ARPHA Preprints

PREPRINT

Author-formatted, not peer-reviewed document posted on 17/03/2025

DOI: https://doi.org/10.3897/arphapreprints.e153054

Risk assessment in practice: Insights into invasive species risk assessments from a survey of users

Susan Canavan, Kim Canavan, Sabrina Kumschick, Doria R Gordon, John RU Wilson, Deah Lieurance

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

Risk assessment in practice:
Insights into invasive species risk assessments from a survey of users

Susan Canavan[1], Kim Canavan[2,3], Sabrina Kumschick[4,5], Doria R. Gordon[6,7], John R.U.Wilson[4,5], Deah Lieurance[8]

[1]School of Natural Sciences, Ollscoil na Gaillimhe—University of Galway, Galway, Ireland
[2]Centre for Biological Control, Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa
[3]Department of Plant Sciences and Afromontane Research Unit, University of the Free State, Phuthaditjhaba, South Africa
[4]Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa
[5]Kirstenbosch Research Centre, South African National Biodiversity Institute, Cape Town, South Africa
[6]Environmental Defence Fund, New York, NY, USA
[7]Department of Biology, University of Florida, Gainesville, FL, USA
[8]Department of Ecosystem Science and Management, The Pennsylvania State University

Abstract

Risk assessment is an important tool in invasive species prevention and management, providing a structured approach to identify and evaluate the risks posed by non-native species. Despite the widespread development of risk assessment methods, there is a lack of information on which methods are used in practice. We conducted a global survey of risk assessment practitioners from diverse regional, professional, and taxonomic contexts to identify the tools and databases used, the qualifications and experience of assessors, and the implementation and accessibility of risk assessment results. 107 responses were received from practitioners focussed on all continents except Antarctica, with the most from the United States and the United Kingdom. Respondents reported using more than 46 different RA tools, with the Fish Invasiveness Screening Kit and the USDA Plant Protection and Quarantine Weed Risk Assessment the most commonly mentioned, though geographic sampling bias likely influenced this result. Assessments predominantly focused on plants and terrestrial species, though representation from all taxonomic groups and systems exist. Respondents listed 143 generally open-access databases that they frequently use to conduct risk assessments, with the most commonly used sources being the CABI Invasive Species Compendium, occurrence records from the Global Biodiversity Information Facility (GBIF), and taxonomic information from the Integrated Taxonomic Information System (ITIS). Assessors typically had tertiary education, with the majority holding at least a master's degree, though most did not believe that graduate education is necessary to be an effective assessor. After risk assessments were completed, assessments were predominantly reported to government agencies. Most finalized risk assessments included some measure of certainty and were usually accessible to the public, with few including public comment. There is strong support for training or certification programs to standardize qualifications for assessors, as indicated by the majority of respondents. Based on the views expressed in the surveys we discuss the importance of: (1) training and capacity building, (2) open access databases and FAIR (Findable, Accessible, Interoperable and Reusable) data, (3) incorporating stakeholders and the public in the process, and (4) standardisation of tools; if these measures are implemented, they may enhance the consistency, transparency, and effectiveness of risk assessments of non-native species.

Keywords

Biosecurity, weed risk assessment, impacts, CABI, GBIF, ITIS, FAIR, Invasiveness Screening Kit, non-native, alien species

Introduction

Risk assessments for non-native species aim to predict the potential for non-native species to invade and threaten natural and human systems, whether through accidental introductions via trade, tourism, and travel, or through intentional releases. Risk assessments facilitate systematic evaluation or forecasting of the level of threat non-native species pose pre- or post-introduction. As such, they have become a standard practice in many countries, with agencies and organizations using them to guide management decisions (e.g., EPPO, 2011; USDA APHIS, 2020), and consequently, assessments related to species introductions have been incorporated into international trade and environmental policy agendas, quarantine legislation, and procedures at national borders. For example, the International Standards for Phytosanitary Measures (ISPM) and the World Organisation for Animal Health (WOAH) have established standards and guidelines for RAs to restrict the movement of pests and protect human and animal health (FAO 2007a and b).

Risk assessment methods vary in design, scope, and intended use, being tailored to different taxa, regions, and ecosystems. Some focus on screening species for their potential invasiveness, while others provide detailed RAs for specific species, including full impact categorization, pathway analysis, and species distribution mapping. Examples include the Aquatic Species Invasiveness Screening Kit (AS-ISK) for aquatic systems (Copp et al., 2016) and the Australian Weed Risk Assessment (AWRA) for plants (Pheloung et al. 1999). Region-specific assessments include the EPPO framework for Europe (EPPO, 2011) and the Canadian Food Inspection Agency (CFIA) pest risk analysis (CFIA, 2012). However, there is often a lack of consolidation and continuity among these approaches, with varying terminology adding to the confusion (Roy et al., 2018). Terms such as "protocols", "frameworks", "kits", "schemes", and "systems" can incorporate elements of RA to varying degrees, with some terms used interchangeably. Additionally, the term "risk analysis" typically encompasses risk assessment, risk management, and risk communication (e.g., Kumschick et al. 2020). All of these incorporate a predictive process intended for the management of biological invasions. For the sake of brevity, we will collectively refer to these tools and methods as "RAs".

The peer-reviewed literature includes numerous publications on RAs, offering various perspectives on the utility and function of the process (e.g., Leung et al., 2012; Kumschick and Richardson, 2013; Roy et al., 2018; Lieurance et al. 2024). Despite the widespread development of RA methods and extensive literature available to researchers, policymakers, and managers, it remains unclear which tools are regularly used in practice, by whom, and for what purposes. Clarifying these issues is essential for improving the effectiveness, consistency, and transparency of risk assessment processes. Key questions include: Who develops these methods, and who actually implements them? What taxa or ecosystems are being prioritized for assessment, and what data sources underpin these evaluations? Equally important, particularly for decision-makers and the broader public, is understanding how clearly and effectively RA results are communicated. Additionally, identifying the level of expertise and qualifications required of practitioners, as well as the accessibility of training programs, is critical for agencies and organizations seeking to ensure robust and credible risk assessment outcomes.

In this study, our goal was to gain a practical understanding of RA, focusing on its real-world application as applied to non-native species. First, we looked at whether interest in RA in the literature has increased over the years compared with the overall trend in invasive species research. Secondly, we conducted a global survey of practitioners from diverse regional, professional, and taxonomic contexts.

Methods

Trends over time

To understand if the focus on RA in invasive species management has increased in the literature over the past two decades, we obtained the number of search results from Google Scholar for each year from 2004 to 2023. We used two search queries: "risk assessment" AND "invasive species" to ensure the results were specifically related to risk assessment in the context of invasive species, and "invasive species" alone to compare with the general trend of the topic (**Figure 1**).

Survey development

We developed a 29-question survey to gather information directly from risk practitioners, including a list of RA programs (including both risk assessment and risk analysis), databases, and other sources of information, as well as a practical description of risk assessment in practice. The survey was comprised of various questions (**Table 1; Supplementary Table S1**)

Table 1. Overview of survey topics, and key findings.

Theme	Question topic	Results summary
General information		
	Tools used	46 tools identified (**Table 2; Figure 3**)
	Continents covered	89 countries assessed (**Figure 2**)
	Geographic scales	Assessments done mostly at the country-level (40%) and regional scale (39%)
	Taxonomic groups assessed	Predominantly plants (**Figure 4a**)
	Ecosystems assessed	Predominantly terrestrial ecosystems (**Figure 4b**)

Experience with RAs		
	Length of experience	Most respondents >5 years' experience (60%)
	Number of RAs conducted (past 3 years)	Most respondents conducted <10 RAs (44%)
	Time required per assessment	Typically weeks to months (varies by complexity)
	Organizations represented	Government agencies (48%), research institutions (29%)
Qualifications & Opinions		
	Education level of assessors	Majority hold master's (24%) or doctorate (64%) degree
	Necessary education for effective assessment	Bachelor's or master's degree sufficient (78%)
	Availability of training programs	Strong support for formal training and certification programs (73%)
Data and Information		
	Data sources used	143 databases listed, mostly open-access with CABI, GBIF and ITIS being the most cited (**Figure 5; Table S3**)
	Data quality & difficulty	Challenges include outdated or incomplete data
Implementation of RAs		
	Peer review included	88% include peer review (internal/external)
	Uncertainty/confidence reported	Included in 93% of assessments
	Public comment period	Rarely included (41% never, 20% always)
	Accessibility of RA results	Usually publicly accessible (40% always, 37.2% occasionally)
	Results used in policy	Frequently inform policy recommendations

Throughout the data collection process, standard procedures of survey design used in similar studies were followed (e.g., Gozlan et al., 2013; Beaury et al., 2020). The survey was confidential, and respondents' anonymity was maintained. The questions included a mixture of list-all-that-apply, check-all-that-apply, Likert-scaled, multiple choice, and open-ended questions (fill in the blank), with the survey taking an estimated 10-15 minutes to complete. The survey was approved by the University of Florida's Institutional Review Board, ID #202001808.

We used three approaches to solicit responses. 1) The survey was distributed on November 17, 2020, through two listserv groups: Ecolog-L, hosted by the Ecological Society of America, and Aliens-L, hosted by the Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission. At the time of distribution, Ecolog-L had approximately 27,000 subscribers, and Aliens-L had 1,470 subscribers. Both groups primarily consist of students, academics, and practitioners working in the fields of ecology (Ecolog-L) and invasive species (Aliens-L). 2) Finally, the survey was shared on Twitter on 17th November 2020 initially on two main accounts (@ifasassessment and @drdeahlieurance) and then shared from there by other users. Finally, (3) we sent direct invitations to corresponding authors of peer-reviewed papers on invasive species risk analysis or risk assessment. These authors were identified through a targeted search, with a focus on improving geographic representation by reaching out to researchers from underrepresented regions, particularly in Asia and South America, based on preliminary survey responses following the Twitter call, which indicated a deficit from these areas. The Twitter posts promoting the survey received a combined 16,278 impressions (i.e., times a user was served a tweet in their timeline or search results), excluding impressions from approximately 62 retweets. The survey remained open for responses from November 2020 to March 2021.

Data analysis

All analyses and data visualization were performed using the programming language R (v4.0.4.). To extract the survey results, we used the package 'qualtRics' (Ginn et al., 2024). Responses that were at least 80% complete were included, as this threshold ensured that respondents had answered the majority of question, while still allowing for minor omissions that commonly occur in surveys. This yielded 107 usable surveys from the initial 262. We used the longitude and latitude coordinates of the IP addresses to estimate where survey respondents were based and plotted the data using the 'maps' package (**Figure 2**). We then mapped the number of RAs conducted per country based on the results of the survey questions (**Figure 2**). However, we acknowledge that some respondents may have used Virtual Private Networks (VPNs), potentially limiting the accuracy of these location estimates.

We used Likert scale analysis to summarize and visualize responses to specific survey questions regarding the taxonomic groups assessed, the factors that typically initiate a new assessment, and the ecosystems evaluated. Additionally, we summarized the most frequently used databases (those mentioned by more than three respondents) that inform RAs for general, taxonomic, and occurrence information. To illustrate the frequency of database use, we created a heatmap, providing a clear visual representation of the data.

We manually grouped RAs using two objective criteria: (1) AWRA affiliation and (2) geographic region. First, each RA tool was categorized based on its relationship with the AWRA framework, one of the original and most widely adapted frameworks, into three groups: tools primarily based on AWRA, tools derived and modified from AWRA, and tools not based on AWRA. Second, the tools were grouped by the continent in which they were developed and applied. We then counted the number of respondents who mentioned each tool and visualized this classification scheme using the 'Tree Diagram' extension for Tableau (Version: Apple Silicon 2024; LaDataViz)(**Fig. 3**).

The results of all other questions were summarised in **Supplementary Table S3**.

Results and discussion

Risk assessment methods are increasingly being adapted worldwide to aid in the management of invasive species. This is reflected in the literature, where we observed a steady increase in the number of peer-reviewed publications mentioning “risk assessment” and “invasive species”, despite fluctuations in the overall number of articles on invasive species (**Figure 1**). While RA is well discussed academically, we sought to better understand how it is being applied in practice by asking about practitioner’s experiences; below we discuss the results of the survey on the tools and databases used, the qualifications and experience of assessors, and the implementation and accessibility of the tools used.

