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Development and application of a second-generation multilingual tool for invasion risk screening of non-native terrestrial plants

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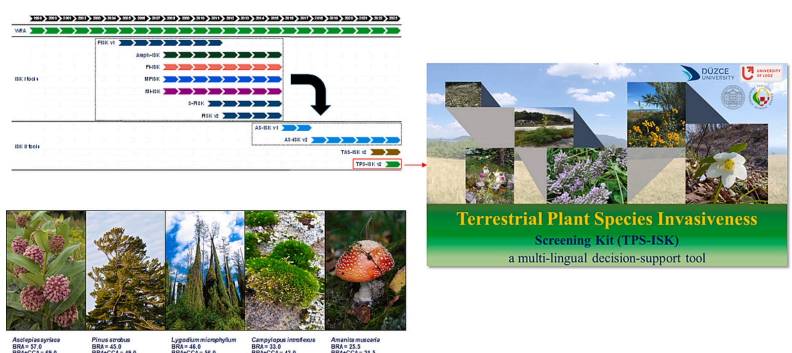
HIGHLIGHTS

- Decision support tools are needed in invasion risk analysis of non-native species.
- The Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK) is developed.
- Five taxonomically representative species and ten angiosperms were screened.
- Screening accounted for current and future climate conditions plus confidence level.
- TPS-ISK is a state-of-the-art comprehensive, updatable and easily deployable tool.

GRAPHICAL ABSTRACT



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ABSTRACT

Under the increasing threat to native ecosystems posed by non-native species invasions, there is an urgent need for decision support tools that can more effectively identify non-native species likely to become invasive. As part of the screening (first step) component in non-native species risk analysis, decision support tools have been developed for aquatic and terrestrial organisms. Amongst these tools is the Weed Risk Assessment (WRA) for screening non-native plants. The WRA has provided the foundations for developing the first-generation WRA-type Invasiveness Screening Kit (ISK) tools applicable to a range of aquatic species, and more recently for the second-generation ISK tools applicable to all aquatic organisms (including plants) and terrestrial animals. Given the most extensive usage of the latter toolkits, this study describes the development and application of the Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK). As a second-generation ISK tool, the TPS-ISK is a multilingual turnkey application that provides several advantages relative to the WRA: (i) compliance with the minimum standards against which a protocol should be evaluated for invasion process and management approaches; (ii) enhanced questionnaire comprehensiveness including a climate change component; (iii) provision of a level of confidence; (iv) error-free computation of risk scores; (v) multilingual support; (vi) possibility for across-study comparisons of screening outcomes; (vii) a powerful graphical user interface; (viii) seamless software deployment and accessibility with improved data exchange. The TPS-ISK successfully risk-ranked five representative sample species for the main taxonomic groups supported by the tool and ten angiosperms previously screened with the WRA for Turkey. The almost 20-year continuous development and evolution of the ISK tools, as opposed to the WRA, closely meet the increasing demand by scientists and decision-makers for a reliable, comprehensive, updatable and easily deployable decision support tool. For terrestrial plant screening, these requirements are therefore met by the newly developed TPS-ISK.

1. Introduction

The introduction and establishment of non-native species worldwide has increased sharply during the last two centuries (Pyšek et al., 2022).

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Even a single introduced species that becomes invasive may cause substantial ecological damage and economic losses (Gallardo et al., 2016; Bradshaw et al., 2021). Consequently, there is an urgent need for decision support tools that can more effectively identify non-native species likely to become invasive (Srėbalienė et al., 2019). Identification of higher risk species is part of environmental risk analysis that consists of three components: risk screening, risk assessment, and risk communication and management (Canter, 1993; Booy et al., 2017; Robertson et al., 2021). Risk screening helps to identify non-native species likely to become invasive in a pre-defined risk assessment area (Copp et al., 2016a). These species are then subjected to follow-up risk assessment (Copp et al., 2005a, 2016a; Baker et al., 2008; Mumford et al., 2010). This allows to inform decision-makers and stakeholders about prioritisation for prevention and management of biological invasions (González-Moreno et al., 2019; Marshall Meyers et al., 2020).

As part of the screening component in non-native species risk analysis, decision support tools have been developed for both aquatic and terrestrial organisms. Amongst the most widely applied schemes is the semi-quantitative Australian Weed Risk Assessment (WRA, also known as AWRA, A-WRA, AWRAS or WRAP) for terrestrial plants (Pheloung et al., 1999) and its adaptations to various biogeographic regions and to aquatic plants (see Gordon et al., 2008). The WRA questionnaire, which consists of 49 questions and a related scoring system, formed the basis for the Fish Invasiveness Screening Kit (FISK) for freshwater fish (Copp et al., 2005a, 2005b; Lawson Jr et al., 2013) and the related toolkits for screening some other groups of aquatic organisms (Copp, 2013). These taxon-specific, 'first-generation' WRA-type ISK tools (hereafter, 'ISK I tools') were eventually replaced by the taxon-generic, multilingual Aquatic Species Invasiveness Screening Kit (AS-ISK: Copp et al., 2016b, 2021). This is part of the 'second-generation' WRA-type ISK tools (hereafter, 'ISK II tools') and is designed for screening all aquatic organisms (freshwater, brackish and marine) under current and future climate conditions. More recently, the AS-ISK 'sibling' Terrestrial Animal Species Invasiveness Screening Kit (TAS-ISK) was developed to screen terrestrial animals (Vilizzi et al., 2022c). Apart from the above WRA-type decision support tools, which share overall the same questionnaire structure and scoring system of the original WRA, other less widely used risk screening toolkits include: *Harmonia*$^{+}$ (D'hondt et al., 2015) for plants, animals and their pathogens, the Canadian Marine Invasive Screening Tool (CMIST: Drolet et al., 2016; Brown and Therriault, 2022) for aquatic invertebrates, and the lesser-known Fish Invasiveness Screening Test (FIST: Singh and Lakra, 2011).

The ISK II tools are currently available for screening aquatic species (AS-ISK) and terrestrial animals (TAS-ISK) but not terrestrial plants. Most risk screening studies for terrestrial plants have relied on the WRA but the toolkit has not 'evolved' in terms of programming architecture and of questionnaire comprehensiveness and scope (cf. accounting for future climate change scenarios) since it was released 25 years ago (Pheloung et al., 1999). The present paper describes the development and application of a second-generation WRA-type decision support tool complementary to the AS-ISK and TAS-ISK for screening terrestrial plants. Following a background overview of the WRA-type decision support tools, the specific aims were to: (i) carry out a review of applications of the WRA-type decision support tools with the objective to compare the potential for adoption and the advantages in employing the second-generation ISK tool scheme and related software relative to the WRA for screening terrestrial plants; (ii) describe the development of the Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK) for screening terrestrial plants as a fully deployable software application based on the AS-ISK and TAS-ISK programming architecture and on the TAS-ISK questionnaire template; (iii) implement a trial screening of the TPS-ISK for one representative species in each of the main taxonomic groups of terrestrial plants supported by this new toolkit; and (iv) compare the outcomes of a re-screening with the TPS-ISK of a set of terrestrial plant species previously evaluated with (an adaptation of) the WRA.

It is anticipated that the availability and deployment of this new multilingual decision support tool for screening terrestrial plants, as a state-of-the-art alternative to the WRA, will better inform decision-makers and stakeholders about prevention of entry and dispersal of non-native (invasive) terrestrial plant species while also accounting for climate change predictions. This is a crucial step in the implementation of early-stage control and eradication measures as part of rapid-response strategies to counteract biological invasions in a changing world (Piria et al., 2017). Of note, as this study focuses on the screening component of non-native species risk analysis, no account will be made of the available risk assessment methods. This is an important distinction in the current context that has been often overlooked in the literature (e.g. González-Moreno et al., 2019; Marcot et al., 2019; Martin et al., 2020; Semenchenko et al., 2023; Soto et al., 2023) and has led to confusion and misinterpretation (see Hill et al., 2020).

2. Overview of Weed Risk Assessment-type decision support tools

The WRA, as originally developed by Pheloung et al. (1999), consists programmatically of a Microsoft Excel self-automated workbook (sensu Bovey et al., 2009), with code written in Visual Basic for Applications (VBA). This spreadsheet (sensu *lato*) has been referred to as being available upon request (e.g. Gordon et al., 2010) or for download from different URLs, though always upon request (e.g. https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis/weeds/system/weed_risk_assessment). The scoring sheet of the WRA has also been made available in paper format with related instructions (Pheloung et al., 1999; see also Gordon et al., 2010; Singh and Priyadarshi, 2014), which allow the assessor to calculate manually the screened species' scores.

The same type of self-automated workbook application architecture, albeit enhanced in terms of graphical user interface, was preserved in the development of the ISK I tools. These comprised the FISK v1 and FISK v2, with the latter version improved to account for a wider variety of environments, including subtropical and tropical climates (Lawson Jr et al., 2013). Other five 'sister' taxon-specific toolkits were developed, namely the Amphibian Invasiveness Screening Kit (AmphISK), the Freshwater Invertebrate Invasiveness Screening Kit (FI-ISK), the Marine Fish Invasiveness Screening Kit (MFISK) and the Marine Invertebrate Invasiveness Screening Kit (MI-ISK) (Copp, 2013), plus the language-specific Spanish freshwater Fish Invasiveness Screening Kit (S-FISK: see Copp et al., 2021). As an improvement to the WRA, the ISK I tools included the provision of a level of certainty for the responses to the questions (Copp et al., 2005a). Unlike the WRA, the ISK I tools were always available for free download from the Centre for Environment, Fisheries and Aquaculture Science website (www.cefas.co.uk/nns/tools). These toolkits were removed in 2019, hence no longer technically supported, because superseded since release of the AS-ISK (see Vilizzi et al., 2019).

