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Breaking down barriers to consistent, climate-smart regulation of invasive plants - a case study of northeast states

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Abstract

Efforts to prevent the introduction and spread of new invasive plants are most effective when regulated species are consistent across jurisdictional boundaries and proactively prohibit species before they arrive or in the earliest stages of invasion. Consistent and proactive regulation is particularly important in the northeast U.S. which is susceptible to many new invasive plants due to climate change. Unfortunately, recent analyses of state regulated plant lists show that regulated species are neither consistent nor proactive. To understand why, we focus on two steps leading to invasive plant regulation across six northeast states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Vermont): which sets of species are evaluated and how risk is assessed. Our analysis confirms previous findings that invasive plant regulations are inconsistent and reactive. Of the 128 plants regulated by one or more states, 54 were regulated by a single state and only 16 were regulated by all six states; regulated species tended to be widespread across the region (not proactive). These outcomes are largely driven by different sets of evaluated species. For example, neighboring states Vermont and New Hampshire evaluated 92 species in total, but only 26 overlapped. In addition, states rarely evaluated species that were absent from the state. Risk assessment protocols varied considerably across states, but consistently included criteria related to ecological impact, potential to establish, dispersal mechanisms, and life history traits. While none of the assessments explicitly consider climate change, they also did not contain language that would preclude regulating species that have not yet arrived in the state. To increase consistency and proactivity, states would benefit from 1) evaluating species identified as high risk by neighboring states as well as high risk, range-shifting invasives, both of which we compiled here and 2) explicitly considering climate change when assessing 'potential distribution' or 'potential impact' of target species.

Additionally, a mechanism for sharing knowledge and risk assessments regionally would benefit states with fewer resources to address invasive species threats. Presenting a unified defense against current and future threats is critical for reducing impacts from invasive species and is achievable with better state-to-state coordination.

Keywords: Climate change, invasive plant, prohibited plant list, regulation, weed risk assessment

Introduction

    Risk assessments are commonly used to identify potentially invasive plants in order to

prevent their initial or continued introduction to a country, state, or management area (e.g.,

Pheloung et al. 1999, Koop et al. 2012, Conser et al. 2015, Roy et al. 2018). Regulations that

prevent the introduction of invasive species have the greatest ecological and economic benefits if

they are enacted before the species is present (Keller et al. 2007) or early in the invasion process

when eradication of existing populations is still achievable (Rejmánek and Pitcairn 2002,

Westbrooks 2004, Strayer 2009). Unfortunately, analyses of U.S. state regulated invasive plant

species show that proactive regulation (i.e. prohibiting a species before it is introduced into a

state) is rare (Lakoba et al. 2020, Beaury et al. 2021). Moreover, species are inconsistently

regulated across state borders, creating a 'patchwork' of regulation likely to be ineffective at

preventing invasions at regional scales (Quinn et al. 2013, Lakoba et al. 2020, Beaury et al.

2021).

    In the northeast, the plant regulatory process starts by states selecting a set of potentially

invasive species to evaluate using a state-specific weed risk assessment (WRA). WRAs aim to

identify species likely to cause ecological and/or socio-economic harm within the state. WRAs

often include many different criteria, but typically consider information about biological traits,

geography, and impacts in order to assess risk (e.g., Pheloung et al. 1999; Koop et al. 2012;

Conser et al. 2015). In some cases, evaluated species are already present and causing harm in the

state by the time they are assessed. In the northeast, WRAs contain either Yes/No questions

(Connecticut, Maine, Massachusetts), with species needing to meet a set of criteria to be

designated as a priority for regulation (termed "invasive" in these states), or contain questions

assigned a numeric score (New Hampshire, New York), with higher scores associated with

higher risk. Vermont's assessment does not indicate how its evaluation criteria should translate into risk. If the outcome of the WRA reveals that a species is "invasive" (CT, ME, MA), high risk (NH, NY), or is judged to have risky attributes (VT), it can then be considered for the state's regulatory list.

Although plant regulatory aims are broadly similar (preventing the spread of harmful invasive plants or noxious weeds), a recent analysis showed that across the U.S., regulated plant lists for neighboring states had only a 17% species overlap (Beaury et al. 2021). There are several factors that could lead to this low level of consistency. First, states could select different sets of species to evaluate for potential regulation. Across the U.S., there are hundreds of unique species regulated as noxious or invasive by one or more states (Lakoba et al. 2020; Beaury et al. 2021). Conducting a risk assessment for a single invasive species could take as many as 40 hours, depending on the complexity of the protocol and availability of information about the species (Verbrugge et al. 2010). With limited funding and personnel (Beaury et al. 2020, Meyers et al. 2020), states cannot evaluate every invasive plant. Thus, choices made by the individual state agencies or advisory boards that inform regulation could lead to differing pools of evaluated species.

Second, most states have unique WRA protocols, which could lead to different outcomes for the same species in different states. While it is unclear how much the content in these assessments could influence perceived risk, Buerger et al. (2016) evaluated risk assessment outcomes for six midwest states and found that the 14 invasive plants most consistently evaluated also consistently ranked as high risk. However, these 14 species are also some of the best-known invasive plants in the region, suggesting that the protocols agree on the most problematic species, but leaving it unclear whether they would also be consistent in evaluating

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lesser known species or those that are not yet present in the region. While little information exists about risk assessments for invasive plants, a case study of risk assessments for invasive fish reports only 64% overlap in species identified as high risk (Verbrugge et al. 2010), highlighting the potential for differing outcomes between risk assessments.

Third, WRAs typically require that the assessor reference the white and/or gray literature to draw conclusions about potential for risk. The use of different sources or differing interpretations of the same sources could lead to different outcomes. Verbrugge et al. (2010) report low to moderate correlations between quantitative risk assessment scores from the same protocol performed on the same invasive fish species in the U.K., Belgium, and Belarus. Correlations (R^2) between assessment scores ranged from 0.42-0.70, suggesting that differences in sources of evidence, geography, and individual perspective will also affect risk assessments. Similarly, in an analysis of invasive plant scores from 89 experts using the same protocols, González-Moreno et al. (2019) report a correlation (spearman R) of only 0.49. Thus, even using the same protocols and evaluating the same species, assessors' interpretations can lead to different evaluations of risk.

