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Inconsistencies in the risk classification of alien species and implications for risk assessment in the European Union

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Abstract. Invasive alien species (IAS) are species whose introduction or spread outside their native range threatens biological diversity, ecosystem functioning, economy, and/or public health. The recent European Union (EU) regulation on the management of IAS emphasizes the need for a consistent approach to alien species assessment that will underpin international measures for the early identification of newly introduced IAS followed by rapid action aimed at the prevention of introduction, spread, and negative impacts. The goals of the present study were (1) to present the risk classifications of 18 aquatic alien species for The Netherlands using the Invasive Species Environmental Impact Assessment protocol, (2) to compare these with available risk classifications made for countries spanning similar climatic and biogeographical regions to the EU, and (3) to provide explanations for inconsistencies between different risk classifications. Five species were classified as high risk: *Carassius gibelio* (Prussian carp), *Cyprinus carpio* (common carp), *Sander lucioperca* (pike-perch), *Cabomba caroliniana* (fanwort), and *Dreissena rostriformis bugensis* (quagga mussel). Of the 14 species with existing risk classifications for countries spanning similar climatic and biogeographical regions to the EU, all but two of the assessed species (*C. gibelio* and *D. rostriformis bugensis*) were classified inconsistently. Reasons for these inconsistencies are the application of different risk assessment schemes, application on a national rather than biogeographical scale, differences in the definition and application of criteria, differences in habitat availability, and uncertainties that are intrinsic to risk assessment methodologies. Approaches that increase transparency by highlighting these methodological aspects, normative choices, and uncertainties are vital to the legitimacy of any risk assessment method and will increase acceptance among decision makers, nature managers, and stakeholders.

Key words: invasiveness; non-native species; prevention; rapid action; risk assessment; risk prioritization.

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INTRODUCTION

Invasive alien species (IAS) are species whose introduction and/or spread outside their natural past or present distribution threatens biological

diversity, economy, and/or public health (United Nations 1992, Verbrugge et al. 2016). IAS are considered to be one of the leading causes of global biodiversity loss (Moyle et al. 1986, Vitousek et al. 1997, García-Berthou et al. 2005,

McGeoch et al. 2010). Costs relating to monitoring, eradication, control, and impact mitigation of IAS are significant. Reported estimates for the European Union (EU) and globally are 12.5 billion (Kettunen et al. 2008) and 1.4 trillion euros per year (Pimentel et al. 2001), respectively. Multiple introductions of potential IAS within the EU can be attributed to human-mediated pathways. For example, the recent rise in (online) retailers offering species for sale internationally has been considered to be mainly responsible for the introduction of many invasive species (Faulkes 2015, Humair et al. 2015, Mazza et al. 2015).

Aquatic ecosystems are particularly vulnerable to the impacts of species invasion. Declines in biodiversity as a result of IAS introductions have been more severe for aquatic species relative to terrestrial species in the most affected ecosystems (Dudgeon et al. 2006). Impacts may be dramatic because freshwater systems feature the greatest density of species per unit surface area on the planet (Thomaz et al. 2015, Lozano and Brundu 2016). Invasive alien species negatively impact aquatic communities, particularly macrophyte, zooplankton, and fish assemblages, and promote physical alterations in nitrogen and organic matter concentration, and changes to water turbidity (Gallardo et al. 2016). Examples of IAS that have been introduced to aquatic ecosystems in Western Europe as a result of the international trade in alien species are *Lagarosiphon major* (curly waterweed), *Cabomba caroliniana* (fanwort), and *Lepomis gibbosus* (pumpkinseed sunfish) (Kay and Hoyle 2001, Van Kleef et al. 2008, Matthews et al. 2012b, 2013a).

The Convention on Biological Diversity (CBD) specifically requires that signatories prevent the introduction of, and control or eradication of potential IAS (United Nations 1992). Moreover, the European Commission has stated that a significant subset of alien species can become invasive, leading to serious adverse ecological, social, and economic impacts which should be prevented (European Commission 2014). Most expenses generated by IAS in Europe result from reactive eradication measures (Colautti et al. 2006, Vilà et al. 2009, Sinden et al. 2011). As a result, measures that prevent the initial introduction and spread of IAS have become the most attractive management approach (Pyšek and Hulme 2005,

Shirley and Kark 2006, Essl et al. 2011, European Commission 2014). Therefore, predicting which alien species may become invasive by applying a risk assessment process has gained much interest as a method to support the management decisions of policy makers (Byers et al. 2002, Andersen et al. 2004, Verbrugge et al. 2012, Vanderhoeven et al. 2015). Risk assessment has already proven to be an important tool for assessing which alien species should be subject to trade restrictions, eradication, and control measures that are fundamental to the EU's strategy on the prevention and management of the introduction and spread of IAS (European Commission 2014, Roy et al. 2015).

In this study, we define risk as the chance that a particular hazardous event (e.g., competition, hybridization) may actually cause damage, and regard it as a product of three factors: exposure $\times$ likelihood $\times$ consequence (D'hondt et al. 2015). Risk assessment is defined as the identification of risks and their assessment with regard to the likelihood and consequences of the introduction, establishment, spread, and impact of an alien species using science-based information (CBD COP6 Decision VI/23, 2002). Risk classifications are the outcomes of risk assessments and are usually expressed using three or five risk classes (e.g., low, medium, or high).