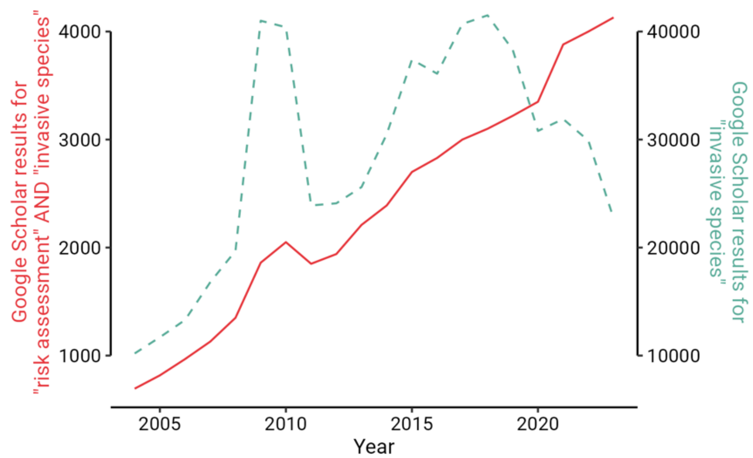

Figure 1. Trends in Google Scholar results from 2004 to 2023 for search results. The solid line represents the number of search results for "risk assessment" AND "invasive species", while the dashed line represents the number of search results for "invasive species" (scaled down by a factor of 10). The left y-axis shows the number of results for "risk assessment" AND "invasive species", and the right y-axis shows the number of results for "invasive species" multiplied by ten for visualization purposes. The colors of the y-axis labels match the colors of the corresponding lines in the plot. The search results for "invasive species" were scaled down by a factor of ten to facilitate comparative analysis and ensure both datasets could be visualized concurrently on a single plot.

Geographic scope of assessments

Our survey gathered responses from 107 assessors, reflecting a global response, albeit with a notable concentration from anglosphere countries and Europe (**Figure 2**). The smaller showings from Africa and Asia are consistent with other studies within invasion biology which identify geographic biases (e.g., Pyšek et al., 2008; Nuñez et al., 2022; Chiu et al., 2023) that may be attributed to language barriers (Nuñez et al., 2022). Because we only shared this survey in English, we will have missed potential respondents. Given the bias toward assessors from anglophone countries and Europe, it is not surprising that the majority of RAs mentioned have been conducted in these regions (**Figure 2**), especially in the United States and the United Kingdom. At the continental level, North America accounted for 31% (n = 44) and Europe for 21% (n = 30) of regions assessed, with smaller contributions from Asia (12%, n = 17), Australasia (11%, n = 15), Africa (11%, n = 15), and South America (6%, n = 8). We did note that some assessors indicated that they had assessed multiple countries and regions. We also found examples of regions that have been assessed despite there being no survey respondents located in those countries at the time of the survey, such as countries in North Africa and Central Asia. In terms of the scale, RAs often focus on smaller geographic regions that may not span geopolitical boundaries, which may limit their effectiveness in preventing widespread invasions (Riley et al., 2009). Our findings largely support this trend: assessments were mainly conducted at the country level (n = 53; 40%) or a regional scale (e.g., state, province, territory, county; n=51; 39%), with fewer at the continental scale (n=18; 14%).

Successful transnational cooperation is evident in certain regions, such as the European Union's Invasive Alien Species Regulation (Regulation (EU) 1143/2014), which aims to standardize RAs across EU member states, resulting in the compilation of the 'Union List'—a comprehensive record of invasive alien species of Union concern. To this end, the European and Mediterranean Plant Protection Organization (EPPO) have developed tools and protocols available in different languages for 52 member countries (EPPO, 2024) to assess invasive species. Our survey identified at least five key elements or methods actively used as part of or adapted from EPPO, including Pest Risk Analysis (PRA), Harmonia+, the UK risk assessment scheme for all non-native species, Computer-Aided Pest Risk Analysis (CAPRA) software, and Invasive Species Environmental Impact Assessment (ISEIA) (See **Table 2** for references**; Figure 3**). This skewed geographic distribution may reflect underlying weaknesses in biosecurity practices in these regions, as a paucity of RAs could signal limited capacity for early detection and management of invasive species. Consequently, this not only hampers our understanding of how, why, and when RAs are conducted but also restricts a global comprehension of invasion patterns (Nuñez et al., 2022).

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

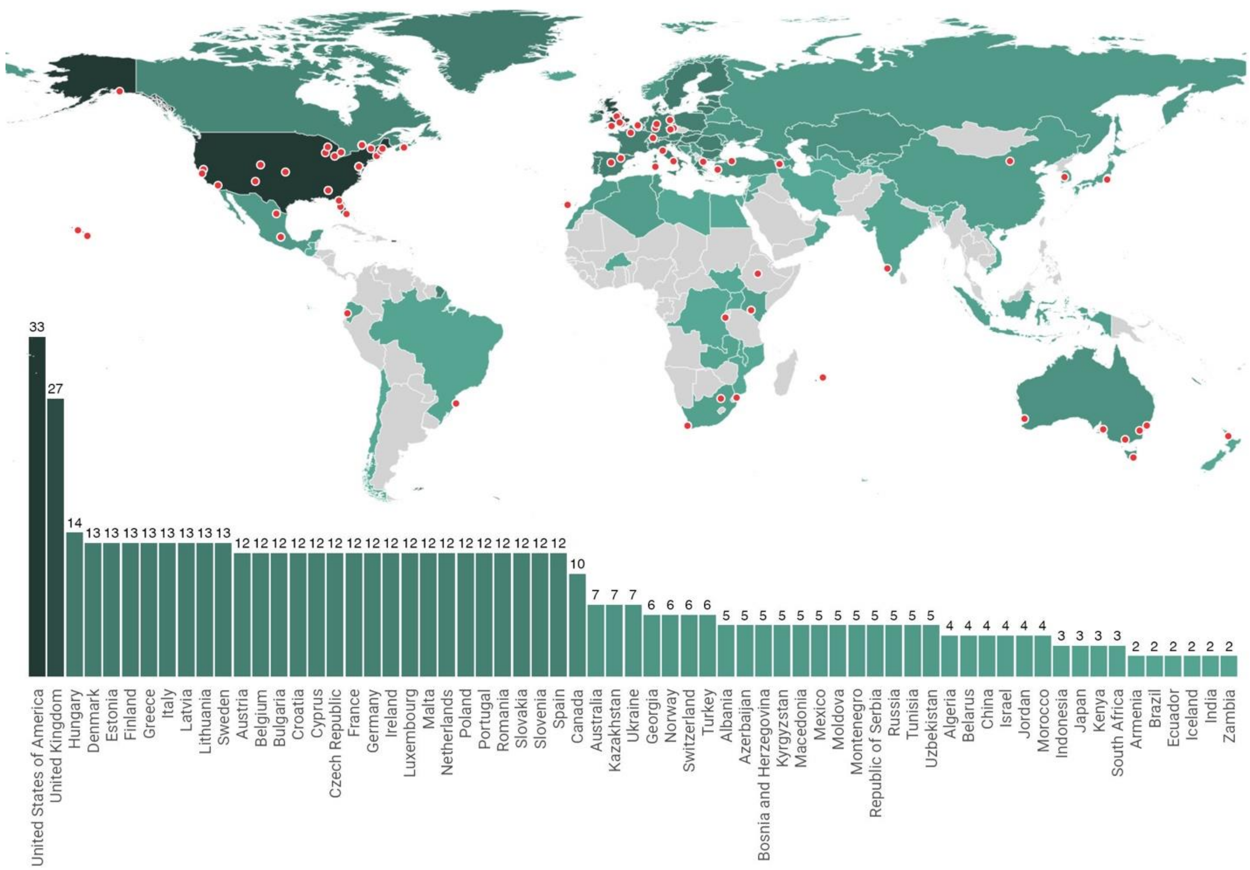

Figure 2. Map of assessed areas and assessor locations. Map showing respondents' locations (pink dots; n = 107) and the regions where they have conducted risk assessments (green shaded areas). The bar graph below indicates the number of respondents who have assessed each country. Only regions assessed by two or more respondents are shown on the bar graph (an additional 25 countries had only been assessed by one respondent). The shade of green represents the number of respondents, with darker green indicating higher numbers and lighter green indicating lower numbers. This shading is consistent across both the map and the bar graph. Note that if a respondent specified a broad region such as Europe, each country within that region was counted.

Risk assessment methods

In total, respondents listed 46 different RA methods that they have actively used (**Figure 3**). Of which, At least five of the tools included by respondents were Australian WRAs, which is possibly the best-known example of a RA for invasive species (Kumschick & Richardson, 2013; Lieurance et al., 2024; **Figure 3**). An additional six tools were derived or modified versions of the Australian WRAs, including adaptations of the original tool for Armenia, Florida, the Galapagos, the Hawaiian Pacific, and Samoa. Modifications include changing the language of four questions related to climate and soil type to better reflect the conditions of the area at risk as well as to expand beyond plants (Gordon et al., 2008). However, other tools incorporate completely different approaches. Some were designed for speed and ease to complete such as the Horizon Scanning Rapid Risk Assessment (HS-RRA; e.g., Roy et al., 2014; Lieurance et al., 2023) and the US Department of Agriculture's PPQ Weed Characterization Tool (PPQ-WC). Four tools evaluate impacts alone (EICAT, GISS, ISEIA and SEICAT) and climate matching tools were also mentioned (i.e., MaxEnt, Climatch). Although these later schemes assess aspects of risk, they should not be considered RAs as they do not consider either the likelihood of invasion or their consequences (e.g., Kumschick et al. 2020a, 2024).

The most widely used RA was the Fish Invasiveness Screening Kit (FISK) (Copp et al. 2009) and the Plant Protection and Quarantine Weed Risk Assessment (PPQ-WRA) (Koop et al. 2012), both adaptations of the Australian WRA System (Pheloung et al. 1999). The FISK is a global standard for evaluating the invasive potential of freshwater fish species. According to a global review by Vilizzi et al. (2019), FISK has been extensively applied in 45 countries, with 1973 RAs conducted by 70 experts across 372 taxa. There are two variations of the FISK mentioned in the responses, the FI-ISK or Freshwater Invertebrate Screening Kit and the AS-ISK or Aquatic Species Invasiveness Screening Kit. The AS-ISK is described as a generic screening tool which is applicable to any aquatic species and incorporates the minimum standards a RA scheme should include (Copp et al., 2016; Roy et al., 2018). The AS-ISK has effectively replaced five taxon-specific toolkits including the FISK and FI-ISK (Copp et al., 2016). This consolidation of ISK tools increases comparability across all aquatic taxa.

In contrast, PPQ-WRA developed by the Plant Health Inspection Service (APHIS) for the U.S. Department of Agriculture (USDA), has a more limited geographic and taxonomic scope. Introduced in 2010, it assesses the likelihood of plants becoming weedy or invasive in the United States (including its territories) and incorporates some minimum standards outlined by Roy et al. (2018). As of 2024, it has been used for at least 163 species (APHIS 2023). While the PPQ-WRA has been used in a limited scope by states like Maryland, Michigan, and Nebraska and is currently implemented by the Canadian government as a part of their Canadian FIA Pest Risk Assessment (Anthony Koop Pers. Comm.), it has not been adopted outside North America.

Overall, a large number of RA methods were mentioned by respondents, with some categories having multiple tools available based on the same framework, as seen with weed RAs (**Figure 3**). This variety of approaches reflects the challenge in RAs to balance locally relevant applications with broader tools that are comparable across regions (Kumschick et al. 2020b; Wilson et al., 2020). For example, some RAs take an idiographic approach and they assess risks on a case-by-case basis, such as the PPQ-WRA, which is relevant only within one country. In contrast, other assessment tools aim to be globally applicable and allow for generalizations (Wilson et al., 2020). In general, there has been a growing sentiment among invasion scientists to have fewer frameworks that have consistent, broad-scale, and synthetic approaches to harmonize information and improve responses across different scales (Diagne et al., 2020; Wilson et al., 2020). Wilson et al. (2020) recommended moving towards a hierarchy of frameworks that provides contextual details to help in selecting the most appropriate RA for a given objective. A good example of this is the development of the EICAT, which, while not strictly a RA on its own, has largely become the standard for measuring impact (Wilson et al., 2020).