Finally, other considerations beyond a weed risk assessment could factor into whether a species is ultimately regulated. For example, some states might prioritize economic harm over ecological harm, while others might weigh economic gains to the ornamental plant industry as more important than potential harm from invasion. In the northeast, laws pertaining to regulation of invasive plants all include a focus on ecological harm. However, recommendations for regulation based on weed risk assessment are either vetted by a panel of ecologists and industry representatives and/or are presented for public comment prior to regulation. Thus, final

decisions may be influenced by public perception and industry lobbying in addition to invasion risk.

On top of these barriers to consistent regulation there is a pressing need to make regulations more proactive. Regulating proactively would mean prohibiting the sale of a species that is not yet present in the state. Proactive regulation is a critical and cost-effective management tool for reducing future harm to ecosystems and economies from species in the early stages of invasion (Keller et al. 2007). Hundreds of new invasive plants could expand into the northeast region with climate warming (Allen and Bradley 2016), and many of these range-shifting invasive plants could be introduced rapidly as ornamentals (Beaury et al. 2021). Additionally, some non-native, invasive species already have established populations in the northeast but are currently limited by the colder climate and could begin expanding as the climate warms (sleeper species; Duursma et al. 2013, Spear et al. 2021). New threats from range-shifting and sleeper invasive plants are a top management priority (Ernest Johnson 2018, 2020, Beaury et al. 2020). Despite the importance of proactive regulation, few WRAs explicitly consider climate change (Roy et al. 2018) - including none of the northeast state WRAs. Additionally, northeast states are more likely than states in other regions to regulate species that are already widespread and present in all or most counties in the state (Beaury et al. 2021). Thus, it is important to identify any barriers to proactive regulation in the northeast.

Here, we evaluate regulatory WRA protocols for six northeast states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Vermont) to identify potential barriers to 1) consistent regulated plant lists across state borders and 2) proactive regulation of species that are not yet present in the state (e.g., range-shifting invasive plant species). We present lists of

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evaluated, regulated, and range-shifting invasive species that northeast states could assess to achieve consistent and proactive regulation.

Methods

How consistent and proactive are northeast regulated plants?

We analyzed six states in the northeast U.S.: Connecticut, Maine, Massachusetts, New Hampshire, New York, and Vermont. We did not include Rhode Island because the state currently has neither a WRA protocol nor a regulated plant list. We excluded seed law from our analysis because seed laws focus on species most problematic to agriculture and were only available for three states (Maine, New Hampshire, and Rhode Island). Regulated plant lists, in contrast, generally aim to prevent the spread of invasive plants into natural areas and reduce harm to ecosystems (e.g., Connecticut General Statutes §22a-381a through §22a-381d, Beck et al. 2008).

To assess the current status of state plant regulation, we compiled regulated plant lists as of 4/30/2021, including both terrestrial and aquatic 'Noxious Weeds'. We excluded Federal Noxious Weeds (USDA APHIS n.d.) that were relisted by individual states. Federal Noxious Weeds are prohibited from import, export, and interstate commerce in all states. We also excluded five species (*Sagittaria japonica*, *Typha gracilis*, *Typha laxmannii*, and *Typha minima* listed in New Hampshire, and the hybrid *Myriophyllum heterophyllum* x *Myriophyllum laxum* listed in New York) whose scientific names were not listed in the USDA PLANTS database (USDA PLANTS 2021). Following Beaury et al. (2021), we measured consistency between states by aggregating all regulated species into a single 'regional list' and we calculated the percentage of this regional list that was regulated within each state. Also following Beaury et al.

(2021), we calculated the proportion of counties within the state where each regulated species was present as a metric of proactivity. Occurrence data were sourced from Allen and Bradley (2016), the Early Detection and Distribution Mapping System, the USGS Biodiversity Information Serving Our Nation Database, and the USDA PLANTS Database. Regulation of species present in zero or few counties can be considered more proactive than regulation of species present in many or all counties

Are evaluated species consistent and proactive?

Lack of consistency in regulated species lists between states could be due to states evaluating different sets of potentially invasive species. To assess this, we assembled all completed risk assessments (of both regulated and non-regulated species) from five states (Maine, Massachusetts, New Hampshire, New York, and Vermont; evaluations were not available from Connecticut and no species have been evaluated in Rhode Island) and measured the percentage overlap of evaluated species between all pairs of states.

Similarly, lack of proactivity in regulated species lists could happen because states have not yet assessed risk from potentially invasive plants that have just arrived, or have not yet arrived. The sets of species regulated by states were very similar to the sets of species evaluated for all states except New York (i.e. most states regulated the majority of evaluated species). For the state of New York, which had hundreds of evaluations of non-regulated species, we compared the within-state county distributions of evaluated/regulated species to the within-state county distributions of all evaluated/non-regulated species. We excluded six non-regulated species (*Cenchrus purpurascens, Ludwigia adscendens, Nitellopsis obtusa, Phyllostachys nuda, Prunus incisa*, and *Typha orientalis*) whose scientific names were not listed in the USDA PLANTS

database (USDA PLANTS 2021). If New York was evaluating proactively, but failing to list proactively, we would expect the evaluated/non-regulated species to be less widespread than the evaluated/regulated species. We used a t-test to make this comparison.

Do risk assessment protocols support consistency and proactivity?

Lack of consistency between states could also be due to risk assessments producing different outcomes (i.e. one assessment identifies a species as high risk, while another does not). Different assessment outcomes for the same species could stem from 1) diverging scope of questions used to assess risk, or 2) differences in the sources of evidence used to conduct the risk assessment. It is also plausible that different geographies between states lead to different levels of risk (e.g., rare habitat is vulnerable in one state, but not the other), but we were unable to evaluate this here.

To determine whether risk assessment outcomes differed for the same species, we compared the raw numeric scores (0-100) for all species evaluated by New York and New Hampshire (the only two northeast states with a numeric WRA protocol) using an ordinary least squares regression. The New York assessment was designed by state experts and contains two steps, an ecological assessment then a socio-economic one. New Hampshire's assessment is adapted from the NatureServe iRank protocol (Morse et al. 2004). Because New Hampshire's protocol more closely resembles New York's ecological assessment, we excluded the socio-economic portion of the New York protocol from the numerical analyses. The two protocols had some small differences in scope: New Hampshire included some socio-economic impacts and New York's ecological assessment included questions related to management difficulty. To test if these differences in scope affected the comparison, we removed the dissimilar questions and repeated the regression using the sum of the remaining scored criteria.