The introduction of the new regulation (EU) No 1143/2014 of the European Parliament and of the council 22 October 2014 on the prevention and management of the introduction and spread of IAS requires the standardization of alien species risk assessment and management across Europe. One of the major tasks relating to the regulation is the creation of a list of IAS considered to be of Union concern through the application of standardized criteria (European Commission 2014). Until recently, legislative and regulatory requirements applied to EU member states concerning the risk assessment and management of potential IAS have been fragmented (Hulme 2009, Verbrugge et al. 2010). This has resulted in the development of a number of different risk assessment approaches, for example, the Invasive Species Environmental Impact Assessment (ISEIA) protocol (Branquart et al. 2009, Vanderhoeven et al. 2015), the German-Austrian Black List Information System (GABLIS; Essl et al. 2011), and the

Non-Native Species Risk Analysis Mechanism of Great Britain (NNSS 2016). Moreover, risk assessment methods are usually applied to areas defined politically instead of ecologically, that is, per country rather than per biogeographical region. However, once established, IAS can rapidly expand their range across national borders (Shirley and Kark 2006). The lack of methodological consistency and differences in ecological context between risk assessments prevent direct comparisons of risk classifications and potentially hinder a standardized European approach that facilitates rapid preventative action in different countries within the same biogeographical region (Verbrugge et al. 2012). In addition, limited attention has been devoted to the influence of different approaches to uncertainty applied by different risk assessment methods used to classify the risks of alien species in Europe (Essl et al. 2011, Verbrugge et al. 2012), hindering the potential for future methodological improvement.

The aims of this paper are as follows:

1. Present the risk classifications of 18 aquatic alien species for The Netherlands, derived using the ISEIA protocol, that can be used for prioritization and to design management measures in lowland northwestern Europe (e.g., The Netherlands, Belgium, Germany, and Denmark).
2. Analyze the level of consistency between risk classifications from The Netherlands and those derived for countries spanning similar climatic and biogeographical regions to the EU.
3. Discuss possible reasons for potential inconsistencies between risk classifications, their implications for the prioritization of IAS on an EU level, and opportunities for uncertainty reduction.

METHODS

Species selection

The species were selected from a group that were risk-assessed for The Netherlands Food and Consumer Product Safety Authority by Radboud University in association with partner organizations of The Netherlands Centre of Expertise for Exotic Species who specialize in monitoring and

field studies of particular species groups. The species were selected on the basis of the following criteria: (1) The species is alien to The Netherlands and potentially invasive, (2) no valid risk classification existed for the species in The Netherlands prior to the ones presented here, and (3) the species is recorded in freshwater habitats. The risk-assessed species were chosen to facilitate government decisions regarding their management and to allow the sound evaluation of proposals for the listing of IAS of EU concern relating to the new regulation (EU) No 1143/2014 of the European Parliament and of the council 22 October 2014 on the prevention and management of the introduction and spread of IAS. The assessed species include 12 fish, four macrophyte, and two mollusk species (Appendices S1–S4). While all of these species are alien to The Netherlands, 11 are also alien to Western Europe: *Romanogobio belingi* (northern whitefin gudgeon), *Ctenopharyngodon idella* (grass carp), *Oncorhynchus mykiss* (rainbow trout), *Salvelinus fontinalis* (brook trout), *Umbra pygmaea* (eastern mud-minnow), *Cabomba caroliniana* (fanwort), *Egeria densa* (Brazilian waterweed), *Lagarosiphon major* (curly waterweed), *Vallisneria spiralis* (tapegrass), *Bellamya chinensis* (Chinese mystery snail), and *Dreissena rostriformis bugensis* (quagga mussel). All fish were assessed because they are included in the Dutch Fisheries Act that allows introduction by the holders of fish rights of these species if certain criteria are complied with. However, the potential risks of these species had not been previously assessed for The Netherlands (Schiphouwer et al. 2014). The macrophyte and mollusk species were assessed to provide more insight into their current distribution, probability of entry, establishment, and spread, and potential impacts in The Netherlands.

Literature surveys for risk inventories

Literature reviews were carried out to provide an overview of the current knowledge on the distribution and invasion biology (i.e., a risk inventory) of each species listed in Appendices S1–S3. Literature data were collected on the habitat, physiological tolerances, substrate preference, colonization vectors, ecological and socio-economic impacts, and potential measures for the management of the species using the official Latin name and frequently applied synonyms. The searches were Internet-based, supported by

the use of a university library. Web of Knowledge and Google Scholar search engines were queried. Web of Knowledge includes only peer-reviewed literature, a part of which is not available freely online, while Google Scholar includes both peer-reviewed and gray literature that is often freely available online. All search results from the Web of Knowledge were examined, while the first 50 results per search term from Google Scholar were examined due to the decreasing relevance of search results returned using this search engine.

Consensus method for classification of risks

Each risk assessment was carried out by an expert team. Each expert completed an assessment form independently, based on the results of the literature review (i.e., a standard knowledge document with risk inventory). Therefore, each expert based their individual risk scores on the same information. Risks were scored using a hierarchical method where evidence from within The Netherlands was given priority over evidence derived from impacts occurring abroad. Following this individual assessment, the entire expert team met, elucidated differences in risk scores, discussed diversity of risk scores, and interpreted key information during a workshop. Discussion during the workshop led to agreement on consensus scores and risk classification relating to the four sections contained within the ISEIA protocol. The consensus scores, risk classification, and justifications for the scores were entered into a draft report that was reviewed by the expert team. If complete agreement on the contents of the draft report was not achieved, additional face-to-face or email discussions between team members took place until consensus was achieved.

