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A global census of WRAs

A global census of weed risk assessment standards

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Abstract

Weed Risk Assessments (WRAs) aim to distinguish potentially invasive plants from non-invasive plants using traits including the likelihood that the species will be introduced, establish, spread, have negative impacts, and (sometimes) whether it can be managed effectively. International standards for the criteria used to assess risk have been proposed to improve the sharing and transferability of WRA results. However, it is unclear whether existing WRAs follow these standards. Here, we compiled a global database of national-level and subnational-level (state/province) WRAs and evaluated their assessment criteria relative to an amended list of proposed minimum standards. We searched for WRAs in 240 countries and retrieved 20 unique assessments associated with 81 countries. The most comprehensive WRA was the "Guidelines for the Generic Ecological Impact Assessment of Alien Species" created by Norway, which satisfied 23 of 24 standards. The International Plant Protection Convention (IPPC) Pest Risk Analysis Framework and the European and Mediterranean Plant Protection Organization (EPPO) Express Pest Risk Analysis were also comprehensive, fulfilling 21 of 24 standards. All national-level WRAs included a description of the focal species' taxonomy, a description of risk assessment area, an assessment of the likelihood of spread of the focal species, and an assessment of the likelihood of impact of the focal species. Conversely, it was rare for WRAs to include a history of spread of the focal species or an evaluation of the possible effects of climate change. States/provinces showed a similar pattern (i.e. rarely discussed climate change), but also frequently lacked assessment of impact on ecosystem services and metrics of uncertainty. Many WRAs are shared between countries, but few are shared between states/provinces. Adopting similar WRA standards would allow policy makers and governing bodies to more effectively share information and results from completed weed risk assessments, improving consistency of regulated plants across jurisdictional borders.

Keywords: invasive plants, invasive species policy, pest risk analysis, plant biosecurity, preventative management

Management Implications

Preventing the introduction of invasive species is well known to be the most effective form of management (Cuthbert et al. 2022; Leung et al. 2002). For invasive plants, which are predominantly introduced through horticulture, prevention is largely achieved by regulating and restricting the sale of species that are known to be (or have the potential to become) invasive. Unfortunately, invasive plant regulations in many locations (except for some European nations) are inconsistent across national and state/provincial borders, leading to an ineffective patchwork of laws that do little to slow the introduction of invasive plants. Sharing completed weed risk assessments (WRAs), which are used to evaluate invasion risk, could increase capacity and improve regulatory consistency across borders if risk assessment criteria are similar in different regions. Here we compiled global WRA protocols used to inform regulations at the national scale and state/provincial scale. For each, we evaluated the scoring criteria relative to a proposed set of minimum standards. It was common for multiple countries to use the same WRA protocol, but rare for states or provinces. All national and state/provincial WRAs evaluated the likelihood of species spread and almost all WRAs evaluated the likelihood of negative impacts. This information about target species could be readily shared across borders to decrease redundancy and improve consistency in invasive plant regulations. In contrast, national and state/provincial WRAs rarely included any consideration of climate change, which misses an opportunity to proactively regulate emerging invasive plants.

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Introduction

Invasive species regulations are inconsistent across national (Early et al. 2016) and state/provincial borders (Beaury et al. 2021a; Lakoba et al. 2020), making it more likely that potentially harmful plants will be introduced to new locations. One way to improve regulatory consistency would be to standardize pre-border and post-border weed risk assessments (WRAs). Pre-border WRAs aim to identify high-risk invasive plants that are not yet present to prevent their intentional introduction and planting (often at the national level), while post-border WRAs aim to identify high-risk plants that may or may not be present to prevent their further introduction and spread (often at the state/provincial level). Increasing the consistency of WRA criteria across political boundaries could improve the consistency of regulations and also facilitate the sharing of risk assessment information across borders. Minimum standards for invasive species risk assessments have been proposed (Roy et al. 2018), but it is unclear whether existing WRA protocols meet these standards such that results could be easily shared to improve regulatory consistency.

WRAs are formalized lists of criteria that researchers or land managers can use to evaluate the invasion risk of a target plant. "Invasion risk" refers to the likelihood of a target non-native species spreading and causing negative impacts in a new location. A wide variety of variables can be used to predict a species' invasion risk. Each WRA combines a set of these predictive variables to estimate invasion risk for incoming non-native species prior to their introduction. WRAs were first introduced in the 1990s and were used primarily in Australia and New Zealand to inform regulations that prohibited the introduction of high-risk, potentially invasive plants (Pheloung et al. 1999; Scott and Panetta 1993; Williams 1996). Since then, WRAs have become a common tool worldwide for evaluating the likelihood that a plant will become invasive (e.g., Chong et al. 2011; Koop et al. 2012; MacLeod 2010; Pheloung et al. 1999; Roy et al. 2018) and general guidelines about information to include in WRAs have been presented (Roy et al. 2018; Food and Agriculture Organization of the United Nations 2019b). While WRAs vary in their ability to correctly differentiate invasive from non-invasive species, they demonstrate high cost-effectiveness (Keller et al. 2007) because they enable the management of non-native species prior to invasion.

During the WRA process, assessors (who are often researchers or management specialists at governmental, academic, or non-profit institutions) gather data pertaining to the predictive variables (criteria) using published literature, gray literature (e.g., agriculture, horticulture, or forestry publications), or personal experiences, and subsequently aggregate the results to determine the overall invasive potential of a target plant in the focal area. Criteria within a WRA may be qualitative (e.g. the COSAVE WRA requires the assessor to describe the "effects on ecological systems or processes") or quantitative (e.g. the WRA for Brazil requires the assessor to determine the amount of economic damage that could be caused by a species) and they typically focus on plant traits and environmental tolerances that influence establishment and spread as well as observed ecological and/or socio-economic impacts (Bartz and Kowarik 2019; Roy et al. 2018; Vilà et al. 2019). WRAs can be used to evaluate species that are likely to be introduced into a region both intentionally (e.g., as ornamental plants; Reichard and White 2001) or accidentally (e.g., as seed contaminants; Lehan et al. 2013). Ultimately, information from WRAs may be weighed by policymakers against potential benefits (e.g., agricultural or ornamental value; Roberts et al. 2011) to determine whether a species should be regulated (Simberloff 2005).