To evaluate the potential of diverging questions, we compared the format and contents of risk assessments among the six northeast states, as well as two national protocols: the Animal and Plant Health Inspection Service (APHIS) Plant Protection & Quarantine (PPQ) risk assessment (Koop et al. 2012), and the National Association of Invasive Plant Council (NAIPC 2017) recommendations for WRAs. We identified commonalities across risk assessments to determine whether states include similar criteria in assessing invasion risk.

To address the potential for differing sources of evidence, we compared the sources (e.g., scientific papers, websites, gray literature) cited in risk assessments for species evaluated by New York and New Hampshire. We focused on these two states because the structure of their risk assessments was similar (leading to numeric scores for each species), there was a substantial overlap in evaluated species, and the completed risk assessments were well documented and contained full citation lists.

Lack of proactive regulation could be caused by risk assessments that preclude or down weight the importance of species that are not currently present or widespread in the state. For the six northeast states, we identified how each risk assessment defined geographic scope (i.e. whether range-shifting invasive plants could be listed) and whether they contained any sort of climate matching criteria. We also assessed whether any of the assessments explicitly considered climate change, as recommended by Roy et al. (2018).

Identifying priority sets of species for evaluation

In order to support the evaluation of consistent and proactive sets of potentially invasive species, we compiled three databases. First, we compiled a list of all regulated terrestrial and aquatic noxious weeds from the six northeast states (Connecticut, Maine, Massachusetts, New

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Hampshire, New York, and Vermont). We included in the database the states where the species is currently regulated, whether the species is readily available for sale (From Beaury et al. 2021), and how widespread the species is across the northeast counties according to USDA Plants occurrence records (USDA Plants 2021). Second, we compiled completed risk assessments from invasive plant councils or advisory boards in five northeast states (reports were unavailable for Connecticut) and created a summary table of risk assessment outcomes for all evaluated species. Lastly, we compiled a list of range-shifting invasive species with reported ecological impacts on native species or communities from Rockwell-Postel et al. (2020) and Coville et al. (2021). We included in the database a summary of how many impact papers were found, whether the species also had socio-economic impacts, whether the species was reported to impact ecosystems present in the northeast, and whether the species is readily available for sale (From Beaury et al. 2021).

Results

How consistent and proactive are northeast regulated plant lists?

There were a total of 128 terrestrial and aquatic invasive plants that are regulated in one or more northeast states as of 4/30/2021 and that are not Federal noxious weeds (Figure 1A, B): 33 in Vermont (26% of the regional list), 43 in Maine (34%), 54 in New Hampshire (42%), 69 in Massachusetts and New York (54%), and 77 in Connecticut (60%), with zero plants regulated in Rhode Island. There were 74 species regulated by multiple states (58%; including 16 regulated by all six states) versus 54 species regulated by a single state (42%). Maine had the highest overlap with other northeast states, with 42 of its 43 regulated plants also regulated by one or more other northeast states. In contrast, Connecticut was the most likely to regulate unique invasive species, with 19 of its 77 regulated plants (25%) only regulated in Connecticut. The full

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set of invasive plants regulated in one or more northeast states is presented in Supplemental

Dataset 1.

Northeast states regulate invasive plant species that are absent, rare, and widespread within

the state (Figure 1C). Maine, New Hampshire, and New York tended to list species in the earlier

stages of invasion (more proactive), with the majority of regulated species reported as present in

less than half of counties. In contrast, Connecticut and Massachusetts tended to list species in the

later stages of invasion (more reactive), with a majority of regulated species reported as present

in almost all counties in the state. How often states update regulatory lists could affect

proactivity if plants have spread subsequent to listing. For example, Connecticut (the most

reactive) created and last updated its prohibited plant list in 2004, whereas Maine (the most

proactive) created its prohibited plant list in 2016 and is updating it in 2021. While most

regulated plants were present or even widespread within states, every northeast state included at

least one species that was not yet present within the state, ranging from one of 69 regulated

species in Massachusetts to ten of 43 species in Maine (Figure 1C).

Are evaluated species consistent?

Just as there was low regional consistency between regulated plant lists (Figure 1A, B), there

was also low overlap between evaluated species lists (Figure 2; Supplemental Dataset 2). A total

of 370 species were evaluated by one or more states. While there was reasonable overlap

between most states in terms of the number of species evaluated, there is also room for

improvement. For example, neighboring states Vermont and New Hampshire evaluated 26

species in common (67% and 33% of total species evaluated by each state, respectively). States

were most likely to have evaluated species in common with New York, which has performed risk

assessments for 361 species (98% of the regional pool). Inconsistent regulation of species (Figure 1) thus appears to be a direct result of inconsistent sets of evaluated species (Figure 2).

Are evaluated species proactive?

Most states regulate almost all of the species that they have evaluated: in Maine 48 species were evaluated and 43 regulated, in Massachusetts 90 were evaluated and 69 regulated, in New Hampshire 80 were evaluated and 54 regulated, and in Vermont 40 were evaluated and 33 regulated. Thus, given that regulated species pools tended to be reactive (present and even widespread in the state; Figure 1C), the majority of evaluated species for these states are also reactive.

New York was the only state that evaluated substantially more species than it regulated (361 total; 292 not regulated; 69 regulated). Of all species evaluated by New York, regulated species were significantly more widespread than non-regulated species (Figure 3) ($t = -4.57$; p-value < 0.0005); on average, regulated species occupy 44% ($\pm$ 34% SD; median 35%) of New York's 62 counties whereas non-regulated species occupy 24% ($\pm$ 30% SD; median 11%) of counties (Figure 3). Similarly, regulated species were less likely to be absent from the state (7%; 5 of 69 regulated species) than non-regulated species (21%; 62 of 292 non-regulated species). Non-regulated species that are rare or absent from New York were often ranked as 'high risk', with 47 of 103 'high risk' species present in zero or one county (Figure 3). Thus, it appears that New York state is evaluating a substantial proportion of species that are rare or absent from the state and that these proactive evaluations are uncovering high risk species.