Assessment scheme

The ISEIA protocol is a decision support tool that classifies species according to their potential invasiveness, informing the decisions of nature managers, policy makers, and stakeholders (Vanderhoeven et al. 2015). ISEIA is applied in the risk assessment of alien species in Europe alongside the more recent Harmonia⁺ risk assessment protocol, and has been used in the Belgian early warning and rapid response system, an approach that is key to management approaches advocated in the new EU regulation on the

prevention and management of IAS (European Commission 2013, 2014, Vanderhoeven et al. 2015). The ISEIA protocol is more extensive than Harmonia⁺ regarding the assessment of impacts on biodiversity and ecosystem functioning, elements that are key impact categories requiring assessment in relation to the new EU regulation (European Commission 2013, 2014). Moreover, assessments undertaken after the introduction of Harmonia⁺ also applied the ISEIA protocol to allow direct comparisons between the results of all risk assessments. Risk assessment is carried out through the application of 10 criteria that match the last steps of the invasion process (i.e., the potential for spread, establishment, and adverse impacts on native species and ecosystems; Branquart et al. 2009, Vanderhoeven et al. 2015). These criteria are divided over the following four risk sections: (1) dispersion potential or invasiveness, (2) colonization of high conservation habitats, (3) adverse impacts on native species, and (4) alteration of ecosystem functions. Section 3 contains sub-sections referring to (i) predation/herbivory, (ii) interference and exploitation competition, (iii) transmission of diseases to native species (parasites, pest organisms, or pathogens), and (iv) genetic effects such as hybridization and introgression with native species. Section 4 contains sub-sections referring to (i) modifications in nutrient cycling or resource pools, (ii) physical modifications to habitats (changes to hydrological regimes, increase in water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.), (iii) modifications to natural successions and (iv) disruption to food webs, that is, a modification to lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance. The potential positive impacts of alien species are not considered by the ISEIA protocol.

Each criterion of the ISEIA protocol was scored. Scores ranged from 1 (low risk) to 2 (medium risk) and 3 (high risk). If knowledge obtained from the literature review was insufficient, then the assessment was based on expert judgment and field observation leading to a score of 1 (unlikely) or 2 (likely). If no answer could be given to a particular question (no information), then no score was given (dd, deficient data). Finally, the total score for the species was derived by adding the highest score of each section.

Subsequently, the Belgian Forum Invasive Species list system for preventive and management actions was used to categorize the species of concern (Branquart et al. 2009). This list system was designed as a two-dimensional ordination (Environmental impact $\times$ Invasion stage; Fig. 1). It is based on guidelines proposed by the CBD (CBD decision VI/7) and the EU strategy on IAS. Species' ecological impact was classified based on the total risk score which is converted to a letter/risk classification: C, low risk (scores 4–8); B, moderate risk (9–10); and A, high risk (11–12). This letter is then combined with a number representing the invasion stage: (0) absent, (1) isolated populations, (2) restricted range, or (3) widespread. Absent species scoring moderately or highly for ecological impact are placed on an alert list. Species that have been recorded in the area under assessment and that score a moderate or high risk are placed on a watch list or black list, respectively.

Comparison with other risk classifications

Risk classifications derived from risk assessment methods were obtained from other lowland northwestern European countries (Germany, Belgium, The Netherlands, and the UK) and from

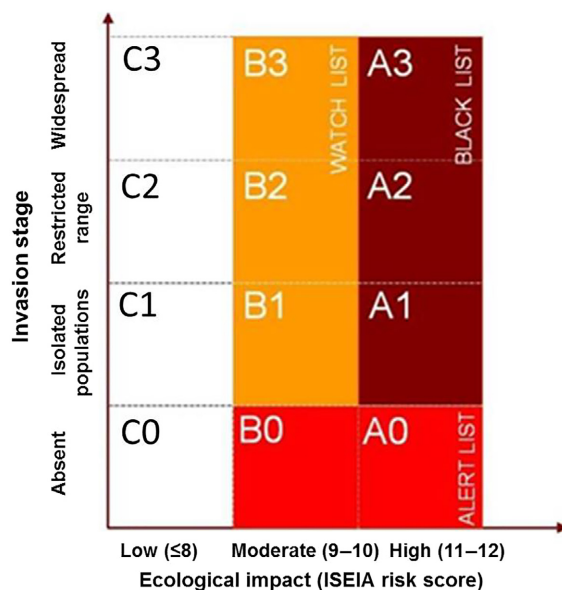


Fig. 1. The Belgian Forum Invasive Species list system to identify species of most concern for preventive and mitigation action (Branquart et al. 2009).

the State of New York (USA) that, according to the Köppen-Geiger climate zones of Kottke et al. (2006), is climatically matched with large parts of Europe (Table 1). These risk classifications were then compared to risk classifications derived for The Netherlands with the ISEIA protocol and inconsistencies between classifications were identified. The protocols compared vary in their approach but many share the aim of measuring ecological risk, which suggests that their outcomes should be broadly similar when assessing the same species, in similar biogeographical and climate regions. The Fish Invasiveness Screening Kit (FISK) and Harmonia⁺ protocols and the New York Invasiveness Ranking System contain criteria addressing both ecological and socio-economic impacts. To maintain consistency, we limited comparisons to the ecological risk components of the FISK, Harmonia⁺, and New York Invasiveness Ranking System assessments. All criteria received equal weighting during all the assessments considered. A number of species were classified according to systems that do not allocate a low-, medium-, or high-risk score, applying different terminology to define risk. This prevents direct comparisons of risk classifications produced by different protocols for the same species. Therefore, the following standardization was applied. Species allocated to the gray and black lists of GABLIIS were considered as high-risk species. White list species were considered low risk (Essl et al. 2011). Thomas (2010) applied the categorization critical (red) in the horizon scanning for invasive alien plants in Great Britain if a more detailed risk assessment was required. Species allocated to this risk category were assumed to be high priority (high-risk) species. Species allocated to both the high- and very high-risk categories of the New York Invasiveness Ranking System were considered high risk.