WRAs are especially useful because they are implemented prior to the introduction of non-native plants into the focal area (Kumschick and Richardson 2013). The most cost-effective way to reduce the impacts of invasive species is to prevent their introduction, rather than attempting to control or remediate the negative effects of the species post-invasion. Recent analyses of expenses incurred by species invasion emphasize the efficacy of investment and intervention pre-invasion (Ahmed et al. 2022; Cuthbert et al. 2022). WRAs are one proven method for maximizing pre-invasion investments, as they allow managers to triage non-native species and (ideally) lead to regulations of high-risk species while allowing for the introduction (and subsequent economic benefits) of low-risk species.

Several studies have compared existing risk assessment protocols, often finding large differences in the types of approaches (Essl et al. 2011) and the criteria within each (Bartz and Kowarik 2019; Roy et al. 2018; Vilà et al. 2019). Inconsistent criteria can lead to different evaluations of risk for the same species across different protocols (i.e. asking different questions yields different answers; González-Moreno et al. 2019), which could further reduce consistency in regulated species lists (Bradley et al. 2022). However, previous comparisons have not differentiated between regulatory risk assessments and those developed primarily for academic

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purposes (e.g., Bartz and Kowarik 2019; Essl et al. 2011; Roy et al. 2018; Vilà et al. 2019), and several new regulatory WRAs have been adopted in recent years. Therefore, a new census of regulatory pre-border WRAs is necessary to determine the extent of inconsistencies worldwide for national and subnational (state/provincial) geographies.

Here, we compiled all available pre-border national-level and pre/post-border state/provincial-level WRAs that have been adopted for invasive plant regulation. We adapted the proposed minimum standards for risk assessments developed by Roy et al. (2018) to create an amended list of 24 standards, which we used to evaluate consistency across protocols, identifying criteria that are commonly (and less commonly) included. This analysis provides a comprehensive snapshot of existing pre-border regulatory frameworks, highlighting opportunities to enhance consistency and strengthen the prevention of invasive plant introductions across nations, states, and provinces.

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Materials and Methods

Compiling national-level weed risk assessments

We searched for pre-border weed risk assessments that applied to any of the countries included in the International Organization for Standardization (ISO) 3166 classification scheme (https://www.iso.org/home.html). Using Google and Google Scholar, we searched the name of each country and the keywords "weed risk assessment," "wra," "pest risk analysis," "pra," "invasive policy," "phytosanitary measures," and "invasive plant law." When searching, we combined these keywords one-by-one with the name of each country (e.g., "Armenia" "weed risk assessment"), and we examined the first two pages of results on Google Scholar and the equivalent number of results (20) on Google. We performed these searches between June 2022 and June 2025. We only collected WRAs that had been officially adopted (or otherwise implemented) through regulations/legislation or by a government official or agency of the respective country. When there were multiple WRAs that met these guidelines for a country, we included the one that had been cited most often at the time of data collection. We excluded WRAs that were published in academic literature but were not officially adopted for regulation in a specific country. For completeness, we also checked all WRAs listed in prior reviews by Bartz and Kowarik (2019), Essl et al. (2011), Roy et al. (2018), Vila et al. (2019), and Canavan et al. (2025), and retained the ones that were aligned with our objectives. For countries that yielded no results using these methods, we sent email requests to the phytosanitary contacts listed on the International Plant Protection Convention (IPPC) website (https://www.ippc.int/en/countries/all/contactpoints/) requesting a copy of their national-level WRA (if one existed). We sent follow-up emails to contacts that had not responded within two months of our initial request. This approach is likely to have missed some national WRAs that were not available in English.

Compiling state/province-level weed risk assessments

To better understand whether pre-border WRAs at the subnational level follow international guidelines, we also searched for state/province-level WRAs in countries that had developed an independent national-scale weed risk assessment (i.e. those not implementing an international protocol). These countries were: Australia, Belgium, Brazil, Canada, Germany, Ireland, Latvia, Mexico, New Zealand, Norway, South Africa, South Korea, United Kingdom, United States, and Zambia (Canada created their own WRA, but later adopted the WRA

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developed by the United States, which we learned through personal communication. This is why we searched for province-level WRAs in Canada even though they do not appear to have their own national-scale WRA.) Kesler (2021) previously evaluated the content of state-level WRAs in the United States using similar methods, so we did not repeat searches for the United States and instead incorporated the results from Kesler (2021) directly. Where methods differed, we used notes provided by Kesler's Appendix S1 to rescore WRAs using our methods. Kesler (2021) provided web links to WRA sources, some of which had subsequently become defunct. For links that were still live, we downloaded the relevant WRAs. For defunct links, we re-searched for updated versions of WRAs, and downloaded them when available.

Between April 2024 and August 2025, we used Google and Google Scholar to search for the name of each state/province/territory and the keywords "weed risk assessment," "wra," "pest risk analysis," "pra," "invasive policy," "phytosanitary measures," and "invasive plant law." When searching, we combined these keywords one-by-one with the name of each state and country (e.g., "Victoria" "Australia" "weed risk assessment"), and we examined the first two pages of results on Google Scholar and the equivalent number of results (20) on Google. State/province-level weed risk assessments were rare and our search process was time-intensive, therefore we started with each country's most populous state or province. If we could not find a weed risk assessment for a country's most populous state or province, we did not continue searching the remaining states or provinces. It is possible that these methods may have overlooked WRAs in countries where less-populous states have been quicker to adopt WRAs than more populated states (as was the case in Australia), or in instances where less-populous states are of particular importance for conservation (e.g. the Galapagos Islands in Ecuador).