With the advent of the ISK II tools (i.e. AS-ISK and, more recently, TAS-ISK), the self-automated workbook application format of the ISK I tools was upgraded to that of a turnkey application (sensu Walkenbach, 2007; Bovey et al., 2009) – incorrectly referred to as 'Excel sheet' by Srėbalienė et al. (2019: their Table 2). This advancement in Excel VBA software development has resulted not only in a major enhancement of the ISK II tools' graphical user interface but has also improved data exchangeability and better software deployment across users (Copp et al., 2016b, 2021; Vilizzi et al., 2022a). Additionally, the ISK II tools comply with the 'minimum standards' for screening non-native species under EC Regulation No. 1143/2014 on the prevention and management of the introduction and spread of invasive alien species (EU, 2014; Roy et al., 2018). Other improvements in the ISK II tools have included: (i) the provision of a 'preamble' about the risk screening context (cf. minimum standards) describing the reason for carrying out the screening, taxonomy, and native and introduced ranges of the species to be screened; (ii) an additional set of six questions (hence, bringing the total number of questions to 55) focusing on how climate change predictions may influence the screened species' risk of introduction, establishment, dispersal and impacts in the risk assessment area; (iii) the inclusion of a level of confidence for the responses to questions as an upgrade from the ISK I tools level of certainty (Copp et al., 2016b); and (iv) the provision of a justification to the response to each question based on literature sources (see Vilizzi and Piria, 2022). The ISK II tools are available for free download (see Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*).

A schematic representation of the 'evolution' of the WRA-type toolkits over the last 25 years is provided in Fig. 1. Unlike the 'unevolved' WRA, the ISK tools have undergone a long series of improvements. Since first release of the FISK, the ISK I tools diversified in terms of applicability to organism groups other than freshwater fish (i.e. AmphISK, FI-ISK, M-FISK, MI-ISK), support of a language other than English (S-FISK), and inclusion of a level of certainty. Since release of the AS-ISK as a taxon-generic and multilingual tool available as a stand-alone application incorporating all previous ISK I tools and extending beyond that by including all aquatic organisms and 32 languages, the ISK II tools have recently further diversified with the release of the TAS-ISK and the current development (and release) of the TPS-ISK.

3. Methodology

3.1. Weed Risk Assessment-type applications

A literature review was conducted of the applications of the WRA-type decision support tools to date with the aim to compare the adoption and usage of the WRA (including its various adaptations) over time with that of the ISK I and ISK II tools. For each application reviewed, details were retrieved of: (i) the risk assessment area; (ii) the organism group of the screened species (applicable to the ISK I and ISK II tools); and (iii) for the WRA, whether terrestrial or aquatic plant species were screened and whether the original questionnaire or an adaptation of it was used. A first comparison was then made of the number of WRA, ISK I and ISK II tools applications starting from 2005 (i.e. the year of release of the FISK, hence of first application of the ISK tools: Copp et al., 2005b) to date (i.e. as of 09/12/2023, given on-going publication especially of the ISK II applications). In a second comparison, the combined number of applications of the ISK I and ISK II tools was adjusted by removing those not dealing with fish. This is because the WRA was developed for screening plants (both terrestrial and aquatic). Whereas the ISK I tools Amph-ISK, FI-ISK and MI-ISK were developed for screening aquatic organisms other than fish (see Section 2: *Overview of WRA-type decision support tools*), and the ISK II tools AS-ISK and TAS-ISK for screening all aquatic organisms and terrestrial animals, respectively. Therefore, the comparison was made between applications of the WRA vs those of the FISK v1, FISK v2, MFISK and AS-ISK, with applications of the latter including only or also fish (as in the case of multiple taxonomic groups being screened).

For the purposes of the review, the distinction was made between applications of the FISK v1 and FISK v2, because the latter version was developed to include modifications in the questionnaire aimed at expanding the toolkit's climatic applicability (see Section 2: *Overview of WRA-type decision support tools*). Conversely, no distinction was made between applications of AS-ISK v1 and v2 since the latter version does not include any substantial modifications to the underlying questionnaire and related scoring system of AS-ISK v1, hence regardless of the inclusion of major improvements to the underlying code and graphical user interface, support for additional taxonomic groups of aquatic organisms, and inclusion of a much larger number of languages (Copp et al., 2021).

3.2. Toolkit development

As an ISK II tool, the TPS-ISK is largely a clone of the AS-ISK and TAS-ISK with which it shares the same programming architecture and graphical user interface features. In developing the TPS-ISK questionnaire, the same number and arrangement of the 55 questions in total (each consisting of Text and Guidance) of the AS-ISK and TAS-ISK were preserved, including the underlying scoring system. Accordingly, the first 49 questions, which are comparable in overall structure and arrangement to those of the WRA, comprise the Basic Risk Assessment (BRA) and the last six questions comprise the Climate Change Assessment (CCA) (Copp et al., 2016b; Vilizzi et al., 2022a). The BRA part of the questionnaire consists of two sections with eight categories: Section A *Biogeography/Historical* including Categories *Domestication/Cultivation*, *Climate*, *distribution and introduction risk*, and *Invasive elsewhere*; Section B *Biology/Ecology*, including Categories *Undesirable* (*or persistence*) *traits*, *Resource exploitation*, *Reproduction*, *Dispersal mechanisms* and *Tolerance attributes*. The CCA questions comprise Section C (and Category) *Climate change*. This results in two separate risk outcome scores, namely for the BRA (ranging from −20 to 70) and for the BRA+CCA (ranging from −32 to 82). For the response to each question, a

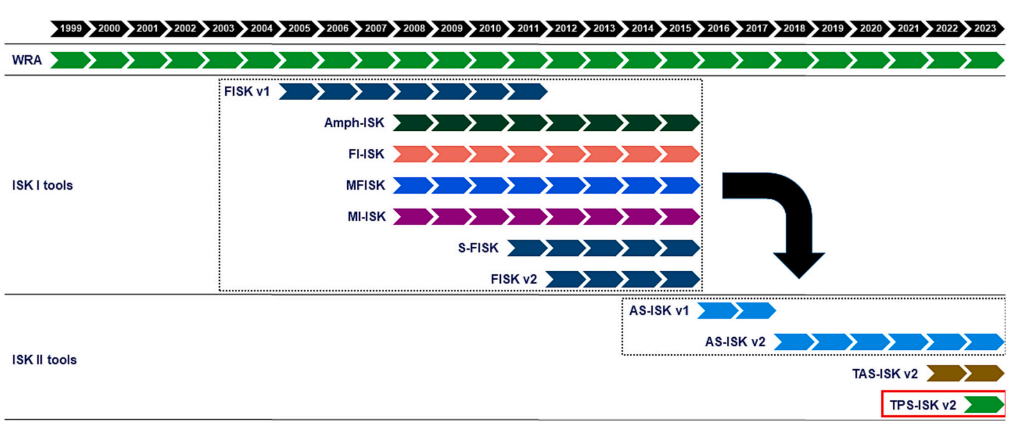

Fig. 1. Timeline of the development of the Weed Risk Assessment (WRA) type toolkits from 2009 to 2023 including the original WRA. The Invasiveness Screening Kit (ISK) I tools include the freshwater Fish Invasiveness Screening Kit (FISK v1 and v2), the Amphibian Invasiveness Screening Kit (AmphISK), the Freshwater Invertebrate Invasiveness Screening Kit (FI-ISK), the Marine Fish Invasiveness Screening Kit (MFISK), the Marine Invertebrate Invasiveness Screening Kit (MI-ISK) and the Spanish freshwater Fish Invasiveness Screening Kit (S-FISK). The ISK II tools include the Aquatic Species Invasiveness Screening Kit (AS-ISK v1 and v2), the Terrestrial Animal Species Invasiveness Screening Kit (TAS-ISK v2) and the newly developed Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK v2) described in this paper (highlighted in a red frame). The arrow indicates the inclusion of the (aquatic) ISK I tools as part of the AS-ISK (v1 and v2). Note that the versions of the TAS-ISK and TPS-ISK (v2) mirror the version of the AS-ISK available at time of their release (see also Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*).

confidence level must be provided resulting in a confidence factor (CF) that is averaged over all questions (CF_{Total}), over the BRA questions (CF_{BRA}) and over the CCA questions (CF_{CCA}) (Vilizzi et al., 2022a). As for the AS-ISK and TAS-ISK, to achieve a valid screening, the assessor must provide for each question a response, a confidence level, and a justification based on literature sources (Vilizzi and Piria, 2022).

Following the same approach as for the adaptation of the AS-ISK to TAS-ISK (changing from aquatic organisms to terrestrial animals: Vilizzi et al., 2022c), in developing the TPS-ISK questionnaire, first the question Text and Guidance for terrestrial animals of the TAS-ISK were reviewed and modified for adaptation to terrestrial plants. Then, the resulting template was finalised though a series of consensus meetings aimed at improving clarity, conciseness and accuracy. The final template was then circulated amongst the 44 author-translators for translation into their corresponding 30 native languages of the parts of Text and Guidance modified from the original TAS-ISK template. Lastly, an extensive, multi-stage quality-control check was performed to ensure that the final translation mirrored exactly the original English text in terms of keywords (both specific to the questionnaire and pertaining to the graphical user interface) and consistency in the structure of the questions' Text and Guidance. Consistency was ensured both between and amongst related questions, as well as in terms of keywords between Text and Guidance for all questions.

In line with the AS-ISK and TAS-ISK in which the species for screening are arranged taxonomically by organism group (see Ruggiero et al., 2015), the TPS-ISK allows screening of four main taxonomic groups of terrestrial plants: Angiosperms, Gymnosperms, Ferns and Lycopods, Bryophytes. Terrestrial Fungi are also included in the TPS-ISK for completeness with the aquatic Fungi supported by the AS-ISK (Copp et al., 2016b). Two more taxonomic groups, namely Other eukaryotes and Prokaryotes are included, again for completeness with the AS-ISK and TAS-ISK (in their new release v2.4; see Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*). The arrangement of the taxonomic groups for land plants in the TPS-ISK reflects their evolution (Donoghue et al., 2021) and is at the same time consistent with the classification of living organisms by Ruggiero et al. (2015). Accordingly, in the TPS-ISK the Kingdom Plantae includes the Superphylum Embryophyta with the Phyla Bryophyta (mosses), Anthocerotophyta (hornworts) and Marcantiophyta (liverworts), collectively grouped as 'Bryophytes', and with the Phylum Tracheophyta including the Subphyla Polypodiophytina and Lycopodiophytina (Ferns and Lycopods) and Spermatophytina with the Superclasses Gymnospermae (Gymnosperms) and Angiospermae (Angiosperms).

