Blackburn et al. 2014). This is unfortunate when considering that INNS management should be based on informed and quantified assessment of the joint ecological and economic costs of species (McLaughlan et al. 2014). Therefore, the extensive discrepancies of currently available protocols reduce the comparability of risk classifications between countries and taxa. This prevents authorities from making informed and objective decisions on INNS, especially when working at trans-national scales.

To address the limitations outlined above, we carried out a trans-national horizon-scanning exercise including INNS from all taxa and habitats, and considering both their ecological and economic impacts, including those on human health and infrastructure. The exercise focused on four countries in western Europe: Great Britain, France, Belgium and The Netherlands (Fig. 1). The four countries share similar environmental (e.g. geography, geology, vegetation) and socio-economic (e.g. population density, landscape modification, transport) characteristics, thereby offering comparable susceptibility to the establishment of invasive species. The level of invasion in the region is particularly high (>6000 non-native species according to Zieritz et al. 2014), as is the potential for human-mediated species dispersal from the European continent and elsewhere in the world (Chytrý et al. 2009; Gallardo and Aldridge 2013; Jackson and Grey 2013). Furthermore, the density of non-native species in the region is only comparable to that in South Africa but an order of magnitude greater than USA and Australia (Table 1). Additionally, the number of non-native species per million inhabitants is comparable with the USA and is exceeded only by South Africa and Australia (Table 1). This has been attributed to the relatively high habitat disturbance, the presence of several big ports and dense transportation networks, a high population density and high degree of economic activity (Gallardo and Aldridge 2013).

In recent years, three of the four countries have independently developed national inventories of INNS and have identified potential future invaders. For example, Roy et al. (2014a) used consensus building across expert groups to identify 93 INNS with at least medium risk of arrival, establishment and impact on biodiversity in Great Britain. The Dutch Biodiversity registry (http://www.nederlandsesoorten.nl) lists 960 INNS as not yet present in the country but likely to

Table 1 Level of invasion of the focus area (W Europe) and some other industrialized countries

	Area[a]	Population[a]	Non-native sps (NNS)	NNS/population	NNS/Area	Source
W Europe	86.7	155 mill	6661	42.9	77	Zieritz et al. (2014)
South Africa	122.1	54 mill	8818	163.3	72	Pimentel et al. (2000, 2001)
United States	769.2	319 mill	9808	30.74	10	Pimentel et al. (2001)
Mexico	197.2	118 mill	1000	8.47	5	www.conabio.gov.mx
Australia	769.2	24 mill	2241	93.27	3	Pimentel et al. (2001)
Argentina	278.0	42 mill	652	15.52	2	www.inbiar.org.ar

[a] Area ($\times$10,000 km^2) and population (million) extracted from Wikipedia (http://en.wikipedia.org/)

enter in the near future based on their presence in neighbouring countries. In contrast, only 14 non-established INNS have been highlighted by the Belgian information system Harmonia (http://ias.biodiversity.be). However, methods used to identify INNS of future concern are unclear, and the resulting lists are geographically and taxonomically biased. Moreover, no similar initiatives exist in France. Such extreme differences in predictions of future threats between neighbouring countries highlight the conspicuous lack of trans-national collaboration in this area, even though the INNS in question are likely to disperse across national borders.

The aim of this study is to horizon-scan emerging INNS risks in the area comprising Great Britain, France, Belgium and The Netherlands, in order to provide a trans-national prioritised list of INNS that may pose a threat to regional ecosystems in the future. We did this by following a four-step structured approach, combining existing knowledge about the invasive potential, management difficulty, ecological and economic impacts of invasive species, with a collaborative identification of priorities for research and management (Sutherland et al. 2011). This horizon scan was not taxonomically restricted and covered plants, fungi, vertebrates and invertebrates that invade terrestrial, freshwater and marine habitats.

Methods

To horizon scan for INNS in the focus region we followed a structured approach that involved four steps (Fig. 2): (1) screen national and international lists of 'the worst' INNS to compile a meta-list of problematic invaders worldwide; (2) evaluate presence/absence of these problematic INNS in each the four countries concerned; (3) rank high-risk INNS currently absent from all four countries (Alert List); and (4) identify the most problematic INNS present in at least one of the four countries (Black List).

