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Research article

Lessons learned from rapid environmental risk assessments for prioritization of alien species using expert panels

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ABSTRACT

Limiting the spread and impacts of invasive alien species (IAS) on biodiversity and ecosystems has become a goal of global, regional and national biodiversity policies. Evidence based management of IAS requires support by risk assessments, which are often based on expert judgment. We developed a tool to prioritize potentially new IAS based on their ecological risks, socio-economic impact and feasibility of management using multidisciplinary expert panels. Nine expert panels reviewed scientific studies, grey literature and expert knowledge for 152 species. The quality assessment of available knowledge revealed a lack of peer-reviewed data and high dependency on best professional judgments, especially for impacts on ecosystem services and feasibility of management. Expert consultation is crucial for conducting and validating rapid assessments of alien species. There is still a lack of attention for systematic and methodologically sound assessment of impacts on ecosystem services and weighting negative and positive effects of alien species.

1. Introduction

Limiting the introduction, spread, establishment and impacts of invasive alien species (IAS) on biodiversity and ecosystems has become a focal point of global biodiversity goals, as described in the Convention on Biological Diversity and the Sustainable Development Goals from the United Nations. As such, most countries in the world are committed to implement measures to prevent the introduction and significantly reduce the impact of IAS, and control or eradicate priority species, by 2020. Prioritizing and implementing such measures requires detailed information on introduction pathways and the current spread and impacts of IAS, as well as on the feasibility of management options in the area of concern.

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Recently, the European Commission adopted the EU-regulation 1143/2014 on the prevention and management of IAS. This regulation sets specific targets to limit the threat of IAS in order to halt the loss of biodiversity and ecosystem services. At the core of the regulation is a list of 'IAS of Union concern' (hereafter 'Union list'), including some of those species that cause the most damage to native biodiversity, and for which concerted measures are required across the EU. The regulation imposes restrictions on the keeping, importing, selling, breeding and growing of the listed species. Member States are also required to take measures for early detection and rapid eradication of listed species, and to manage populations that are already widely spread in a member state. Prevention has priority because established populations can be expensive to manage and difficult or impossible to eradicate. An overview of the procedure for listing IAS of EU concern has been summarized in the Supporting Information (Fig. S1 in SI). If species do not qualify for the Union list, two other approaches remain: 1) regional listing (Article 11, EU Regulation 1143/2014), or 2) national listing of IAS (Article 12, EU Regulation 1143/2014). All these approaches require prioritizing of alien species based on sound risk assessments (Carboneras et al., 2018).

Evidence based management of IAS needs to be supported by empirical knowledge and requires appropriate methods for synthesizing this information in a policy context (cf. Pullin et al., 2016). Risk assessments of alien species also need to comply with minimum requirements to be considered for Union listing, such as a description of the potential pathways of introduction and spread of the species, and a thorough assessment of the risk of introduction, establishment and spread in relevant biogeographical regions in current conditions and in foreseeable climate change conditions (Roy et al., 2014, 2015; 2018b). This has triggered the scientific community to develop or adapt risk and prioritization schemes, including horizon- scanning (the systematic search for potential IAS, their impacts on biodiversity and opportunities for impact mitigation; Matthews et al., 2017; Roy et al., 2019), and prioritization tools and economic approaches that aim to meet these requirements. However, despite efforts to converge approaches to risk assessment of alien species, they remain limited in the types of impacts they address (Roy et al., 2018b; Vilá et al., 2019) and their policy relevance (e.g. in assessing management options for established and widespread IAS; Vanderhoeven et al., 2017). Therefore, prioritizations or listings of IAS require additional species information, such as structured evaluations of management options and feasibility of eradication (Booy et al., 2017) and socio-economic impacts (Bacher et al., 2018; Gallardo et al., 2016).

Expert knowledge is widely used in risk assessments of IAS due to a lack of peer reviewed or other documented information on their introduction pathways, impacts and possibilities for management. These aspects need often to be assessed before they actually happened. Martin et al. (2012) define expert knowledge as "substantive information on a particular topic that is not widely known by others" and expert judgment as "predictions by experts of what may happen in a particular context". While expert judgement is useful and practical, it also warrants a cautious approach in order to minimize the impacts of subjectivity and 'group thinking' (Martin et al., 2012; Sutherland and Burgman, 2015). Structured elicitation techniques may aid in identifying and reducing potential sources of bias and error among experts, and reaching consensus among experts to inform policy decision (McBride et al., 2012). Recently, this approach has been applied in a number of exercises for prioritization of alien species of EU, regional or national concern (Gallardo et al., 2016Matthews et al., 2014, 2017; Roy et al., 2014, 2015) and can serve as a quality control of risk assessments through formalized feedback procedures between experts (Vanderhoeven et al., 2017). Factors affecting the confidence of such assessments include the availability, reliability and type of data used and the spatial scale over which they were collected as well as the ease of interpretation of the available data and whether they are in agreement with each other (Hawkins et al., 2015). Although many papers highlight these issues, it remains unclear what the contribution of expert judgment actually is in comparison to other types of knowledge and how it can support cost-effective management of IAS.