Do risk assessment protocols support consistency?

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Even if states evaluated the same species, a focus on different risk criteria (e.g., ecological

impacts versus plant traits versus potential distribution) could lead to different outcomes.

Although the structure of the risk assessment protocols varied, including Yes/No questions (MA,

ME, CT), numeric scoring (NH, NY), and open-ended questions (VT), the risk assessments

broadly focused on similar themes (Table 1; Supplemental Dataset 3). Similar themes also

overlapped with national recommendations for WRA from the Animal and Plant Health

Inspection Service's Plant Protection and Quarantine protocol (PPQ; Koop et al. 2012) as well as

North American Invasive Plant Council (NAIPC 2017). All risk assessment protocols included

some form of evaluation of ecological impact, most commonly impacts on native flora and fauna

or ecological communities. All protocols also evaluated species' life history. For half of the

protocols (MA, NY, ME, and CT), this involved a question related to how quickly the species

grows, while the remaining protocols (VT, NH, PPQ, NAIPC) asked specifically about short

generation times. Most protocols also assessed the species potential to invade habitat within the

state, including its current distribution within the state. Four of six states included a criterion of

whether the species has been found to be invasive elsewhere - including this type of question

could enable more data sharing across state borders. The amount of specific information about

species varied considerably between states, with New Hampshire, New York, and Vermont

asking for more information within these categories and Connecticut, Maine, and Massachusetts

asking for less.

Our comparison of New Hampshire versus New York outcomes revealed low correlation in

scores, low overlap in data sources, but reasonable overlap in regulatory outcomes. New

Hampshire and New York evaluated 52 species in common. Both assessments focus on

assessing a species' ecological impacts, dispersal ability, and potential range within the state

(Table 1), and numeric scores increase with higher risk associated with these factors. There was

a weak correlation between risk assessment scores in the two states ($R^2 = 0.18$; Figure 4). When

we removed assessment categories that were unique to NY and NH to make the assessments

more comparable, similarity in assessment outcomes declined ($R^2 = 0.12$).

Low correlation in assessment scores could result from different data sources used to inform

risk assessments. Data sources included websites, scientific articles, and gray literature. New

Hampshire assessments used an average of 9 (+/- 8 SD) sources, while New York assessments

used an average of 19 (+/- 13 SD) sources. For the 52 species evaluated by both states, on

average only two information sources were used by both states (2.1 +/- 1.7 SD; Figure 5).

Overlapping sources tend to be websites that compile information about species (e.g., CABI

Invasive Species Compendium (https://www.cabi.org/isc/) or the U.S. Forest Service Fire Effects

Information System (https://www.feis-crs.org/feis/). Thus, it is clear that different sources of

evidence are being used by different evaluators, which could lead to different assessment

outcomes.

Despite dissimilar risk assessment scores and different sources used for assessments, New

York and New Hampshire had reasonable consistency in the species that became regulated

following evaluation. Of the 52 species assessed by both states, 24 were regulated in both states

and 12 were non-regulated in both states, resulting in an overall agreement between the two

states of 69% (36/52 species). An additional 10 species were regulated only in New York and six

species were regulated only in New Hampshire (Figure 4).

Do risk assessment protocols support proactivity?

None of the northeast risk assessments explicitly included climate change in their evaluations (Table 1). However, they did not explicitly prevent the evaluation of range-shifting invasive species either. Some states limit the geographic scope of species that could be evaluated. For example, to be considered invasive in New Hampshire, the species must have escaped cultivation in one or more New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and/or Vermont). To be considered invasive in New York, the species must be established in natural areas in any state in the northeastern U.S. or eastern Canada, which is defined as extending as far west as Minnesota and as far south as Virginia. To be considered in Massachusetts, the species must be invasive "in other areas of the northeast", while in Maine the species must be invasive "in nearby states and provinces". These geographic criteria leave ample room for interpretation.

Risk assessment criteria in several states could lead to a down weighting range-shifting or sleeper invasive plants. In Connecticut, Maine, and Massachusetts, a species not yet present in the state can receive a maximum ranking of 'potentially invasive' (as opposed to species present in the state, which can receive a maximum ranking of 'invasive'). Nonetheless, in all three states 'potentially' invasive species are regulated. Several protocols also include some form of climate or hardiness zone matching. For example, Connecticut requires that "under average conditions, the plant has the biological potential for rapid and widespread dispersion and establishment in the state", while Maine mentions "areas with similar climates". New Hampshire species receive higher scores if they can establish in Hardiness zones 3-6, which exist under current climate conditions. New York species receive higher scores if the native range includes climates similar to New York. In none of these cases would a range-shifting species be excluded from

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consideration, but in all cases those species could be down-weighted or ranked in a way that could be construed as lower priority.

Discussion

By regulating invasive plants consistently, states have an opportunity to prevent continued propagation of invasive ornamental plants, prioritize harmful species for management, and control other pathways of invasive plant introduction at the regional scale. By regulating proactively, states have an opportunity to create 'climate-smart' regulations that reduce risk from range-shifting species (Allen & Bradley 2016). The lack of consistent and proactive regulation found here and in recent studies (Lakoba et al. 2020; Beaury et al. 2021) is influenced by the sets of species chosen for risk assessment and could also be affected by the risk assessment protocols. Differences between states reveal opportunities for renewed coordination, information sharing across state borders, and incorporating climate change within existing WRA frameworks.

Northeast states tend to regulate invasive terrestrial plants inconsistently (Figure 1A,B). In the northeast, states have considerable overlap in terms of native ecosystems and both risk assessments (Table 1) and prohibited plant laws have similar goals of protecting native species and ecosystems https://nationalplantboard.org/laws-and-regulations/). As a result, northeast states should agree about which plants are high risk, ideally leading to similar regulatory lists. Unfortunately, inconsistent regulatory lists are common internationally (Early et al. 2016, Courchamp et al. 2017) and across U.S. states (Lakoba et al. 2020; Beaury et al. 2021). For example, Buerger et al. (2016) evaluated regulated species in six midwestern states and found only 14 species that were regulated in the majority of those states. The northeast region is no exception (Figure 1A,B).