As per the other ISK II tools, the TPS-ISK is available for free download in its v2.4 (see Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*). Despite the TPS-ISK having just been developed, its version number aligns with the latest versions of the AS-ISK and TAS-ISK. These share the same latest improvements of the TPS-ISK in terms of across-toolkit alignment for grammar and consistency of the available languages and updating of the supported taxonomic groups for screening (see Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*).

3.3. Trial screenings

Trial screenings with the TPS-ISK were conducted for one representative species in each of the four taxonomic groups of plants supported by the toolkit plus Fungi. The five species screened were: the common milkweed *Asclepias syriaca* L. (Angiosperms) for the EU countries; the eastern white pine *Pinus strobus* L. (Gymnosperms) for the Pannonian Region; the Old World climbing fern *Lygodium microphyllum* (Cav.) R.Br. (Ferns and Lycopods) for the United States; the heath star moss *Campylopus introflexus* (Hedw.) Brid. (Bryophytes) for Lithuania; the fly agaric *Amanita muscaria* (L.) Lam. (Fungi) for Australia. In total, six assessors (HBS, MB, SLF, IJ, LP, IV-K) conducted the screenings, with four species each screened by a single assessor and one species screened by two assessors jointly (Table 1). As per risk screening requirements (Vilizzi and Piria, 2022), each assessor chose the non-native species for screening for which they were most knowledgeable in terms of their environmental biology and risk assessment area.

Upon completion of the screenings, the ranking of species into 'medium risk' and 'high risk' was based on two provisional thresholds, namely with the first one set at ≥29 (after Yazlık and Ambarlı, 2022) and the second at ≥44. Setting of the latter threshold at a higher value was based on the rationale that the WRA scores can range from a minimum value of −20 to a maximum value of 55, whereas the BRA scores range from −20 to 70 (Vilizzi et al., 2022a; see Section 3.2: *Toolkit development*), hence with the maximum BRA score value being 15 units higher than that of the WRA. In both cases, the low-risk threshold was set at <1 in line with that used in all WRA-type toolkit applications (see Vilizzi et al., 2022b) and in agreement with the same minimum possible score value achievable by both the WRA and BRA. The use of provisional thresholds in this study was dictated by the inability to meet the requirements for risk assessment area-specific calibration. This could not be implemented due to the screening of only one species per risk assessment area and the unavailability of a generalised threshold because of the lack of any previous applications (see Vilizzi et al., 2021, 2022a). Of note, this approach has been used in the first applications of the AS-ISK following their release, whereby the FISK (predecessor tool's) threshold ≥18 was provisionally employed (i.e. Filiz et al., 2017; Castellanos-Galindo et al., 2018).

Differences in CF between components (i.e. BRA and BRA+CCA) were statistically evaluated with permutational univariate analysis of variance. Analysis was implemented in PERMANOVA+ for PRIMER v7 (Anderson et al., 2008), with normalisation of the data and using a Bray-Curtis dissimilarity measure, 9999 permutations of the raw data, and with effects evaluated at $\alpha = 0.05$ (Monte-Carlo permutational value,

Table 1
Published applications of the Weed Risk assessment (WRA) type decision-support tools from 1999 to 2023. For each toolkit and related organism group (s), the number (*n*) of applications and corresponding percentages relative to the toolkit Generation (WRA, ISK I and ISK II) and to the Total are provided. ISK I = first generation WRA-type tools including the freshwater Fish Invasiveness Screening Kit (FISK v1 and v2), the Amphibian Invasiveness Screening Kit (AmphISK), the Freshwater Invertebrate Invasiveness Screening Kit (FI-ISK), the Marine Fish Invasiveness Screening Kit (MFISK) and the Marine Invertebrate Invasiveness Screening Kit (MI-ISK). ISK II = second generation WRA-type tools including the Aquatic Species Invasiveness Screening Kit (AS-ISK) and the Terrestrial Animal Species Invasiveness Screening Kit (TAS-ISK). See also Fig. 2 and Tables S1 and S2.

Generation/ Toolkit	Organism group(s)	*n*	Toolkit (%)	Total (%)
WRA	Terrestrial plants	76	90.5	31.1
	Aquatic plants	8	9.5	3.3
		84	**100.0**	34.4
ISK I				
FISK v1	Fish	15	20.0	6.1
FISK v2	Fish	39	52.0	16.0
AmphISK	Amphibians	1	1.3	0.4
FI-ISK	Invertebrates	16	21.3	6.6
MFISK	Fish	1	1.3	0.4
MI-ISK	Invertebrates	3	4.0	1.2
		75	**100.0**	30.7
ISK II				
AS-ISK	Fish	63	74.1	25.8
	Aquatic plants	2	2.4	0.8
	Fish, Aquatic plants (and other)	4	4.7	1.6
	Invertebrates	13	15.3	5.3
	Terrestrial reptiles[a]	1	1.2	0.4
TAS-ISK	Terrestrial animals	2	2.4	0.8
		85	**100.0**	34.8
		244		**100.0**

[a] Surrogate application of the AS-ISK.

best for small sample sizes).

3.4. Terrestrial Species Invasiveness Screening Kit vs Weed Risk Assessment screenings

The ten angiosperm species recently screened by Yazlık and Ambarlı (2022) with their WRA adaptation for Turkey (TR-WRA) were re-screened in this study with the TPS-ISK. These species, which consist of five 'dominant native' (sensu Yazlık and Ambarlı, 2022) and five non-native angiosperms, were evaluated for their risk of invasiveness in Turkey (the risk assessment area) based on the hypothesis that dominant native plant species can be as high risk as non-native plant species. The dominant native species were creeping thistle *Cirsium arvense* L. (Scop.), common ivy *Hedera helix* L., Scotch thistle *Onopordum acanthium* L., common reed *Phragmites australis* (Cav.) Trin. ex Steud., and Johnson grass *Sorghum halepense* (L.) Pers. The non-native species were tree of heaven *Ailanthus altissima* (Mill.) Swingle, golden dodder *Cuscuta campestris* Yunck., pokeweed *Phytolacca americana* L., black locust *Robinia pseudoacacia* L., and bur cucumber *Sicyos angulatus* L.

Using the same background knowledge and rationale as for the TR-WRA screenings, the assessor (AY) screened each species following the standard protocol developed for the ISK II tools (Vilizzi and Piria, 2022). This involved the inclusion of additional information relative to the climate change component of the TPS-ISK and the provision of a level of confidence for the responses to each of the 55 questions in total (i.e. BRA and CCA). As per the trial screenings (see above), the thresholds ≥29 and ≥44 were used to distinguish between medium-risk and high-risk species. Differences in CF between components (BRA, BRA+CCA) were statistically evaluated with permutational univariate analysis of variance as per the trial screenings.

4. Results

4.1. Weed Risk Assessment-type applications

Review of the WRA-type toolkits yielded 236 references (=studies) published from 1999 to 2023. There were 244 applications in total due to eight studies dealing with applications of two different (ISK I or ISK II, or both) tools (Table 1; Tables S1 and S2). These applications were almost equally distributed amongst the WRA (n = 84, 34.4 %), ISK I (n = 75, 30.7 %) and ISK II (n = 85, 34.8 %) tools, with the combined ISK tools therefore accounting for 160 (65.6 %) applications.

The 84 applications of the WRA screened plants for 45 risk assessment areas (plus one application at the global scale), and the first ever study (Pheloung et al., 1999) was carried out for two risk assessment areas (Table 1; Table S1). Of these applications, 38 (n = 45.2 %) relied on the original WRA questionnaire for Australia developed by Pheloung et al. (1999) and 46 (n = 54.8 %) on an adaptation of it, and with three applications using an adaptation of a previous adaptation. Of the eight applications screening aquatic plants, four were published from 2011 to 2015, hence before release of the AS-ISK in 2016, and four thereafter (2016–2021).

The 75 applications of the ISK I tools dealt mainly with freshwater fish (n = 54, 72.0 %) and, secondarily, with freshwater invertebrates (n = 16, 21.3 %), with the remaining applications (n = 5, 6.7 %) screening amphibians, marine fish and marine invertebrates (Tables 1, S2). Screenings were conducted for 57 risk assessment areas in total. The first application was published in 2005 and the last one in 2023, hence seven years since development of the AS-ISK.

Of the 85 applications of the ISK II tools, 83 were of the AS-ISK and two of the TAS-ISK. These applications dealt mainly with fish (n = 67, 78.8 %) followed by invertebrates (n = 13, 15.3 %), and in both cases freshwater, brackish and marine (Tables 1; S2). Another six applications screened aquatic plants, two screened terrestrial animals (TAS-ISK), and one used the AS-ISK as a surrogate for screening terrestrial reptiles. Four of the AS-ISK applications screened different taxonomic groups (i.e. fish, plants and/or other). There were 65 risk assessment areas in total, with the TAS-ISK applications screening species for six of them and one AS-ISK application conducted at the global scale. The first application was published in 2016.

Comparison of the number of WRA vs AS-ISK applications on aquatic plants during the same time span of both toolkits' availability (i.e. 2016–2023) revealed a wider usage of the ISK tool framework relative to that of the WRA (Tables 1; S1 and S2). The number of applications using the WRA, ISK I and ISK II tools (Fig. 2a) showed overall a moderate asymptotic increase over time for the WRA. Applications of the ISK I tools outnumbered those of the WRA from 2013 to 2017, and then decreased following release of the AS-ISK (cf. ISK II tools). Unlike the WRA, applications of the ISK II tools showed a sharp and steady (exponential) increase since 2017 and outnumbered those of the WRA from 2018 (and even more so from 2021). Comparison of the number of WRA applications with those of the ISK toolkits restricted to fish revealed overall the same trends as described above (Fig. 2b).

4.2. Toolkit development

4.2.1. Languages and questionnaire structure

Given the similarity with the AS-ISK and TAS-ISK, details of the TPS-ISK features, with special reference to the graphical user interface, are provided in the toolkit's User Guide (Supplementary material 1; see also Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*). Regarding the multilingual support, the translation process involved 30 languages in total – noting that Urdu, which was present in both the AS-ISK and TAS-ISK in their v2, was eventually removed because of failure by the corresponding translators to meet the required procedural and quality-control standards. As a result, like the AS-ISK and TAS-ISK in their release v2.4 (see Section 7: *Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools*), the TPS-ISK supports 31 languages in total: English, Albanian, Arabic, Bulgarian, Chinese, Croatian, Czech, Dutch, Filipino, French, Georgian, German, Greek, Hebrew, Hungarian, Italian, Japanese, Korean, Macedonian, Persian, Polish, Portuguese, Romanian, Russian, Slovak, Slovenian, Spanish, Swedish, Thai, Turkish, Vietnamese.