In a separate statistical analysis, contingency tables were derived based on the risk classifications for the same set of species that were assessed (1) in the UK and in The Netherlands, (2) using the New York Invasiveness Ranking System and ISEIA protocol, and (3) using the FISK and ISEIA protocols. Subsequently, a Pearson's chi-squared test was applied to both contingency tables using R statistics version 3.3.1 (R Development Core Team 2016).

Table 1. Overview of protocols included in the comparison of risk classifications for The Netherlands and regions with similar climate and biogeography.

Protocols	Assessment type	Geographical scope	Taxonomical scope	Ecological assessment	Socio-economic assessment	References
Fish Invasiveness Screening Kit (FISK)	Rapid risk assessment	UK, Belgium	Fish	X	X [‡]	Copp et al. (2005, 2009)
German-Austrian Blacklist Information System (GABLIS)	Risk assessment	Central Europe (Germany, Austria)	All species	X	...	Essl et al. (2011)
Harmonia [†]	Risk assessment	European Union	All species	X	X [‡]	D'hondt et al. (2015)
Invasive Species Environmental Impact Assessment (ISEIA)	Risk assessment	Belgium, The Netherlands	All species	X	...	Branquart et al. (2009)
Modified Australian Weed Risk Assessment (Rapid Risk Assessment) [†]	Rapid risk assessment	UK	Plants	...	...	Thomas (2010)
New York Invasiveness Ranking System	Rapid risk assessment	New York State, USA	Plants	X	X [‡]	New York Invasive Species Information (2017)
Rapid risk assessment and consensus method (horizon scan)	Rapid risk assessment	UK	All species	X	...	Sutherland et al. (2011), Roy et al. (2014b)

[†] Defines invasiveness in terms of spread only.

[‡] Scores relating to socio-economic risk were removed to allow a direct comparison of classifications relating to ecological impact scores only.

RESULTS

The risk classifications for all aquatic species prioritized using the ISEIA protocol are displayed in Table 2. Five species were classified as high risk, a plant species: *Cabomba caroliniana*, a mollusk: *Dreissena rostriformis bugensis*, and three fish species: *Carassius gibelio* (Prussian carp), *Cyprinus carpio* (common carp), and *Sander lucioperca* (pike-perch). *Dreissena rostriformis bugensis*, *C. gibelio*, *C. carpio*, and *S. lucioperca* are widely distributed, while *C. caroliniana* has a restricted range in The Netherlands. *Cabomba caroliniana* and *D. rostriformis bugensis* were the only species that received a maximum overall risk score. Eight species were assessed as moderate risk. These were a plant species: *Lagarosiphon major*, a mollusk: *Bellamyia chinensis*, and six fish species: *C. carpio* X *Carassius* sp. (cross carp), *Salvelinus fontinalis*, *Romanogobio belingi* (northern whitefin gudgeon), *Ctenopharyngodon idella*, *Leuciscus aspius* (asp), and *Oncorhynchus mykiss*. Five species were considered low risk, two plant species: *Egeria densa* and *Vallisneria spiralis* (tape-grass), and three fish species *Salvelinus alpinus* (Arctic charr), *Coregonus albula* (vendace), and *Umbra pygmaea*.

High-risk fish species

The highest scoring fish species, *C. gibelio*, *C. carpio*, and *S. lucioperca*, all scored maximally for both dispersion potential and colonization of high conservation value habitats (Table 2). *Carassius gibelio* and *S. lucioperca* scored maximally for the category direct or indirect adverse impacts on native species due to their high impacts relating to the sub-categories predation/herbivory, and interference or exploitation competition. *Cyprinus carpio* was the only high-risk species to score maximally for the category direct or indirect alteration of ecosystem functions. All sub-categories, that is, modification of nutrient cycling or resource pools, physical modifications of habitat, modification to natural succession, and disruption to food webs, were scored maximally for this species.

High-risk macrophytes

Cabomba caroliniana was one of only two species that scored high in all four categories of the ISEIA protocol (dispersal potential and invasibility, colonization of habitats with a high conservation value, direct and indirect effects on native species, and direct and indirect effects on ecosystem functioning). This species scored high in the sub-category interference or exploitation competition

Table 2. Overview of risk scores and classifications for species assessed with the Invasive Species Environmental Impact Assessment (ISEIA) protocol.