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Northeast states tend to regulate invasive terrestrial plants reactively, with prohibited species already present and widespread within the state (Figure 1C). Addressing invasive species before they spread and become problematic is the most effective approach for reducing invasive species harm to ecosystems and economies (Keller et al. 2007, Reaser et al. 2020). In a survey of invasive species professionals, managers reported spending less than 10% of their time monitoring for new invasive species (Beaury et al. 2020). One reason why monitoring may receive little time investment is a lack of direction from state agencies about which species to look out for. Many new invasive plants are likely to shift into northeast states with climate change (Allen and Bradley 2016), so prioritizing proactive prevention and management is essential to protecting native ecosystems from invasion.

Choosing sets of species to evaluate to build consistency and proactivity

Evaluated species from Maine, Massachusetts, New Hampshire, and Vermont were nearly identical to those states' regulatory lists. In other words, these states evaluated species considered immediate threats to the state (Figure 1C), with a high likelihood of being assessed as invasive, and proceeded to regulate them. Given that there are 128 regulated invasive plants in the northeast and over 500 regulated plant taxa across all U.S. states (Beaury et al. 2021), it should not come as a surprise that there are plenty of potentially invasive plants to choose from. While differences in the process between risk assessment and regulation could add more inconsistency (e.g., weight given to economic profits, length of public comment period, and the regulatory body), our evidence suggests that inconsistent and reactive regulations in the northeast are predominantly the result of a failure to evaluate similar sets of species (Figure 2).

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To create more consistent regulatory lists, northeast states could start by evaluating the

species already regulated by other northeast states (Figure 6), with the 85 regulated plants that

are available for sale as ornamentals a top priority (Supplemental Dataset 1). State risk

assessments tend to focus on similar criteria (Table 1; Supplemental Dataset 3), making it likely

that states could use the information from risk assessments performed by neighboring states in

their own assessments. For example, all state and national WRA protocols had questions related

to dispersal. Questions typically focused on potential for quick dispersal over long distances

(e.g., mechanisms and distances of seed dispersal), and answers to these questions should not

vary among states.

To improve proactivity in existing regulations, state invasive species councils and regulatory

boards could consider species regulated in mid-Atlantic states or species on climate watch lists

for evaluation (Figure 6). For example, the range shift listing tool in EDDMapS can produce a

list of invasive species likely to expand into any state in the conterminous U.S.

(https://www.eddmaps.org/rangeshiftlisting/). New York State has been able to assess range-

shifting species thanks to substantial resources to support risk assessment and availability of

species lists (Allen & Bradley 2016; Figure 3). Of the invasive plants expanding into the

northeast, the 27 species reported as having potential for population or community-level

ecological impacts on northeast ecosystems and readily available for sale as ornamental plants

could be a top priority for evaluation (Supplemental Dataset 4).

In addition to range shifting species, future efforts to make regulations more proactive could

consider assessing risk from species newly entering the ornamental plant trade. Newly arriving

ornamentals tend to be 'pre-adapted' to warmer climates (Bradley et al. 2012), potentially

creating an opening for future invasion. Similarly, it is plausible that some established non-native

plant populations could become invasive with climate change, highlighting a need to identify and consider risk from 'sleeper' invasive species (Duursma et al. 2013, Spear et al. 2021). Horizon scanning efforts, such as Báyon and Vilà (2019), have used risk assessments to create watch lists of potentially invasive plants, which could then be considered for regulation.

Improving the risk assessment process to support consistent and proactive regulation

One key aspect that would build consistency across state regulations would be a renewed focus on (and funding for) risk assessments (Meyers et al. 2020). New York regularly updates risk assessments and Maine legislation requires an update every five years, but other states currently conduct risk assessments only when resources are available. For example, Connecticut assessed invasive plant risk to create prohibited plant regulations in 2004, and the regulated list has not been updated since. With no new risk assessments conducted in nearly two decades, it is not surprising that Connecticut has the most reactive set of regulated species. With new species constantly being introduced (Bradley et al. 2012, Seebens et al. 2017), and new information becoming available, states must legislate and support more regular evaluations of invasive species.

Because many evaluated and regulated species are already widespread in the state that conducted the evaluation (Figure 1C), it is difficult to tell whether existing WRA protocols could reduce the likelihood of proactive regulation of range-shifting species. Although evaluated and regulated species tended to be reactive, every state had at least one species regulated proactively (i.e. a regulated species not yet present in the state; Figure 1C). Thus, it is clearly possible for evaluators in the northeast to evaluate species not yet present in the state, assess them as high risk, and regulate them. Nonetheless, the following criteria and questions within the risk

assessment protocols could cause range-shifting species to be downweighted in priority or excluded altogether.

First, criteria that exclude species from consideration based on geography may prevent proactive regulation. All state protocols allow for the consideration of species invasive in a 'nearby state' or 'the region'. New Hampshire and New York both explicitly define the region (as New England and the eastern half of the U.S. + Canada, respectively), but other states keep it vague. By mid-century, climate in many northeast states is projected to be similar to the mid-Atlantic, so instructing evaluators to think broadly in terms of region would benefit proactive regulation, particularly for ornamental invasive plants that could arrive quickly once climate is suitable.

Second, some states explicitly include a climate matching criterion. For example, the New York protocol asks whether the species' native range includes climates similar to those in New York, while the Maine protocol asks whether the species is "invasive in ... areas with similar climates". Any climate matching criteria should be evaluated in the context of climate change.

Third, other Northeast risk assessments ask about the 'potential' for an invasive plant to establish, spread, and/or have impact. 'Potential' could be used to implicitly incorporate climate change. Instructing assessors to consider range-shifting invasive species as having potential to naturalize in the state and/or match future climate conditions would support climate-smart risk assessments and ultimately lead to more proactive regulation.