Scoring weed risk assessments

To assess the scope and content of each WRA, we applied a list of "minimum standards" adapted from Roy et al. (2018; Table 1), which are intended to improve the consistency and quality of invasive species risk assessments. The first three minimum standards contain multiple parts (e.g., standard 2 asks whether the risk assessment considers the likelihood that the target species will be introduced, establish, spread, and/or have impact). Because these component parts are sometimes considered separately in WRAs (e.g., multiple WRAs include information about the history of negative impacts but not the history of spread), we considered the component parts individually, resulting in a final list of 24 standards (Table 1). For our

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assessment, we rephrased each of the minimum standards in the form of yes/no questions to reduce ambiguity (Table 1). If the standard was partially, but not fully met, we answered no (e.g., for standard 4 about vectors of secondary spread, some WRAs included criteria about long distance dispersal by animals but did not include long distance dispersal associated with human activity; these criteria were scored as not fulfilling the minimum standards for vectors of secondary spread, since they do not account for both intentional and unintentional vectors). For each national and subnational WRA, we evaluated whether each of the 24 minimum standards were satisfied and summed the results. A minimum of three co-authors independently reviewed each weed risk assessment to ensure that we consistently applied the 24 standards to each WRA. We reconciled scoring differences between co-authors by collectively reviewing the WRA and discussing the standards until a consensus was reached. We created maps to visualize how many minimum standards were met by global WRAs. We also identified standards that were less often met and visualized the countries and states/provinces that met those standards. For each WRA, we also recorded the total number of questions/criteria used, the year of initial publication, and whether each WRA was primarily derived from an earlier, preexisting WRA.

To further understand the global landscape of risk assessments, we assigned each WRA to a category based on the structure of its decision-making process. We used the same categories previously described by Hulme (2012) and Council for Agricultural Science and Technology (2024). Quantitative WRAs are those that apply statistical models to trait or distribution data for plant species to determine the risk of invasion of each. Qualitative WRAs are those that combine expert opinions about the invasion risk of plant species to determine invasion risk (qualitative WRAs may lack a consistent or well-defined system for arriving at final determination). Finally, semi-quantitative WRAs combine aspects of qualitative and quantitative WRAs. For a given species, semi-quantitative WRAs generate scores for multiple invasion risk factors, often using expert opinions. These scores are subsequently summed (or otherwise combined using a predetermined method) to arrive at a final invasiveness ranking or management outcome.

Results and Discussion

Geography of weed risk assessments

We found 20 unique national-level weed risk assessments used by a total of 81 countries (Table 2). Twelve WRAs were used by a single country; eight were used by multiple countries. We were unable to find WRAs for 159 countries, only four of which (Bahrain, Cabo Verde, Colombia, Nigeria) confirmed via email that they do not have a WRA. It is concerning that we were only able to locate weed risk assessments for 81 of 240 countries (34%). Most invasive plants are introduced intentionally as ornamental plants (Beaury et al. 2021b; Reichard and White 2001), making WRAs and subsequent regulations highly effective for proactively preventing invasions when they are used to consistently screen new species before import. WRAs and border control policies are cost effective (Keller et al. 2007), particularly when considering the high economic costs of invasive plants (Diagne et al. 2021). Moreover, proactive exclusion of invasive plants prevents substantial negative impacts on native species and ecosystems (Roy et al. 2024). While we only searched for WRAs in English, the spatial pattern of border control measures (or lack thereof) is consistent with a previous analysis of other proactive invasive species policies based on U.N. Convention on Biological Diversity implementation documents (Early et al. 2016). Nevertheless, we acknowledge that it is possible that our methods excluded some WRAs written in languages other than English.

Encouragingly, our analysis identifies opportunities for sharing WRA policies across neighboring countries - at least one country on every continent except Antarctica uses a WRA (Figure 1). Seven WRAs applied to countries in Europe; three WRAs applied to countries in Africa; three WRAs applied to countries in North America (including the Caribbean); two WRAs applied to countries in each of Asia, South America, and Oceania; and one WRA applied to Australia. The most-represented continents were South America (9/14 countries used a WRA; 64%), Europe (28/51; 55%), Oceania (14/26; 54%), and North America/Caribbean (20/41; 49%). In contrast, much smaller percentages of the countries in Asia (6/53; 11%) and Africa (4/60; 7%) used WRAs. The lack of WRAs in Asia and Africa is consistent with existing biases in invasive plant ecology which illustrate that most studies focus on a subset of species that are harmful in wealthier nations (Laginhas et al. 2022; Pyšek et al. 2008;). Pyšek et al. (2008) suggested that the lack of data on invasive species in many locations is a result of an overall lack of funding invested in research by these countries. Lack of WRAs may also be related to political will and maturity of an import assessment process. For example, invasion scientists in both India (Sreekanth et al. 2022) and China (Wang et al. 2024) have developed WRAs but they have not yet been implemented as regulations.

Similar patterns of lack of scientific capacity and/or lack of political will may also exist within countries. In the U.S., state invasive plant councils often lack the necessary funding to conduct risk assessments for all potentially harmful species. Thus, increasing the consistency of existing WRAs across national and state/provincial borders could enable sharing of completed risk assessments, which would stretch limited resources farther by reducing duplicate effort while also potentially increasing consistency in regulated species lists (Bradley et al. 2022). Similarly, several states that have yet to implement a WRA or regulate invasive plants could adopt protocols from neighbors.

Countries located in tropical regions were particularly unlikely to have national WRAs. Notably, WRAs were lacking across tropical regions of Central America, Central Africa, and Southeast Asia. A recent analysis of plant invasion risk suggested that the tropics are particularly susceptible to invasions and that the low number of previously reported invasions in the tropics was more likely due to fewer introductions rather than lack of susceptibility (Pfadenhauer and Bradley 2024). This analysis also noted that WRAs are likely to be most useful in areas such as these, with high ratios of invasive to established plant species. The lack of WRA protocols coupled with elevated risk to tropical regions highlights a major gap in proactive invasive plant policy and management at a global scale. However, a past analysis of the Australian WRA applied to multiple regions suggests that the same criteria effectively identify invasive plants in both temperate and tropical regions (Gordon et al. 2008). This finding suggests that using one of the existing national WRAs would lead to effective invasive plant identification for any country.