Species group	Scientific name	ISEIA protocol categories												Total score	BFIS list category†
		1.	2.	3.	3.1.	3.2.	3.3.	3.4.	4.	4.1.	4.2.	4.3.	4.4.		
Macrophytes	<i>Cabomba caroliniana</i> ‡	3	3	3	na	3	dd	1	3	2	3	2	2	12	A2
	<i>Lagarosiphon major</i> §	3	2	2	na	2	dd	1	2	2	2	2	2	9	B1
	<i>Egeria densa</i> ¶	2	2	2	na	2	dd	1	2	2	dd	dd	dd	8	C1
	<i>Vallisneria spiralis</i> #	3	2	1	na	1	dd	dd	1	1	1	1	1	7	C1
Mollusks	<i>Dreissena rostriformis bugensis</i>	3	3	3	3	3	dd	dd	3	3	3	3	3	12	A3
	<i>Bellamya chinensis</i> ††	2	3	3	2	3	2	dd	2	2	2	2	2	10	B1
Fish	<i>Carassius gibelio</i> ‡‡	3	3	3	3	3	1	2	2	2§§	1	1	1	11	A3
	<i>Cyprinus carpio</i> ‡‡	3	3	2	2	2	2	2	3	3	3	3	3	11	A3
	<i>Sander lucioperca</i> ‡‡	3	3	3	3	3	2	1	2	dd	dd	dd	2	11	A3
	<i>Cyprinus carpio</i> X <i>Carassius</i> sp.‡‡	2	2	3	2	2	1	3	2	2	2	2	2	9	B1
	<i>Salvelinus fontinalis</i> ‡‡	2	3	2	2	2	2	2	2	dd	dd	dd	2	9	B1
	<i>Romanogobio belingi</i> ‡‡	3	3	2	dd	2	dd	dd	1	1	1	1	1	9	B2
	<i>Ctenopharyngodon idella</i> ‡‡	1	3	3	3	3	2	1	3	3	3	3	3	10	B3
	<i>Leuciscus aspius</i> ‡‡	3	3	2	2	dd	1	1	1	dd	dd	dd	1¶¶	9	B3
	<i>Oncorhynchus mykiss</i> ‡‡	2	3	3	3	2	2	1	2	1	1	1	2	10	B3
	<i>Salvelinus alpinus</i> ‡‡	2	1	2	2	2	2	1	1	1	1	1	1	6	C0
	<i>Coregonus albula</i> ##	2	2	2	2	2	1	1	1	1	1	1	1	7	C1
	<i>Umbra pygmaea</i> ‡‡	2	3	2	2	dd	dd	1	1	1	1	1	1	8	C2

Notes: ISEIA protocol categories: 1. **dispersion potential or invasiveness**; 2. **colonization of high conservation value habitats**; 3. **direct or indirect adverse impacts on native species**: 3.1. predation/herbivory, 3.2. interference or exploitation competition, 3.3. transmission of parasites and diseases, 3.4. genetic effects (hybridization/introgression with natives); 4. **direct or indirect alteration of ecosystem functions**: 4.1. modification of nutrient cycling or resource pools, 4.2. physical modifications of habitat, 4.3. modification to natural succession, 4.4. disruption to food webs. na, not applicable; dd, deficient data. Numbers in italics indicate scores determined using expert knowledge alone.

† Belgian Forum on Invasive Species (BFIS) list category A: high environmental hazard (black list); B: moderate environmental hazard (watch list); C: low environmental hazard (unclassified); 0: absent from The Netherlands; 1: isolated populations in The Netherlands; 2: restricted range in The Netherlands; 3: widespread in The Netherlands.

‡ Matthews et al. (2013b).

§ Matthews et al. (2012c).

¶ Koopman et al. (2014).

Matthews et al. (2012a).

|| De Hoop et al. (2015).

†† Collas et al. (2017).

‡‡ Schiphouwer et al. (2014).

§§ Based on a single study containing correlation evidence linking nutrient enrichment with the species.

¶¶ Has some impact but this is not large enough for the species to be categorized under medium risk.

Schiphouwer et al. (2014), M. Schiphouwer (personal communication).

within the category direct and indirect effects on native species. However, there was not enough information to classify risk relating to the transmission of parasites and diseases, and *C. caroliniana* poses a low genetic risk to native species in The Netherlands. Within the category direct or indirect alteration of ecosystem functions, *C. caroliniana* scored high for the sub-category physical modifications of habitat, and moderate for all other sub-categories.

High-risk mollusks

Dreissena rostriformis bugensis was classified as high risk in all four categories of the ISEIA

protocol (dispersal potential and invasibility, colonization of habitats with a high conservation value, direct and indirect effects on native species, and direct and indirect effects on ecosystem functioning; Table 2). All sub-categories were scored maximally apart from one where there were insufficient data (transmission of disease to native species: parasites, pest organisms, or pathogens) and a second that was not considered applicable as there are no native species that are likely to interbreed with *D. rostriformis bugensis* (genetic effects such as hybridization or introgression with native species). Of all the aquatic species risk-assessed using the ISEIA protocol,

D. rostriformis bugensis was one of only two species that received a maximum overall score of 12 for ecological impact in The Netherlands.

Comparison of risk classifications

Only two out of the 14 species compared were classified consistently across all regions (*C. gibelio* and *D. rostriformis bugensis*). Risk classifications for The Netherlands were either the same or lower than other available classifications for climatically similar regions in all but three cases (*S. lucioperca*, *C. caroliniana*, and *B. chinensis*; Table 3). Classification consistency of the most frequently assessed species (four or more classifications) was ranked *C. gibelio* and *D. rostriformis bugensis* > *C. caroliniana* and *C. idella* > *O. mykiss* and *S. lucioperca* > *U. pygmaea*. *Umbra pygmaea* has been assessed in Belgium twice using different protocols and received different risk classifications. All species assessed in the UK were attributed an equal or higher-risk classification than classifications from other countries.

Statistical analysis

UK-based risk classifications were found to be significantly higher compared to ISEIA classifications from The Netherlands for the same species pool, $\chi^2(2, N = 11) = 10.27, P = 0.006$. Risk classifications derived using the New York Invasiveness Ranking System were not found to be significantly higher compared to ISEIA classifications from The Netherlands for the same species pool, $\chi^2(2, N = 8) = 1.6, P = 0.45$. Similarly, risk classifications derived using the FISK protocol in the UK yielded significantly higher scores for the same species pool compared to classifications derived using the ISEIA protocol in The Netherlands, $\chi^2(2, N = 7) = 7.78, P = 0.02$.

DISCUSSION

This study presents the results of risk assessments using the ISEIA protocol of 18 aquatic species alien to The Netherlands, and highlights inconsistencies with risk classifications between climatically similar regions. We chose to analyze aquatic species; however, the conclusions drawn here apply to a wide range of risk assessment methods and habitat types. In this section, methodological differences and other sources of uncertainty which may cause the observed

inconsistencies are discussed. Many of the uncertainties discussed are generic and apply to a wide range of risk assessment methods.