Step 1: systematic identification of INNS of concern

To guarantee high relevance to regulatory authorities, we selected for evaluation the INNS that would potentially incur the greatest ecological and economic harm in the region. Several national and international institutions have produced tentative lists of INNS potentially causing the worst impacts, generally on biological diversity. These include, for example, the list of the International Union for Conservation of Nature (IUCN) of '100 the world's worst invasive species' (Lowe et al. 2000), and the 'list of 100 of the worst European invasive species' compiled by the EU-funded project DAISIE (DAISIE 2009). In the present work, we consulted 17 similar source lists to compile a meta-list of 347 of the worst current and potential INNS (*cf.* data sources in Supplementary Information, Table S1). As the geographic scope of some of these lists exceeded our study area, the meta-list included some species that are unlikely to be introduced or pose a threat to the region because of limits to introduction pathways, barriers to dispersal or climatic constraints. Nevertheless, as invasion history may not necessarily provide a good prediction of future spread (Gallardo et al. 2013), the precautionary principle calls for inclusion of all INNS in the evaluation.

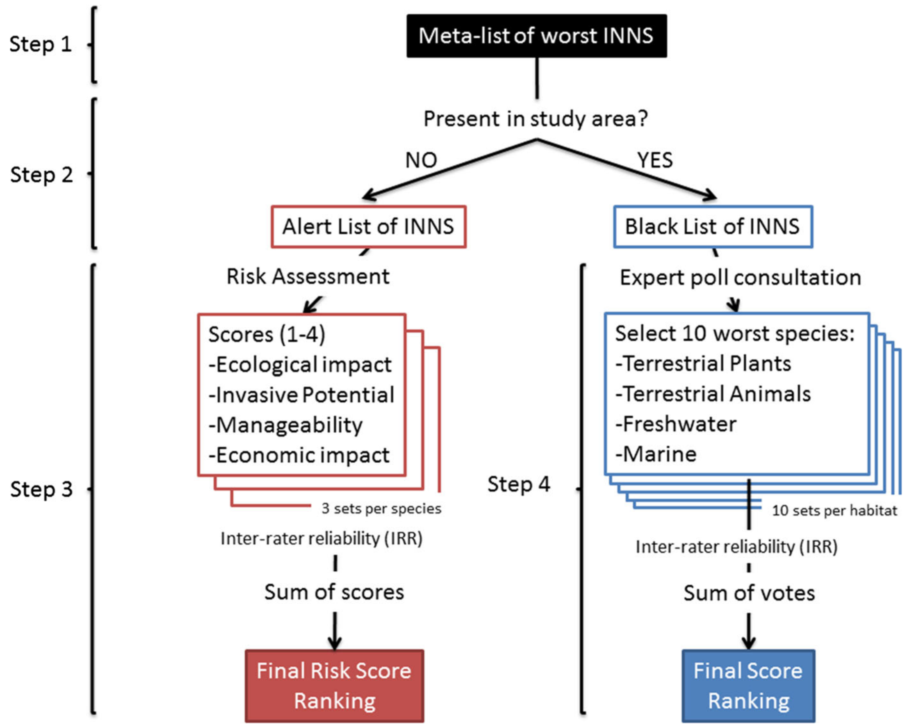

Fig. 2 Structured approach followed for the identification and prioritization of existing and future invasive non-native species (INNS) in the focus region. The process involved four clear steps: (1) identification of INNS of concern, (2) discrimination of INNS into Alert (present) and Black (absent) Lists, (3) risk analysis and ranking of species in the Alert List, and (4) in the Black List

Step 2: discrimination of INNS into Alert and Black Lists

We then divided species in the meta-list into two main groups: (1) INNS Alert List, comprising species not yet present in the region, and (2) INNS Black List, incorporating INNS already present in at least one of the four countries within the region. We did so by consulting Zieritz et al. (2014), which combines information from multiple sources and is thus the most updated and comprehensive database available for the study area.

The next step was the organisation of an Experts Workshop where 22 invited experts attended, representing all four countries. During this workshop, we arranged experts into three topical working groups (terrestrial animals, terrestrial plants and aquatic organisms), and asked them to use the common scoring framework and guidelines described in Steps 3 and 4 to rank species in the Alert and Black Lists respectively. Afterwards, we consulted ten additional experts by email to complement these assessments for a total of 32 experts (see a full list of contributors in Acknowledgements).