Modification of the TAS-ISK questionnaire for adaptation to terrestrial plants in the TPS-ISK resulted in changes to the Text for one question, to the Guidance for 14 questions, and to both Text and Guidance for ten questions (Table S3). As a result, 25 (n = 45.5 %) questions were modified out of the 55 comprising the questionnaire. In particular (Table S3): for *Domestication/Cultivation*, changes involved the Guidance for questions (Qs) 1 and 2; for *Climate, distribution and introduction risk*, the Text and Guidance for Q6; for *Invasive elsewhere*, the Guidance for Qs 9 and 12; for *Undesirable (or persistence) traits*, the Guidance for Qs 19, 23 and 24, and the Text and Guidance for Qs 18 and 22; for *Resource exploitation*, the Guidance for Q27, and the Text and Guidance for Q26; for *Reproduction*, the Text for Q29, the Guidance for Qs 32 and 34, and the Text and Guidance for Q33; for *Dispersal mechanisms*, the Guidance for Qs 36 and 40, and the Text and Guidance for Qs 37, 38, 39 and 41; for *Tolerance attributes*, the Guidance for Qs 44 and 49, and the Text and Guidance for Q48. Whereas all questions (Qs 50–55) for *Climate change* stayed the same as in the TAS-ISK (and AS-ISK) in term of both Text and Guidance.

With regard to the Text, the changes relative to the TAS-ISK involved eleven questions in total and were related to: (i) cultivation in plants as opposed to captivity in animals (Qs 6 and 22); (ii) production of propagules, seeds, spores, fragments or seedlings in plants as opposed to gametes, offspring, eggs and larvae/juveniles in animals (Qs 29, 33, 38, 39, 41); (iii) lack of disruption in ecosystem function, predation and means of hiding in plants as opposed to animals (Qs 18, 26, 37); and (iii) additional tolerance of (soil) salinity in plants (Q48). With regard to the Guidance, the changes involved 24 questions in total and were related not only to the above questions (except for Q29 for which the Guidance remained the same) but also to the examples provided being specific to

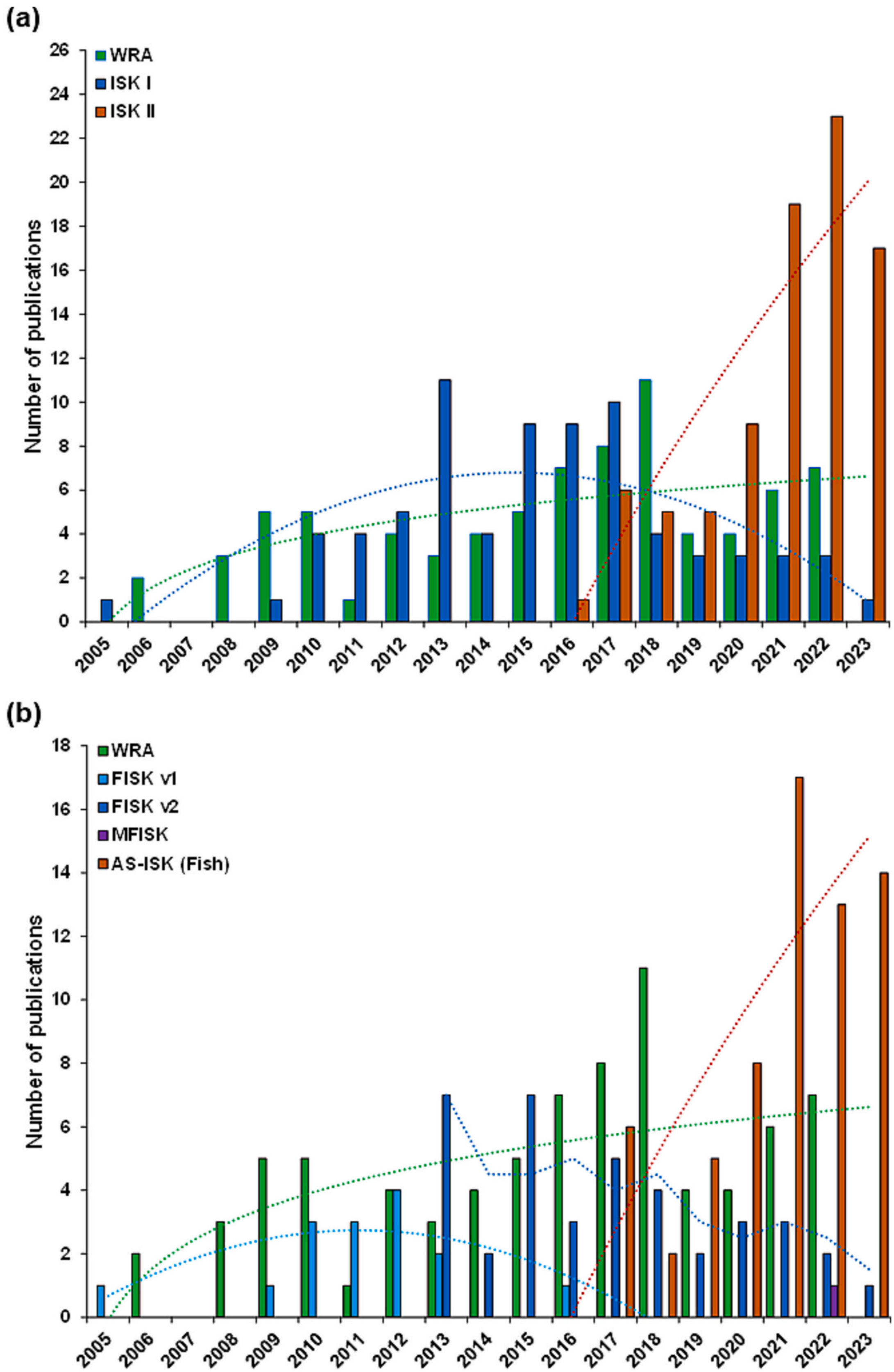

Fig. 2. Comparison of published applications of the Weed Risk Assessment (WRA) with those of the Invasiveness Screening Kit (ISK) I and ISK II tools (see Fig. 1 for list of toolkits) from 2005 to 2023. (a) WRA vs ISK I and ISK II tools applications with trends over time shown respectively by a logarithmic, polynomial and logarithmic curve, in each case as best fit; (b) WRA vs freshwater Fish Invasiveness Screening Kit (FISK) v1, FISK v2, Marine Fish Invasiveness Screening Kit (MFISK) (ISK I tools) and Aquatic Species Invasiveness Screening Kit (ISK II tools) applications restricted to fish and with trends over time shown respectively by a logarithmic, polynomial, moving average of period 2 and logarithmic curve, in each case as best fit. See also Table 1.

plants (i.e. Qs 1, 2, 9, 12, 19, 23, 24, 27, 32, 34, 36, 40, 44, 49).

4.2.2. Terrestrial Species Invasiveness Screening Kit vs Weed Risk Assessment questionnaire

Upon comparison of the TPS-ISK (BRA component) and WRA questionnaires, of the 49 questions in total, 38 (n = 77.6 %) in the TPS-ISK were comparable to those of the WRA and 11 (n = 22.4 %) were not (Table 2). Section-wise, the number of questions in the *Biogeography/Historical* and *Biology/Ecology* Sections remained the same (i.e. 13 and 36 questions, respectively). Conversely, category-wise (Table 2):

- *Domestication/Cultivation* – Two questions (Qs 1, 3) were comparable with those of the WRA and one (Q2) was not. For Q1, a minimum number of 20 generations was specified with reference to domestication; for Q3, the term 'weedy' was replaced with the more generic term 'invasive' and three additional taxonomic entities were included other than races. The non-comparable question (Q2) referred to the taxon's harvesting and its commercial use.
- *Climate, distribution and introduction risk* – Two questions (Qs 4, 5) in this Category (referred to as *Climate and distribution* in the WRA) were comparable, whereas the other three (Qs 6–8) were not. The applicability of Q4 was expanded to include all climatic conditions, whereas the text for Q5 remained virtually the same as in the WRA. The non-comparable questions referred to the risk assessment area in terms of the taxon's presence outside of cultivation (Q6), its potential vectors of introduction (Q7), and its proximity to and likelihood of introduction into the risk assessment area (Q8).
- *Invasive elsewhere* – Four questions (Qs 9–12) in this Category (referred to as *Weed elsewhere* in the WRA) were comparable, whereas Q13 was not. For Q9, the text remained overall the same as in the WRA; for Q10, emphasis was placed on the taxon's adverse impacts; for Qs 11 and 12, the WRA text was expanded in terms of the taxon's adverse impacts. The non-comparable question (Q13) dealt with any known adverse socio-economic impacts.
- *Undesirable* (*or persistence*) *traits* – Eight questions (Qs 14–16, 19–21, 23, 24) in this Category (referred to as *Undesirable traits* in the WRA) were comparable, whereas the other four (Qs 17, 18, 22, 25) were not. For Qs 14–16, the text was (substantially) expanded relative to that of the WRA, with Q14 being comparable to Q20 of the WRA; for Q19, reference to fire hazards in Q21 of the WRA was generalised in terms of adverse impacts on ecosystem services; for Qs 20 and 21, a distinction was made between recognised pests and pathogens being absent (Q20) or present (21) in the risk assessment area relative to the corresponding Q19 of the WRA; for Q23, the text was generalised in terms of taxon's versatility in habitat use and the question was comparable not only to Q23 of the WRA but also to Q22; for Q24, the text also was generalised to include noxious modes of existence or behaviours and included not only Q24 but also Qs 14, 17, 18 and 25 of the WRA. The non-comparable questions referred to the taxon's adaptability to climatic and environmental conditions (Q17) and to its likelihood of disrupting ecosystem function (Q18), being released from cultivation (Q22), and being able to maintain a viable population even at low densities (Q25).
- *Resource exploitation* – This Section, which had no equivalent with the (numerically) corresponding WRA *Plant type* Section 5, included two questions relative to the taxon's likelihood to put threatened or protected native species under competitive pressure (Q26) and to sequester resources to the detriment of native species (Q27).
- *Reproduction* – All seven questions (Qs 28–34) were comparable to those of the WRA, with the only difference that the corresponding number was shifted back by two units as a result of the *Resource exploitation* Section (see above) comprising two instead of four questions as in the WRA *Plant type* Section. In all cases, the WRA text was expanded and for Q32 hybridisation with native species was specified.