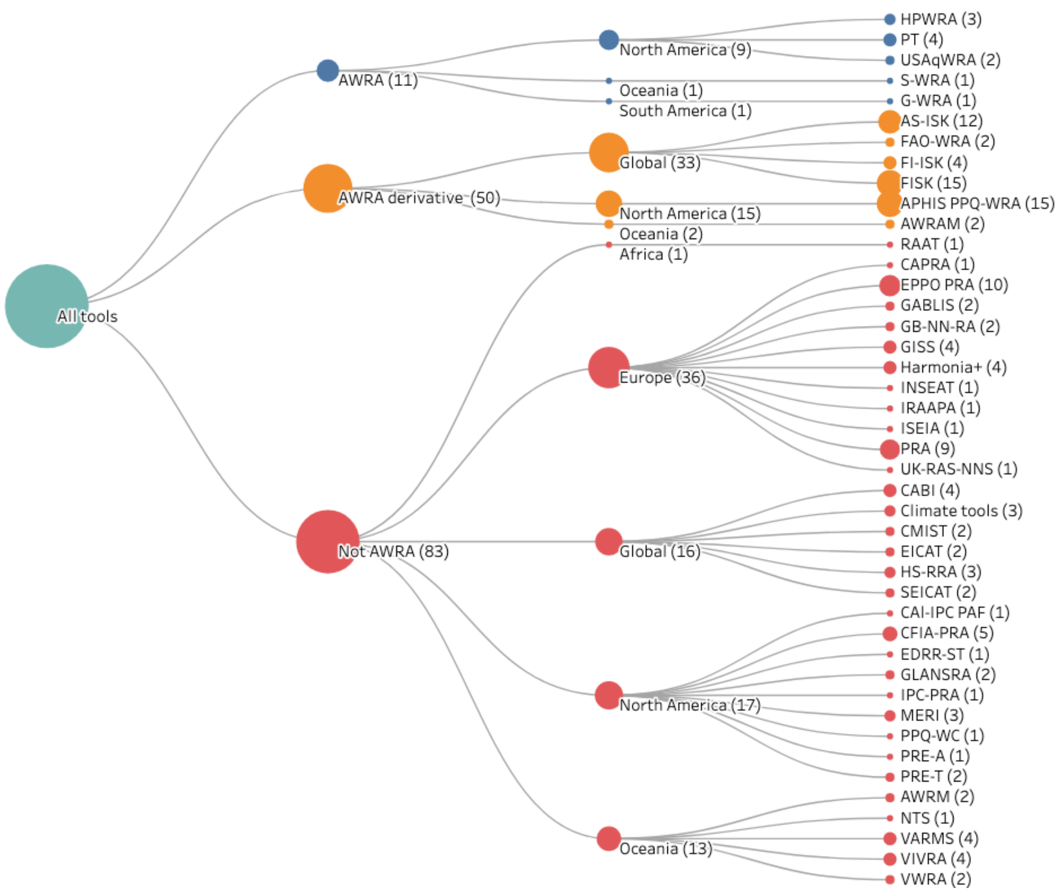

Figure 3. Hierarchical Organization of Risk Assessment (RA) Tools. The tree diagram organizes RA tools in a three-level hierarchy. At the first level, tools are grouped by their Weed Risk Assessment (AWRA) affiliation indicating whether a tool is based on or derived from the AWRA or not. The second level categorizes tools by the continent where they were developed and applied, and the terminal nodes display the RA tool acronyms (see **Table 2** for full names and references). In each node, the number in brackets indicates the number of respondents reporting the use of the tool, this applies at all levels (i.e., AWRA, region, and tool). Circle sizes are proportional to the number of respondents (n) for that node, and the node colour is based on AWRA affiliation. RA tools here encompass a wide range of approaches from preliminary screening protocols to comprehensive assessments involving impact categorization and pathway analysis, as well as related methods such as climate tools. Note that some respondents have used multiple RA tools.

Table 2. List of all risk assessment methods, and their given acronyms for Figure 3, used by survey respondents.

Acronym	Full name	Reference
APHIS PPQ-WRA	Animal Plant Health Inspection Service Plant Protection and Quarantine Weed Risk Assessment	Koop et al. 2012
AS-ISK	Aquatic Species Invasiveness Screening Kit	Copp et al. 2016

AWRAM	Aquatic Weed Risk Assessment Model	Champion & Clayton 2000
AWRM	Australian Weed Risk Management	Virtue 2010
CABI	Centre for Agriculture and Biosciences International - International Plant Protection Convention - Pest Risk Analyses Tools	CABI 2019
CAl-IPC PAF	California Invasive Plant Council - Plant Assessment Form	Cal-IPC. (n.d.)
CAPRA	EPPO's Computer Assisted Pest Risk Analysis tool	Griessinger et al. 2012
CFIA-PRA	Canadian Food Inspection Agency Pest Risk Assessment	Canadian Food Inspection Agency (2020)
Climate tools	MaxEnt; Climatch	-
CMIST	Canadian Marine Invasive Screening Tool	Drolet et al. 2016
EDRR-ST	Greater Everglades Rapid Response Screening Tool	Romagosa 2018
EICAT	IUCN's Environmental Impact Classification for Alien Taxa	Hawkins et al. 2015
EPPO PRA	EPPO PRA Express/ German Express Risikoanalyse (express PRA)	Brunel et al. 2010
FAO-WRA	Food and Agriculture Organisation - Weed Risk Assessment	Williams & Peter 2002
FI-ISK	Freshwater Invertebrate Invasiveness Scoring Kit	Tricarico et al. 2010
FISK	Fish Invasiveness Scoring Kit	Copp et al. 2005
G-WRA	Galapagos Weed Risk Assessment	Rogg et al. 2003
GABLIS	The German-Austrian Black List Information System	Essl et al. 2011
GB-NN-RA	Great Britain Non-Native Risk Assessment	Baker et al. 2008
GISS	Generic Impact Scoring System	Nentwig et al. 2016
GLANSRA	Great Lakes Aquatic Non-indigenous Species Risk Assessment	Davidson et al. 2017
Harmonia+	Harmonia+	D'hondt et al. 2015
HPWRA	Hawaii-Pacific Weed Risk Assessment	Daehler et al. 2004
HS-RRA	Horizon Scanning Rapid Risk Assessment	Roy et al. 2014
INSEAT	Invasive Species Effects Assessment Tool	Martinez-Cillero et al. 2019
IPC-PRA	USDA Imported Plant Commodity PRA Framework	USDA APHIS PPQ 2020
IRAAPA	invasiveness risk assessment of arboreal plants in Armenia	Fayvush et al. 2018
ISEIA	Invasive Species Environmental Impact Assessment protocol	Branquart et al. 2007
MERI	Método de Evaluación Rápida de Invasividad	Mandujano et al. 2021
NTS	Biosecurity New Zealand Pest Risk Analysis	Government of New Zealand MPI 2020
PPQ-WC	PPQ Weed Characterization	Koop Pers. Comm.
PRA	EU template European Commission	EPPO 2019
PRE-A	Plant Risk Evaluator Assessment	Conser et al. 2015
PRE-T	Plant Risk Evaluation Tool	Conser et al. 2015
PT	Predictive Tool	Gordon et al. 2008b
RAAT	Risk Analysis for Alien Taxa	Kumschick et al. 2020b
S-WRA	Samoa WRA	Space et al. 2000
SEICAT	Socio-Economic Impact Classification for Alien Taxa	Bacher et al. 2018
STAIR	Science-Based Tools for Assessing Invasion Risk	Gantz et al. 2015
UK-RAS-NNS	The UK Risk Assessment Scheme for all Non-Native Species	Baker et al. 2008
USAqWRA	United States Aquatic Weed Risk Assessment	Gordon et al. 2012
VARMS	Post-border vertebrate animals risk management systems	Bomford et al. 2008

VIVRA	Victorian Invasive Vertebrate Risk Assessment	Bomford et al. 2008
VP-PPP	Victorian Pest Plant Prioritisation Process	Weiss et al. 2002
VWRA	Victorian Weed Risk Assessment	Weiss et al. 2002

Taxonomic scope of assessments

In terms of the taxonomic group most frequently assessed, plants dominate RA efforts (**Figure 4a**). This emphasis on plants may stem not only from potential research priorities but also from inherent mechanistic limitations in species-level RAs. For instance, species-level approaches are less applicable for many microbes, where detection and taxonomic identification are challenging. In cases of intentional introductions, the focus is naturally taxonomically biased. For example, Pyšek et al. (2008) found that although nearly half of all studied invasive species were plants, they were less intensively researched than expected based on their relative numbers compared to non-native animal species in Europe. RAs were also predominately done for terrestrial taxa, this might be as for many marine and freshwater systems, a species-level approach may not be appropriate, instead, pathway-based risk analyses might offer a more effective management strategy (McGeoch et al., 2016). Nonetheless, aquatic and marine invasive species tend to be overlooked overall, often going unnoticed until impacts occur due to infrequent monitoring (Zaiko et al., 2014). In addition, RAs rely heavily on species-specific information, which can be difficult to obtain, especially for new or poorly studied species. The focus on certain taxonomic groups over others by invasion biologists has knock-on effects in monitoring and managing under-studied invaders, as groups that are overlooked in RAs often receive less taxonomic attention (Strayer, 2010). Furthermore, the prevalence of plant-focused databases (**Figure 5**) likely reinforces the heavier focus on plant invaders in RA efforts.

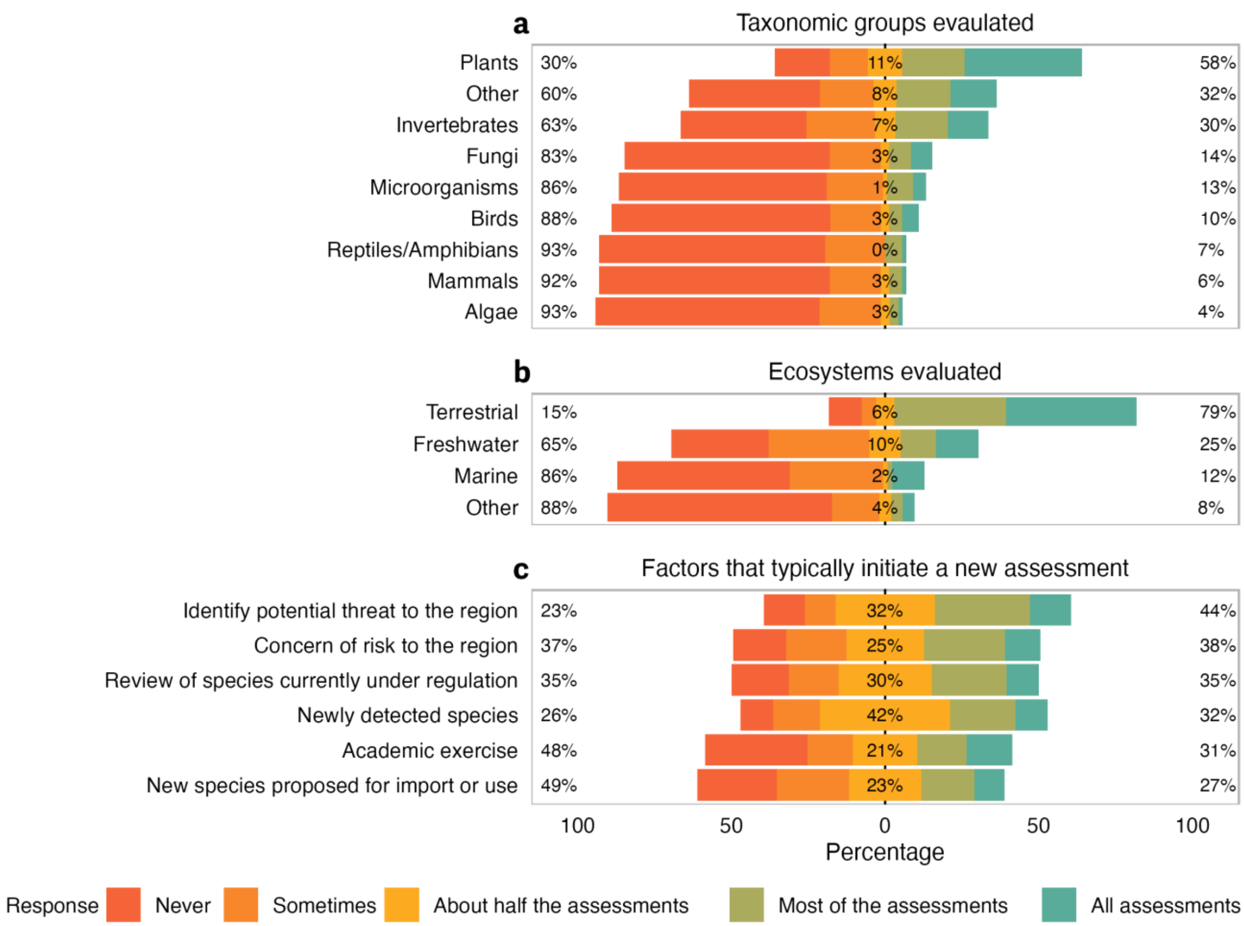

Figure 4. The survey responses regarding the evaluation of taxonomic groups, ecosystems, and factors that prompt new risk assessments or risk analyses (collectively RAs here). Answers were provided on a 5-point Likert scale with the categories: never, sometimes, about half of assessments, most of assessments, all assessments. Each plot represents the proportion of respondents who indicated the extent to which they assess specific groups, ranging from 'None' (red; left-hand side) to 'All assessments' (green; right-hand side). The percentages on the left side of each plot indicate the proportion of responses for lower frequency categories ('None' and 'Sometimes'), the middle percentages reflect 'About half of assessments', and the right side shows the percentage of higher frequency responses ('Most of assessments' and 'All assessments'). Categories are cantered at 0% on the x-axis, and the width of each bar reflects the relative percentage of respondents for each category, summing up to 100%. The "Other" category in panels (A) and (B) was provided for respondents whose assessments did not fit into the listed taxonomic groups or ecosystems.