Step 3: risk analysis of the Alert List of INNS

In order to prioritise species of the Alert List, each INNS was assigned four risk scores on (1) its likelihood of introduction, establishment and spread (invasive potential score), (2) likelihood and magnitude of ecological impact, (3) likelihood and magnitude of economic impact, and (4) reversibility of the invasion (management difficulty score) by experts (Table 2). The risk scoring system was thereby modified from Molnar et al. (2008) and combines several elements of the invasion process. Because biological invasions are context dependent (Ricciardi et al. 2013), we asked experts to score the potential impacts of species under a 'worst case scenario'; an imaginary situation where preventive measures have failed and the species are widespread in the study area.

Three different experts assessed each of the INNS in the Alert List. To measure uncertainty, we performed an inter-rater reliability (IRR) analysis to assess the degree at which experts agreed in their evaluation of species (Hallgren 2012). IRR analysis aims to determine how much of the variance in the observed scores is due to variance in the true scores

Table 2 Guidelines provided to experts to score invasive non-native species in the Alert List, based on Molnar et al. (2008)

Ecological impact	
U	Unknown or not enough information to determine score
1	Little or no disruption
2	Disrupts single species with little or no wider ecosystem impacts
3	Disrupts multiple species, some wider ecosystem function, and/or keystone species or species of high conservation value
4	Disrupts entire ecosystem processes with wider abiotic influences
Invasive potential	
U	Unknown or not enough information to determine score
1	Very unlikely future introduction because of its environmental preferences, vectors and pathways of introduction
2	Likely introduction of propagules but unlikely establishment of populations in the wild because of environmental constraints
3	Likely introduction and establishment in the long term because of suitable environmental conditions/high propagule pressure
4	Very likely introduction in the short term because of suitable environmental conditions, closeness to invaded regions/suitable vectors and pathways, and high potential of spread
Management difficulty	
U	Unknown or not enough information to determine score
1	Easily reversible, with no ongoing management necessary (eradication)
2	Reversible with some difficulty and/or can be controlled with periodic management
3	Reversible with difficulty and/or can be controlled with significant ongoing management
4	Irreversible and/or cannot be contained or controlled
Economic impact	
U	Unknown or not enough information to determine score
1	Little or no economic impact
2	Affects one economic sector (agriculture, livestock, forestry, human health and infrastructure) with little or no wider economic impacts
3	Affects multiple economic sectors (agriculture, livestock, forestry, human health and infrastructure), requiring periodic investment to control damage
4	Affects multiple and/or key economic sectors (agriculture, livestock, forestry, human health and infrastructure), requiring ongoing significant investment to control damage

after the variance due to measurement error between experts has been removed. Because each species was assessed by a different set of experts, we used Fleiss' kappa (Fleiss 1971). Possible values for Fleiss' kappa statistics range from −1 to 1, with 1 indicating perfect agreement and −1 indicating perfect disagreement. Non-significant IRR scores indicate that differences in expert opinion are too high to guarantee an unbiased ranking of species. To interpret positive significant IRR values, we used the following scale: values from 0.0 to 0.2 indicate slight agreement, 0.21–0.40 indicate fair agreement, and values over 0.41 indicate robust agreement (Hallgren 2012).

The total score of a species equalled the sum of the four category scores, and thus potentially ranged from 4 (for a species of unlikely introduction, little ecological and economic impacts) to 16 (for species with the maximum score in all categories). Thus, the four components of risk were considered as equally important (as in D'hondt et al. 2015). We assessed significant differences in risk scores among terrestrial plants, terrestrial animals, freshwater and marine organisms with non-parametric analysis of variance (Kruskal–Wallis Rank Sum test) followed by post hoc Mann–Whitney *U* tests, after checking that variables were not-normally distributed (Shapiro–Wilk test, $P > 0.05$). Statistical analyses were performed with packages "stats" and "irr" (Gamer et al. 2012) in R v.3.1.1 (R Core Team 2014).