We found state/provincial-level WRAs for Australia, Canada, the United States (previously collected by Kesler 2021), and Ecuador. For Belgium, Brazil, Germany, Ireland, New Zealand, Norway, South Africa, South Korea, United Kingdom, and Zambia, we were unable to find WRAs for their most populous state/province, and therefore did not search for the remaining states and provinces. We found unique WRAs for seven of the nine states/territories in Australia, two of the 13 provinces/territories in Canada, and one of the 24 provinces in Ecuador. For comparison, Kesler (2021) found unique WRAs for 31 states within the United States, with two additional states using a WRA that was created by a different state (we were unable to locate

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the WRAs for some of these states; our results include WRAs for 28 states within the U.S.). Although it was common for countries to use the same WRAs across borders, it was less common for states/provinces to use the same WRAs. For states/provinces that do not yet have WRAs, using an existing protocol from a neighboring state rather than creating a new one could be more efficient and enable more direct sharing of completed risk assessments. Even though state WRAs are often unique, sharing of completed risk assessments would still benefit others because risk assessment criteria often overlap (Bradley et al. 2022).

Meeting minimum standards

The average number of standards met by each national-level WRA was 17.6 ± 3.2 (sd) out of 24 total standards. For the state/provincial-level WRAs in Canada, Australia, the United States, and Ecuador, the average was 14.4 ± 3.7 (sd). There were several standards that were commonly met by both national-level and state/provincial-level WRAs that could be shared across jurisdictions to reduce replication of effort (Figure 2). Almost all assessments included criteria related to the likelihood that the species will establish, spread, and have negative impacts within the region (standards 2B-D; Figure 2). Broadly, this information aligns with the general guidelines for WRAs recommended by the IPPC (Food and Agriculture Organization of the United Nations 2019b). This type of information could readily inform risk assessment for neighboring regions and beyond, given the many similarities between climate and ecoregions globally. Similarly, most WRAs included information about negative environmental (standard 5) and socio-economic impacts (standard 7; Figure 2). Roy et al. (2018) noted that many of the risk assessments they evaluated did not include socio-economic impacts, while our analysis found that most did. One possible explanation for this pattern may be that regulatory WRAs (i.e. the ones we sampled) are more likely to include a wider range of possible impacts that reflect a country's widely varied interests. Moreover, the IPPC (Food and Agriculture Organization of the United Nations 2019b), which provides general guidelines for national WRAs, emphasizes socio-economic impacts but not ecological impacts. In contrast, risk assessments developed primarily for academic purposes (which were included in Roy et al.'s analysis) may primarily reflect a researcher's area of expertise (e.g., ecology), without evaluating possible consequences in other disciplines. Nevertheless, given that our analysis focused only on regulatory WRAs, it is encouraging that both ecological and socio-economic impacts are usually included. Lastly, most WRAs included a list of data sources (standard 11). This suggests that a considerable amount of similar information and associated sources is being compiled about invasive plant distributions and impacts across jurisdictions. We reiterate calls for global, open-source repositories of invasive species information (Barney et al. 2015; Culina et al. 2018; Fusco et al. 2023) to reduce the likelihood of redundant efforts to compile that same information (e.g., documentation of ecological impacts, introduction pathways, or potential habitat).

Conversely, there were several minimum standards that were frequently missing from WRAs. Fewer than 50% of both national and state/provincial-level WRAs included information about the native range (standard 1C) or socio-economic benefits (standard 1F) - both of these standards are part of the 'basic species description.' Native range is not relevant as a risk factor by itself, but instead can inform assessments of likelihood of introduction and establishment (standards 2A-B). Socio-economic benefits are also not a risk factor (Carneiro et al. 2024), but could be useful for contextualizing the motivation for introducing the species. Additionally, fewer than 50% of WRAs included information about potential impacts on ecosystem services (standard 6) or the effects of climate change on invasion risk (standard 9). These latter two were also sparse in Roy et al. (2018)'s analysis, and were surprisingly absent in some of the most recently adopted regulatory WRAs in our analysis (COSAVE, BRA, RAAT, and CABI). One plausible explanation for these omissions is that both impacts on ecosystem services and interactions with climate change are challenging to estimate without existing scientific data and are therefore unlikely to be observed based on expert knowledge alone.

The persistent lack of explicit consideration of climate change (standard 9; Figure 3) is particularly concerning because climate change is likely to change the sets of species that pose high risk within countries or states (Bradley et al. 2023; Colberg et al. 2024) and is a top concern for invasive species management (Beaury et al. 2020). The Global South in particular appears ill-prepared to assess interactions between invasive plants and climate change. Models of climate change impacts on invasive species range shifts are becoming increasingly common at both global and regional scales such that assessors in the future could more easily find information about potential for establishment (e.g., Allen and Bradley 2016; Bezeng et al. 2017; Gallagher et al. 2013) and abundance/impact (e.g., Evans et al. 2024; O'Neill et al. 2021). In the absence of future distribution or abundance projections, assessors could consider whether the species currently poses a risk to ecosystems warmer than their target region and extrapolate risk. Explicitly including climate change in WRAs, even if data are currently lacking, ensures that

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assessors are thinking about changing likelihood of establishment and impact due to warming. Failing to include climate change misses an opportunity to proactively prevent future invasions (Bradley et al. 2023).