Data and information sources

Sourcing data is a foundational aspect of RA. Assessors often depend on specific databases to source and gather information to inform their assessments. These databases provide baseline data, distribution data, and survey data on establishment and spread of invasive species. They also provide data on impacts, environmental tolerances, and sometimes time since introduction or propagule pressure data. We found that assessors rely on a wide variety of databases, with a total of 107 databases mentioned as frequently used by assessors for sourcing general (n = 43 databases), occurrence (n = 43), and taxonomic (n = 57) information (some database were used for multiple purposes). Many of these were repeatedly mentioned by different respondents (**Figure 5**; For the full list see Supplementary **Figure S1).** The most commonly used general information databases were CABI's Invasive Species Compendium, the Global Invasive Species Database (GISD), the European Plant Protection Organisation (EPPO) Global Database, the Global Compendium of Weeds (GCW), and Delivering Alien Invasive Inventories for Europe (DAISIE). When obtaining species occurrence records, respondents primarily relied on the Global Biodiversity Information Facility (GBIF), CABI's Invasive Species Compendium, iNaturalist, EDDMapS (Early Detection and Distribution Mapping System), and the Global Register of Introduced and Invasive Species (GRIIS). The Integrated Taxonomic Information System (ITIS) and Tropicos were the most commonly used taxonomic databases, along with more specialized resources such as FishBase, the International Plant Names Index (IPNI), the World Register of Marine Species (WoRMS), The Plant List, and World Flora Online. The most frequently used databases are primarily managed by academic or research institutions (40 databases), government agencies (36), non-profit organizations (36), and intergovernmental entities (23). Of these databases, 43% provided global data.

Of the databases mentioned, 94.4% (101 out of 107) were open access, meaning that their data are freely available (**Table S2** for a list of databases). The higher utilization of open-access resources is perhaps expected as they tend to be easier to access and do not require funding to use. This shift to open data has likely further increased since this study, since the COVID-19 pandemic there has been widespread change in how researchers disseminate their results and often seeking open access options (Waltman et al. 2021). The shift towards open access aligns with the principles of the FAIR system (Findable, Accessible, Interoperable, and Reusable), which aims to improve the infrastructure supporting the reuse of scholarly data (Wilkinson et al., 2016). However, it is important to note that some databases while open, are poorly managed or no longer updated, resulting in outdated information. This poses a significant challenge, as reliance on outdated data can compromise the accuracy and effectiveness of RAs. We encourage the use of primary data whenever possible, as much of the information in some databases is not underpinned by traceable evidence, making it difficult to verify its accuracy.

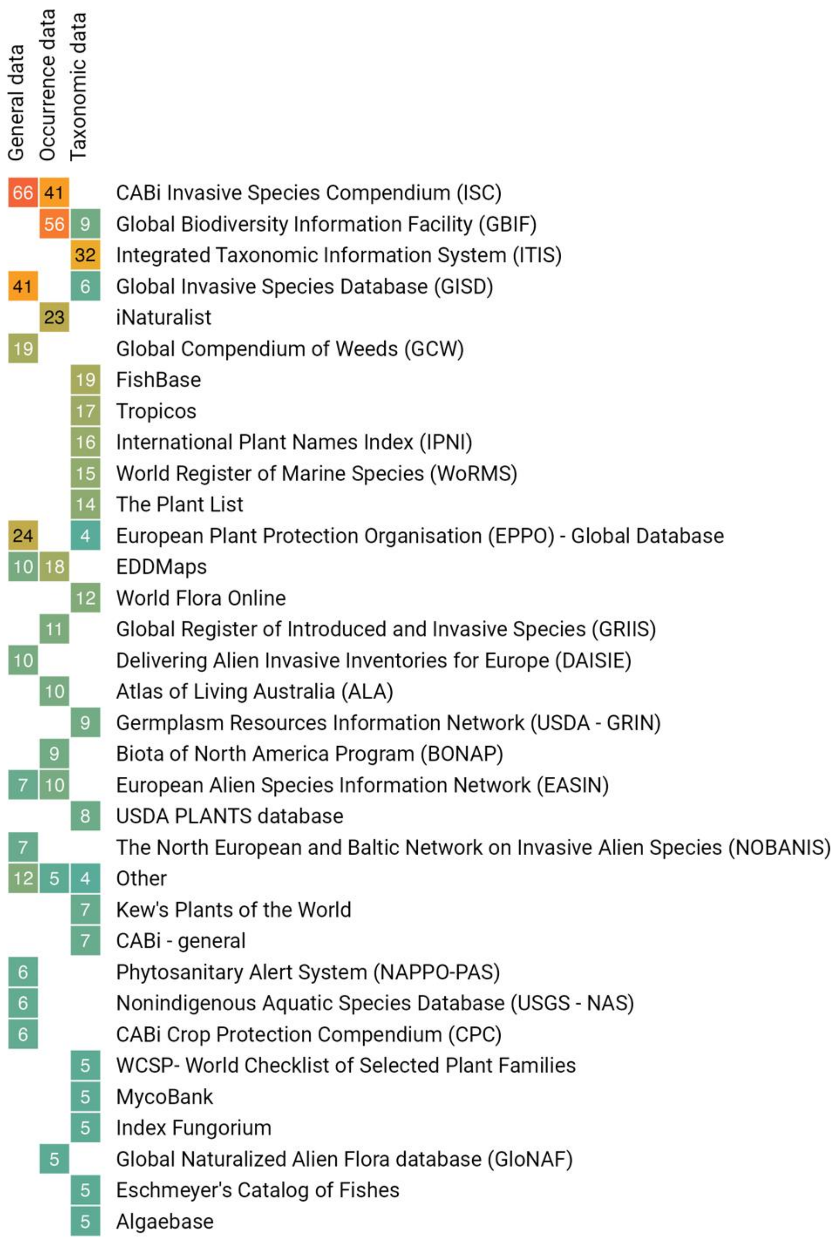

Figure 5. Most frequently used databases by respondents for risk assessments and risk analyses (collectively RAs), categorized by their purpose in gathering general, occurrence, or taxonomic information. Numbers (n) are shown in each box, with colour shades corresponding to n: green for lower numbers and red for higher numbers. Only databases used by five or more respondents are included in this figure (See Supplementary **Table S2** for the full list of 107 databases listed).

Data limitations

Uncertainty is an unavoidable aspect of RAs. There are many stages of the process in which uncertainty can impact the results, such as human error in the data, incomplete information searches, species misidentification, insufficient survey data, or resolution issues in data scaling (McGeoch et al., 2016; Probert et al. 2020). Additionally, assessors may have a lack of knowledge or face limitations in accessing data, leading to low confidence in the final risk outputs. Despite these uncertainties, decisions regarding the management and prevention of invasive species must still be made. Including uncertainty into RAs helps stakeholders understand the limitations of the assessment (McGeoch et al., 2016). As such, Roy et al. (2018) recommend that acknowledging data limitations should be a standard in RAs, by providing a statement or score indicating the assessor's confidence level in the quality and reliability of the data/information. Encouragingly, we found that a very high proportion (93.2%) of assessors said they incorporate uncertainty or confidence, with three out of four always doing so.

Evaluation of assessment

A peer-review process is crucial in evaluating the scientific rigour, accuracy, and validity of data, methodologies, and conclusions in RAs (Warren et al., 2017). There are growing calls to make peer-review standard practice, facilitating feedback between assessors and reviewers to mitigate inherent biases. Our study found a positive trend toward the incorporation of peer review in practice, with 88.1% of assessor saying assessments they include some form of peer review, and 61% of assessors consistently integrating peer review. The type of peer review matters as well: whether it is internal (e.g., conducted within the organization) or external (e.g., involving independent experts from outside the organization) may influence the objectivity of the evaluation process (Hill et al. 2020). Among assessors who conduct peer reviews of assessments (n = 85), 42% used a combination of internal and external review, 17% exclusively used external peer review, and 40% relied solely on internal review.

While expert-based RA is common, the incorporation of public comment and consensus-building approaches is notably rare, as evidenced by the lack of documentation on these practices in the literature. When the public is involved in the decision-making process, there is a higher likelihood of successful implementation of management measures, as stakeholders feel a sense of ownership and responsibility for the outcomes (Reis et al., 2013). However, our findings highlight disparities in the integration of public input within RAs and that stakeholders and the public may not be adequately engaged in the decision-making process. In 41% of the cases reported by assessors (n = 30), public comment was absent from their RAs, while only 20% consistently incorporated it, and 29% included it occasionally or infrequently. Despite these variations, a majority of assessors indicated that their final RAs are accessible to the public, with 40% affirming consistent availability, 37.2% reporting occasional or rare accessibility, 14% expressing uncertainty, and 9.4% stating their assessments were never accessible.

Experience, qualifications of assessors and training

The survey respondents predominantly held graduate degrees, with nearly 90% holding master's (24%) or doctoral degrees (64%). Only 3.1% did not possess a tertiary degree. In terms of experience in conducting RAs, the respondents had variable levels of expertise. Most had accumulated at least a decade of experience (34%) or a minimum of five years (26%). However, a notable proportion (44%) reported conducting fewer than ten RAs over the last three years. The next largest cohorts, those who conducted between 11 and 50 RAs and those who completed more than 50 assessments, accounted for 34% and 22.4% of the responses, respectively. Finally, 8.4% of respondents were highly experienced, having conducted over 100 RAs.

Regarding the qualifications needed for a risk assessor, while 63% of respondents hold doctorate degrees, only 3% believe that a PhD is necessary to conduct assessments proficiently. Most respondents consider tertiary education sufficient, with 41% citing a bachelor's degree and 37% a master's degree as the minimum requirements. This suggests that the current practice of relying predominantly on PhD-holding academics for RAs should be reconsidered. Academic scientists are frequently overwhelmed by additional administrative and peripheral tasks, which detracts from their ability to focus on research. This has been found to lead to exhaustion and high levels of burnout that have resulted in calls to adjust management of academic work (Ferreira 2022). Since a majority of assessors had completed less than 10 assessments, RA may not be a primary job responsibility. Therefore, delegating RAs to dedicated and trained assessors could enhance efficiency and cost-effectiveness. However, this approach should be evaluated individually, as the complexity of RAs can vary between schemes, with some requiring less interpretation of scientific studies and more focus on collecting information on traits.

We also identified a significant gap in formal training programs and certification for structured education designed to train assessors on conducting RAs. This gap is underscored by the fact that the majority of respondents (73.2%) strongly support the implementation of a training or certification program as a prerequisite for assessors. A large portion of respondents (35%) believed that 17 - 40 hours of training (up to a week) were required to become proficient at conducting a typical RA, while many (23%) indicated that up to a month (40-160 hours) might be necessary. Few respondents suggested that more than a month of training was needed, indicating that a full college-term course is unnecessary. However, a short workshop (lasting only a few days or a week) would be insufficient. Therefore, the optimal length of the course would be between a week and a month. Even with such training, working alongside or having assessments reviewed by a more experienced assessor would likely be beneficial initially.