Step 4: ranking of species in the Black List

Due to the large number of INNS in the Black meta-list (over 260 species), we prioritised these using a simpler expert poll consultation. Voting systems aggregate specialist perceptions efficiently, representing a rapid, cost-effective method for ranking species according to their risk in the environment (Burgman et al. 2014). Prior to the poll, we divided the Black List into four groups with a manageable number of species: terrestrial plants and fungi, terrestrial animals, freshwater organisms and marine organisms. We designed an online Survey Monkey (https://www.surveymonkey.com) to ask experts to select the 10 INNS from their group of expertise that they regarded as the most concerning in terms of their current and/or potential impacts (either environmental or socio-economic) in the study area. Because the number of INNS per group ranged between 58 and 73, each species had a similar probability of being selected. The online survey was active until 10 different sets of votes were obtained. The score of a species equalled the number of votes received, and thus potentially ranged from 0 to 10. We must underline that species receiving no votes are not necessarily risk-free, but simply regarded as less pressing than their high-vote counterparts. An inter-rater reliability (IRR) analysis was again performed to assess consistency between voters.

Results

Alert List

The Alert List comprised 80 INNS not yet present in the four countries of concern, with a balanced representation between terrestrial plants (25 species), terrestrial animals (23), freshwater (16) and marine (16) organisms (Table S2). The majority of INNS originated from Asia (32), followed by North America (14), Europe (12) and South America (12) (Fig. S1A). Most of the species were primary producers (28), including terrestrial plants, aquatic plants and algae (Fig. S1B).

Total risk scores were highest for terrestrial plants (10.5 ± 2.3), followed by freshwater organisms (8.6 ± 2.7), terrestrial animals (8.6 ± 2.3), and marine organisms (7.8 ± 2.8) (Kruskal–Wallis test χ^2 (3, N = 77) = 13.28, $P < 0.05$, Table S2). Some of the INNS that were considered as particularly high-risk included the Emerald ash borer (*Agrilus planipennis* Fairmaire 1888), big sage (*Lantana camara* L.) and Amur clam (*Potamocorbula amurensis* Schrenck, 1861) (Table 3). Of the four groups, terrestrial plants scored particularly high for ecological (Kruskal–Wallis test χ^2 (3, N = 77) = 23.32, $P < 0.05$) and economic (Kruskal–Wallis test χ^2 (3, N = 77) = 16.76, $P < 0.05$) impacts (Fig. 3; Table S2), whereas freshwater organisms scored highest for invasive potential (Kruskal–Wallis test χ^2 (3, N = 77) = 9.12, $P < 0.05$) and management difficulty (Kruskal–Wallis test χ^2 (3, N = 77) = 10.98, $P < 0.05$) (Fig. 3; Table S2). The IRR analysis indicated significant fair to robust agreement between experts (Table 4). The level of agreement was highest for scores on economic impact, followed by scores on ecological impact and invasive potential of species. Non-significant agreement was found for scores on management difficulty of terrestrial plants and marine organisms.

Black List

Most of the species identified as some of the worst invaders by a range of national and international organizations were already present in at least one of the four countries in the study area (77 %), and were therefore assigned to a Black List of INNS. This list comprised 69 terrestrial plants, 58 terrestrial animals, 73 freshwater and 67 marine organisms. Asia was again the main donor region of these species (79), followed by North America (77) (Fig. S1C). The proportion of filter-feeders and primary producers was notably higher in the Black List when compared to the Alert List; whereas the proportion of omnivores and predators was lower (Fig. S1D). Most of the Black-List species (55 %) were present in all four countries of concern, whereas only 13 % of species had been recorded in only one of the four countries, usually France (Fig. S2).

Invasive species consistently highlighted as some of the worst in the study area included the Japanese knotweed (*Fallopia japonica* [Houtt.] Ronse Decr.), Himalayan balsam (*Impatiens glandulifera* Royle), zebra mussel (*Dreissena polymorpha* Pallas 1771) and killer shrimp (*Dikerogammarus villosus* Sowinsky, 1894) (Table 3; Table S3). On the other hand, over half of the organisms in the Black List (147 out of 267 INNS) received no votes by any of the participants (Table S3). The overall agreement across votes in the Black List was on average fair, showing highest accord for terrestrial plants and freshwater invaders (Table 4). Because of the high divergence in opinion