Limitations

Although Roy et al. (2018)'s minimum standards include a comprehensive set of criteria for weed risk assessment, all of these criteria are not necessarily strong predictors of invasion risk. Past studies of risk assessment efficacy have found high levels of accuracy with fewer criteria or questions (Caley and Kuhnert 2006; Conser et al. 2015; Gordon et al. 2008; Koop et al. 2012). Criteria with high predictive power include whether a species has established and/or become invasive elsewhere (Caley and Kuhnert 2006; Conser et al. 2015; Koop et al. 2012), whether the species has negative ecological impacts (Conser et al. 2015; Koop et al. 2012), whether the species has an invasive congener (Buonaiuto et al. 2023; Conser et al. 2015), and whether the species has broad climatic tolerance (Higgins and Richardson 2014; Pfadenhauer et al. 2023). Including additional criteria (as is typical in the WRAs we assessed) makes it likely that more information will be available to potentially inform assessments in other jurisdictions. However, additional criteria may also make the process of weed risk assessment time-prohibitive for some countries or states. For example, Verbrugge et al. (2010) estimated that some comprehensive risk assessments could take up to a week of time to complete for a single species. Given that an estimated 14,000 plants have been introduced and established outside of their native range (van Kleunen et al. 2015), it might be a more realistic approach to start with a shorter risk assessment process such as horizon scanning (Kendig et al. 2022) and then only complete full WRAs for higher priority species that result from the initial screening process.

As implemented here, the minimum standards are also biased towards environmental impacts. Three separate standards focus on various components of environmental effects (standard 5: biodiversity, standard 6: ecosystem services, and standard 8: threatened species and habitats) while only one standard focuses on socio-economic impacts (standard 7). To reduce bias towards environmental impacts, future reviews of WRAs may opt to split standard 7 into three separate standards, with one for social, economic, and cultural impacts, respectively. Similarly, future assessors may choose to include separate questions about these three categories of impact in their WRAs.

Conclusions

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Our analysis reveals a high degree of consistency across both national and state/provincial-level WRA criteria. Broad adoption of the same protocols (e.g., EPPO, IPPC, PAC IS, CARIB, and COSAVE) across national borders supports the sharing of completed risk assessments, reducing duplication of effort in a field with limited resources (Beaury et al. 2020). Using the same or similar protocols and sharing results would be an important advance towards unified defenses against potential invasive plants. An approach of sharing completed assessments is also critical at state/provincial levels, where regulated species are highly inconsistent across borders (Beaury et al. 2021a; Lakoba et al. 2020), leading to patchy defenses against potential invasive plants.

Unfortunately, most nations and states do not appear to have weed risk assessments or a regulatory process for preventing the introduction of invasive plants. While it is probable that some WRAs in non-English languages were not captured, our study, combined with previous analyses of proactive invasive species policies (Early et al. 2016), nevertheless suggests that many gaps remain in phytosanitary practices globally. Countries without WRAs would benefit from adopting one of the established protocols outlined here, optimally from a neighbor, to increase regional consistency in approach. It is well known that preventing introductions is the most environmentally- and cost-effective approach to managing invasive species, underscoring the need for broader implementation of these critical tools. Policymakers should prioritize adopting comprehensive WRAs that account for climate change, uncertainty, and ecosystem service impacts to enhance regulatory consistency and effectiveness.

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Competing Interests

The authors declare none.

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Table 1. Minimum standards for invasive species risk assessments proposed by Roy et al. (2018; left column) and corresponding standards used to evaluate global weed risk assessments used in the present analysis (right column). WRA stands for weed risk assessment.

Minimum standards from Roy et al. 2018 (verbatim)	**Altered and rephrased standards used to score WRAs in the present analysis**
1. Description (taxonomy, invasion history, distribution range (native and introduced), geographic scope, socio-economic benefits)	1A. Does the WRA require a specific focal taxa to be identified for assessment?
	1B. Does the WRA ask whether the focal taxa is invasive in a location outside of the WRA area? Or, does the WRA ask for the previous locations invaded by the focal taxa?
	1C. Does the WRA require the assessor to describe or list the area(s) where the focal taxa is native?
	1D. Does the WRA require the assessor to describe or list the area(s) where the focal taxa is introduced? Or, does the WRA ask whether an introduced range exists for the focal taxa?
	1E. Does the WRA require the assessor to define the WRA area? Or, is the WRA explicit about only being used for a specific area?
	1F. Does the WRA require the assessor to list or describe any socio-economic benefits of the focal taxa?
2. Likelihood of introduction, establishment, spread and magnitude of impact	2A. Does the WRA attempt to determine the likelihood that the focal taxa will be introduced to the WRA area? (This may include questions about human-mediated dispersal or primary introduction pathways).
	2B. Does the WRA attempt to determine the likelihood that the focal taxa will establish (once introduced) in the WRA area? (This

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	may include questions about climate matching, habitat suitability, or the presence of a needed host organism).
	2C. Does the WRA attempt to determine the likelihood that the focal taxa will spread (once established) in the WRA area? (This may include questions about methods of reproduction or natural dispersal syndromes).
	2D. Does the WRA attempt to determine the likelihood that the focal taxa will cause negative impacts (once established) in the WRA area? (This may include questions about potentially harmful traits, like allelopathy, or impacts caused by the focal taxa in other locations).
3. Description of the current and potential distribution, spread and magnitude of impact	3A. Does the WRA require the assessor to describe or list all area(s) within the global distribution of the focal taxa? Or, does the WRA require the assessor to describe or list all area(s) within the WRA area that are likely to be suitable for the focal taxa?
	3B. Does the WRA require the assessor to explicitly consider or describe the history of spread of the focal taxa? (This is different from 1B "Invasion history" because a species can spread without causing negative impacts and vice versa.)
	3C. Does the WRA require the assessor to explicitly consider or describe the magnitude of existing negative impacts of the focal taxa? (This is different from 1B "Invasion history" because the severity of impacts can vary widely across invasive species. This can either include magnitude of direct effects, or magnitude of control costs.)
4. Inclusion of multiple pathways and vectors of	4. Does the WRA require the assessor to consider possible vectors of introduction/spread into/within the WRA area, including those