The aim of this paper is to evaluate a rapid assessment method for prioritization of potentially new IAS based on their ecological risk, socio-economic impact and feasibility of management using expert panels. For this purpose, the following research questions have been derived:

1) How to rapidly assess ecological risks, societal impact and feasible management options for prioritization of potentially new IAS of a region or state?
2) Which alien species can be prioritized as high risk invaders with feasible management options for a specific area of concern, i.e. The Netherlands?
3) What is the relative contribution of expert judgment in comparison to more formal types of knowledge?

The lessons learned from this rapid assessment of potentially new IAS for the Netherlands will be discussed within the context of global IAS policy and management.

2. Material and methods

2.1. Rapid assessment procedure

We developed a generic rapid assessment method for prioritization of IAS that can be applied to any area of concern (e.g. a state, region or protected area). It relies on information about a species' ecological risk, socio-economic impact and feasibility of management. The assessment includes both quantitative scoring (i.e. for ecological risk and feasibility of management) and qualitative data (e.g. pathways, socio-economic impacts).

The rapid assessment method was applied to prioritize potential IAS for the Netherlands (Verbrugge et al., 2015; NVWA, 2019). Scientific literature, grey literature and expert knowledge were used to select and list potentially IAS, select and operationalize assessment criteria in a questionnaire, and rapidly assess risks of alien species (Fig. 1). For all listed species, the information resulting from the rapid risk assessment was collected in a database in order to conduct a meta-analysis, and finally led to a set of recommendations for rapid assessment procedures.

2.2. Selection of potentially invasive alien species

Species were preselected based on earlier indications of their potential risk of introduction, establishment, spread and impact or invasiveness in areas with similar climate and habitat conditions as the Netherlands. These included:

- species that were evaluated as high risk (with high certainty) in a recent horizon-scanning project carried out in the Netherlands (Matthews et al., 2014, 2017);
- species that received a high risk indication in a risk assessment for the Netherlands (NVWA, 2015);
- species that are already included in Dutch policies, such as the code of conduct for aquatic plants (Verbrugge et al., 2014);
- species that were suggested by experts during a workshop on invasive species of EU-concern hosted by the Netherlands Food and Consumer Product Safety Authority on 24 June 2014 (Leferink et al., 2014);
- species which were expected to be nominated by other Member States for the Union list, including species that are part of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES, 1973).

Species that are native in (a part of) the EU or regulated by existing EU-legislation, such as phytosanitary measures, were excluded

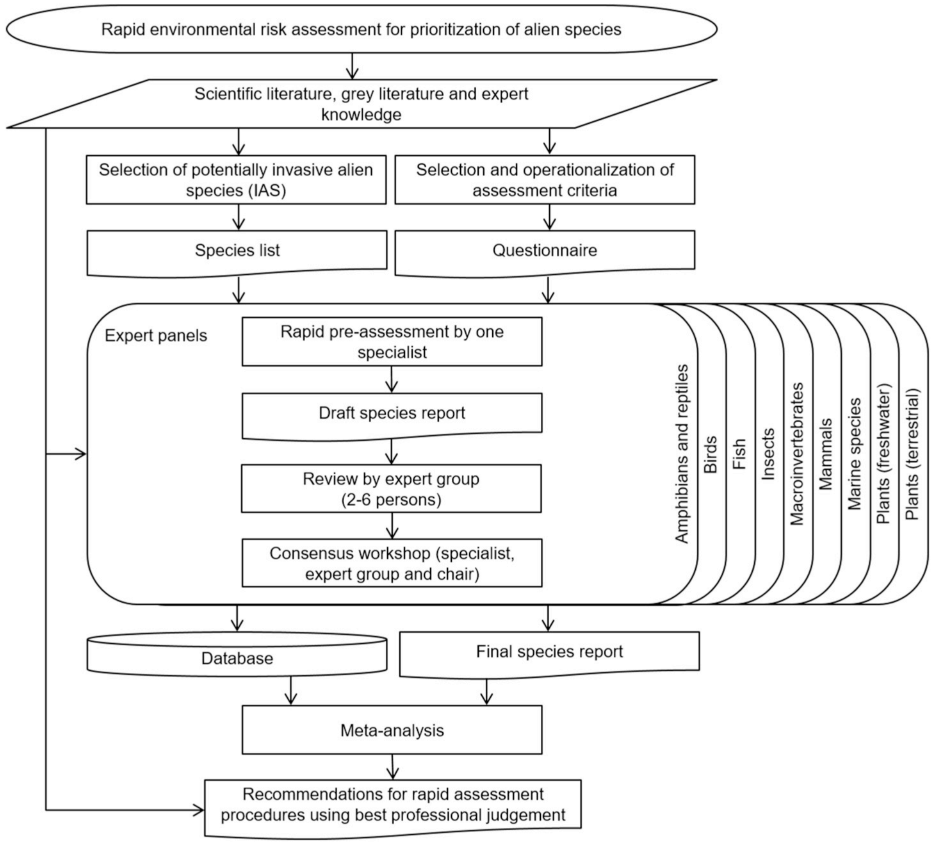

Fig. 1. Schematic overview of the rapid assessment procedure and meta-analysis.

beforehand, which is in line with EU-regulation 1143/2014 on IAS (European Commission, 2014). In total 152 species were evaluated and divided over nine groups: freshwater plants (19), terrestrial plants (41), insects (5), freshwater macro invertebrates (11), freshwater fish (17), marine species (18), amphibians and reptiles (9; this number includes two high impact pathogens affecting native species of these taxonomic groups), birds (9), and mammals (23). Online species databases were used to obtain the scientific and common names, such as the World Register of Marine Species and the Dutch Species Register (DSR, 2017; WoRMS, 2017). A complete list of the species' scientific and common names is available in Table S1 of the SI.