Table 3 Prioritized lists of invasive species not yet present in the focus area (Alert List), and already present in at least one country (Black List species), with notes on their English name, habitat, functional role and origin

Taxa	English name	Habitat	Functional role	Origin	Score
Alert List					
Heracleum sosnowskyi	Sosnowski's hogweed	TP	Prim	Eur	13.3 ± 0.6
Lantana camara	Big sage	TP	Prim	Sam	13.3 ± 1.7
Agrilus planipennis	Emerald ash borer	TA	Herb	As	13.7 ± 2.9
Solenopsis invicta	Red fire ant	TA	Pred	Sam	11.3 ± 3.7
Pomacea canaliculata	Apple snail	F	Herb	Sam	13.0 ± 2.7
Perccottus glenii	Amur sleeper	F	Pred	As	12.3 ± 1.7
Potamocorbula amurensis	Amur clam	M	Filt	As	13.3 ± 1.7
Asterias amurensis	Japanese seastar	M	Pred	As	12.3 ± 2.9
Black List					
Fallopia japonica	Japanese knotweed	TP	Prim	As	10
Impatiens glandulifera	Himalayan balsam	TP	Prim	As	10
Mustela vison	American mink	TA	Pred	Nam	6
Sciurus carolinensis	Grey squirrel	TA	Herb	Nam	6
Harmonia axyridis	Harlequin ladybird	TA	Pred	As	6
Dikerogammarus villosus	Killer shrimp	F	Omn	Eur	9
Dreissena polymorpha	Zebra mussel	F	Filt	As	9
Caulerpa taxifolia	Caulerpa	M	Prim	As	4
Codium fragile	Green sea fingers	M	Prim	As	4

The complete Alert and Black Lists can be consulted in Tables S2 and S3

Habitat: *TP* terrestrial plant, *TA* terrestrial animal, *F* freshwater and *M* marine. *Functional role*: *Herb* herbivore, *Pred* predator, *Omn* omnivore, *Filt* filter-feeder and *Prim* primary producer. *Origin*: *Sam* South America, *Nam* North America, *As* Asia, *Au* Australia, *Eur* Europe. Score: mean and SD of three independent sets of scores for the Alert List (ranging from 4 to 16), and total number of votes for the Black List (ranging from 0 to 10)

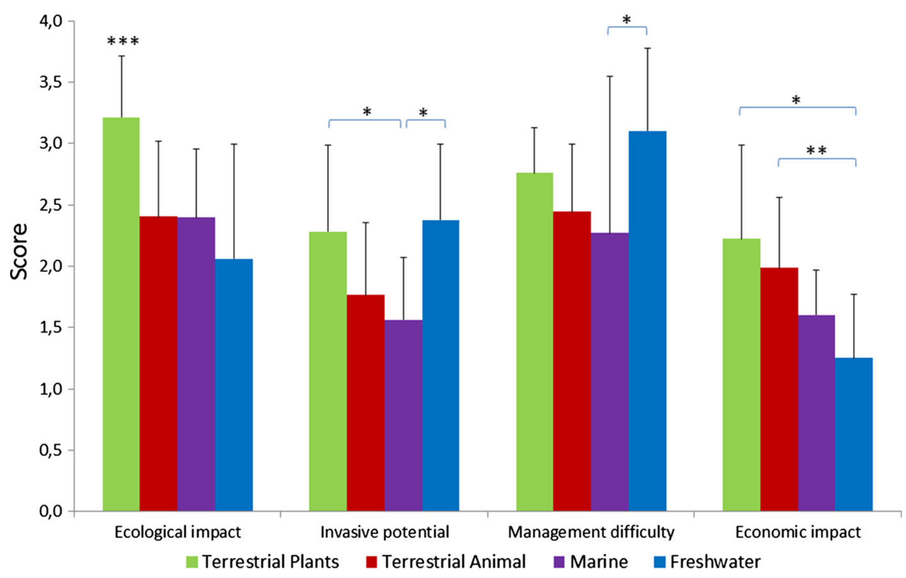

Fig. 3 Mean and SD of evaluation scores for invasive non-native species in the Alert List. Results presented by four major habitats. Significant differences in risk scores among habitats are highlighted as *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Table 4 Results from inter-rater reliability (IRR) analysis of risk analysis scores