Some organizations already provide training programs, though these efforts are not widespread. For instance, in the European Union, EPPO has provided courses on pest risk analysis of invasive alien plant species as per the requirements of certain EU regulations. Similarly, South Africa developed a risk analysis training course in

2018, which has since certified 52 participants across 19 courses as of April 2024 (Wilson and Kumschick 2024). The capacity for training even on limited budgets is more realistic now with the advent of e-Learning tools (Shannon et al., 2020). Many agencies have shown the value and ease to which online training is possible such as the 'Better Biosecurity e-Learning course' designed by the University of Leeds, Environment Agency (Shannon et al., 2020). Research has shown that online training can provide an effective alternative to face-to-face training in higher education and achieve the same performance (Azeiteiro et al., 2015).

These results suggest that programs to train risk assessors should focus on individuals with at least a bachelor's degree. However, this conclusion should be interpreted with caution and considered on a case-by-case basis, as the feedback is heavily influenced by perspectives from the global North. For example, in South Africa, the Alien Species Risk Analysis Review Panel (ASRARP)—which provides independent scientific advice to the Department of Forestry, Fisheries and the Environment (DFFE)— found that assessors with at least an MSc degree or some experience authoring a peer-reviewed publication (and in particular with responding to reviewer comments) had the necessary skills to draft and revise risk analyses (Kumschick personal observation).

Initiating, reporting and implementing

When asked which factors initiate a RA, the responses were distributed relatively evenly across all options, suggesting there are a variety of triggers, such as regulatory requirements, stakeholder concerns, or emerging threats (**Figure 4**).

We found that a large portion of RAs are reported to higher authorities, with nearly half (n=71; 48%) reported to government agencies and a third (n=43; 29%) to university or research institutions. Fewer assessments were directed to non-profit/non-governmental organizations (n=16; 11%), private consultancies (n=7; 4.7%), and other organizations (n=11; 7.4%). This distribution reflects the results of Roy et al. (2018), who noted that government agencies and research institutions are primary stakeholders in the utilization of RAs for policy development and implementation. However, there are examples of non-governmental organizations developing RA (e.g., The Nature Conservancy helped to develop the IFAS Assessment to prioritize both management and advocacy effort; Gordon et al. 2008b).

Several studies have highlighted the need for standardization in terminology, methods, and criteria for RA to reduce inconsistencies and uncertainties in outcomes, particularly crucial for regions with limited funding capacity (Colautti et al., 2016; Kumschick et al., 2015; Roy et al., 2018). The development of multiple tools tailored to specific taxa, regions, and habitats, along with the use of jargon and acronyms, pose significant barriers to the effectiveness of RAs as decision-support tools. The proliferation of different tools at varying scales can hinder the discipline's ability to track broader and regional-scale patterns effectively. However,

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

country-specific requirements for RAs often necessitate tailored approaches. While having a single standardized framework could facilitate comparisons and information-sharing across regions, it might not serve the needs of specific policy- and decision-makers. Country-specific adaptations are often necessary to align with local regulations and management priorities.

Recommendations

Based on the views expressed by the responders to the survey, we identified five broad areas where people felt specific focus is important for RAs and eleven specific recommendations.

1. Training and capacity building
   - 1.1. Standardised qualifications: training or certification programs are important to ensure practitioners possess the necessary skills and knowledge.
   - 1.2. Minimum requirements: while a specific undergraduate degree or postgraduate degree might not be needed, scientific literacy is an essential pre-requisite for RA training to be effective; in practice most people conducting RA have at least an MSc.
   - 1.3. Course duration: training courses probably need to be between one week and one month, ideally including a practical component.
2. Databases and information sources
   - 2.1. Facilitate access: Utilize open-access databases and other sources to ensure researchers, policymakers, and the public can access critical data without financial or institutional barriers.
   - 2.2. Data sharing: improve the quality of RAs by promoting data sharing, especially for new or understudied invasive species
3. Cooperation and standardization of tools
   - 3.1. Reduce duplication: Establish mechanisms for data sharing, collaborative risk assessments, and mutual recognition of assessments across regions to minimize redundant efforts, particularly in resource-limited areas.
   - 3.2. A common framework: if a similar basic framework is used, data can be shared among regions and countries, while still recognising the need for country-specific requirements and regulations.
4. Communication of results
   - 4.1. Specify the rationale: Clearly explain why each RA was initiated to enhance stakeholder understanding.
   - 4.2. Incorporate uncertainty: Ensure assessments include measures of uncertainty to support informed decision-making.

  4.3. Raise awareness: the communication of RA results need to be in a clear and effective manner to boost public and stakeholder awareness of invasive species risks and encourage support for necessary interventions
5. Open access
  5.1. Enhance transparency and accountability: Provide access to completed RAs, where possible, to allow stakeholders to understand the basis for recommendations, identify knowledge gaps, and ensure the RA process is based on the best available evidence.

Funding information

This work is/was supported by the USDA National Institute of Food and Agriculture and Hatch Appropriations under Project #PEN05000 and Accession #7008007. JRUW and SK thank the South African Department of Forestry, Fisheries and the Environment (DFFE) for funding, noting that this publication does not necessarily represent the views or opinions of DFFE or its employees.

Author contributions

SC and DL conceived the ideas; SC and DL distributed the survey and collected the data; SC analysed the data. SC and DL led the writing of the manuscript with help from KC, SK, DRG, JRUW. All authors contributed critically to the drafts and gave final approval for publication.

Acknowledgements

We sincerely thank Sam Scherneck for their valuable contributions to this research.

Conflict of interest

None declared.

References

Andersen MC, Adams H, Hope B, Powell M (2004) Risk assessment for invasive species. Risk Analysis: An International Journal 24: 787–793. https://doi.org/10.1111/j.0272-4332.2004.00478.x

Animal and Plant Health Inspection Service (APHIS) (2024) Noxious Weeds Program Risk Assessments. APHIS. https://www.aphis.usda.gov/plant-pests-diseases/noxious-weeds/noxious-weeds-program-risk-assessments [accessed 19 July 2024].

Bacher S, Blackburn T, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul WC, Scalera R, Vila M, Wilson JRU, Kumschick S (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9(1): 159–168. https://doi.org/10.1111/2041-210X.12844

Baker RHA, Black R, Copp GH, Haysom KA, Hulme PE, Thomas MB, Brown A, Brown M, Cannon RJC, Ellis J, Ellis E, Ferris R, Glaves P, Gozlan RE, Holt H, Howe L, Knight JD, MacLeod A, Moore NP, Mumford JD, Murphy ST, Parrott D, Sansford CE, Smith GC, St-Hilaire S, Ward NL (2008) The UK risk assessment scheme for all non-native species. NeoBiota 7: 46–57.

Bomford M (2008) Risk assessment models for the establishment of exotic vertebrates in Australia and New Zealand. Invasive Animals Cooperative Research Centre, Canberra, Australia.

Branquart E (Ed.) (2007) Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium, Version 2.5.

Brunel S, Branquart E, Fried G, van Valkenburg J, Brundu G, Starfinger U, Buholzer S (2010) The EPPO prioritization process for invasive alien plants. EPPO Bulletin 40(3): 407–422.

CABI (2019) Pest Risk Analysis Tool. https://www.cabi.org/PRA-Tool/signin?returnUrl=%2FPRA-Tool%2F

Champion PD, Clayton JS (2000) Border control for potential aquatic weeds. Department of Conservation, New Zealand.

Cal-IPC (n.d.) Cal-IPC Weed Risk Assessment. https://www.cal-ipc.org/solutions/research/riskassessment/

Canadian Food Inspection Agency (2020) Pest Risk Analysis: How we evaluate fruits, vegetables and plants from new countries of origin. https://inspection.canada.ca/plant-health/horticulture/imports/how-we-evaluate/eng/1425496755404/1425496838700

Conser C, Seebacher L, Fujino DW, Reichard S, DiTomaso JM (2015) The development of a Plant Risk Evaluation (PRE) Tool for assessing the invasive potential of ornamental plants. PLoS ONE 10(3): e0121053. https://doi.org/10.1371/journal.pone.0121053

Copp GH, Vilizzi L, Tidbury H, Stebbing PD, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. Management of Biological Invasions 7(4): 343–352.

Copp GH, Garthwaite R, Gozlan RE (2005) Risk identification and assessment of non-native freshwater fishes: concepts and perspectives for the UK. CEFAS Science Series Technical Report 129: 32 pp.

Copp GH, Vilizzi L, Mumford J, Fenwick GV, Godard MJ, Gozlan RE (2009) Calibration of FISK, an invasiveness screening tool for nonnative freshwater fishes. Risk Analysis 29(3): 457–467. https://doi.org/10.1111/j.1539-6924.2008.01159.x

Caton BP, Koop AL, Fowler L, Newton L, Kohl LM (2018) Quantitative uncertainty analysis for a weed risk assessment system. Risk Analysis 38: 1972–1987. https://doi.org/10.1111/risa.12979

Copp GH, Vilizzi L, Mumford J, Fenwick GV, Godard MJ, Gozlan RE (2009) Calibration of FISK, an invasiveness screening tool for non-native freshwater fishes. Risk Analysis 29: 457–467. https://doi.org/10.1111/j.1539-6924.2008.01159.x

Copp GH, Vilizzi L, Tidbury H, Stebbing PD, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. Management of Biological Invasions 7: 343–350.

Daehler CC, Denslow JS, Ansari S, Kuo HC (2004) A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific islands. Conservation Biology 18(2): 360–368. https://doi.org/10.1111/j.1523-1739.2004.00066.x

Davidson AD, Fusaro AJ, Sturtevant RA, Kashian DR (2017) Development of a risk assessment framework to predict invasive species establishment for multiple taxonomic groups and vectors of introduction. Management of Biological Invasions 8(1): 25–36. https://doi.org/10.3391/mbi.2017.8.1.03

D'hondt B, Vanderhoeven S, Roelandt S, Mayer F, Versteirt V, Adriaens T, Ducheyne E, San Martin G, Grégoire JC, Stiers I, Quoilin S, Cigar J, Heughebaert A, Branquart E (2015) Harmonia+ and Pandora+: risk screening tools for potentially invasive plants, animals, and their pathogens. Biological Invasions 17: 1869–1883.

Drolet D, DiBacco C, Locke A, McKenzie CH, McKindsey CW, Moore AM, Therriault TW (2016) Evaluation of a new screening-level risk assessment tool applied to non-indigenous marine invertebrates in Canadian coastal waters. Biological Invasions 18: 279–294. https://doi.org/10.1007/s10530-015-1008-y

EPPO (2011) Guidelines on Pest Risk Analysis: Decision-support scheme for quarantine pests. European and Mediterranean Plant Protection Organization. http://archives.eppo.org/EPPOStandards/pra.html [accessed 21 June 2024].

EPPO (2019) EPPO Technical Document No. 1079, Review of EPPO's approach to Pest Risk Analysis. EPPO, Paris.

EPPO (2024) EPPO Platform on PRAs. European and Mediterranean Plant Protection Organization. https://pra.eppo.int/[accessed 21 June 2024].

Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C, Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). Journal for Nature Conservation 19: 339–350. https://doi.org/10.1016/j.jnc.2011.08.005

FAO (2007a) Glossary of Phytosanitary Terms. International Standards for Phytosanitary Measures No. 5. IPPC-FAO, Rome, Italy.

FAO (2007b) Framework for Pest Risk Analysis. International Standards for Phytosanitary Measures No. 2. IPPC-FAO, Rome, Italy.

Fayvush G, Vardanyan Z, & Aleksanyan A (2018). Invasiveness risk assessment of woody plants of Armenia. Thaiszia - Journal of Botany, 28(2), 81–91.

Fei S, Phillips J, Shouse M (2014) Biogeomorphic impacts of invasive species. Annual Review of Ecology, Evolution, and Systematics 45: 69–87. https://doi.org/10.1146/annurev-ecolsys-120213-091928

Gallardo B, Clavero M, Sánchez MI, Vilà M (2016) Global ecological impacts of invasive species in aquatic ecosystems. Global Change Biology 22: 151–163. https://doi.org/10.1111/gcb.13004

Gantz CA, Gordon DR, Jerde CL, Keller RP, Chadderton WL, Champion PD, & Lodge DM (2015). Managing the introduction and spread of non-native aquatic plants in the Laurentian Great Lakes: a regional risk assessment approach. Management of Biological Invasions, 6(1), 45-55.