2.3. Questionnaire and selection criteria

The questionnaire consisted of four main parts: (1) risk level, (2) feasibility of minimizing or preventing the risk of introduction, (3) feasibility of management measures, and (4) positive effects (Text section S1 of the SI).

The first part addressed the species' potential risks for negatively affecting biodiversity, ecosystems and the availability of ecosystems services. The questions on biodiversity and ecosystem impacts were based on the recently developed Harmonia$^+$ protocol (D'hondt et al., 2014, 2015) and could be answered on a four-point scale (no impact, low impact, medium impact and high impact; Table 1). The adverse impact on biodiversity was scored using categories of genetic integrity loss caused by hybridization and categories of population decrease caused by predation, herbivory, competition and parasitism for a minimum of one native species that is or is not protected by nature policies. The adverse impact on ecosystems was scored using categories on the reversibility of alterations to ecosystems that are or are not subject to nature conservation policy. Ecosystem services are defined in EU-regulation as "direct and indirect contributions of ecosystems to human wellbeing" and include provisional, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005). The scoring of these impacts was based on examples rather than predefined criteria but using the same four-point scale. Examples were obtained from the Harmonia$^+$ protocol and are available in Text section S2 of the SI (D'hondt et al., 2014). Other potential negative effects, i.e. socio-economic effects, such as human health risks and negative impacts on infrastructure or agriculture, could be registered using an open-ended question. These additional impacts did not contribute to the calculation of a risk score. The questionnaire was discontinued in case a species' risk scores for all three categories (i.e. biodiversity, ecosystems and ecosystem services) were lower or equal to one. The same procedure accounted for species that could not be assessed due to a lack of scientific and expert knowledge.

The second part of the questionnaire addressed the relevant introduction pathways of the species into the EU. A maximum of four pathways were listed per species using the framework developed by Hulme et al. (2008) which has been adopted by the Convention on Biological Diversity (UNEP, 2014). Considerably reducing the introduction risk via the pathways was assessed to be completely, partially or not technically feasible by using management measures. At this point, considerations regarding costs, public support and enforcement were excluded.

The third part of the questionnaire assessed the current and future spread (i.e. sustaining viable populations at local, regional or widespread scale) of an alien species in the area of concern and the technical feasibility of its eradication. If eradication was assessed technically feasible, the associated costs of measures (i.e. < €100 K, €100 K–1,000 K or > €1,000 K) and side effects were estimated. These estimations were made assuming that all populations and individuals could technically be removed from the natural environment. If elimination was not technically feasible, the questions on species eradication were skipped and an estimate was made of feasible measures for mitigation of adverse effects (completely/partially/none) and the

Table 1
Risk level and criteria for assessing the negative impact on biodiversity and ecosystems.

Risk level		Impact on native species diversity			Impact on ecosystems	
Score	*Impact*	*Population decrease*	*Loss of genetic integrity*	*Effects on protected species*	*Alterations reversible*	*Effects on protected areas for biodiversity conservation*
0	No	None	None	No	Not relevant	No
1	Low	Limited	Limited	No	Yes	No
2	Medium	Limited	Limited	Yes	Yes	Yes
		Severe	Severe	No	No	No
3	High	Severe	Severe	Yes	No	Yes

associated costs and side effects.

Part four addressed whether potential positive ecological effects of the species outweighed the negative effects on biodiversity, ecosystems or ecosystem services.

2.4. Pre-assessment and expert panels

The procedure for the species' assessments consisted of a rapid pre-assessment by an individual expert followed by a peer review and validation of risk levels using expert panels. Each species group was assigned to an expert from a research institute or consultancy (i.e. Bargerveen Foundation, Bureau Natuurbalans – Limes Divergens, Sovon Dutch Centre for Field Ornithology, Plant Conservation Netherlands (FLORON), Reptile, Amphibian & Fish Conservation Netherlands RAVON, Dutch Mammal Society, and NIOZ Royal Netherlands Institute for Sea Research) and who fulfilled the role of 'secretary' to ensure that all available information was taken into account.

These assigned taxonomic experts performed a pre-assessment for each species using the questionnaire. Next, the pre-assessments were send for review to the expert panels consisting of an additional two to six experts involved in research and management of alien species and to the workshop chair. They individually provided written comments which were compiled and send out in preparation for the workshops per species group. The chair participated in the reviews and was also responsible for quality assurance. The aim of the workshops was to discuss the comments on and additions to the pre-assessments and to reach consensus on risk scores for each species in the group. If no consensus was reached there was a possibility for a minority point of view. However, in none of the workshops this option was used when assigning the risk scores. In order to ensure that all experts interpreted the criteria and answered categories in the same way, the discussions on risk scores during the workshop started with full reading of the completed questionnaire for each species. After the workshops, all species assessments were updated and published on the website of the Dutch Food and Consumer Product Safety Authority (NVWA, 2019).