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introduction and spread both intentional and unintentional	that are both intentional and unintentional?
5. Assessment of environmental impacts with respect to biodiversity (and ecosystem) patterns and processes	5. Does the WRA require the assessor to explicitly consider the environmental impacts of the species? This can be either within the WRA area or in other locations, but should require the assessor to name, list, quantify, or otherwise delineate the individual components of environmental impacts as they pertain to biodiversity or ecosystem functioning.
6. Assessment of adverse impacts with respect to ecosystem services	6. Does the WRA require the assessor to explicitly consider the impacts of the species on ecosystem services? This can be either within the WRA or in other locations, but should require the assessor to name, list, quantify, or otherwise delineate the individual components of effects of ecosystem services. These impacts should only be negative. Positive effects on ecosystem services are encompassed by 1F.
7. Assessment of adverse socio-economic impacts	7. Does the WRA require the assessor to explicitly consider the social, economic, or cultural impacts of the species? These impacts should be negative. Positive effects are encompassed by 1F.
8. Status (threatened or protected) of species or habitat under threat	8. Does the WRA require the assessor to explicitly consider the status (threatened, endangered, protected, rare, endemic, etc.) of the species or habitat under threat? This does not include any potential positive impacts of the species to threatened species.
9. Possible effects of climate change in the foreseeable future	9. Does the WRA require the assessor to consider future climate change scenarios (or resulting effects of future climate change scenarios) when estimating climate suitability or establishment risk? WRAs cannot fulfil this standard by suggesting re-assessment in the future when/if the climate changes. The purpose of this

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	standard is to encourage assessors to incorporate future impacts into *current* risk assessments.
10. Data limitations	10. Does the WRA have a defined procedure for dealing with unanswered questions (i.e. questions for which data are limited or unavailable)?
11. Information sources	11. Does the WRA require the assessor to list references or information sources?
12. Summary of the different components of the risk assessment in a consistent and interpretable form and an overall summary	12. Does the WRA provide a standardized way of summarizing all components of risk? And does the WRA have a standardized way of translating the summarized risk value into appropriate management actions?
13. Uncertainty (confidence)	13. Does the WRA have a way for the assessor to describe or quantify their confidence or uncertainty associated with the *answered* questions? Unanswered questions are assumed to be completely uncertain and are addressed in standard 10.
14. Quality assurance	14. Does the WRA have a way to ensure that different assessors will produce consistent and accurate results? And, does the WRA have a way to ensure that the standards are applied consistently across species?

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Table 2. National-scale weed risk assessments (WRAs) and their corresponding scores (number of 'minimum standards' met out of 24, see Table 1). More details about each WRA and its score can be found in Appendix S2. PDFs of each WRA can be found on GitHub at the following link: https://github.com/wpfadenhauer/Global-WRAs/tree/main/WRA_Documents

Name	Abbr.	Countries	Score	Type	Reference
Australian Weed Risk Assessment System	AUS	Australia	15	Semi-quantitative	(Pheloung et al. 1999)
Harmonia +	BEL	Belgium, Netherlands	18	Semi-quantitative	(D'hondt et al. 2015)
Guide for Developing Pest Risk Analysis	BRA	Brazil	14	Qualitative	(Brazil Ministry of Agriculture and Livestock 2021)
CABI Pest Risk Analysis Tool	CABI	Zimbabwe, Eswatini	18	Qualitative	(Centre for Agriculture and Bioscience International 2021)
Guidelines for Pest Risk Analysis of Imported Plants and Plant Products	CARIB	Anguilla, Antigua and Barbuda, The Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, The Cayman Islands, Dominica, Grenada, Guyana, Haiti,	15	Semi-quantitative	(Goldsmith 2016)

		Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, The Turks and Caicos Islands			
Southern Cone Plant Health Committee Guidelines of Procedures for Risk Assessment of Plants as Pests (Weeds)	COSAVE	Argentina, Bolivia, Chile, Paraguay, Peru, Uruguay	18	Qualitative	(Inter-American Institute for Cooperation on Agriculture 2018)
European and Mediterranean Plant Protection Organization Express Pest Risk Analysis	EPPO	Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden	21	Qualitative	(European and Mediterranean Plant Protection Organization 2012)
Methodology of	GER	Germany	20	Semi-	(Nehring et al.

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Nature Conservation Invasiveness Assessment for Alien Species				quantitative	2013)
International Plant Protection Convention Pest Risk Analysis Framework	IPPC	Bangladesh, Japan, Solomon Islands, Pakistan, Philippines	21	Qualitative	(Food and Agriculture Organization of the United Nations 2019a)
Risk analysis and prioritisation for invasive and non-native species in Ireland and Northern Ireland	IRE	Ireland	19	Semi-quantitative	(Kelly et al. 2013)
Assessing Ecological Risk of Invasive Alien Plants in South Korea	KOR	South Korea	10	Semi-quantitative	(Kil et al. 2004)
Guidelines for Species Inclusion on the List of Invasive Species in Latvia	LAT	Latvia	19	Semi-quantitative	(Ozols et al. 2021)
Rapid Assessment of Invasiveness	MEX	Mexico	16	Semi-quantitative	(CONABIO 2015)

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Method for Exotic Species in Mexico					
Guidelines for the Generic Ecological Impact Assessment of Alien Species	NOR	Norway	23	Semi-quantitative	(Sandvik et al. 2017)
New Zealand Weed Risk Assessment Model	NZ	New Zealand	16	Semi-quantitative	(Williams 1996)
Hawai'i Pacific Islands Weed Risk Assessment	PAC IS	American Samoa, Cook Islands, Kiribati, Marshall Islands, Micronesia, Niue, Samoa, Tonga, Tuvalu, Vanuatu	15	Semi-quantitative	(Daehler and Carino 2000)
A Framework to Support Alien Species Regulation: the Risk Analysis for Alien Taxa	RAAT	South Africa	20	Semi-quantitative	(Kumschick et al. 2020)
The UK Risk Assessment Scheme for All Non-Native Species	UK	United Kingdom	20	Semi-quantitative	(Baker et al. 2008)