Finally, range-shifting and sleeper invasive species are likely to be unfamiliar to state experts, and therefore more challenging to evaluate, particularly with limited access to experts in neighboring states. As a result, it is more likely that information will be missing about these species. Roy et al. (2018) presented standards for risk assessment protocols, including

"completion possible even when there is a lack of information." Thus, states should consider whether their protocols can still identify high risk species when some information is lacking. Evidence for invasiveness should ideally be as expansive as possible (i.e. global) given the rapid pace of novel species introductions (Seebens et al. 2017). Global databases that document invasive plants based on rigorous observational criteria (e.g., CABI - https://www.cabi.org/isc/) and/or the peer-reviewed literature (e.g., Global Plant Invaders - Laginhas & Bradley, In Press) are good sources to support risk assessment.

Evidence from New York suggests that existing risk assessment protocols can identify range-shifting species as high risk. A substantial proportion of species scored as 'high risk' were rare or absent in the state (Figure 3). New York's assessments are likely more proactive due to a recent focus on evaluating risk from range-shifting species (Allen and Bradley 2016). Many of these species are currently being considered by the state for regulation. Regulatory boards should similarly prioritize high-risk, range-shifting species.

Supporting regulation and management regionally

Building consistency across state borders would benefit from increased support for information and data sharing. National leadership is needed to create easy to use invasive species information repositories (Meyers et al. 2020) and increased support for data sharing has repeatedly been called for to support invasive species management (Hulme et al. 2009, Gatto et al. 2013) and ecological restoration (Clark et al. 2019). For example, the New Hampshire protocol requires estimates of the invasive species' rates of spread, management difficulty, and number of state biogeographic units potentially affected. This level of detail is particularly challenging to gather for species not yet present in the state and for which state experts have no

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experience. A national repository would allow states to share risk assessments and expert knowledge while reducing the likelihood of 'reinventing the wheel' and wasting limited resources (Meyers et al. 2020). In the absence of a national repository, states could aim to make completed risk assessments more readily available on websites, as is done in New York (http://nyis.info/non-native-plant-assessments/; Figure 6). This level of transparency allows for easy data sharing not only within regional working groups, but supports efficient risk assessment anywhere in the world. Our comparison of New York vs. New Hampshire assessments suggests that there is a considerable amount of information for many species, but lack of information sharing leads to assessments that leverage only a portion of the available science (Figure 5), potentially leading to inconsistent outcomes (Figure 4).

In addition to data sharing, more consistency in the weed risk assessments themselves would allow states to quickly build on information already compiled by neighbors. All northeast states have developed or adopted their own protocols, which adds to the challenge of comparing outcomes. For states that have not yet created a weed risk assessment (including Rhode Island), we recommend using Roy et al. (2018), the assessment criteria from the National Invasive Plant Council (NAIPC 2017), and risk assessments from neighboring states (e.g., Table 1) to inform the scope of questions. Existing WRAs used by multiple states include the APHIS Plant Protection & Quarantine Assessment (Koop et al. 2012, used by Nebraska and Maryland), the Australian Weed Risk Assessment (Pheloung et al. 1999, adapted by Florida and Wyoming), and Cal-IPC's Plant Risk Evaluator (Conser et al. 2015, used by Arizona, California, Nevada, and Texas). Choosing or adapting any of these risk assessments would increase opportunities to share information directly relevant to state risk assessments.

Building consistency and proactivity would also benefit from more opportunities to meet and share information across state and jurisdictional boundaries. Invasive species managers report that conversations with colleagues and experts are the most valuable source of information affecting their management decisions (Beaury et al. 2020). Information sharing between assessors could reduce the likelihood that different data sources and interpretations lead to different conclusions about risk (González-Moreno et al. 2019). It could also support the exchange of information about management strategies for range-shifting invasive species - managers in recipient states need access to the firsthand knowledge of colleagues in warmer states who are already dealing with those same species. Yet managers in the northeast have limited access to networks of colleagues that span state borders. Building stronger regional collaboration and information sharing would benefit from regional boundary spanning organizations (e.g., Morelli et al. 2021). Models for boundary spanning organizations exist at the national (e.g., the North American Invasive Species Management Association) and regional scales (e.g., Upper Midwest Invasive Species Council; Regional Invasive Species & Climate Change Networks). Supporting regional boundary spanning organizations in the northeast would lead to more coordination, collaboration, and consistency in invasive species management.

Supplemental Datasets

Supplemental Datasets 1-4 are available at [DOI link to UMass' Scholarworks to be added]

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Table 1. Categories included in Northeast state WRAs as well as the Animal and Plant Health Inspection Service's Plant Protection and Quarantine protocol (APHIS PPQ), and the North American Invasive Plant Council (NAIPC) recommendations for risk assessment. Subcategories included in all protocols are marked with †; subcategories included in all but one protocol are marked with ‡. Category and subcategory definitions are available in Supplemental Dataset 3.

Category	Subcategory	CT	MA	ME	NH	NY	VT	NAIPC	PPQ
Distribution	general Information						x		x
Distribution	potential for invasion	x	x	x		x			
Distribution	potential for naturalization†	x	x	x	x	x	x	x	x
Distribution	presence in natural areas‡	x	x	x		x	x	x	x
Distribution	presence in region			x	x	x	x	x	x
Distribution	state naturalized	x	x	x	x	x	x		
Distribution	state non-native	x	x	x	x				
Distribution	trend						x		x
Distribution	widespread	x	x	x		x		x	x
Abundance	general information	x						x	
Abundance	in natural areas		x						
Abundance	in region					x			
Abundance	in state		x	x					
Species traits	dispersal ability†	x	x	x	x	x	x	x	x
Species traits	human dispersed				x	x	x	x	x
Species traits	growth form					x			x
Species traits	hardiness		x		x	x	x		x
Species traits	life history†	x	x	x	x	x	x	x	x

Species traits	reproduction	x			x	x	x	x	x
Species traits	seed bank longevity				x	x		x	x
Species traits	disturbance responsive					x		x	x
Impacts	ecological - community composition‡	x	x		x	x	x	x	x
Impacts	ecological - community structure				x	x	x	x	x
Impacts	ecological - ecosystem processes				x	x	x	x	x
Impacts	ecological – fauna‡		x	x	x	x	x	x	x
Impacts	ecological – flora†	x	x	x	x	x	x	x	x
Impacts	ecological - high priority resource				x	x		x	x
Impacts	ecological - other				x		x	x	x
Impacts	socioeconomic - cultural					x			x
Impacts	socioeconomic - economic				x	x	x		x
Impacts	socioeconomic - safety				x	x	x		x
Impacts	socioeconomic - benefits					x	x		
Niche	climate matching			x	x	x			x
Niche	habitat matching	x			x	x			
Other	invasive elsewhere		x	x		x	x		x
Other	degree of uncertainty						x		x
Other	management feasibility					x	x		x