2.5. Different types of knowledge used for rapid risk assessment

The amount of available (scientific) knowledge on alien species depends among others on the species' presence in a country and the availability of previously performed risk analyses. Experts in the field of ecological effects and management of alien species used expert judgement if documented information was lacking. The type of knowledge used in the assessment was categorized into four different types to be able to interpret its quality and highlight data gaps (Table 2). These four types mirror confidence levels distinguished in Environmental Impact Classification for Alien Taxa (EICAT) guidelines of Hawkins et al. (2015). Preferably, information from existing risk assessments for the area of concern (i.e. the Netherlands) was used (RA1). If these were not available, risk assessments from other, if possible neighboring, countries were used (RA2). Additionally, an earlier horizon-scanning contained information on risk classifications and pathways for 83 of the listed alien species (Matthews et al., 2014, 2017). These data were provided to the experts together with the available risk assessments.

Table 2
Overview and hierarchy of types of knowledge used in the assessment.

Type	Description	Coding
1	Risk assessment and/or horizon-scanning performed in the area of concern (i.e. The Netherlands)	RA1
2	Risk assessment and/or horizon-scanning performed in other countries	RA2
3	Expert judgment supported by documented literature	E1
4	Best professional judgement supported by a facilitated discussion of experts' personal expertise and unpublished field observations	E2

Expert judgment or personal observations could be supported by documented grey literature (E1) or theoretical arguments or expertise (E2). The invasion success of an alien species in other countries is thus implicitly considered when answering questions on the risk level and current presence and spread, because documented literature from other countries is included in the different types of knowledge used in the assessment. In the questionnaire, the experts were requested to label the type of knowledge and note the references used to answer each question. For species without any available documentation, expert opinions were discussed during the workshop to reach a best professional judgment.

2.6. Database and meta-analysis

The data obtained from the alien species' rapid risk assessments were compiled in a Microsoft Excel database and is available from the website of the Dutch Food and Consumer Product Safety Authority (NVWA, 2019). An overview of the content of the database, including an example of data for an alien species (i.e. Giant hogweed *Heracleum mantegazzianum*) is available in the Supporting Information (Table S2). First, a meta-analysis was performed on the risk levels resulting from the rapid assessments. The overall species' potential risks were classified into three categories using the risk scores for biodiversity, ecosystems and ecosystem services: High risk (minimum of one score 3), moderate risk (minimum of one score 2 and lower than 3), and low risk (equal to or smaller than 1). Risk scores were also used to compare the number of species per species group with a low, medium or high impact on biodiversity, ecosystems and ecosystem services. Second, the feasibility of minimizing or preventing the risk of introduction was analyzed using the assessed introduction pathways, proposed measures and their socio-economic impacts. Third, the feasibility and costs of eradication and mitigation measures were analyzed in relation to the alien species' presence. Fourth, the alien species with positive effects outweighing negative effects were exemplified. Finally, the relative contribution of the different types of knowledge was compared between the different parts of the questionnaire.

3. Results

3.1. Risk level

Three species (2%) were not assessed due to a lack of available

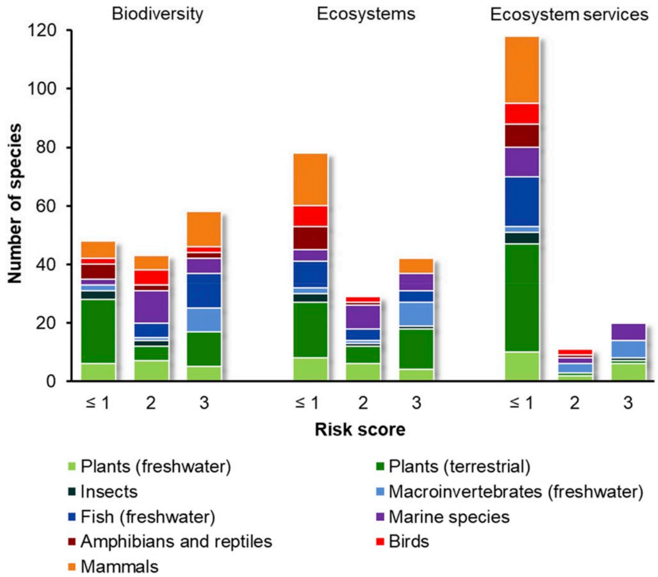

Fig. 2. Selection of alien species (n = 149) classified according to their potential risk for biodiversity, ecosystems and ecosystem services in the Netherlands (≤1: no or low impact, 2: moderate impact, 3: high impact).

information, i.e. the aquatic plant *Hydrilla verticillata* and the terrestrial plants *Gaultheria mucronata* and *Persicaria perfoliata*. Of the remaining 149 alien species, 28% were assessed to be of low, 26% of moderate and 44% of high potential ecological risk to the Netherlands. Of the same group, 68% were assessed to have a moderate or high impact on biodiversity, compared to 48% and 21% on ecosystems and ecosystem services, respectively (Fig. 2). For 68 species no negative impacts on ecosystem services were recorded (score 0). Expert panels identified additional adverse socio-economic impacts for 82 species, including all insects (100%), many macro-invertebrates (91%), birds (89%), mammals (87%) and marine species (83%), fewer terrestrial plants (49%), amphibians and reptiles (33%), freshwater plants (11%), and no fish (0%).