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United States Department of Agriculture Animal and Plant Health Inspection Service Plant Protection and Quarantine Weed Risk Assessment	USA	United States, Canada	20	Semi-quantitative	(Koop et al. 2012)
Pest Risk Assessment: A Zambian Perspective	ZAM	Zambia	13	Semi-quantitative	(Msiska 2013)

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Figures

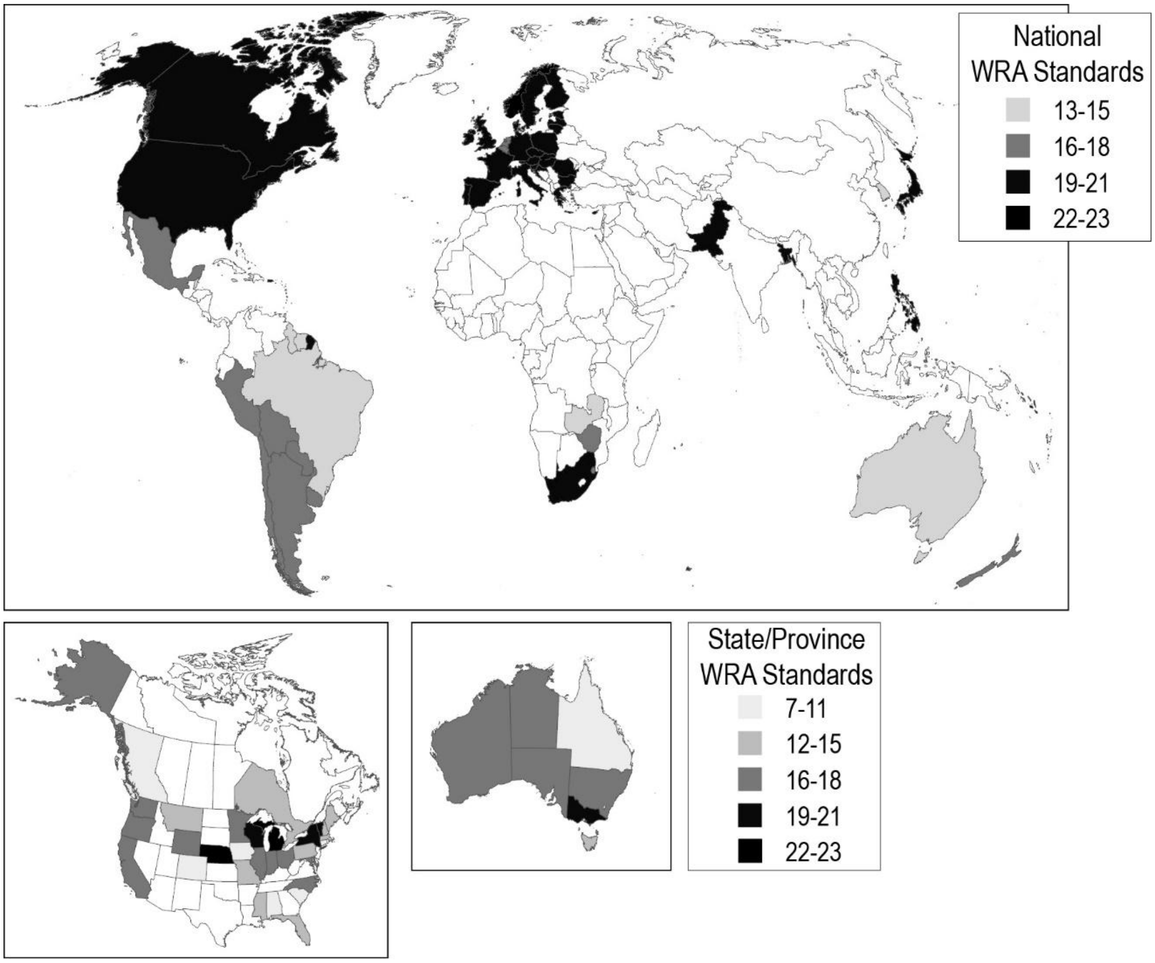

Figure 1. Weed risk assessment standards met by nations and states. The global map (top panel) displays the number of minimum standards (out of 24) met by 20 unique weed risk assessments used by 81 countries. The global map uses a Robinson projection and is at a scale of 1:200,000,000. The continental maps (bottom panels) display weed risk assessment used by 38 states or provinces (37 total WRAs). The continental maps use Albers equal area conic projections and are at a scale of 1:150,000,000. We were unable to find weed risk assessments for countries and states/provinces shown in white.