High-risk species

Of the most frequently assessed species considered in the present study, a fish species, *Carassius gibelio*, and a bivalve mollusk, *Dreissena rostriformis bugensis*, were most frequently allocated the highest risk scores in The Netherlands and in other regions. The high-risk scores of *C. gibelio* may be attributed to its high dispersal potential and ability to colonize natural habitats, which has led to a decline in native cyprinid species, invertebrates, and plants, and potential hybridization with the threatened crucian carp (*Carassius carassius*; Paschos et al. 2004, Lenhardt et al. 2010, Lusková et al. 2010, Perdikaris et al. 2012). *Dreissena rostriformis bugensis* has a strong reproductive potential and spreads via hydrochory or facilitated by human vectors such as watercraft. Due to a highly efficient filtering capacity, high densities of *D. rostriformis bugensis* exert significant influence on the integrity of the ecosystem by affecting biotic factors (e.g., decrease in algal biomass) and abiotic factors (e.g., increase in transparency and an accumulation of benthic organic matter in the form of (pseudo)feces; De Hoop et al. 2015).

Consistency of risk classifications

The need for a consistent assessment of risk is emphasized in the recent EU regulation on the prevention and management of the introduction and spread of IAS, which demands the standardization of risk assessment approaches across the EU (European Commission 2013, 2014). Despite differences in methodological approaches and species groups analyzed, ecological risk assessments should result in classifications that are broadly similar for similar biogeographical and climate regions, and the same species. However, risk classifications from climatically similar regions generally showed a low level of consistency with risk classifications for The Netherlands. Only risk classifications for the fish *C. gibelio* and the mollusk *D. rostriformis bugensis* were consistent. Moreover, systematic inconsistency was observed between risk classifications obtained from the UK and risk classifications from other countries (consistently equal or higher

Table 3. Comparison of risk classifications for The Netherlands and regions with similar climate and biogeography.

Species	Location	Protocol	Classification	References
<i>Cabomba caroliniana</i>	The Netherlands	ISEIA	High	This study
	Belgium	ISEIA	Medium	Baus et al. (2009)
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
	UK	Modified Australian Weed Risk Assessment	High	Thomas (2010)
<i>Egeria densa</i>	The Netherlands	ISEIA	Low	This study
	Belgium	ISEIA	High	Branquart et al. (2007)
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
<i>Lagarosiphon major</i>	The Netherlands	ISEIA	Medium	This study
	UK	Modified Australian Weed Risk Assessment	High	Thomas (2010)
<i>Vallisneria spiralis</i>	The Netherlands	ISEIA	Low	This study
	UK	Modified Australian Weed Risk Assessment	High	Thomas (2010)
<i>Bellamyia chinensis</i>	The Netherlands	ISEIA	Medium	Breedveld (2015)
	The Netherlands	Harmonia ⁺	Medium	Collas et al. (2017)
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
<i>Dreissena rostriformis bugensis</i>	The Netherlands	ISEIA	High	This study
	The Netherlands	Harmonia ⁺	High	De Hoop et al. (2015)
	UK	Rapid risk assessment and consensus method (Horizon scan)	High	Roy et al. (2014b)
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
<i>Carassius gibelio</i>	The Netherlands	ISEIA	High	This study
	Belgium	FISK	High	Verreycken et al. (2009)
	Belgium	ISEIA	High	Anseeuw et al. (2007a)
	UK	FISK	High	Copp et al. (2009)
<i>Ctenopharyngodon idella</i>	The Netherlands	ISEIA	Medium	This study
	Germany	GABLIS	High	Nehring et al. (2010)
	UK	FISK	High	Copp et al. (2009)
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
<i>Cyprinus carpio</i>	The Netherlands	ISEIA	High	This study
	New York State, USA	New York Invasiveness Ranking System	High	New York Invasive Species Information (2017)
<i>Leuciscus aspius</i>	The Netherlands	ISEIA	Medium	This study
	UK	FISK	High	Copp et al. (2009)
<i>Oncorhynchus mykiss</i>	The Netherlands	ISEIA	Medium	This study
	Germany	GABLIS	High	Nehring et al. (2010)
	New York State, USA	New York Invasiveness Ranking System	Medium	New York Invasive Species Information (2017)
<i>Salvelinus fontinalis</i>	UK	FISK	High	Copp et al. (2005)
	The Netherlands	ISEIA	Medium	This study
	Germany	GABLIS	High	Nehring et al. (2010)
<i>Sander lucioperca</i>	UK	FISK	High	Copp et al. (2005)
	The Netherlands	ISEIA	High	This study
	Belgium	ISEIA	Medium	Anseeuw et al. (2007b)
<i>Umbra pygmaea</i>	UK	FISK	High	Copp et al. (2009)
	New York State, USA	New York Invasiveness Ranking System	Medium	New York Invasive Species Information (2017)
	The Netherlands	ISEIA	Low	This study
	Belgium	ISEIA	Low	Anseeuw et al. (2007c)
	Belgium	FISK	Medium	Verreycken et al. (2010)
	Germany	GABLIS	Low	Nehring et al. (2010)
	UK	FISK	High	Copp et al. (2009)

Note: ISEIA, Invasive Species Environmental Impact Assessment; FISK, Fish Invasiveness Screening Kit; GABLIS, German-Austrian Black List Information System.