3.2. Feasibility of minimizing the introduction risk

A maximum of four most relevant introduction pathways, of a total of 35 introduction pathways described in UNEP (2014), were ascribed to each of the 105 alien species with a potential moderate and high risk to the EU. In total, 277 data entries are depicted in Fig. 3. Natural dispersal of alien species across borders into uncolonized countries within the EU (while introduced through other pathways) was identified as the most important pathway for all species groups. The presence of a species in border regions was therefore recognized as a potential pathway for introduction. In addition, escapes of pets or other species kept in aquaria or terraria was identified as an important pathway. Horticulture, ornamental use and spread via machinery and equipment were identified as important pathways for alien plant species.

Measures for considerably reducing the introduction risk were identified for 35% of the pathways, compared to a partial feasibility for 22% and no feasibility for 43% of the pathways. Most often proposed interventions included raising awareness among owners and stakeholders, implementation and enforcement of legislation and more extensive surveillance. A ban on the possession, breeding and trade of alien animals and plants might reduce specific pathways, such as escapes from confinements of animals in domestic homes and zoos, and plants for horticulture or ornamental purposes. This would require international agreements, such as listing of species as IAS of EU concern. Thorough checks of different transport mechanisms, such as used machinery, ships, and other vehicles, confinements, and garden waste were also suggested by the experts. Introduction via natural dispersal across borders and interconnected waterways, basins and seas cannot be prevented. The suggested measures will have significant socio-economic effects, due to the need for more law enforcers, reducing the income for breeders and traders and social unrest among members of the public.

3.3. Feasibility of eradication and mitigation measures

The feasibility of eradication measures is related to the extent of distribution of a species in a region (Fig. 4A), but also depends on species and habitat characteristics (e.g. open or inaccessible environments). Complete eradication was expected to be technically feasible for 94% (n = 31) of the moderate and high risk species that are not yet present in the Netherlands compared to only 12% (n = 4) for the widespread species. Approximately half of the locally and regionally spread species (55%) were expected to be eradicable. Overall, eradication measures were expected to be technically feasible for 45% the assessed alien species (Fig. 4B). Expected eradication costs were below €100 K for 13 species that are not yet present in the Netherlands, 8 locally spread and 1 regionally spread species. Costs were above €1,000 K for 3 wide spread, 2 regionally and 1 absent alien species. In the hypothetical situation that each species is widespread in the Netherlands, complete mitigation of effects of IAS was assessed to be less feasible for a higher percentage of species than partial mitigation (Fig. 4C) in various cost categories. The Brushtail possum (*Trichosurus vulpecula*) and the Red king crab (*Paralithodes camtschaticus*) were not assessed due to a very low introduction risk into the wild and an unsuitable climate for establishment, respectively.

The occurrence of adverse side effects during or after the execution of eradication or control measures for alien species were scored between 0 (no side effects) and 4 (severe side effects) (Fig. S2 in SI). Measures were expected to disrupt the ecosystem and/or adversely affect native species (score 1 or higher) for 79% and 82% of the assessed alien species, respectively. These side effects were ascribed to be most severe for the Northern highbush blueberry (*Vaccinium corymbosum*) and the Oriental weatherloach (*Misgurnus anguillicaudatus*). In addition, social unrest was expected for the eradication and mitigation of 64% and 48% of the alien species, respectively. Few measures were expected to contribute to environmental pollution or other effects (e.g. increased opportunities for other alien species to establish in the area).

3.4. Positive effects

Significant positive effects on native biodiversity, ecosystems or ecosystem services were ascribed to the establishment of two alien species. In addition to a high ecological risk, the quagga mussel (*Dreissena bugensis rostriformis*) and the Pacific oyster (*Crassostrea gigas*) were also expected by the experts to have positive effects on the native biodiversity and ecosystems in the Netherlands, for example due to an increase in water clarity through filtering, an increase in substrate and shelter for epibenthic fauna, or as a food source for predators. These expert judgments are highly contextual and apply specifically for the Netherlands where the effects of these species have been studied in deteriorated and heavily modified ecosystems (e.g. Noordhuis et al., 1992; Waajen et al., 2016). While information about positive effects on ecosystems can be useful for decision makers, it also leads to discrepant findings, as these species can also be classified as high ecological risk (e.g. *C. gigas* in Table S4).

3.5. Contribution of different knowledge types

The main source of knowledge used for eight out of 14 questions of the rapid risk assessment was expert judgement based on personal