	Overall agreement	Terrestrial plants	Terrestrial animals	Freshwater	Marine
Alert List					
Ecological impact	0.44***	0.37***	0.35***	0.29*	0.37***
Invasive potential	0.49***	0.49***	0.43***	0.40***	0.42***
Management difficulty	0.28***	0.15 n.s.	0.43***	0.43***	0.08 n.s.
Economic impact	0.53***	0.26*	0.59***	0.53***	0.66***
Black List					
Expert poll	0.30***	0.39**	0.27*	0.39***	0.16 n.s.

ns not significant, * significant at $P < 0.05$, ** significant at $P < 0.01$, *** significant at $P < 0.001$

regarding marine INNS (IRR = 0.16, $P > 0.05$), we should interpret results from this group with caution.

Discussion

Most of the species identified as some of the worst invaders by a range of national and international organizations were already present in at least one of the four countries in the study area (77 %), and were therefore assigned to a Black List of INNS. Moreover, more than half of the established Black List invaders were already widespread in the four countries, which is consistent with the high level of vulnerability towards biological invasions of the focus region, their similar bioclimates and their close proximity to one-another (Chytrý et al. 2009; Gallardo and Aldridge 2013, 2015; Jackson and Grey 2013). To establish some reference, the total number of registered non-native species in the region stands at 6661 (Zieritz et al. 2014), which roughly represents 47 % of all the non-natives registered in Europe (ca. 14,000 according to DAISIE; www.europe-aliens.org) despite representing only 10 % of its area. In fact, with 77 invasive species per square kilometre, the spatial density of non-native species in the region is the highest known in western countries (Table 1). Furthermore, the number of invasive species in the region is growing at an accelerating rate. For instance, in Flanders (Belgium), the percentage of non-native plant species in the regional flora increased from 5 to 10 % since the 1970s and is still increasing (Demolder et al. 2014). Also, the time lag between the arrival of new freshwater invasive species in the Netherlands and UK has decreased from 30 to 5 years over the last century (Gallardo and Aldridge 2015). However, these figures come from a variety of sources and should be therefore taken with caution. In any case, based on the data collected in this study together with previous investigations, it is evident that the region, although relatively small in surface area, is host to a remarkably high number of non-native species, identifying it as a global INNS hot-spot.

The Alert List of INNS

In the Alert List, terrestrial plants generally yielded highest ecological and economic impact risk scores in comparison to other types of organisms. Invasive plants can have far-reaching environmental and economic impacts, can display high potential propagule pressure and are very difficult to control and eradicate (Mack and Lonsdale 2002). Since the majority of invasive plants in Europe have been intentionally introduced and cultivated for horticulture, agriculture, forestry or ornamental purposes (63 % of invasive plants; DAISIE 2009), the risk of plant invasion in a densely populated area such as the study region is extremely high. Thus, given their potential impacts, substantially stronger enforcement of existing laws and regulations are needed if further introductions into un-invaded areas are to be prevented, as recently highlighted by the European Commission (European Commission 2014).

Freshwater organisms received the highest scores for invasive potential and management difficulty in the assessment. The high vulnerability of freshwater ecosystems to invasion is related to the high intrinsic dispersal ability of aquatic species across interconnected habitats, and the high level of human disturbance in aquatic ecosystems that facilitates biological invasions (Gherardi 2007). Considering that extensive aquaculture, fishing and leisure activities are collectively responsible for more than 40 % of the introductions of aquatic species in Europe (DAISIE 2009), these activities should be controlled in order to prevent further introductions (Britton and Gozlan 2013). Once established, the eradication of invasive species—and especially those in aquatic ecosystems—is strategically difficult, rarely feasible, expensive and ultimately unlikely to be of considerable ecological benefit (Britton et al. 2011; Mack and Lonsdale 2002).

The highest risk INNS in the Alert List included a mix of primary producers (e.g. Sosnowski's hogweed and the big sage), herbivores (e.g. the emerald ash borer and apple snail) and predators (e.g. red fire ant, Amur sleeper and Japanese sea star). Most of these top Alert List INNS are not yet present in Europe, which reduces their likelihood of establishment in the focus region, at least through natural dispersal processes, in the short term. Even though some of these species are currently largely restricted to tropical and subtropical regions, their risk of invasion in the focus region should not be underestimated due to their wide environmental tolerances, high adaptive capacity and potential for range changes following climate change (Walther et al. 2009; Davidson et al. 2011).