risk in all cases) and from The Netherlands and other countries (consistently equal or lower risk in the majority of cases). Only in the cases of *S. lucioperca* and *C. caroliniana* was the risk classification for The Netherlands higher than that of other countries. These observations are supported by Verbrugge et al. (2012) who showed that risk assessments of the same species but undertaken in different European countries and with different protocols resulted in differing risk classifications for 18 out of 25 species reviewed. Inconsistencies in risk classifications for the same species and region but for different assessment methods have been observed by a number of authors. Krivánek and Pyšek (2006) used three previously developed risk assessment schemes to categorize 180 alien woody species commonly planted in the Czech Republic to assess their consistency when applied in central Europe: the Australian Weed Risk Assessment (WRA) scheme; the WRA with additional analysis by Daehler et al. (2004); and the decision tree scheme of Reichard and Hamilton (1997) developed in North America. The WRA+Daehler model produced results that were most consistent (85.5% consistency) with classifications of invasiveness defined in Richardson et al. (2000) and Pyšek et al. (2004). Reichard and Hamilton's decision tree model produced the least consistent results (61.6% consistency). Copp et al. (2009) compared classifications based on expert opinion from FishBase (Froese and Pauly 2016), a global information system on fish, with the results of risk analyses of the same fish species using FISK applied to the UK. Out of 60 species classified as high risk by FISK, 39 were categorized on FishBase as harmless, with the remaining 21 categorized as potential pests (Copp et al. 2009).

Risk classifications from neighboring countries may not always produce consistent results, even when the same methodology is applied. Nehring et al. (2010) provided a risk prioritized list of 31 alien fish species for Germany. In total, 30 of these species were also selected for a list for Austria (Nehring et al. 2010). Both lists were assessed using GABLIS. In total, 90% of species were classified equally. However, three species were classified differently, which means that 10% of these fish species classifications are not transferable between neighboring countries. Moreover, both Verreycken et al. (2010) and Verbrugge et al. (2010)

observed that risk classifications generated by FISK for alien fish species in Belgium were consistently lower than mean UK scores for the same species. Leuven et al. (2016) analyzed the results of risk analyses of 20 alien species (aquatic plants, mollusks, and fish) carried out by different risk assessors who applied the same protocol, in a dissimilar biogeographical setting and with access to the same information. The resulting risk classifications varied between 50% and 90% for various assessment criteria (Leuven et al. 2016).

Potential sources of inconsistencies between risk classifications

The large number of variables included in the comparison of risk classifications precludes the direct attribution of a single determining factor for the inconsistencies observed in this study. Differences in classifications may be related to the number and differences between criteria, and the way in which they are applied. Firstly, risk classifications are usually determined and applied according to political borders and not biogeographical boundaries. For example, risk classifications derived for Belgium using the ISEIA protocol incorporate both the Belgian Atlantic and continental biogeographical regions. The Harmonia⁺ protocol has been promoted as a method suitable for assessing alien species risk on the EU scale (D'hondt et al. 2015). However, the EU spans a wide range of different biogeographical regions. Risk classifications derived using the GABLIS methodology apply to both Germany and Austria, countries that span the Atlantic, continental, and Alpine biogeographical regions. Species distributions are strongly determined by biogeographical characteristics (Wallace 1876, Lomolino et al. 2006, Kreft and Jetz 2010). Therefore, a single risk classification is unlikely to be consistently accurate across an assessment area containing multiple biogeographical regions. Secondly, different assessment methods may apply different types of data when deriving risk classifications. GABLIS allocates species to particular categories according to the quality of available information as well as the potential invasiveness of the species (Essl et al. 2011). ISEIA considers only ecological impacts, whereas assessment schemes such as Harmonia⁺, FISK, and the New York method consider ecological, economic, and social aspects (Copp et al. 2005, D'hondt et al.

2015, New York Invasive Species Information, 2017). Thirdly, different rating systems applied by assessment schemes may influence risk classifications due to the application of normative cut-off thresholds. Small changes in an assessment, for example, slight differences in the interpretation of the same information by different assessors, or differences in the number of cut-off thresholds, may lead to different risk classifications (Verbrugge et al. 2012). The New York method applies insignificant, low-, moderate-, high-, and very high-risk categories, whereas other assessment methods, such as ISEIA, apply low-, medium-, and high-risk categories. The application of weighting factors may also lead to different outcomes. The Harmonia⁺ protocol allows the application of individual weighting factors to individual questions, among modules and impact types (D'hondt et al. 2015). Finally, assessment schemes that are specific to particular taxonomic groups (e.g., FISK) may more accurately assess potential species invasiveness compared to generic assessments such as ISEIA.

Blackburn et al. (2014) recently proposed a tool that defines the impacts of alien species according to five sequential categories. In ascending order of impact, these categories are minimal, minor, moderate, major, and massive. Impacts are classified based on the level of biological organization affected, that is, individuals, populations, communities (reversible) and communities (irreversible), setting this methodology apart from other existing risk assessment methods such as Harmonia⁺, the New York method, GABLIS, FISK, and ISEIA. Similar to many of the protocols considered here, the tool proposed by Blackburn et al. (2014) does not consider economic or societal impacts or ecosystem services, which, according to Roy et al. (2014a), are elements required to achieve the minimum standards for risk assessments in Europe. The tool proposed by Blackburn et al. (2014) was implemented by Hawkins et al. (2015) within the Environmental Impact Classification for Alien Taxa (EICAT). To attribute a risk classification, EICAT requires information on the current impact as well as the potential maximum impact level that may be caused by a particular taxon.