Sources available online:

MA: https://www.massnrc.org/mipag/docs/MIPAG_FINDINGS_FINAL_042005.pdf

ME: https://www.maine.gov/dacf/php/horticulture/invasiveplants.shtml

NH:

https://www.natureserve.org/sites/default/files/publications/files/invasive_species_assessment_pr
otocol.pdf

NY: http://nyis.info/wp-content/uploads/2017/10/invasive062910-2.pdf

NAIPC:

https://bugwoodcloud.org/mura/naeppc/assets/File/Checklist_Invasive_Plant_Listing_by%20Stat
e_and_Regional_Invasive_Plant_Councils_2017_07_20.pdf

PPQ: https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-
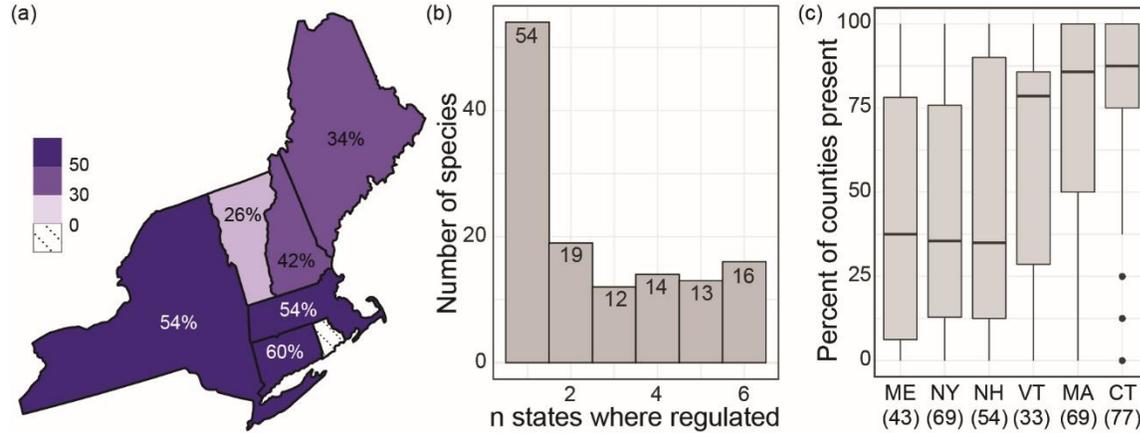programs/pests-and-diseases/SA_Weeds/SA_Noxious_Weeds_Program/CT_Riskassessments