The Black List of INNS

Most of the Black List's INNS (55 %) were already present in all four countries of concern. This exemplifies the long history and high level of biological interchange resulting from intensive trade, transport and travel in the region. The opportunity to prevent the introduction of these widespread species into the focus area has thus been missed. Nevertheless, efforts should focus on controlling their further spread and impact towards uninfected areas as well as mitigating their impacts within the invaded region. In fact, all four countries have actually implemented management plans for a number of the Black List species. As way of example, a range of mechanical, chemical, and in rare cases also biological, methods have been employed to control Australian swamp stonecrop (Dawson 1996), Himalayan balsam and giant hogweed (Wadsworth et al. 2000), floating pennywort, water primrose Japanese knotweed and Parrot's feather (see control sheets in Q-bank: Comprehensive Databases on Quarantine Plant Pests and Diseases, http://www.q-bank.eu/). Trapping, hunting and shooting are the preferred management options for animals such as the ruddy duck (Robertson et al. 2014), American bullfrog (Louette et al. 2014), grey squirrel and American mink (Bonesi and Palazon 2007). Additional cross-country collaborations would be of great benefit to share experiences and enhance effectiveness of management measures.

Controlling marine invasive species is far more challenging than their land counterparts (Secord 2003). This may be partially the result of poor understanding of the economic and environmental costs of marine invasions, whose impacts are less conspicuous, and hence less well-documented, than those of terrestrial species (Bax et al. 2003; Katsanevakis et al. 2014). Such lack of awareness, expertise and information can explain the high uncertainty regarding the impacts of marine invaders registered in our risk assessment. Yet, examples of marine introduced species emerging as a major management issue within the last 20 years are numerous (Bax et al. 2003). Because invasive species know no marine borders, trans-national cooperation and information-sharing is particularly important to design early detection and control strategies in coastal and open waters.

Horizon scanning as a tool for prioritisation

The prioritisation of the Alert and Black Lists of INNS was based on a systematic compilation of INNS of concern and independent expert consultation, which was presumed to provide an unbiased, cost-effective and rapid screening of the risk associated with the introduction of each species. Based on this experience, a number of recommendations can be drawn to optimize the use of this tool.

A systematic review of current invasive species listings was employed to compile a meta-list of invaders. However, there may be other invasive high-risk species not included in the worst INNS meta-list that was used as a basis for this consultation. To complement current INNS listings, it is recommended to include additional species regarded by experts as potentially worrisome despite not yet being listed (Roy et al. 2014a).

Species selection was discussed and agreed at an expert workshop, yet risk screening of species was based on individual assessment. This has the advantage of objectivity, as assessors cannot influence the judgment of others. However, this approach also hinders mutual learning. To resolve this and refine horizon scanning in the future, species with a high uncertainty level could be selected for a second round of consensus building, where interaction can help to resolve misunderstanding (as in Roy et al. 2014a). This also has the advantage of conveying a clear and unified message to the end-user of the species lists.

The prioritization of invasive species can be influenced by the researchers who participate in the horizon-scanning exercise, their particular research experience and interests, and their access to scientific literature or facts regarding particular invasive species and their capacity to influence ecosystems (Sutherland et al. 2011). In our case, a diverse and moderately large group of 32 experts from all four nationalities and fields of expertise, clear criteria for prioritization, and specific measures of reliability helped reduce the impact of these various sources of uncertainty.

Uncertainty across assessors was furthermore quantified using a statistical approach based on the reliability of inter-rater agreement. This method has the advantage of producing comparable, repeatable measures of reliability. The aggregation of independent expert opinions provides indicators of risk that tend to be closer to the true risk than all of the separate individual assessments (the so-called "wisdom from the crowd", Sutherland and Woodroof 2009). Such collaborative methods have been successfully used to identify priorities in various ecological contexts, including biological invasions (e.g. Roy et al. 2014a). Other methods to measure uncertainty can be used to complement inter-rater reliability scores, such as requiring the assessor to use one of four levels of certainty: very certain, mostly certain, mostly uncertain and very uncertain (e.g. Copp et al. 2009; D'hondt et al. 2015).