Table 2
List of the 49 questions comprising the Basic Risk Assessment (BRA) of the Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK) questionnaire and comparison with the corresponding Weed Risk Assessment (WRA) questions whenever applicable. Questions are arranged according to Section (A and B) and Category (1–8), with the corresponding denomination for the WRA in parentheses whenever different. For each question, the corresponding number (No.) and ID are provided. For the TPS-ISK questions with a WRA equivalent, the comparable WRA question is shown in italics, and in case of a different No. or No. and ID these are also marked in italics.

No.	ID	Question
A. Biogeography/historical		
1. Domestication/cultivation		
1	1.01	Has the taxon been the subject of domestication for at least 20 generations?
		Is the species highly domesticated?
2	1.02	Is the taxon harvested in the wild and likely to be sold or used in its live form?
3	1.03	Does the taxon have invasive races, varieties, sub-taxa or congeners?
		Does the species have weedy races?
2. Climate, distribution and introduction risk (*Climate and distribution*)		
4	2.01	How similar are the climatic conditions between the risk assessment area and the taxon's native range?
		Species suited to Australian climates
5	2.02	What is the quality of the climate-matching data?
		Quality of climate match data
6	2.03	Is the taxon already present outside of cultivation in the risk assessment area?
7	2.04	How many potential vectors could the taxon use to enter the risk assessment area?
8	2.05	Is the taxon currently found in close proximity to, and likely to enter, the risk assessment area in the near future (e.g. unintentional or intentional introductions)?
3. Invasive elsewhere (*Weed elsewhere*)		
9	3.01	Has the taxon become naturalised outside its native range?
		Naturalised beyond native range
10	3.02	In the taxon's introduced range, are there any known adverse impacts to wild or commercial species?
		Garden/amenity/disturbance weed
11	3.03	In the taxon's introduced range, are there any known adverse impacts to agriculture or forestry?
		Weed of agriculture
12	3.04	In the taxon's introduced range, are there any known adverse impacts to ecosystem services?
		Environmental weed
13	3.05	In the taxon's introduced range, are there any known adverse socio-economic impacts?
B. Biology/ecology		
4. Undesirable (or persistence) traits (*undesirable traits*)		
14	4.01	Is the taxon likely to be poisonous or pose other risks to human health?
20	*4.07*	*Causes allergies or is otherwise toxic to humans*
15	4.02	Is the taxon likely to suppress the growth of one or more native species?
		Allelopathic
16	4.03	Are there any threatened or protected native species that the taxon would parasitise in the risk assessment area?
		Parasitic
17	4.04	Is the taxon adaptable in terms of climatic and other environmental conditions, thus enhancing its potential persistence if it has invaded or is likely to invade the risk assessment area?
18	4.05	Is the taxon likely to disrupt terrestrial ecosystem function if it has invaded or is likely to invade the risk assessment area?
19	4.06	Is the taxon likely to exert adverse impacts on ecosystem services in the risk assessment area?
21	4.08	*Creates a fire hazard in natural ecosystems*
20	4.07	Is the taxon likely to host or function as a vector for recognised pests and pathogens that are present in the risk assessment area?
19	*4.06*	*Host for recognised pests and pathogens*
21	4.08	Is the taxon likely to host or function as a vector for recognised pests and pathogens that are absent in the risk assessment area?
19	*4.06*	*Host for recognised pests and pathogens*
22	4.09	Is the taxon likely to be released from cultivation?
23	4.10	Is the taxon versatile in habitat use?
22	*4.09*	*Is a shade tolerant plant at some stage of its life cycle*

(*continued on next page*)

Table 2 (*continued*)

No.	ID	Question
		Grows on infertile soils
24	4.11	Is it likely that the taxon's mode of existence or behaviours will reduce habitat quality for native species?
14	*4.01*	*Produces spines, thorns or burrs*
17	*4.04*	*Unpalatable to grazing animals*
18	*4.05*	*Toxic to animals*
		Climbing or smothering growth habit
25	*4.12*	*Forms dense thickets*
25	4.12	Is the taxon likely to maintain a viable population even when present in low densities (or persist in adverse conditions by way of a dormant form)?
5. Resource exploitation (*plant type*)		
26	5.01	Is the taxon likely to put threatened or protected native species under competitive pressure in the risk assessment area?
27	5.02	Is the taxon likely to sequester resources to the detriment of native species in the risk assessment area?
6. Reproduction		
28	6.01	Is the taxon likely to exhibit changes in reproductive strategy in response to environmental conditions?
30		*Evidence of substantial reproductive failure in native habitat*
29	6.02	Is the taxon likely to produce viable propagules in the risk assessment area?
31		*Produces viable seed*
30	6.03	Is the taxon likely to hybridise with native species under natural conditions?
32		*Hybridises naturally*
31	6.04	Is the taxon likely to be hermaphroditic or to exhibit asexual reproduction?
33		*Self-compatible or apomictic*
32	6.05	Is the taxon dependent on the presence of another species (or specific habitat features) to complete its life cycle?
34		*Requires specialist pollinators*
33	6.06	Is the taxon likely to produce a large number of propagules?
35		*Reproduction by vegetative fragmentation*
34	6.07	How many time units (days, months, years) does the taxon require to reach the age at first reproduction?
36		*Minimum generative time* (*years*)
7. Dispersal mechanisms		
35	7.01	How many potential vectors or pathways could the taxon use to disperse within the risk assessment area (with suitable habitats nearby)?
37		*Propagules likely to be dispersed unintentionally* (*plants growing in areas with much vehicle movement*)
38		*Propagules dispersed intentionally by people*
36	7.02	Will any of these vectors or pathways bring the taxon in close proximity to one or more protected areas?
37		*Propagules likely to be dispersed unintentionally* (*plants growing in areas with much vehicle movement*)
38		*Propagules dispersed intentionally by people*
37	7.03	Does the taxon have a specialised means of attachment such that it enhances the likelihood of dispersal?
39		*Propagules likely to disperse as a produce contaminant*
38	7.04	Is natural dispersal of the taxon likely to occur as seeds or spores in the risk assessment area?
40		*Propagules adapted to wind dispersal*
41	*7.05*	*Propagules water dispersed*
39	7.05	Is natural dispersal of the taxon likely to occur as fragments or seedlings in the risk assessment area?
40	*7.04*	*Propagules adapted to wind dispersal*
41		*Propagules water dispersed*
40	7.06	Are any life stages of the taxon likely to migrate into the risk assessment area for reproduction?
41	7.07	Are propagules of the taxon likely to be dispersed in the risk assessment area by other species?
42	*7.06*	*Propagules bird dispersed*
43		*Propagules dispersed by other animals* (*externally*)
44	7.08	*Propagules survive passage through the gut*
42	7.08	Is dispersal of the taxon along any of the vectors or pathways mentioned in the previous seven Questions (35–41: i.e. either unintentional or intentional) likely to be rapid?
43	7.09	Is dispersal of the taxon density dependent?
8. Tolerance attributes (*Persistence attributes*)		
44	8.01	Is the taxon able to withstand being in water for extended periods (e.g. minimum of one or more hours) at some stage of its life cycle?
45	8.02	Is the taxon tolerant of a wide range of soil or air quality conditions?
46	8.03	Can the taxon be controlled or eradicated in the wild with chemical, biological or other agents/means?
47		*Well controlled by herbicides*
47	8.04	Is the taxon likely to benefit from environmental or human disturbance?
48		*Tolerates, or benefits from, mutilation or cultivation*
48	8.05	Is the taxon able to tolerate soil acidity, salinity or other parameter levels that are higher or lower than those found in its usual environment?
49	8.06	Are there effective natural enemies of the taxon present in the risk assessment area?
49	*8.05*	*Effective natural enemies present in Australia*

- *Dispersal mechanisms* – This Section included nine questions in total, hence one more question than in the WRA as a result of the *Resource exploitation* Section (see above) comprising two questions instead of the four in the WRA *Plant type* Section. Of these questions, six (Qs 35–39 and 41) were comparable to those of the WRA (except for their corresponding number shifted back by one to three units), and three (Qs 40, 42, 43) were not. For Qs 35 and 36, reference to unintentional and intentional dispersion in WRA Qs 37 and 38 was redefined in terms of vectors and pathways; for Q37, reference to dispersion as a produce contaminant in WRA Q39 was redefined in terms of means of attachment; for Qs 38 and 39, the wind and water dispersal referred to in WRA Qs 40 and 41 was redefined in terms of seeds or spores and fragments or seedlings; for Q41, reference to dispersal by other birds and other animals and by passage through the gut in WRA Qs 42, 43 and 44 respectively (i.e. three separate questions) was summarised into dispersion by other species. With regard to the non-comparable questions: Q40 referred to the migration ability of the taxon life stages, and Qs 42 and 43 respectively dealt with the speed and density-dependence of the taxon's dispersal.
- *Tolerance attributes* – This Section (referred to as *Persistence attributes* in the WRA) included six questions in total, hence one more question than in the WRA as a result of the *Resource exploitation* Section (see above) comprising two questions instead of four as in the WRA *Plant type* Section. Of these questions, three (Qs 46, 47, 49) were comparable to those of the WRA (except for their corresponding number shifted back by one unit in the case of the first two questions), and three (Qs 44, 45, 48) were not. For Q46, reference to herbicides was expanded to include chemical, biological or other agents or means; for Q47, tolerance of mutilation of cultivation was extended to environmental or human disturbance; for Q49, the presence of effective enemies was expanded to include any region or country or other geographical entity where the risk assessment area is located. The non-comparable questions referred to the taxon's ability to survive under water (Q44), and tolerance of a range of soil or air quality conditions (Q45) and of high values of various environmental parameters (Q48).