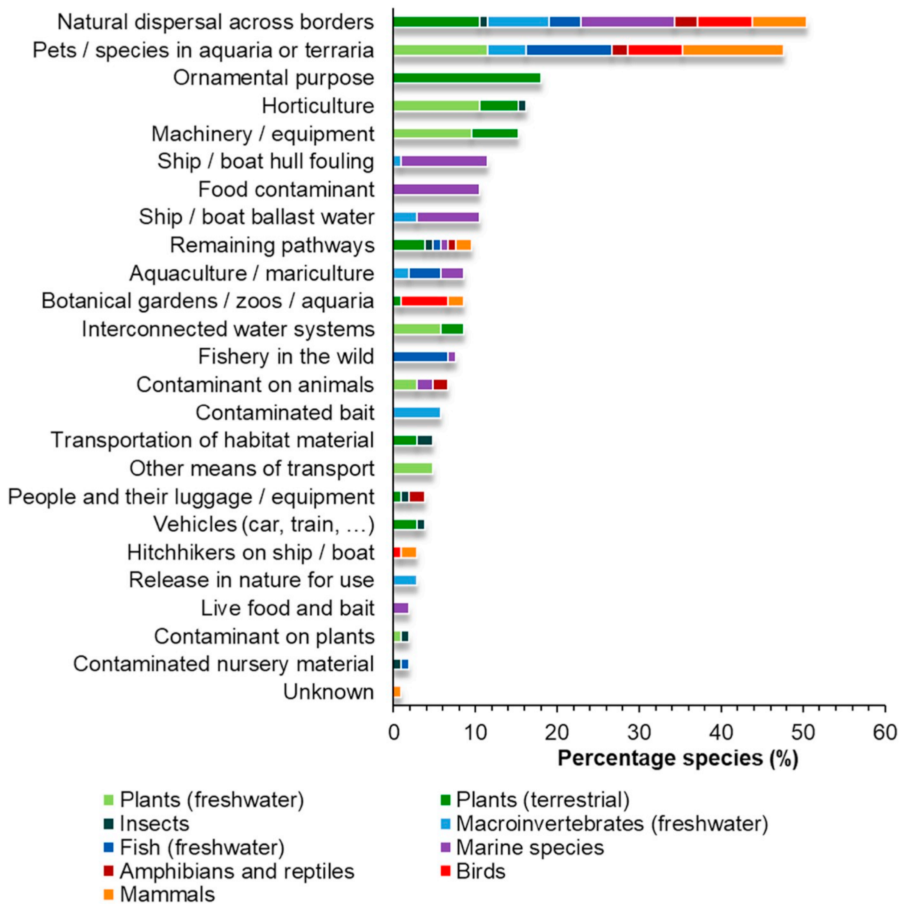

Fig. 3. The relative contribution of moderate and high risk species (n = 105) to various pathways for introduction in the European Union.

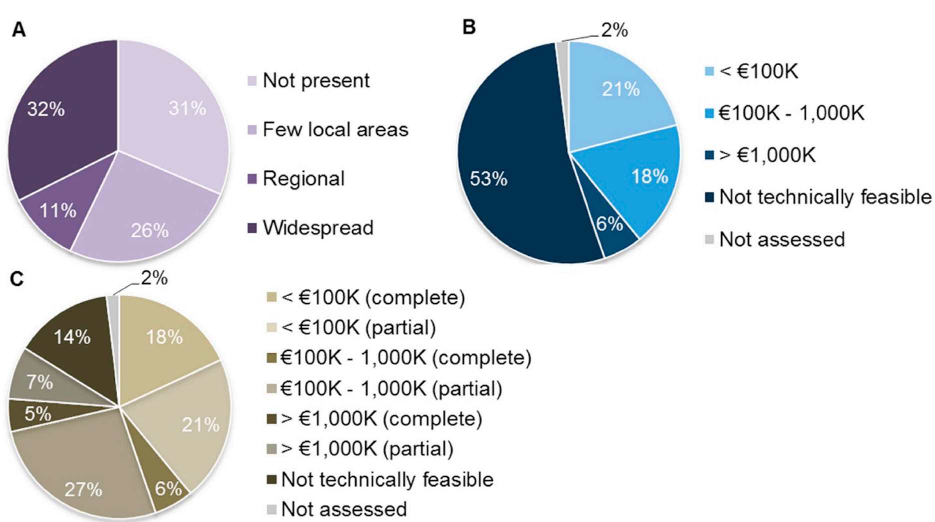

Fig. 4. Percentage of moderate and high risk species (n = 105) classified according to A) their spread in the Netherlands, B) the estimated non-recurring expenses for the eradication of species (if deemed possible), and C) the estimated yearly expenses for complete or partial mitigation (in the hypothetical situation that the species becomes widespread).

expertise or observations (36–83% of the species; E2), followed by risk assessments and/or horizon-scanning performed in the Netherlands (36–48% of the species, RA1) for five questions of the questionnaire (Fig. 5). Documented literature was mostly available for assessing the impacts on biodiversity and ecosystems and the species' presence (86–94% of the species). Expert judgement was mainly needed to assess the impact on ecosystem services, potential pathways, costs and side effects of eradication and mitigation measures, mitigation feasibility and positive impacts for these species (Fig. 5).