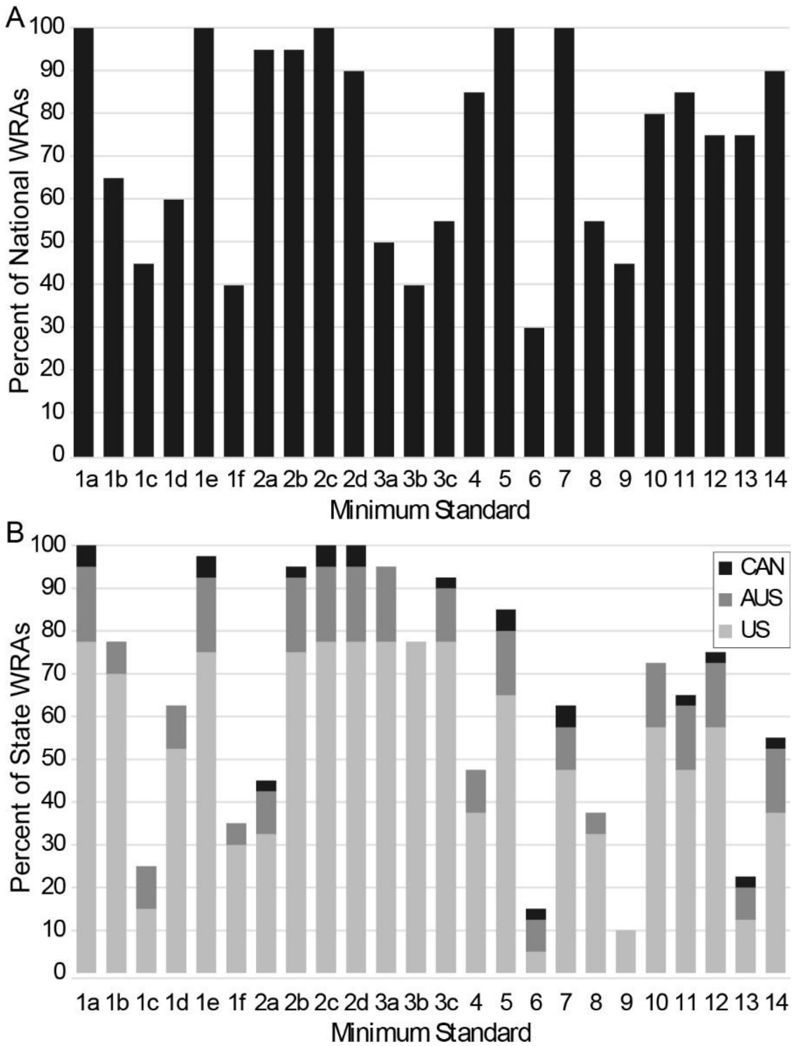

Figure 2. Percentage weed risk assessments (WRAs) that fulfilled each minimum standard. (A) Fulfilment of minimum standards by national WRAs (out of 20 total) and (B) fulfilment of minimum standards by state WRAs (out of 37 total; CAN = 2, AUS = 7, ECU = 1, US = 27). See Table 2 for descriptions of each minimum standard.

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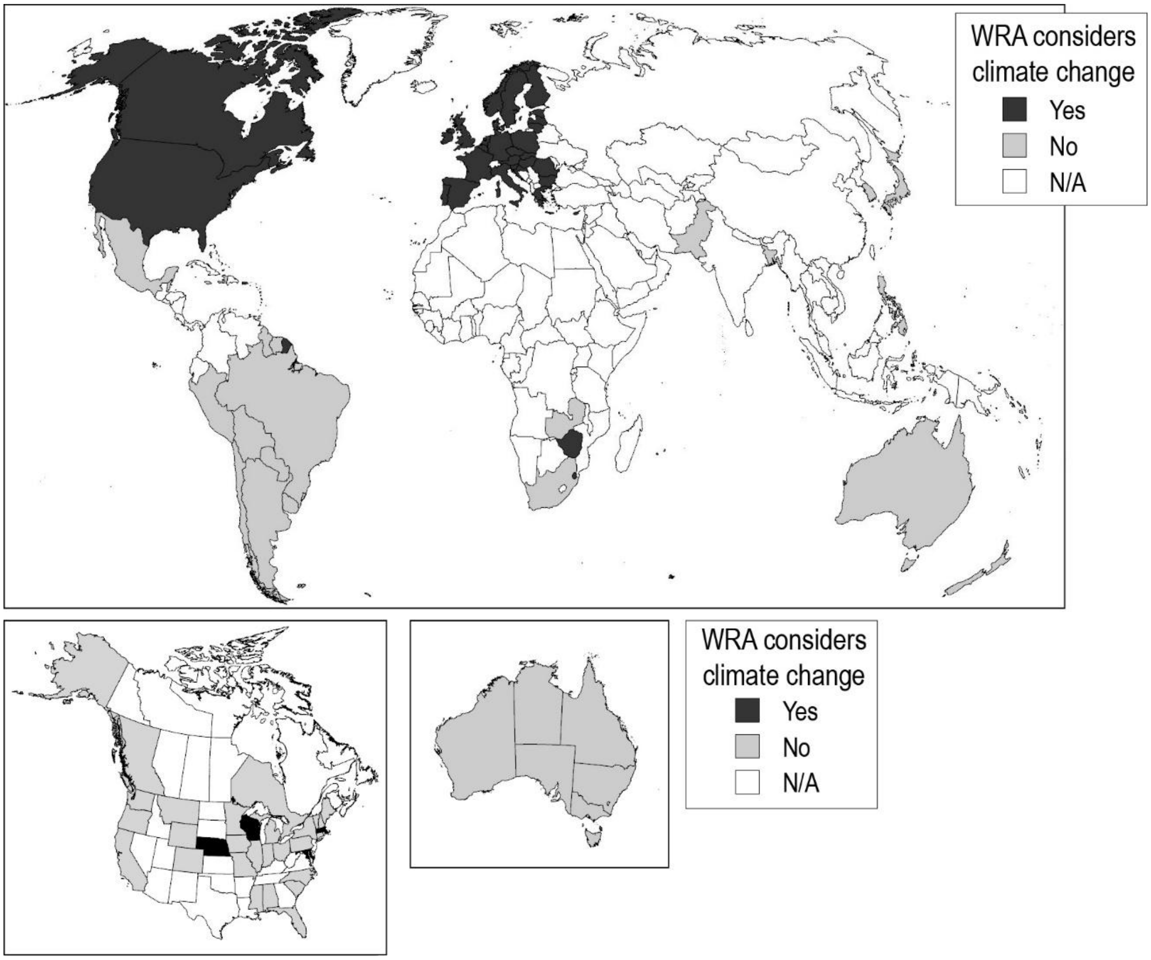

Figure 3. Climate change consideration (standard 9) remains rare in national-level and state/provincial-level weed risk assessments. The global map (top panel) uses a Robinson projection and is at a scale of 1:200,000,000. The continental maps (bottom panels) display weed risk assessment used by 38 states or provinces (37 total WRAs). The continental maps use Albers equal area conic projections and are at a scale of 1:150,000,000. We were unable to find weed risk assessments for countries and states/provinces shown in white.

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