4.3. Trial screenings

Based on the TPS-ISK, for both the BRA and BRA+CCA, the highest scoring species were *Asclepias syriaca*, *Pinus strobus* and *Lygodium microphyllum* followed by *Campylopus introflexus* and *Amanita muscaria*, with the latter achieving comparatively lower scores (Table 3). Based on the threshold of 29, for the BRA all species were ranked as high risk except for *A. muscaria*, which was ranked as medium risk, whereas for the BRA+CCA *A. syriaca*, *P. strobus* and *L. microphyllum* were ranked as high risk and *C. introflexus* and *A. muscaria* as medium risk (combined report in Supplementary material 2). Based on the threshold ≥44, the risk rank for all species was the same as under the threshold of 29 except for *C. introflexus*, which was ranked as medium risk also for the BRA. *Asclepias syriaca* and L. *microphyllum* achieved the highest scores in the

Biogeographical/Historical Section as a result of their *Invasive elsewhere* characteristics, and *A. syriaca* also in the *Biology/Ecology* Section because of its *Undesirable* (*or persistence*) *traits*. As a result of the CCA, the BRA scores for all species increased except for *A. muscaria* whose BRA score decreased. *Asclepias syriaca* and *L. microphyllum* had the highest CF for both the BRA and CCA, whereas *A. muscaria* had the lowest CF for the CCA. (Table 3). The mean CF_{Total} was 0.65 ± 0.20 SE, the mean CF_{BRA} 0.75 ± 0.33 SE, and the mean CF_{CCA} 0.55 ± 0.25 SE. The mean CF_{BRA} was higher than the mean CF_{CCA} ($F^{\#}_{1,8}$ = 9.19, P^{MC} = 0.016; # = permutational value; MC = Monte Carlo permutational value).

4.4. Terrestrial Species Invasiveness Screening Kit vs Weed Risk Assessment screenings

For both the BRA and BRA+CCA (TPS-ISK screenings), the highest scoring species was the dominant native *Phragmites australis* and the lowest scoring the non-native *Sicyos angulatus*, with all other species achieving overall similar outcome scores (Table 4). Based on both thresholds of 29 and 44 and for both the BRA and BRA+CCA, all species were ranked as high risk (combined report in Supplementary material 3). The higher BRA score for *P. australis* was related to its reproductive characteristics (*Biology/Ecology – Reproduction*), whereas the lower BRA score for *S. angulatus* was a result of its reproductive characteristics and dispersal abilities (*Biology/Ecology – Dispersal mechanisms*) but also of its lack of cultivation (*Biogeography/Historical – Domestication/Cultivation*). Upon comparison of the dominant native and non-native species, the former (except for *Sorghum halepense*) scored higher in terms of cultivation and the latter in terms of climate compatibility (*Biogeography/Historical – Climate, distribution and introduction risk*). The risk of invasiveness of all species increased when accounting for the CCA and it was higher for *S. halepense* (maximum possible value of +12) and lower for *Cirsium arvense* and *Onopordum acanthium*. For all species, the CF values were overall high (Table 4). The mean CF_{Total} was 0.86 ± 0.27 SE, the mean CF_{BRA} 0.87 ± 0.28 SE, and the mean CF_{CCA} 0.78 ± 0.25 SE. Statistically, the mean CF_{BRA} was higher than the mean CF_{CCA} ($F^{\#}_{1,18}$ = 11.71, P^{MC} = 0.004).

Comparing BRA vs WRA outcome scores (Table 3), *P. australis* was in both cases the highest scoring species, and *Robinia pseudoacacia* and *C. arvense* the third and fourth higher scoring species, respectively. Conversely, *Hedera helix* was the second higher scoring species based on the BRA, but the lowest scoring based on the WRA. Although the relative score ranking for the other species differed between BRA and WRA, except for highest scoring *P. australis*, the range of the outcomes scores for all other species were overall similar between the two questionnaires (i.e. 51–59 for the BRA and 28–33 for the WRA).

Of note, the WRA score of 28 reported for *Ailanthus altissima* in Yazlık and Ambarlı (2022) was found to be incorrect due to wrong summation of the partial (i.e. question-related) scores and was therefore recomputed in the present study as 29. Further, the classification of all species screened by Yazlık and Ambarlı (2022) as invasive (cf. high risk) was also incorrect. Thus, *H. helix* with its score of 28 must be re-classified as ‘pending further evaluation’ (cf. medium risk), whereas *A. altissima*, previously incorrectly classified as invasive given the incorrect score of 28, was correctly classified in the present study as invasive (high risk) as a result of its recomputed score of 29.

5. Discussion

The development of the TPS-ISK for screening terrestrial plants as a readily deployable, turnkey application has expanded the range of non-native species that can now be screened with the ISK II tools framework to all groups of aquatic and terrestrial organisms (Ruggiero et al., 2015). As per the AS-ISK and TAS-ISK, the TPS-ISK also complies with the minimum standards for screening non-native species. The applicability of the TPS-ISK to all climate conditions, which overcomes the many application-specific adaptations of the WRA, will enable comparability of risk scores and related outcomes, but also of risk assessment area-specific thresholds across applications (see Vilizzi et al., 2019, 2021). Unlike the WRA, the TPS-ISK provides in perspective scope for much wider applicability and adoption by virtue of its multilanguage capabilities meant to facilitate communication amongst scientists and decision-makers (Copp et al., 2021). The inclusion of a level of confidence for the responses provides further support to the validity and reliability of the risk screening outcomes. Finally, the new CCA component included in the TPS-ISK provides additional information about the future risks of a plant species' introduction, establishment,

Table 3
Scoring output and related risk outcomes for the sample species screened with the TPS-ISK. For each species, the partial Section- and Category-related scores and resulting BRA (Basic Risk Assessment) and BRA+CCA (Climate Change Assessment) scores are provided together with the confidence factor for all 55 questions (Total) and for the BRA and CCA separately. BRA and BRA+CCA risk outcomes (H = High; M = Medium) based on the thresholds ≥29 (outcome I) and ≥ 44 (outcome II). See also Supplementary material 2 for the screened species reports.

Section/category	*Asclepias syriaca*	*Pinus strobus*	*Lygodium microphyllum*	*Campylopus introflexus*	*Amanita muscaria*
A. Biogeography/historical					
1. Domestication/cultivation	4.0	4.0	2.0	−2.0	0.0
2. Climate, distribution and introduction risk	2.0	4.0	2.0	4.0	4.0
3. Invasive elsewhere	14.0	14.0	18.0	6.0	4.5
	20.0	*22.0*	*22.0*	*8.0*	*8.5*
B. Biology/ecology					
4. Undesirable (or persistence) traits	11.0	9.0	7.0	7.0	6.0
5. Resource exploitation	7.0	5.0	7.0	0.0	0.0
6. Reproduction	3.0	1.0	2.0	4.0	0.0
7. Dispersal mechanisms	9.0	5.0	4.0	9.0	8.0
8. Tolerance attributes	7.0	3.0	4.0	5.0	3.0
	37.0	*23.0*	*24.0*	*25.0*	*17.0*
BRA score	**57.0**	**45.0**	**46.0**	**33.0**	**25.5**
BRA risk outcome I	**H**	**H**	**H**	**H**	**M**
BRA risk outcome II	**H**	**H**	**H**	**M**	**M**
C. Climate change					
9. Climate change	12.0	4.0	10.0	10.0	−4.0
BRA+CCA score	**69.0**	**49.0**	**56.0**	**43.0**	**21.5**
BRA+CCA risk outcome I	**H**	**H**	**H**	**M**	**M**
BRA+CCA risk outcome II	**H**	**H**	**H**	**M**	**M**
Confidence factor					
BRA	0.78	0.77	0.77	0.73	0.72
CCA	0.63	0.54	0.71	0.54	0.33
Total	0.76	0.75	0.76	0.71	0.68

Table 4
Scoring output and related risk outcomes for the dominant native and the non-native angiosperms screened with the WRA adaptation for Turkey (TR-WRA) by Yazlık and Ambarlı (2022) and re-screened in this study with the TPS-ISK. For each species screened with the TPS-ISK, the partial Section- and Category-related scores and resulting BRA and BRA+CCA scores are provided together with the confidence factor for all 55 questions (Total) and for the BRA and CCA separately. For each species screened with the TR-WRA, the partial Section- and Category-related scores and resulting score are provided. BRA and BRA+CCA risk outcomes (H = High; M = Medium) based on the thresholds ≥29 (outcome I) and ≥44 (outcome II). WRA risk outcomes based on the threshold ≥29. See also Supplementary material 3 for the TPS-ISK species reports.