Several horizon scans have been performed in the study area by the Belgium Forum on Invasive Species (BFIS; D'hondt et al. 2015), the Great Britain Non-Native Species Secretariat (GB-NNSS; Parrott et al. 2009), and the Netherlands Centre of Expertise on Exotic Species (NCEES; Matthews et al. 2014) (see the complete list of sources used in this study in Table S1). Despite differences in methodology, several of the same species were considered in different studies as some of the worst current and potential invaders, indicating a high agreement in scoring. For example, the Amur sleeper, emerald ash-borer and Sosnowski's hogweed were highlighted as some of the worst future invaders by Great Britain, Belgium and The Netherlands. Among top Black List species, the Japanese knotweed, killer shrimp, zebra mussel, American vison, grey squirrel and Himalayan balsam were consistently listed as priority invasive species for control and eradication by all four countries in the study area.

Experts voluntarily participated in this risk assessment, and for this reason we decided to employ a relatively quick and easy risk scoring system that combines several elements of the invasion process (based on Molnar et al. 2008). Yet, other comprehensive risk assessment methods exist. In a recent report for the European Commission, Roy et al. (2014b) critically reviewed risk assessment methodologies against a set of minimum standards and highlighted four as the most compliant: the Great Britain Non-Native species Risk Assessment (GB-NNRA, Baker et al. 2008), the European Plant Protection Organization Decision Support Scheme for quarantine pests (EPPO-DSS, Kenis et al. 2012), the Belgian Harmonia^{+} (D'hondt et al. 2015) and the European Non-native Species in Aquaculture Risk Analysis (ENSARS, Copp et al. 2014). These protocols provide a full description of the species, the likelihood of entry, establishment, spread and magnitude of its impacts, the current and potential distribution, pathways of entry and spread, and they broadly assess not only ecological but also the socio-economic implications of invasions. In our horizon scan we applied a simpler cost-effective protocol that presented two major advantages. First, it allowed the systematic evaluation of a large and varied range of invaders across trans-national scales, a task that would be difficult and certainly costly to perform using one of the four compliant schemes for risk assessment. Second, it was based on a consensus approach, which can overcome some of the shortcomings (e.g. knowledge gaps, high levels of uncertainty) of methods solely based on literature and individual expert opinion (Roy et al. 2015). While the selection of a risk assessment protocol will ultimately depend on the time and resources available, we advocate for the use of protocols with broad taxonomic and geographic applicability, such as Harmonia^{+}, whenever possible.

It is also important to bear in mind that our assessment of risk is based on the evidence available at the time of assessment, and substantial new scientific evidence on the invasiveness, impact and management of species may prompt a re-evaluation of the risks. Likewise, the perception of risk and manageability for a particular region can change depending on the progression of the species. As such, prioritized lists should be subject to frequent re-evaluation to reflect changes in knowledge and management options.

Finally, our approach provides a tool that can be integrated into broader invasion management toolkits focusing on prevention and prioritization. Ideally horizon-scanning exercises as the one proposed here should be applied across several countries, so that information compiled in one country can benefit others.

Conclusions

In comparison with other European risk analyses, the current horizon scanning uses a simple methodology for screening potential invaders at national to transnational scale, systematically assesses the risk associated to a varied range of invaders, employs sound statistical analyses to assess the reliability of scorings, and produces results for a region of relevance in Europe. In addition, although originally designed for marine species, application of the risk protocol was not restricted to a particular habitat or taxonomic group, integrating a wide range of terrestrial plants, terrestrial animals, freshwater and marine organisms. Such integrative horizon scanning allows for comparison of the risks associated with different species, which is not possible when habitats are assessed separately. Drafting Alert and Black Lists of emerging and established INNS can help to identify priority INNS for prevention, inform biosecurity policies, raise awareness amongst stakeholders and better communicate to the public about emerging biological threats in the region. To conclude, this simple approach offers an efficient and overall cost-effective solution for environmental managers and stakeholders who have to make best use of available scientific evidence to prioritize limited resources in INNS prevention and management.

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