Ginn J, Curtis J, Jackson S, Kaminsky S, Knudsen E, O'Brien J, Seneca D, Silge J, Wong P (2024) qualtRics: Download 'Qualtrics' Survey Data (Version 3.2.0) [R package]. CRAN. https://CRAN.R-project.org/package=qualtRics

Gordon DR, Gantz CA, Jerde CL, Chadderton, W. L., Keller, R. P., & Champion, P. D. (2012). Weed risk assessment for aquatic plants: modification of a New Zealand system for the United States. PLoS ONE, 7(7), e40031.

Gordon DR, Onderdonk DA, Fox AM, Stocker RK (2008a) Consistent accuracy of the Australian weed risk assessment system across varied geographies. Diversity and Distributions 14: 234–242. https://doi.org/10.1111/j.1472-4642.2007.00460.x

Gordon DR, Onderdonk DA, Fox AM, Stocker RK, Gantz C (2008b) Predicting invasive plants in Florida using the Australian Weed Risk Assessment. Invasive Plant Science and Management 1: 178–195. https://doi.org/10.1614/IPSM-07-037.1

Government of New Zealand MPI. (2020). Biosecurity Science and Risk Assessment Procedures: Import Risk Analysis Overview.

Griessinger D, Baker RHA, Black R, Breukers A, Brunel S, Holt J, ... & Petter F (2012). CAPRA: the EPPO computer-assisted PRA scheme. EPPO Bulletin, 42(1), 42-47.

Hawkins CL, Bacher S, Essl F, Hulme PE, Jeschke JM, Kühn I, ... & Kumschick S (2015). Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). Diversity and Distributions, 21(11), 1360-1363.

Hill JE, Copp GH, Hardin S, Lawson KM, Marcot BG (2020) Comparing impacts of invasive species risk assessment frameworks: Response to Marcot et al. (2019). Management of Biological Invasions 11(2): 325–341.

Koop A (2012) Special applications of pest risk analysis—weed risk assessment. In: Devorshak C (Ed.) Plant Pest Risk Analysis: Concepts and Application. CABI, Wallingford, UK: 237–255.

Koop AL, Fowler L, Newton LP, & Caton BP (2012). Development and validation of a weed screening tool for the United States. Biological Invasions, 14(2), 273-294.

Kumschick S, Richardson DM (2013) Species-based risk assessments for biological invasions: Advances and challenges. Diversity and Distributions 19: 1095–1105. https://doi.org/10.1111/ddi.12110

Kumschick S, Bacher S, Bertolino S, Blackburn TM, Evans T, Roy HE, Smith K (2020a) Appropriate uses of EICAT protocol, data and classifications. NeoBiota 62: 193–212. https://doi.org/10.3897/neobiota.62.51574

Kumschick S, Wilson JR, Foxcroft LC (2020b) A framework to support alien species regulation: The Risk Analysis for Alien Taxa (RAAT). NeoBiota 62: 213–239. https://doi.org/10.3897/neobiota.62.51031

Kumschick S, Bertolino S, Blackburn TM, Brundu G, Costello KE, De Groot M, Bacher S (2024) Using the IUCN Environmental Impact Classification for Alien Taxa to inform decision-making. Conservation Biology 38(2): e14214. https://doi.org/10.1111/cobi.14214

Leung B, Roura-Pascual N, Bacher S, Heikkilä J, Brotons L, Burgman MA, Vilà M (2012) TEASIng apart alien species risk assessments: A framework for best practices. Ecology Letters 15: 1475–1493. https://doi.org/10.1111/ele.12003

Lieurance D, Culley T, Brand M, Canavan S, Daehler C, Evans C, Keller R (2024) Preventing the next plant invasion: Opportunities and challenges. Council for Agricultural Science and Technology (CAST). Issue Paper 73. CAST, Ames, Iowa.

Lieurance D, Canavan S, Behringer DC, Kendig AE, Minteer CR, Reisinger LS, Romagosa CM (2023) Identifying invasive species threats, pathways, and impacts to improve biosecurity. Ecosphere 14(12): e4711. https://doi.org/10.1002/ecs2.4711

Martinez-Cillero R, Willcock S, Perez-Diaz A, Joslin E, Vergeer P., & Peh, K. S. H. (2019). A practical tool for assessing ecosystem services enhancement and degradation associated with invasive alien species. Ecology and Evolution, 9(7), 3918-3936.

Mandujano MC, Golubov FJ, Sifuentes SI, Salomé DJ, & Bayona CA (2021). Adaptación y evaluación de riesgo utilizando métodos estandarizados para especies de plantas exóticas invasoras en México. Universidad Nacional Autónoma de México, Instituto de Ecología. Informe Final. SNIB-CONABIO. Proyecto No. RE001. Ciudad de México.

McGeoch MA, Spear D, Kleynhans EJ, Marais EM (2012) Uncertainty in invasive alien species listing. Ecological Applications 22(3): 959–971. https://doi.org/10.1890/11-1252.1

McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biological Invasions 18: 299–314. https://doi.org/10.1007/s10530-015-1013-1

Nentwig W, Bacher S, Pyšek P, Vilà M, & Kumschick S (2016). The Generic Impact Scoring System (GISS): a standardized tool to quantify the impacts of alien species. Environmental Monitoring and Assessment, 188, 315. https://doi.org/10.1371/journal.pbio.1001850.

Pheloung PC, Williams PA, Halloy SR (1999) A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57(4): 239–251. https://doi.org/10.1006/jema.1999.0297

Probert AF, Volery L, Kumschick S, Vimercati G, Bacher S (2020) Understanding uncertainty in the Impact Classification for Alien Taxa (ICAT) assessments. NeoBiota 62: 387–405. https://doi.org/10.3897/neobiota.62.52010

Pyšek P, Richardson DM, Pergl J, Jarošík V, Sixtová Z, Weber E (2008) Geographical and taxonomic biases in invasion ecology. Trends in Ecology & Evolution 23(5): 237–244. https://doi.org/10.1016/j.tree.2008.02.002

Reis CS, Marchante H, Freitas H, Marchante E (2013) Public perception of invasive plant species: assessing the impact of workshop activities to promote young students' awareness. International Journal of Science Education 35(4): 690–712. https://doi.org/10.1080/09500693.2011.610379

Riley S (2009) Preventing transboundary harm from invasive alien species. Review of European Community and International Environmental Law 18(2): 198–209. https://doi.org/10.1111/j.1467-9388.2009.00641.x

Rogg, H., Buddenhagen, C., & Causton, C. (2003). Experiences and limitations with pest risk analysis in the Galapagos Islands. In Identification of risks and management of invasive alien species using the IPPC framework: Proceedings of the workshop on invasive alien species and the International Plant Protection Convention (pp. 1–8).

Romagosa CM (2018) Greater Everglades Ecosystem Rapid Response Screening Tool (GEERReST). User guide and Executive summary for Committee on Independent Scientific Review of Everglades Restoration Progress.

Roy HE, Peyton J, Aldridge DC, Bantock T, Blackburn TM, Britton R, Walker KJ (2014) Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. Global Change Biology 20(12): 3859–3871. https://doi.org/10.1111/gcb.12603

Roy HE, Rabitsch W, Scalera R, Stewart A, Gallardo B, Genovesi P, Zenetos A (2018) Developing a framework of minimum standards for the risk assessment of alien species. Journal of Applied Ecology 55(2): 526–538. https://doi.org/10.1111/1365-2664.13025

Space JC, Flynn T (2000). Observations on invasive plant species in American Samoa. USDA Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry.

Tricarico E, Vilizzi L, Gherardi F, Copp GH (2010). Calibration of FI-ISK, an invasiveness screening tool for nonnative freshwater invertebrates. Risk Analysis: An International Journal, 30(2), 285-292.

United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. (2020). WI E-522 Imported Plant Commodity Pest Risk Assessment Framework. Plant Epidemiology and Risk Analysis Laboratory. https://www.aphis.usda.gov/sites/default/files/imported-plant-commodity-pra-framework.pdf.

Vilizzi L, Copp GH, Адамович БВ, Almeida D, Chan J, Davison PI, Zeng Y (2019) A global review and meta-analysis of applications of the freshwater fish invasiveness screening kit. Reviews in Fish Biology and Fisheries 29(3): 529–568. https://doi.org/10.1007/s11160-019-09562-2

Virtue JG (2010) South Australia's Weed Risk Management System. Plant Protection Quarterly, 25(2), 90–94. https://search.informit.org/doi/10.3316/informit.137773171097151

Waltman L, Pinfield S, Rzayeva N, Henriques SO, Fang Z, Brumberg J, Swaminathan S (2021) Scholarly communication in times of crisis. Research on Research Institute, Report No. 10. https://doi.org/10.6084/m9.figshare.17125394

Warren RJ, King JR, Tarsa C, Haas BJ, Henderson JS (2017) A systematic review of context bias in invasion biology. PLoS ONE 12(8): e0182502. https://doi.org/10.1371/journal.pone.0182502

Weiss J, McLaren D, Edgar R (2002) Victoria's pest plant prioritisation process. In H. S. Jacob, J. Dodd, & J. H. Moore (Eds.), Proceedings of the 13th Australian Weeds Conference (pp. 509–512). Plant Protection Society of Western Australia.

Williams PA (2002). Proposed guidelines for weed risk assessment in developing countries. Expert Consultation on Weed Risk Assessment.

Wilson JR, Bacher S, Daehler CC, Groom QJ, Kumschick S, Lockwood JL, Richardson DM (2020) Frameworks used in invasion science: Progress and prospects. NeoBiota 62: 1–30. https://doi.org/10.3897/neobiota.62.58738

Wilson JR, Kumschick S. The regulation of alien species in South Africa. South African Journal of Science. 2024 Jun;120(5-6):1-4. https://doi.org/10.17159/sajs.2024/17002

Zaiko A, Minchin D, Olenin S (2014) "The day after tomorrow": Anatomy of an 'r' strategist aquatic invasion. Aquatic Invasions 9(2): 145–155.

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

Supplementary

Table S1. Survey questions

Question no.	Question	Question type	Response options
General information			
Q1	Which Risk Assessment tool(s) have you used? (Please list all)	Fill in the blank	e.g. Australian Weed Risk Assessment (A-WRA), Freshwater Fish Invasiveness Scoring Kit (FISK), EPPO's Express Pest Risk Analysis, etc.)
Q2	What risk assessment tool do you currently use most frequently? (Please list only one)	Fill in the blank	
Q3	What continents at risk have you conducted risk assessments for? (Select all that apply. If your risk assessments apply to other regions such as marine water bodies, please select 'Other' and explain)	Multiple choice	Africa, Asia, Australasia, Europe, North America, South America, Other
Q3 (other)	For what regions have you conducted risk assessments? (Answer this question only if you selected 'Other' for the previous question)	Fill in the blank	
Q4	Please list the specific countries/regions/areas at risk you completed risk assessments for. (Please list all that apply)	Fill in the blank	
Q5	To what geographic scale do most of the risk assessments you have completed apply? (Please select all that apply)	Multiple choice	continental, country, regional (state, province, territory, county), other
Q5 (other)	To what geographic scale do your risk assessments apply? (Answer this question only if you selected 'Other' for the previous question)	Fill in the blank	
Q6 (a)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? PLANTS	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (b)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? BIRDS	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (c)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? MAMMALS	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments

Q6 (d)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? REPTILES/AMPHIBIANS	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (e)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? INVERTEBRATES	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (f)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? FUNGI	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (g)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? ALGAE	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (h)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? MICROORGANISMS (BACTERIA, VIRUSES, ETC.)	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (i)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups? OTHER	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q6 (other)	With the risk assessment tools you have used, how often have you evaluated the following taxonomic groups?	Fill in the blank	
Q7 (a)	With the risk assessment tools you have used, what ecosystems have you conducted risk assessments for? (TERRESTRIAL)	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q7 (b)	With the risk assessment tools you have used, what ecosystems have you conducted risk assessments for? (MARINE)	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q7 (c)	With the risk assessment tools you have used, what ecosystems have you conducted risk assessments for? (FRESHWATER)	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q7 (d)	With the risk assessment tools you have used, what ecosystems have you conducted risk assessments for? (OTHER)	Likert	never, sometimes, about half the assessments, most of the assessments, all assessments
Q7 (other)	With the risk assessment tools you have used, what ecosystems have you conducted risk assessments for?	Fill in the blank	
Experience conducting risk assessments			
Q8	How many years have you been conducting risk assessments?	Multiple choice	less than 1 year, at least 1 year (but less than 3 years), at least 3 years (but less than 5 years), at least 5 years (but less than 10 years), at least 10 years
Q9	Over the last 3 years, how many risk assessments have you done?	Multiple choice	10 or less, 11-50, 51-100, over 100