Section/category	Dominant native					Non-native				
	Cirsium arvense	*Hedera helix*	*Onopordum acanthium*	*Phragmites australis*	*Sorghum halepense*	*Ailanthus altissima*	*Cuscuta campestris*	*Phytolacca americana*	*Robinia pseudoacacia*	*Sicyos angulatus*
TPS-ISK										
A. Biogeography/historical										
1. Domestication/cultivation	4.0	4.0	4.0	4.0	2.0	2.0	2.0	0.0	2.0	2.0
2. Climate, distribution and introduction risk	2.0	2.0	2.0	2.0	2.0	4.0	2.0	4.0	4.0	4.0
3. Invasive elsewhere	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	24.0	*24.0*	*24.0*	*24.0*	*22.0*	*24.0*	*22.0*	*22.0*	*24.0*	*24.0*
B. Biology/ecology										
4. Undesirable (or persistence) traits	10.0	10.0	10.0	10.0	10.0	10.0	12.0	10.0	10.0	10.0
5. Resource exploitation	7.0	7.0	5.0	7.0	7.0	5.0	5.0	5.0	7.0	7.0
6. Reproduction	3.0	3.0	4.0	7.0	3.0	3.0	2.0	5.0	2.0	1.0
7. Dispersal mechanisms	8.0	8.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0	4.0
8. Tolerance attributes	5.0	7.0	5.0	7.0	5.0	7.0	7.0	7.0	7.0	5.0
	33.0	*35.0*	*30.0*	*39.0*	*33.0*	*33.0*	*34.0*	*35.0*	*34.0*	*27.0*
BRA score	**57.0**	**59.0**	**54.0**	**63.0**	**55.0**	**57.0**	**56.0**	**57.0**	**58.0**	**51.0**
BRA risk outcome I	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
BRA risk outcome II	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
C. Climate change										
9. Climate change	10.0	10.0	6.0	10.0	12.0	10.0	10.0	10.0	10.0	10.0
BRA+CCA score	**67.0**	**69.0**	**60.0**	**73.0**	**67.0**	**67.0**	**66.0**	**67.0**	**68.0**	**61.0**
BRA+CCA risk outcome I	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
BRA+CCA risk outcome II	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
Confidence factor										
BRA	0.88	0.81	0.85	0.93	0.89	0.93	0.86	0.79	0.89	0.91
CCA	0.79	0.79	0.88	0.79	0.79	0.79	0.79	0.58	0.79	0.79
Total	0.87	0.81	0.85	0.91	0.88	0.92	0.85	0.77	0.88	0.90
TR-WRA										
A. Biogeography/historical										
1. Domestication/Cultivation	1	2	1	2	1	−1	−1	−1	−1	−1
2. Climate and distribution	3	3	3	3	4	5	5	3	5	3
3. Weed elsewhere	5	6	5	6	6	5	6	5	5	5
	9	*11*	*9*	*11*	*11*	*9*	*10*	*7*	*9*	*7*
B. Biology/ecology										
4. Undesirable traits	10	6	10	9	8	9	10	10	7	9
5. Plant type	0	0	0	2	1	0	0	0	1	0
6. Reproduction	5	4	4	5	6	3	5	3	4	4
7. Dispersal mechanisms	7	5	7	10	4	2	6	9	8	8
8. Persistence attributes	0	2	0	3	3	6	1	1	4	1
	22	*17*	*21*	*29*	*22*	*20*	*22*	*23*	*24*	*22*
WRA score	**31**	**28**	**30**	**40**	**33**	**29**	**31**	**30**	**32**	**29**
WRA risk outcome	**H**	**M**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**

dispersal and impacts under predicted global warming scenarios – another feature not available in the WRA (Copp et al., 2016b).

5.1. Weed Risk Assessment-type applications

The wider usage and adoption of the WRA for screening plants is indicated by the few applications with the only other available screening toolkit, namely *Harmonia*+ (D'Hondt et al., 2015; Ries et al., 2020; Van der Loop et al., 2019; Dana et al., 2021; Jensen et al., 2023). Similarly, on a broader scale the employment of the WRA-type framework for screening terrestrial plants and aquatic organisms (cf. WRA and ISK tools, respectively) by far surpasses that of the other available three screening toolkits *Harmonia*+ (Collas et al., 2017; Schaffner and Ries, 2019; Lemmers et al., 2021; Ries et al., 2021; Brevé et al., 2022;

Paganelli et al., 2022; Thunnissen et al., 2022; and references above), CMIST (Drolet et al., 2016; Moore et al., 2018; Therriault et al., 2018; Goldsmit et al., 2020, 2021; Brown and Therriault, 2022) and FIST (Singh and Lakra, 2011; Singh et al., 2013; Magalhães et al., 2017; Saba et al., 2020; Khan et al., 2021; Singh, 2014, 2021; de Camargo et al., 2022; Sandilyan, 2022). On the other hand, because of the recent release of the TAS-ISK (Vilizzi et al., 2022c), the number of applications using this toolkit ($n = 2$; Table S2) is not yet quantifiable relative to that, albeit somewhat limited, based on *Harmonia*+ (D'Hondt et al., 2015; Schaffner and Ries, 2019; Ries et al., 2021), which is the only other available toolkit for screening terrestrial animals.

The increasing trend in the usage of the ISK tool framework relative to that of the WRA, which was preserved upon comparison of the number of WRA applications with those of the ISK tools (even after adjusting for the screening of fish only), was further emphasised by the exponential increase in the number of (fish-adjusted) applications since release of the AS-ISK (Fig. 2). Using a Google Scholar literature search for "non-native plants" AND "risk" vs "non-native fish" AND "risk" as a rough indicator of the extent of research conducted in the field of invasion biology and non-native species risk analysis in particular, ≈12,700 vs ≈7130 results were retrieved respectively (as of 09/12/2023). Given the much larger number of published literature sources available for non-native plants (63 % more), the adoption and usage of the ISK tools for screening non-native fish, and with special reference to the AS-ISK, is therefore even more remarkable. The above trend was further supported by comparing the number of applications of the WRA vs those of the AS-ISK for screening aquatic plants since release of the latter toolkit.

Apart from the inclusion of the AS-ISK (and, consequently, TAS-ISK and TPS-ISK) together with *Harmonia*$^+$ amongst the toolkits found to satisfy all 14 minimum standards against which a protocol should be evaluated within the context of the invasion process and related management approaches (Roy et al., 2018), several researchers (to avoid bias, not directly involved in research carried out in collaboration with the ISK tools developers: see authors of Vilizzi et al., 2021) have emphasised the advantages and strengths of using the AS-ISK as a reliable decision support tool in non-native species risk analysis (e.g. Srėbalienė et al., 2019; Geller et al., 2021; Kourantidou et al., 2022). In addition, despite the AS-ISK achieving the same highest evaluation scores as *Harmonia*+ and CMIST when compared to other risk analysis frameworks as a result of their compliance with all key principles (except for 'comprehensiveness') identified by Srėbalienė et al. (2019), the availability of the ISK II tools as multilingual turnkey applications undergoing 'continuous improvement' (sensu Srėbalienė et al., 2019) does provide for a number of undisputed advantages relative to the original WRA framework.

As demonstrated in this study, these advantages apply also to the TPS-ISK as a clone of the AS-ISK and TAS-ISK (Copp et al., 2016b; Vilizzi et al., 2022c). This is the result of 18 years of constant evolution undergone by the ISK tools as opposed to the 25 year-long static nature of the WRA (see Fig. 1). In this regard, the WRA semi-automated spreadsheet format as still currently available (see Section 2: *Overview of Weed Risk Assessment-type decision support tools*) is designed for Excel 5.x, which was released in 1993 (https://en.wikipedia.org/wiki/Microsoft_Excel), and has never undergone any upgrade in terms of programming architecture. This is unlike the ISK tools, which have been subjected to continuous improvement from the original 'core' WRA spreadsheet (Copp et al., 2005a, 2005b, 2016b; Vilizzi et al., 2022c). With regard to the questionnaire, the only continuous improvement undergone by the WRA during its 25 years of life has been in terms of application-specific adaptations (Table S1). However, as these adaptations have not been made in terms of toolkit's type or release unlike the ISK tools (see Fig. 1), there is no possibility for comparison of either species-specific risk outcomes and ranks or risk assessment area-specific thresholds based on the WRA. This is a crucial aspect in non-native species risk analysis that allows for both comparison and transferability of risk screening outcomes and thresholds amongst applications for the same species, taxonomic groups, or climo- and biogeographic risk assessment areas, as achieved by the ISK tools (Vilizzi et al., 2019, 2021).

5.2. Toolkit development

In view of the prospective adoption of the TPS-ISK by future risk screening applications for terrestrial plants, the advantages provided by this newly developed toolkit relative to the WRA can be summarised in terms of the following key components: (i) questionnaire comprehensiveness and related constraints, plus stylistic consistency; (ii) provision of a level of confidence; (iii) error-free computation of scores; (iv) multilingual support with potential for further expandability; (v) seamless software deployment and accessibility with improved data exchange; (vi) powerful graphical user interface and overall ease-of-use.

In this study, adaptation of the TAS-ISK questionnaire for the screening of terrestrial plants in the TPS-ISK has followed the same approach as for the adaptation of the AS-ISK questionnaire for the screening of terrestrial animals in the TAS-ISK (Vilizzi et al., 2022c). This further supports the flexibility of the ISK II tools (multilingual) questionnaire framework to be ultimately applicable to the screening of all non-native species (i.e. aquatic and terrestrial animals and plants) details of which fall beyond the scope of the present paper and will therefore be addressed elsewhere (L. Vilizzi et al., unpublished). Details of the rationale and scope of the original modification of the ISK II questionnaire framework relative to that of the ISK I tools, which was more closely related to that of the original WRA, are provided elsewhere with reference to the AS-ISK (Copp et al., 2016b). In the current development of the TPS-ISK questionnaire, most of the questions have been formulated so as to expand the scope and context of those of the WRA for which compatibility has been maintained, with some questions combining two or more of those of the WRA (Table 2). Finally, although at first sight trivial, the TPS-ISK questionnaire by definition consists throughout of 'questions' formulated in the grammatical sense of the word, unlike the WRA which often consists of statements or even single terms.

With regard to the confidence ranking component of the TPS-ISK, this was added as part of the adaptation of the WRA template to create the ISK I tools (Copp et al., 2005a, 2005b; Lawson Jr et al., 2013) and has since been an integral part of both the AS-ISK and TAS-ISK. The importance of providing a level of confidence to each response in the ISK II tools questionnaire is discussed in detail elsewhere, including comparison between the BRA and CCA (Vilizzi et al., 2022a; Vilizzi and Piria, 2022). For the purposes of this study, provision of a level of confidence in the TPS-ISK is in line with the recognised requirements in environmental risk analysis, which amongst the available risk screening toolkits has also been part of the CMIST (Drolet et al., 2016). In the case of the WRA, to the best of the authors' knowledge, only the Plant Protection and Quarantine (PPQ) WRA version (available as a basic, i.e. not semi-automated, workbook) developed by the United States Department of Agriculture has so far included a level of uncertainty (USDA, 2019).