Figures

Figure 1. (a) Current overlap of regulated plant lists among northeast states. Percent overlap is between species regulated by the state and species regulated in the region (n=128 species regulated in the region). Albers Equal Area Projection. (b) Number of states in which each of the northeast regulated species is listed; most species are regulated by one state in the region (sample sizes provided at the top of each bar). (c) Box and whisker plots for northeast states showing distributions of regulated species for six northeast states. Black bars represent the median value, boxes are the 25th and 75th percentiles of the data, and whiskers are the boxes ±1.5 multiplied by the interquartile range; points are outliers. Values range from 0 (the species is not present in the state) to 100% (the species is present in all counties in the state); sample sizes are provided in parentheses below each category.
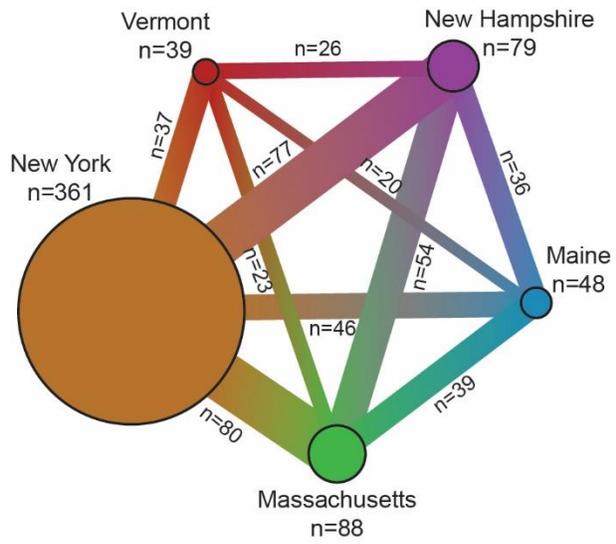
Figure 2. Visualization of overlap in evaluated species across five Northeast states. Numbers represent total species evaluated by single states or overlapping between states.
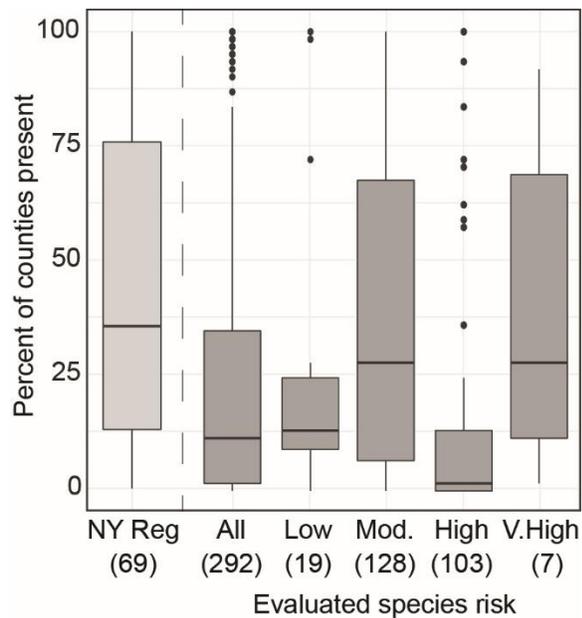
Figure 3. Box and whisker plots for northeast states showing distributions of all species evaluated but not regulated by New York, separated by risk assessment scores. Distributions of regulated species (NY Reg) are repeated here from Figure 1C for comparison. 'All' includes 35 species for which a risk score could not be assigned due to insufficient information. Values range from 0 (the species is not present in the state) to 100% (the species is present in all counties in the state); sample sizes are provided in parentheses below each category. Black bars represent the median value, boxes are the 25th and 75th percentiles of the data, and whiskers are the boxes ±1.5 multiplied by the interquartile range; points are outliers.
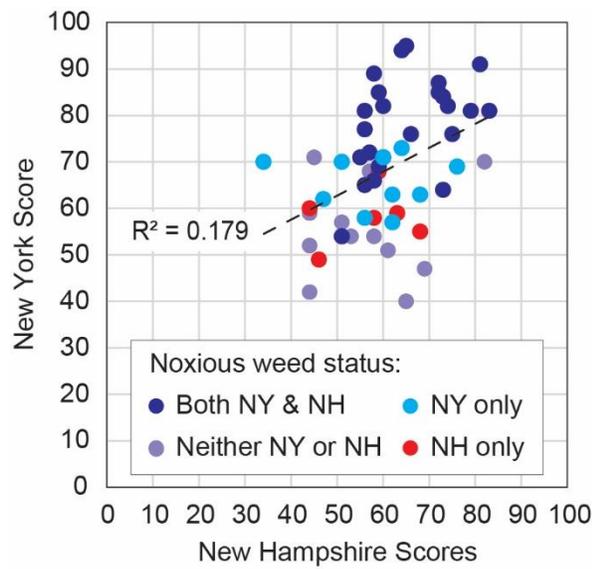
Figure 4. Risk assessment scores for 52 terrestrial invasive plants evaluated by both New Hampshire and New York showed a weak positive correlation ($R^2 = 0.179$). However, 36 of 52 species (69%; light and dark purple dots) have the same regulatory status in both states.
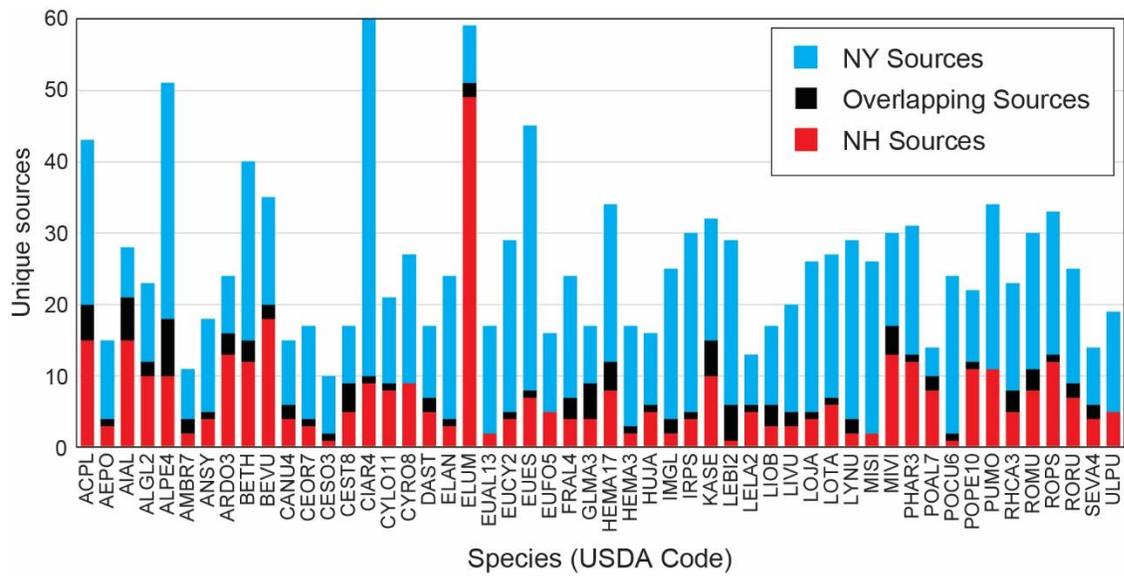
Figure 5. Risk assessments performed for 52 terrestrial invasive plants evaluated by both New Hampshire and New York had low overlap in data sources (black portions of bars). There were a total of 95 sources in the New York assessment for *Cirsium arvense* (CIAR4; data not shown).
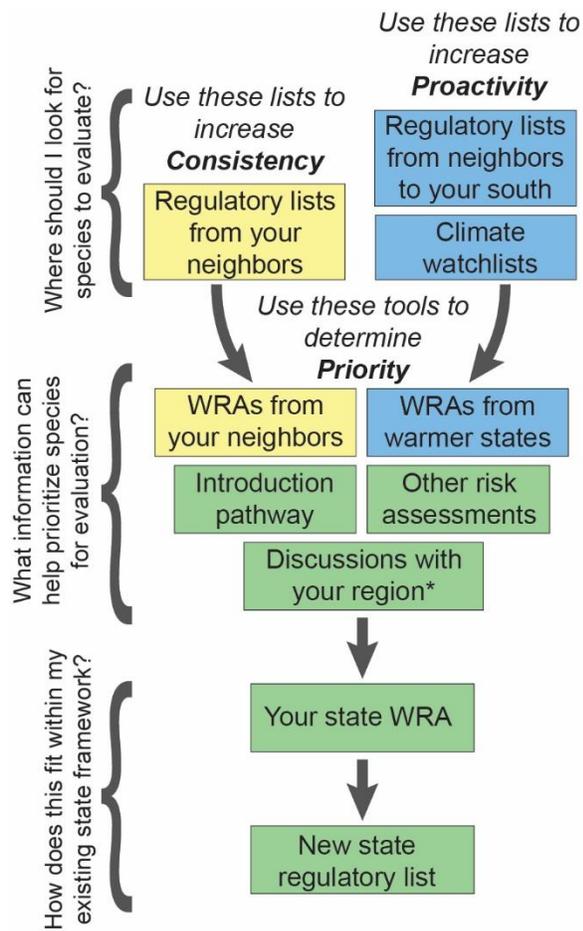
Figure 6. Flowchart showing the components of constructing consistent (yellow) and proactive (blue) state regulatory invasive species lists. Items in green should be considered for both proactive and consistent species. Items with an asterisk were not considered in this analysis, but may be useful additions for states replicating this process.