Q10 (a)	Which factors typically prompt you to initiate a new risk assessment? (ACADEMIC EXERCISE)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (b)	Which factors typically prompt you to initiate a new risk assessment? (NEW SPECIES PROPOSED FOR IMPORT OR USE)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (c)	Which factors typically prompt you to initiate a new risk assessment? (NEWLY DETECTED SPECIES)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (d)	Which factors typically prompt you to initiate a new risk assessment? (IDENTIFY A POTENTIAL THREAT TO THE REGION)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (e)	Which factors typically prompt you to initiate a new risk assessment? (REVIEW OF SPECIES CURRENTLY UNDER REGULATION/REVIEW OF CURRENT POLICY)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (f)	Which factors typically prompt you to initiate a new risk assessment? (OTHER)	Likert	almost never (<5%), rarely (5-15%), sometimes (15-65%)
Q10 (other)	Are there any other factors that typically initiate a new risk assessment not mentioned above? Please explain.	Open	
Q11	For the risk assessment tool you use most commonly, how long does it take you to compete a risk assessment of a species?	Multiple choice	an hour or less, at least an hour but less than a day, at least a day but less than a week, at least a week but less than a month, at least a month
Q12	What organization(s) do you report back to with your completed risk assessments? (Select all that apply. Please select 'Other' and explain if the listed categories do not apply)	Multiple choice	government agency, university or research institutions, private consultancy, non-profit/non-governmental organizations, other
Q12 (other)	If you selected 'Other', please explain.	Fill in the blank	
Opinions regarding qualifications to conduct risk assessments			
Q13	What do you think is the minimum level of education required for an assessor to proficiently conduct a risk assessment?	Multiple choice	Secondary or high school, some college-no degree, associate's degree, bachelor's degree, master's degree, doctorate degree
Q13 (other)	If you selected 'Other', please explain.	Fill in the blank	
Q14	What is your level of education?	Multiple choice	Secondary or high school, some college-no degree, associate's degree, bachelor's degree, master's degree, doctorate degree, other
Q14 (other)	If you selected 'Other', please explain.	Fill in the blank	

Q15	How many hours worth of training (e.g. workshops, in-service training etc) do you think are required to become proficient at conducting a typical risk assessment?	Multiple choice	1-3 hours (half a day), 4-8 hours (full day), 9-16 (up to 2 days), 17-40 (up to a week), 40-160 hours (up to a month)
Q16	Do you feel that the completion of a training/certification program should be a pre-requisite for conducting risk assessments?	Multiple choice	yes, no, unsure
How is the data sourced			
Q17	Please select up to three online databases you most frequently use to find taxonomic data for risk assessments from the options below. If your most frequently used database(s) are not listed please list them in the section below.	Select up to three	None of these, Algaebase, Amphibian Species of the World, ASM Mammal Diversity Database, Avibase, Eschmeyer's Catalog of Fishes, FishBase, Global Lepidoptera Names Index, Index Fungorium, Index Herbarium, International Plant Names Index, ITIS-Integrated Taxonomic Information System, MycoBank, Nomenclator Zoologicus, PESI-Pan-European Species directory Index, The Consortium for the Barcode of Life project, The Reptile Database, TROPICOS, WCSP- World Checklist of Selected Plant Families, Wilson & Reeder's Mammal Species of the World, World Flora Online, WoRMS- World Register of Marine Species, ZooBank
Q17 (other)	Specify database(s) if not listed above.	Open	
Q18	Please select up to three online databases you most frequently use to find general data (i.e., data about species traits, prior invasion history, etc.) for Risk Assessments from the options below. If your most frequently used database(s) are not listed please list them in the section below.	Select up to three	None of these, Aquatic Invasive Alien Species Web portal for ASEAN countries, BioNET's regional networks, CIESM- Atlas of Exotic Species in the Mediterranean, DAISIE-Delivering Alien Invasive Inventories for Europe, EPPO- European Plant Protection Organisation, EASIN- European Alien Species Information Network, FISNA- Forest Invasive Species Network for Africa, GISD- Global Invasive Species Database, Inter-American Biodiversity Information Network, NAPPO-PAS- The North American Plant Protection Organization- Phytosanitary Alert System, NIMPIS- National Introduced Marine Pest Information System, NOBANIS- The North European and Baltic Network on Invasive Alien Species, RBIC- Regional Biological Invasions Centre, GCW- Global Compendium of Weeds, CABi ISC- Invasive Species Compendium, EDDMaps, APFISN-Asia-Pacific Forest Invasive Species Network
Q18 (other)	Specify database(s) if not listed above.	Open	

Q19	Please select up to three online databases you most frequently use to find occurrence data (such as geo-referenced species presence data) for Risk Assessments from the options below. If your most frequently used database(s) are not listed please list them in the section below.	Select up to three	None of these, ALA- Atlas of Living Australia, AquaNIS, BISON- Biodiversity Information Serving Our Nation, BONAP- Biota of North America Program, CABi ISC- Invasive Species Compendium, EASIN- European Alien Species Information Network, eBird, EDDMaps, eDNAtlas database, GBIF- Global Biodiversity Information Facility, GloNAF- Global Naturalized Alien Flora database, GRIIS- Global Register of Introduced and Invasive Species, iDigBio, iNaturalist, Map of Life, National Exotic Marine and Estuarine Species Information System (NEMESIS), OBIS- Ocean Biogeographic Information System, VertNet
Q19 (other)	Specify database(s) if not listed above.	Fill in the blank	
Q20	What Risk Assessment-related data do you have the most difficulty finding? (i.e., what knowledge gaps would you like to address, if any?)	Fill in the blank	
Q21	How much of your data comes from peer reviewed sources?	Multiple choice	none-all from grey literature and/or expert opinion, a small amount, a moderate amount, a large amount, all data comes from peer-reviewed sources
Q22	How much of your data comes from expert opinion?	Multiple choice	none-all from grey literature and/or peer-reviewed publications, a small amount, a moderate amount, a large amount, all data comes from peer-reviewed sources
How the risk assessments are implemented			
Q23	Is there a peer-review process in place for your risk assessments? (e.g. peer-review or an internal/external review process)	Multiple choice	yes-always, yes-sometimes, yes-rarely, no, unsure
Q24	If there is a peer-review process in place, is it internal review or external review?	Multiple choice	internal, external, both, neither
Q25	Do you incorporate uncertainty or confidence into your risk assessments?	Multiple choice	yes-always, yes-sometimes, yes-rarely, no, unsure
Q26	At some point of the process, are your risk assessments open for public comment?	Multiple choice	yes-always, yes-sometimes, yes-rarely, no, unsure
Q27	Are the results of your risk assessments accessible to the public?	Multiple choice	yes-always, yes-sometimes, yes-rarely, no, unsure
Q28	Where are your risk assessments published?	Fill in the blank	

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

Q29	How are the results of your risk assessments used in policy and regulatory measures?	Fill in the blank
Q30	If you would like to share any other information about your experience conducting risk assessments, feel free to use the space below to do so.	Fill in the blank

Table S2. Databases used. Databases most frequently used to inform risk assessments, organised by their specific use for taxonomic (teal), general (green) or occurrence data (orange). Some databases are repeated and used for different purposes. Additionally, the table includes the number of respondents who reported using each database for that purpose (denoted as "n") and whether it has open online access.

	Database name	Website	n	Open online access
General data	Aquatic Invasive Alien Species Web portal for ASEAN countries	https://www.aseanbiodiversity.org/publications/asean-action-plan-forinvasive-alien-species-iasmanagement/	2	yes
	Asia-Pacific Forest Invasive Species Network (APFISN)	https://pipap.sprep.org/content/asia-pacific-forest-invasive-species-network	2	No online database
	Australasian Virtual Herbarium (AVH)	https://avh.chah.org.au	1	yes
	BiolFlor Database	https://knb.ecoinformatics.org/view/farshid25.16.4	1	yes
	BioNET's regional networks	https://bionet.ngo	1	No online database
	CABi - general	https://www.cabi.org	1	Access Restricted
	CABi Crop Protection Compendium (CPC)	https://www.cabidigitallibrary.org/product/QC	6	Access Restricted
	CABi Invasive Species Compendium (ISC)	https://www.cabidigitallibrary.org/product/QI	66	yes
	Comisión nacional para el conocimiento y uso de la biodiversidad (CONABIO) - Inventory of Alien and Invasive species	https://www.gbif.org/dataset/7185a1d5-9dc2-44fc-b3ef-5e4d068f12f1	1	yes
	Delivering Alien Invasive Inventories for Europe (DAISIE)	https://www.gbif.org/dataset/39f36f10-559b-427f-8c86-2d28afff68ca	10	yes

	EDDMaps	https://www.eddmaps.org	10	yes
	EncicloVida	https://enciclovida.mx	1	yes
	European Alien Species Information Network (EASIN)	https://easin.jrc.ec.europa.eu/easin	7	yes
	European Plant Protection Organisation (EPPO) - Global Database	https://gd.eppo.int	24	yes
	European Plant Protection Organisation (EPPO)-Q-Bank Invasive Plants database	https://qbank.eppo.int	1	yes
	FishBase	https://fishbase.se/search.php	1	yes
	Forest Invasive Species Network for Africa (FISNA)	https://dgroups.org/fao/fisnet/fisna	2	yes
	Global Compendium of Weeds (GCW)	http://www.hear.org/gcw/	19	No longer maintained
	Global Invasive Species Database (GISD)	https://www.iucngisd.org/gisd/	41	yes
	Global Pest and Disease Database (GPDD)	https://www.gpdd.info	2	Access Restricted
	Global Register of Introduced and Invasive Species (GRIIS)	https://griis.org	1	yes
	Great Britain Non-native Species Secretariat (GB-NNSS) Database	https://uk-scape.ceh.ac.uk/our-science/projects/GBNNSIP	1	yes
	Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)	https://www.glerl.noaa.gov/glansis/	1	yes
	Instituto Hórus Database	https://bd.institutohorus.org.br	1	yes
	International Committee on Taxonomy of Viruses (ICTV) Database	https://ictv.global	1	yes
	Kew's Plants of the World	https://powo.science.kew.org	1	yes
	LEDA Traitbase	https://uol.de/en/landeco/research/leda	1	yes
	National Introduced Marine Pest Information System (NIMPIS)	https://www.marinepests.gov.au/pests/nimpis	2	yes
	Nonindigenous Aquatic Species Database (USGS - NAS)	https://nas.er.usgs.gov	6	yes
	NSW Weed Risk Management System (WRM)	https://www.dpi.nsw.gov.au/biosecurity/weeds/strategy/nsw-weed-risk-management-system/weed-risk	1	yes
	NZFUNGI: New Zealand Fungi (via Biota of New Zealand)	https://www.landcareresearch.co.nz/tools-and-resources/databases/biota-of-new-zealand/	1	yes
	Other	n/a	12	

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 17/03/2025. DOI: https://doi.org/10.3897/arphapreprints.e153054