Other sources of uncertainty intrinsic to the application of risk assessment protocols relate to risk perception, species environment matches, or

invasion histories that vary between countries, and variability between assessors. Uncertainty relating to qualitative and semi-quantitative approaches was defined by Leung et al. (2012): (1) linguistic uncertainty, (2) stochasticity (also referred to as irreducible uncertainty or natural variation), and (3) epistemic uncertainty (also referred to as reducible uncertainty or incertitude). Linguistic uncertainty occurs because verbal and written communication is frequently open to interpretation, and even exact language may be deciphered in different ways by different assessors (Verbrugge et al. 2016). A lack of unifying definitions within invasion biology potentially magnifies these issues (Verbrugge et al. 2016). Linguistic uncertainty may be increased when risk assessments are applied internationally due to the requirement of a common language that may be non-native to many contributors. For example, in section 5.1 of the ISEIA protocol “dispersal potential and invasiveness,” the criteria for medium risk applies vague terminology such as “remote places,” and “rarely exceeds” leaving assessors to quantify the terms “remote” and “rarely” so that a score may be applied. A German assessor may interpret the term “remote” on a different spatial scale than an assessor in a relatively small country like The Netherlands, making comparisons difficult.

Stochasticity results from temporal and spatial variability, and the probabilistic mechanisms that originate from this variability. For example, the use of cases that are similar in ecological or geographical circumstances when direct evidence appears lacking, as advocated by D'hondt et al. (2015), may be problematic when considering that several species are known to expand to other habitat types once outside their native range (Wittenberg and Cock 2001, Verbrugge et al. 2012). There is no universal explanation of successful invasion of alien species into native communities (Dawson et al. 2015), and only limited research is available on factors that determine invasion success such as particular species traits or combinations of traits (e.g., Moravcová et al. 2015, Pyšek et al. 2015).

Epistemic uncertainty reflects the level of available knowledge and its reliability related to sample size, surrogate measurements, or observer error (Leung et al. 2012). Semi-quantitative methods are particularly vulnerable to data error

relating to observational gaps (e.g., Gasso et al. 2010, Verbrugge et al. 2012). Vilà et al. (2009) state that of the more than 10,000 European alien species registered in the Delivering Alien Invasive Species Inventories for Europe (DAISIE) database, ecological impacts are only documented for 1094 species (11%) and economic impacts for only 1347 species (13%). The establishment of alien species does not automatically lead to negative impacts; however, a lack of recorded impacts may also be due to a lack of observation. Data gaps lead to a heavy reliance on expert opinions and interpretations (Maguire 2004, Strubbe et al. 2011, Leung et al. 2012, Verbrugge et al. 2012). The ISEIA protocol applies strict criteria to define risk categories, which may result in greater instances of data deficiency. For example, in the section “dispersion potential or invasiveness,” the criterion for medium risk includes the sentence: “Natural dispersal rarely exceeds more than 1 km per year.” Seldom does information describing alien species contain such specific data on dispersal and terms such as “rarely” are often not defined resulting in the frequent application of expert judgment with a resulting increase in epistemic uncertainty. Moreover, risk prioritization and assessment methods often do not include an assessment of impacts relating to diseases and pathogens carried by some alien species that may result in additional, severe impacts within the alien range. The transfer of diseases and pathogens to native species increases morbidity and mortality, thereby reducing their ability to compete. For example, *Aphanomyces astaci* (crayfish pest) is a fungal pathogen that was introduced to Europe with American crayfish species or through the transport of water. The disease spreads more quickly than its resistant American host, leading to widespread and severe impacts on European crayfish species, which at the same time paves the way for widespread establishment of the American species in vacated habitats (Spitzzy 1971, Müller 1973). Another example is the introduction and spread of *Sphaerothecum destruens* (rosette agent), a disease that is associated with invasive *Pseudorasbora parva* (topmouth gudgeon). *Sphaerothecum destruens* is spread through invasion by *P. parva* to native cyprinids, which are, in contrast to *P. parva*, not resistant to the disease (Gozlan et al. 2005, 2009, Spikmans et al. 2013).

The precautionary principle

The precautionary principle, or applying the worst-case scenario when different scenarios are possible, is advocated in ISEIA (Branquart et al. 2009). However, the application of the precautionary principle together with potential linguistic biases may encourage assessors to select information that portrays alien species in the worst possible light. A reduction in IAS management effectiveness may result if the same financial budget is applied to the increased number of species classified as high risk. Therefore, it is vital that the application of the precautionary principle is accompanied by an awareness of the potential implications to uncertainty and reduction in discriminatory power.

CONCLUSION

The semi-quantitative methods for the risk assessment of alien species examined here convert what is frequently qualitative data to a quantitative value to enable the calculation of a final risk score and the determination of a risk classification. If not transparently applied, semi-quantitative approaches hide methodological differences and the complexity and potentially variable quality of supporting information. This may obscure the application of expert opinion, and may give a false impression of legitimacy. However, the inclusion of normative aspects in the valuation of ecological effects in qualitative risk assessments of non-native species is unavoidable. Therefore, approaches that increase transparency by highlighting uncertainty are vital to the legitimacy of any assessment method. An awareness on the part of assessors of the influence of methodological difference and sources of uncertainty that accompany a particular assessment method, and the communication of uncertainties during reporting, will contribute to an increased acceptance of risk classifications by decision makers, nature managers, and stakeholders.

The risk classifications examined here were determined for areas defined politically (within national borders) rather than ecologically (per biogeographical region). This potentially reduces the accuracy of risk classifications if the area assessed falls within multiple biogeographical regions. The application of assessment methodologies to biogeographical rather than political

regions or the inclusion of biogeographical differences within current assessment approaches should be considered in an effort to increase the accuracy of risk classifications and provide a basis for more targeted and cost-effective management interventions.

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