3.6. Comparison with EU risk assessments

A comparison of the outcomes of our study with recent findings of detailed risk assessments of the European Commission reveals that our rapid assessment method functions well as a pre-selection tool. In total 51 species (57%) have recently been listed as invasive alien species of EU concern (Union list of EU Regulation 1143/2014) or are in procedure or under consideration for an extension of this list (Table S3 in SI). Of these species, 61% was assessed to be of high ecological risk for the Netherlands. Thirty-five high risk alien species from the rapid risk

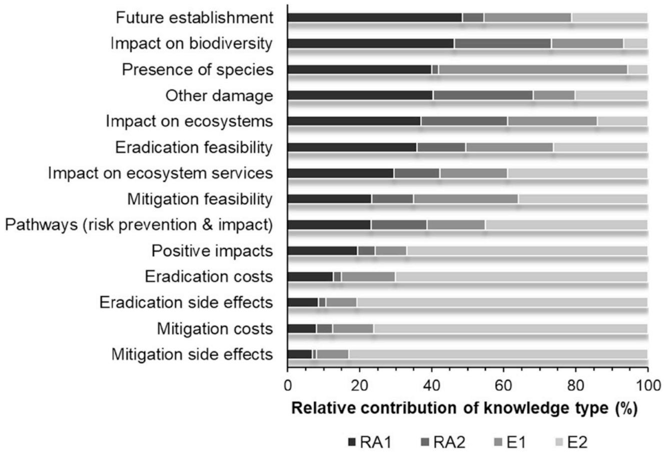

Fig. 5. Relative contribution of different types of knowledge used in different parts of the questionnaire for the rapid assessment. An overview and hierarchy of the types of knowledge used in the assessment (RA1, RA2, E1 and E2) is available in Table 2.

assessment were not (yet) included in the Union list or considered for possible future extensions. These species could be considered for future extensions of the Union list in case of compliance with all criteria set by the EU Regulation 1143/2014 or would be suited for a national approach to prevent an impact on ecology and socio-economics (Table S4 in SI). Here it is important to note that only three marine species are part of or considered for the list of species of EU concern, while our assessment included 18 species, of which 7 were deemed of high concern.

4. Discussion

The aim of this study was to develop and to evaluate a rapid assessment method for prioritization of potentially IAS that are or may be introduced, with a particular focus on the use of different types of knowledge. Here, we reflect on the reliability and validity of our method, the role of expert panels, and the relevance of our findings for research and policy.

4.1. Reliability and validity

For extensive risk screening and assessment several generic and taxon specific tools have been developed, such as the Fish/Aquatic Species Invasiveness Screening Kits (Copp et al., 2016b; Tarkan et al., 2014, 2017) and Harmonia/Pandora protocol (D'hondt et al., 2014, 2015). However, these assessments often demand considerable amounts of time and resources. Our expert based rapid assessment method to prioritize alien species based on potential impacts and the feasibility and cost effectiveness of management options is a useful tool to inform policy in cases where quantitative information is not readily or only partly available. It allows decision makers to weigh certain impacts or prioritize species based on different criteria, dependent on the policy aims, available (expert) information and resources that are at hand.

While the questionnaire has been designed to be as inclusive as possible, it also has some limitations. First of all, no risk score was included for the socio-economic category, therefore this information was not used for the overall species' potential risk categorization. In total, 64 high or moderate risk species, and 18 low risk species were also expected to have an adverse impact on social or economic values. Local governments may still wish to prioritize these species depending on the severity of these impacts. Recently, Bacher et al. (2018) developed a socio-economic impact classification of alien taxa (SEICAT) that can be integrated in our questionnaire.

Second, experts were asked to identify significant positive impacts of alien species on the biodiversity, ecosystems or ecosystem services (i.e. those cases in which positive effects outweighed negative ones). However, a quantitative approach for weighting negative and positive ecological and societal effects is lacking and judgments of unequal effect categories are always subjective. This information did not contribute to the scoring of species and was only supplementary for consideration during decision making on more extensive risk assessment or regulation of IAS of national or continental concern.

Third, a quantitative approach is lacking for the assessment of impacts on ecosystem services, which are not yet clearly defined and classified in the context of IAS (an issue also noted by Roy et al., 2018b). In our case, negative impacts on ecosystem services were recorded for 81 out of 152 species and only in qualitative terms. The discrepancy between the large number of species with high scores for impacts on biodiversity and low number with high scores for impacts on ecosystem services was also noted by Tanner et al. (2017) in their assessments of potentially invasive plant species, and most likely reflect the current lack of data on such impacts. There has been more attention for human and social dimensions of invasion science and management (see Shackleton et al., 2019), however, it will take time for more studies to be published on this topic. Recent efforts of the European Commission can play a key role in the mapping and assessment of ecosystem conditions at a European level (Maes et al., 2012, 2018).

Fourth, the user-experience of the questionnaire could be improved by giving more guidance to the experts on what aspects to consider for each question. This is particularly important for species for which there is little or no information available. One option is to add a list of biological characteristics associated with invasion success (Romanuk et al., 2009).

4.2. The role of expert panels

The quality assessment of knowledge types used in the assessments (Fig. 5) revealed a general lack of peer reviewed data and thus a high dependency on expert judgments. In general, our approach may even underestimate the contribution of expert knowledge, as information derived from previous risk assessments may also be (partly) based on expert judgment. We found that expert opinions are especially needed for the assessment of impacts on ecosystem services (see 4.1) and the feasibility and costs of eradication and mitigation measures. In our study, eradication was not deemed feasible for 53% of the 105 species with potentially high or medium ecological impacts in the Netherlands, and costs exceeded €1,000 K for 6%, highlighting the large proportion of species for which information on management aspects is decisive in prioritization. Therefore, the inclusion of practitioners in expert panels is highly recommended. Moreover, open access to and sharing of data and information about the effectiveness and cost efficiency of invasive species management between organizations and countries is of utmost importance to best inform management practices (e.g. Adriaens et al., 2018; Sarat et al., 2017).