Although the availability of the WRA scoresheet in both PDF (https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/ba/plant/wra/form-c-wra-score-sheet.pdf) and Word (https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/ba/plant/wra/form-c-wra-score-sheet.doc) formats may appear enticing at first, this inevitably increases the likelihood of computational errors by the end-user (cf. assessor). This was exemplified in this study by the erroneous score detected for *Ailanthus altissima* in the TR-WRA application by Yazlık and Ambarlı (2022) and recomputed here accordingly (Table 3). The extent to which manual computation of species-specific scores for the WRA has been performed relative to spreadsheet-based computation is not easily quantifiable based on the reviewed studies (Table S1) due to the overall lack of provision of such information. However, this approach is in general to be discouraged not only because of the intrinsic possibility of a computational oversight (e.g. wrong summation of question-specific scores, as detected in this study) but also because of the intrinsic complexity in the computation of the scores for some questions either as a (weighted) function of the response to other questions or as reliant on lookup tables (Pheloung et al., 1999; Singh and Priyadarshi, 2014; see also score sheets above). This computational structure has been preserved in the ISK tools (Copp et al., 2005b), which have always been available only in electronic format also to avoid incurring in such errors.

The ecology-of-language approach adopted for the development of the TPS-ISK as a multilingual decision support tool with the aim to inform decision-makers and stakeholders in their official country's language about the implementation of legislation for the prevention and management of non-native invasive species is discussed in depth elsewhere relative to the AS-ISK (Copp et al., 2021). In this regard, despite the many adaptations of the WRA to different climates and countries, no attempt has ever been made to translate the underlying questionnaire to a language other than English. This is another key strength of the TPS-ISK relative to the WRA not only in view of its prospective adoption for the screening of terrestrial plants, but also considering the recent evaluation of the multilingual AS-ISK as one of the 'significant developments' in the field of ecolinguistics in 2021 (Zhang, 2022).

The availability of the TPS-ISK for free download from the same website as for all ISK tools (i.e. since the first official release of the FISK v1 in 2008) is another major advantage relative to the WRA. The latter toolkit still remains hard to retrieve, and published applications using the automated workbook format do not generally indicate the source from which it was retrieved. Conversely, the availability of a single (main) repository for the ISK tools has facilitated accessibility, consistent referencing of the download source in published applications, and deployment across users. Further, with the availability of a single software repository new releases of the AS-ISK and TAS-ISK have been made available to the end user over the years, with the TPS-ISK being slated to follow the same approach. Another crucial advantage of the TPS-ISK (as an ISK II tool) relative to the WRA is that, as a turnkey application, it is completely separated from the screened species database. This is instead part of the WRA spreadsheet as a result of its rudimentary programming architecture as a self-automated workbook, which carries some major disadvantages. Firstly, once a new release of the toolkit becomes available as a result of e.g. improvements to the questionnaire or a bug fix, WRA-based screenings cannot be updated but would have to be re-done should the assessor want to use the latest release of the spreadsheet, hence unlike screenings with the TPS-ISK. Secondly, for the WRA there are as many copies of the self-automated workbook as there are screenings for one or more species relative to a single risk assessment area. Whereas with the TPS-ISK, all end-users (cf. assessors) can use the same release of the toolkit for conducting risk screenings also for multiple risk assessment areas that can be included in the same database spreadsheet. Lastly, in terms of data exchange the size of a TPS-ISK database spreadsheet file only reflects the contents of the screening(s), hence does not include the additional and unnecessary 'overhead' represented by the embedded self-automated workbook features.

The Excel VBA-based architecture of the TPS-ISK as a turnkey application as opposed to the basic semi-automated spreadsheet of the WRA represents the most advanced level of software development achievable with this programming language (Bovey et al., 2009). The ensemble of tightly controlled dialogs that make up the graphical user interface of the TPS-ISK (see Supplementary material 1) is fully separated from the data storage layer (cf. database spreadsheet) and with the business logic tier (cf. code) in between. All dialogs have been designed with the user in mind so as to provide the assessor at any time during the entire screening process with a full visualisation of the data and easy access to the sundry features supported by the toolkit. Key features include: (i) shortcuts (e.g. Wizard, Replicate, Batch Edit) designed to expedite the process of complex data handling, as in the case of a representative set of species for screening (e.g. extant and horizon species: see Vilizzi et al., 2022a) or large datasets, as in the case of meta-analytical studies (e.g. computation of generalised thresholds: Tarkan et al., 2021; Vilizzi et al., 2022a); (ii) 'smart controls' with action-dependent display and colour coding (e.g. blanked fields, edit mode) to facilitate end-user interaction and enhance visualisation of the available interface features at runtime; and (iii) online help and User Guide (see Supplementary material 1) accessible at any time from the dialogs.

5.3. Trial screenings

The risk outcomes for the five non-native sample species screened with the TPS-ISK highlighted the most invasive *Asclepias syriaca*, which is included in the list of Invasive Alien Species of Union concern. On the contrary, the medium risk score achieved for *Amanita muscaria* confirms its lower level invasiveness in its introduced areas. Overall, the present results confirm the reliability and accuracy of the TPS-ISK to distinguish between higher and lower risk species, in line with existing applications of the ISK II tools with special reference to the AS-ISK (see Vilizzi et al., 2021). Confidence in the BRA questions was higher than in the CCA questions, which reflects the larger availability of literature sources for the screened species under current climate conditions versus the more limited data on their invasive potential under future climate change scenarios. This outcome is in line with most applications of the ISK II tools (Vilizzi et al., 2022a). Species-specific profiles with discussion of the risk screening outcomes for the five non-native sample species are provided in Supplementary material 4.

5.4. Terrestrial Species Invasiveness Screening Kit vs Weed Risk Assessment screenings

Upon comparison of the risk outcomes for the ten angiosperm species originally screened with the TR-WRA and re-screened with the TPS-ISK, similar results were obtained – except for the medium risk rank achieved by *Hedera helix* as a correction to the erroneous high-risk ranking provided by Yazlık and Ambarlı (2022). Accordingly, nine of the ten plant species were ranked as high risk for Turkey and there were no differences in the ranking of some of the species that achieved the higher risk values (Table 4). Both toolkits highlighted the highest risk of invasiveness posed by the native dominant and expanding *Phragmites australis*, which agrees with the high level of invasiveness in the regions where this species has been introduced (e.g. North America: Eller et al., 2017). Species-specific profiles with discussion of the risk screening outcomes for the ten angiosperm species are provided in Supplementary material 5.

Despite the overall high similarity between species' risk scores and related outcomes from both screening toolkits, the inclusion of the six additional questions in the TPS-ISK regarding the expected risk posed under future climate scenarios (cf. CCA) has allowed for an additional level of evaluation not possible with the WRA. This will contribute to the implementation and refinement of a list of high priority species for the risk assessment area in view of both current and future management actions. The other feature of the TPS-ISK not available in the WRA, namely the provision of confidence levels, indicated that for all screened species confidence was higher under current climate conditions relative to future climate change scenarios (i.e. BRA vs CCA). This outcome, which is in accord with most screening applications with the ISK II tools (Vilizzi et al., 2022a), was due not only to the overall uncertainty surrounding climate change scenarios but also to the possibility that various plant lineages may differ in their responses to changing climatic conditions as in terms of adaptation or range expansion or contraction. For example, some populations of *P. australis* display high phenotypic flexibility, hence they may respond differently to changes in climate conditions (e.g. temperature, floods, droughts, soil salinity levels, atmospheric CO_2: Eller et al., 2017). Further, *P. australis* genotypes with high resilience to environmental change factors can more easily adapt to different climatic conditions and expand their range, whereas those with low resilience may face the risk of local extinction (Eller et al., 2017).

6. Conclusions

Environmental risk analysis is a dynamic, 'work in progress' field of applied science, and in the case of non-native species invasions it has been shown that risk screenings and full assessments should be subject to continuous updating (Vilizzi et al., 2022a). The same applies to decision support schemes developed to facilitate the risk analysis process, which are expected to mirror these requirements. The almost 20 years of continuous development and evolution of the ISK tools, with special emphasis on the release of the AS-ISK (Fig. 1), attests to the need to meet the increasing demand by scientists and decision-makers for a reliable, comprehensive, updatable and easily deployable decision support tool. In the case of terrestrial plant screening, all of these requirements have been shown in this study to be fully satisfied by the newly developed TPS-ISK whose foundations rely on the original WRA structure and the proven history of usage and adoption of the ISK II tools. The re-screening of the ten angiosperms for Turkey in this study has allowed for a comparison between the WRA and the TPS-ISK, so further prospective applications of this kind on species previously evaluated with the WRA are encouraged. As per the other ISK II tools, applications of the TPS-ISK may involve (for the AS-ISK, see references in: Vilizzi et al., 2021, 2022b; Vilizzi and Piria, 2022): (i) lists of potentially invasive non-native species (extant or horizon) for pre-defined risk assessment areas for calibration; (ii) global (meta-analytical) studies for setting generalised thresholds for the taxonomic groups of plants supported by the toolkit; and (iii) specific non-native (invasive) species flagged as high priority for a certain risk assessment area.

Although in some cases it might be ultimately a matter of personal preference for plant invasion biologists whether to continue to use the WRA or switch to the TPS-ISK, we anticipate that the availability and prospective employment of this new decision support tool will contribute to a better understanding and management of terrestrial plant invasions in a changing world. The recent usage of the ISK II tools for screening aquatic plants (cf. AS-ISK) is already an indicator of the reliability of this framework.

7. Second-generation Weed Risk Assessment-type Invasiveness Screening Kit tools

As part of the development of the TPS-ISK as a complementary decision support tool to the AS-ISK and TAS-ISK for screening terrestrial plants, some key improvements were made. Given the similarity of the three toolkits in terms of programming structure, these improvements have been incorporated also in the AS-ISK and TAS-ISK in their new release v2.4 and include:

- An overall across-toolkit alignment of the corresponding questionnaires in terms of grammar and consistency for all available languages, with special emphasis on the consistent use of keywords and terminology across questions and between Text and Guidance.
- A consistent terminology of the taxonomic groups for screening after Ruggiero et al. (2015), noting that this will not affect backward compatibility of the AS-ISK and TAS-ISK in their v2.

The three toolkits are available for free download at www.cefas.co.uk/nns/tools (or, alternatively: https://www.researchgate.net/publication/361026164_AS-ISK, AS-ISK; https://www.researchgate.net/publication/361027286_TAS-ISK, TAS-ISK; https://www.researchgate.net/publication/376521163_TPS-ISK, TPS-ISK), where full details can be found in the corresponding User Guides.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data in Supplementary Tables and in Supplementary Material 1, 2, 3, 4 and 5.

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