	Pacific Island Ecosystems at Risk (PIER)	http://www.hear.org/pier/	3	yes
	Phytosanitary Alert System (NAPPO-PAS)	https://www.pestalerts.org/nappo/	6	yes
	PIRSA's Invasive Species Unit	https://pir.sa.gov.au/biosecurity/introduced-pest-feral-animals	1	yes
	Regional Biological Invasions Centre (RBIC)	https://www.reabic.net	1	yes
	Smithsonian Environmental Research Center's National Estuarine and Marine Exotic Species Information System (NEMESIS)	https://invasions.si.edu/nemesis/	1	yes
	The Institute for Regional Conservation	https://www.regionalconservation.org	1	yes
	The North European and Baltic Network on Invasive Alien Species (NOBANIS)	https://www.nobanis.org	7	No longer maintained
	USDA Forest Service - Fire Effects Information System (FEIS)	https://www.feis-crs.org/feis/	2	yes
	USDA PLANTS database	https://plants.usda.gov/home	1	yes
	Victoria Resources Online (VRO) - Invasive Plants	https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_pest_plants	1	yes
	Weeds of Australia Factsheets	https://weeds.org.au/weeds-profiles/	1	yes
Occurrence data	AquaNIS	http://www.corpi.ku.lt/databases/index.php/aquanis	3	yes
	Atlas of Living Australia (ALA)	https://www.ala.org.au	10	yes
	Australasian Virtual Herbarium (AVH)	https://avh.chah.org.au	1	yes
	Biodiversity Information Serving Our Nation (BISON)	https://www.gbif.us	2	yes
	Biota of North America Program (BONAP)	http://www.bonap.org	9	yes
	CABi - general	https://www.cabi.org	1	Access Restricted
	CABi Crop Protection Compendium (CPC)	https://www.cabidigitallibrary.org/product/QC	3	Access Restricted
	CABi Invasive Species Compendium (ISC)	https://www.cabidigitallibrary.org/product/QI	41	yes
	CABi Plantwise	https://www.cabi.org/plantwiseplus/impact/plantwise/	1	yes
	Calflora Database	https://www.calflora.org	2	yes
	Comisión nacional para el conocimiento y uso de la biodiversidad (CONABIO) - Inventory of Alien and Invasive species	https://www.gbif.org/dataset/7185a1d5-9dc2-44fc-b3ef-5e4d068f12f1	1	yes

	eBird	https://ebird.org/home	1	yes
	EDDMaps	https://www.eddmaps.org	18	yes
	eDNAtlas database	https://www.fs.usda.gov/rm/boise/AWAE/projects/the-aquatic-eDNAtlas-project.html	1	yes
	EncicloVida	https://enciclovida.mx	1	yes
	European Alien Species Information Network (EASIN)	https://easin.jrc.ec.europa.eu/easin	10	yes
	European Plant Protection Organisation (EPPO) - Global Database	https://gd.eppo.int	3	yes
	Florabase Database	https://florabase.dbca.wa.gov.au	1	yes
	FloraWeb Database	https://www.floraweb.de	1	yes
	Global Biodiversity Information Facility (GBIF)	https://www.gbif.org	56	yes
	Global Naturalized Alien Flora database (GloNAF)	https://sebastian-ch.github.io/glonafAtlas/	5	yes
	Global Pest and Disease Database (GPDD)	https://www.gpdd.info	1	Access Restricted
	Global Register of Introduced and Invasive Species (GRIIS)	https://griis.org	11	yes
	Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)	https://www.glerl.noaa.gov/glansis/	1	yes
	iDigBio	https://www.idigbio.org	3	yes
	iMapInvasives Network	https://www.imapinvasives.org	2	yes
	iNaturalist	https://www.inaturalist.org	23	yes
	Kew's Plants of the World	https://powo.science.kew.org	1	yes
	Midwest Invasive Species Information Network (MISIN)	https://www.misin.msu.edu	1	yes
	National Agricultural Pest Information System (NAPIS)	https://napis.ceris.purdue.edu/home	1	Access Restricted
	National Biodiversity Network (NBN) Atlas	https://nbnatlas.org	2	yes
	National Exotic Marine and Estuarine Species Information System (NEMESIS)	https://invasions.si.edu/nemesis/	1	yes
	New Zealand Virtual Herbarium (NZVH)	https://www.nznhn.org.nz	1	yes
	Nonindigenous Aquatic Species Database (USGS - NAS)	https://nas.er.usgs.gov	3	yes
	Ocean Biogeographic Information System (OBIS)	https://obis.org	3	yes

	Other	n/a	5	
	Pacific Island Ecosystems at Risk (PIER)	http://www.hear.org/pier/	2	yes
	Pl@ntNet	https://identify.plantnet.org	2	yes
	The Great Lakes Indian Fish & Wildlife Commission (GLIFWC)	https://glifwc.org	1	yes
	The Institute for Regional Conservation	https://www.regionalconservation.org	1	yes
	U.S. National Fungus Collections - Databases	https://fungi.ars.usda.gov	1	yes
	USDA PLANTS database	https://plants.usda.gov/home	3	yes
	VertNet	http://www.vertnet.org	3	yes
Taxonomic data	Algaebase	https://www.algaebase.org	5	yes
	Amphibian Species of the World	https://amphibiansoftheworld.amnh.org	1	yes
	Atlas of Living Australia (ALA)	https://www.ala.org.au	2	yes
	Australian Plant Census (APC)	https://biodiversity.org.au	1	yes
	Avibase	https://avibase.bsc-eoc.org/avibase.jsp?lang=EN	1	yes
	BioNET's regional networks	https://bionet.ngo	1	No online database
	Bishop Museum Database	https://www.bishopmuseum.org/library-and-archives/	1	yes
	Bugwood Image Database System	https://images.bugwood.org	1	yes
	CABi - general	https://www.cabi.org	7	Access Restricted
	CABi Crop Protection Compendium (CPC)	https://www.cabidigitallibrary.org/product/QC	3	Access Restricted
	CABi Invasive Species Compendium (ISC)	https://www.cabidigitallibrary.org/product/QI	2	yes
	Catalogue of Life	https://www.catalogueoflife.org	1	yes
	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES-IUCN)	https://www.fws.gov/international-affairs/cites	1	yes
	Database of Vascular Plants of Canada (VASCAN)	http://data.canadensys.net/vascan/search	2	yes
	Entomological Society of America	https://entsoc.org/publications/common-names	1	yes

	Eschmeyer's Catalog of Fishes	https://www.calacademy.org/scientists/projects/eschmeyers-catalog-of-fishes	5	yes
	European Plant Protection Organisation (EPPO) - Global Database	https://gd.eppo.int	4	yes
	Fauna Europaea	https://www.gbif.org/dataset/90d9e8a6-0ce1-472d-b682-3451095dbc5a	1	yes
	FishBase	https://www.fishbase.se/search.php	19	yes
	Florida Department of Agriculture and Consumer Services (FDACS) – Division of Plant Industry (DPI) Database	n/a	1	unknown
	Germplasm Resources Information Network (USDA - GRIN)	https://www.ars-grin.gov	9	yes
	Global Biodiversity Information Facility (GBIF)	https://www.gbif.org	9	yes
	Global Invasive Species Database (GISD)	https://www.iucngisd.org/gisd/	6	yes
	Global Lepidoptera Names Index	https://www.nhm.ac.uk/our-science/data/lepindex/	3	yes
	Global Pest and Disease Database (GPDD)	https://www.gpdd.info	1	Access Restricted
	Go Botany - Native Plant Trust	https://gobotany.nativeplanttrust.org	2	yes
	Index Fungorium	https://www.indexfungorum.org/names/names.asp	5	yes
	Index Herbarium	https://sweetgum.nybg.org/science/ih/	3	yes
	Integrated Taxonomic Information System (ITIS)	https://www.itis.gov	32	yes
	International Committee on Taxonomy of Viruses (ICTV) Database	https://ictv.global	3	yes
	International Plant Names Index (IPNI)	https://www.ipni.org	16	yes
	Jepson Online Interchange	https://ucjeps.berkeley.edu/interchange/	1	yes
	Kew's Plants of the World	https://powo.science.kew.org	7	yes
	List of Prokaryotic names with Standing in Nomenclature (LPSN)	https://www.bacterio.net	1	yes
	MycoBank	https://www.mycobank.org	5	yes
	National Center for Biotechnology Information (NCBI)	https://www.ncbi.nlm.nih.gov	1	yes
	Nonindigenous Aquatic Species Database (USGS - NAS)	https://nas.er.usgs.gov	1	yes
	NSW FloraOnline	https://plantnet.rbgsyd.nsw.gov.au/search/simple.htm	1	yes
	Other	n/a	4	n/a
	Pl@ntNet	https://identify.plantnet.org	1	yes

	ScaleNet	https://scalenet.info	1	yes
	SeaBase	https://www.bsaseabase.org	1	No online database
	The Consortium for the Barcode of Life Data project	https://ibol.org	2	yes
	The Plant List	https://wfoplantlist.org	14	yes
	The Reptile Database	http://www.reptile-database.org	2	yes
	TortAI: Tortricids of Agricultural Importance project	https://idtools.org/id/tortai/index.html	1	yes
	Tropicos	https://www.tropicos.org/home	17	yes
	U.S. National Fungus Collections - Databases	https://fungi.ars.usda.gov	3	yes
	USDA PLANTS database	https://plants.usda.gov/home	8	yes
	WCSP- World Checklist of Selected Plant Families	https://powo.science.kew.org	5	yes
	Weeds of Australia Factsheets	https://weeds.org.au/weeds-profiles/	1	yes
	Wikispecies	https://species.wikimedia.org/wiki/Main_Page	1	yes
	Wilson & Reeder's Mammal Species of the World	http://www.departments.bucknell.edu/biology/resources/msw3/	1	yes
	World Flora Online	https://wfoplantlist.org	12	yes
	World Register of Marine Species (WoRMS)	https://www.marinespecies.org	15	yes
	World Spider Catalog	https://wsc.nmbe.ch	1	yes
	ZooBank	https://zoobank.org	1	yes

Table S3. Summarised results of multiple choice questions	N = 107[1]
How many years have you been conducting Risk Assessments?	
At least five years, but less than ten years	25 (26%)
At least one year, but less than three years	15 (16%)
At least ten years	34 (35%)
At least three years, but less than five years	18 (19%)
Less than one year	4 (4.2%)
What is your level of education?	
Bachelor's degree	6 (6.3%)
Doctorate degree	61 (64%)
Master's degree	23 (24%)
Other	3 (3.1%)
Secondary or high school	2 (2.1%)
Some college, no degree	1 (1.0%)
Over the last 3 years, how many Risk Assessments have you done?	
10 or less	42 (44%)
11-50	32 (34%)
51-100	13 (14%)
over 100	8 (8.4%)
For the Risk Assessment tool you use most commonly, how long does it take you to complete the whole review process for a Risk Assessment of a species?	
An hour or less	1 (1.0%)
At least a day, but less than a week	37 (39%)
At least a month	12 (13%)
At least a week, but less than a month	22 (23%)
At least an hour, but less than a day	24 (25%)
What do you think is the minimum level of education required for an assessor to proficiently conduct a Risk Assessment?	
Associate's degree	2 (2.1%)
Bachelor's degree	39 (41%)
Doctorate degree	3 (3.2%)
Master's degree	35 (37%)
Other	8 (8.4%)
Secondary or high school	2 (2.1%)
Some college, no degree	6 (6.3%)
How many hours worth of training (e.g. workshops, in-service training etc.) do you think are required to become proficient at conducting a typical Risk Assessment?	

>160 hours (more than a month)	9 (9.4%)
1-3 hours (half a day)	2 (2.1%)
17-40 hours (up to a week)	34 (35%)
4-8 hours (full day)	12 (13%)
40-160 hours (up to a month)	22 (23%)
9-16 hours (up to two days)	17 (18%)
How much of your data comes from peer-reviewed sources?	
A large amount	61 (64%)
A moderate amount	23 (24%)
A small amount	7 (7.3%)
All data comes from peer-reviewed sources	4 (4.2%)
None - all from grey literature and/or expert opinion	1 (1.0%)
How much of your data comes from expert opinion?	
A large amount	8 (8.3%)
A moderate amount	39 (41%)
A small amount	40 (42%)
All data comes from expert opinion	1 (1.0%)
None - all from published sources (either grey literature or peer-reviewed publications)	8 (8.3%)
Is there a peer-review process in place for your Risk Assessments?	
No	9 (9.3%)
Unsure	3 (3.1%)
Yes, always	59 (61%)
Yes, rarely	4 (4.1%)
Yes, sometimes	22 (23%)
If there is a peer-review process in place, is it internal review or external review?	
Both	36 (40%)
External	15 (16%)
Internal	34 (37%)
Neither	6 (6.6%)
Do you incorporate uncertainty or confidence into your Risk Assessments?	
No	6 (6.2%)
Yes, always	72 (74%)
Yes, rarely	5 (5.2%)
Yes, sometimes	14 (14%)
At some point of the process, are your Risk Assessments open for public comment?	
No	39 (41%)
Unsure	10 (10%)
Yes, always	19 (20%)

Yes, rarely	12 (13%)
Yes, sometimes	16 (17%)
Are the results of your Risk Assessments accessible to the public?	
No	9 (9.4%)
Unsure	13 (14%)
Yes, always	38 (40%)
Yes, rarely	4 (4.2%)
Yes, sometimes	32 (33%)

[1] n (%)