Acknowledging the central role of experts in species assessments calls for a discussion of the role of uncertainty and subjective influences on expert judgments. For example, Dahlstrom-Davidson et al. (2013) found that scientists and practitioners engaged in aquatic biosecurity assigned lower consequence when faced with knowledge gaps and other forms of uncertainty. The use of structured expert elicitation and formalized feedback procedures may limit such processes (Vanderhoeven et al., 2017). In our case, one expert performed a pre-assessment for each species. These pre-assessments were sent for review to expert panels consisting of multiple experts involved in both research and/or management of alien species, followed by a consensus workshop. Such an approach facilitates a general consensus and limits the influence of individuals who hold a strong opinion as well as differences in scoring between individuals (inter-assessor variability). The inclusion of international experts can be a valuable asset for assessments in terms of additional expertise on the invasion biology of specific species (e.g.

Copp et al., 2016a) or when the area of concern spans multiple countries. However, experts should also have profound knowledge of the area of concern to be able to assess the potential risks and management options, which justifies our approach with a national panel.

4.3. Relevance for policy

The results from our assessment inform both national and international policies. On a national level, the list of potential IAS (Table S4 in SI) and underlying data provide a starting point for developing a strategy for IAS management in the Netherlands. Using the database, policy makers can easily select a species or pathway which meet their criteria in terms of impact, feasibility of management and costs.

Our findings regarding pathways, prevention and management are applicable more universally. In the current study, differences in introduction routes between species groups are largely determined by their environment. For example, aquatic animals are mainly introduced via intentional release for fishing, escape from confinement in aquaculture, mariculture and domestic environments, ballast water and hull fouling, and contaminated bait and food. By contrast, plants are mainly introduced via horticulture and ornamental trade, escape from domestic enclosures, and spread via transport routes via large machinery and vehicles. Pergl et al. (2017) found that species with multiple introduction pathways are more likely to have an ecological impact than those with less, and that for plants specific pathways can be targeted to prevent the introduction of harmful species. However, they did not assess the feasibility of managing these pathways, which included intentional releases but also spread via interconnected waterways and natural dispersal across borders. In this respect it remains of vital importance to perform national assessments, a task which is daunting but taken up by other countries as well, such as the UK (Booy et al., 2017) and South Africa (Van Wilgen and Wilson, 2018). While for some pathways, such as ballast water, regulations are already in place, others, such as hull fouling, require urgent attention.

To prevent new introductions, the experts in our study advised to raise awareness, implement and enforce legislation, and increase surveillance. These recommendations are obviously not new (e.g. Hulme et al., 2018) but do stress the importance of assessing their feasibility in (inter)national context. Several recent initiatives aim to increase awareness and involve stakeholders and citizens in early warning and surveillance. For example, the COST Action CA17122 (2018–2022) aims to increase our understanding of alien species through citizen science (Roy et al., 2018a). It is important that such interventions are evaluated in terms of their effectiveness in reaching a wide audience, the influence on people's behavior, and their added value for data collection. While our findings provide information on relevant stakeholders for managing certain pathways or to participate in eradication, additional studies on human behavior and preferences are needed to design effective management strategies (McLeod et al., 2019).

Climate change presents another major challenge for risk management of IAS as global warming leads to on-going major changes in distribution areas of species (e.g. Buczkowski and Bertelsmeier, 2017; Stachowicz et al., 2002). Unfortunately, species distribution models under current and future climate and habitat conditions are only available for a limited number of species and require much data and resources. Our approach may conceptually underestimate potential species of concern and invasion success if the climate and habitat match under current and future environmental conditions have not been included in the available risk assessments.

4.4. Conclusions and recommendations

The use of expert consultation is crucial for conducting rapid assessments of alien species and for validating the outcomes. This is in contrast to current guidelines outlined in the recent EU delegated act (European Commission, 2018), which explicitly refers to the use of peer reviewed documentation. Our method is a useful addition to current rapid assessment tools as the questionnaire is designed to quickly gather multidisciplinary knowledge on alien species' impacts and the feasibility of eradication and mitigation measures. Compared to individual assessors, the use of multidisciplinary expert panels for rapid assessment of species combines insights from research and field practice, both of which are essential for prioritization of species based on impact and feasibility of management. Our approach yields valid results that meet the information needs used for prioritizing species of EU or national concern. In addition to the prioritization of alien species into high, medium and low risk classes, a differentiation of weight factors for different categories of the rapid assessment and assessment of positive effects on biodiversity, ecosystems and ecosystem services may be considered.

Recommendations for further development of rapid risk assessment protocols and national or regional prioritization of IAS are (1) to perform rapid assessments per species group and bioregion, (2) in these assessments, acknowledge the importance of multidisciplinary expert knowledge for the validation of outcomes of rapid assessments, (3) to develop a systematic and methodologically sound approach for assessing impacts on ecosystem services and cost-effectiveness of management measures in line with definitions and ambitions formulated in the EU regulation of IAS and Delegated Act, using quantitative methods, and (4) to develop an integrated approach for weighting negative and positive ecological and societal effects of alien species in rapid assessments.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109405.

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