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High-impact invasive plants expanding into mid-Atlantic states: identifying priority range-shifting species for monitoring in light of climate change

Justin D. Salva[1] and Bethany A. Bradley[2]

[1]Researcher, Department of Environmental Conservation, University of Massachusetts, Amherst, MA, USA; Researcher, Department of Biological Sciences, Purdue University, West Lafayette, IN, USA and [2]Professor, Department of Environmental Conservation, University of Massachusetts, Amherst, MA, USA

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Corresponding author:
Justin D. Salva; Email: jsalva@purdue.edu

Abstract

One way that climate change is projected to affect invasive plant management is by shifting the ranges of invasive plants. In some regions, hundreds of new, potentially invasive species could establish in coming decades. These species are prime candidates for early detection and rapid response. However, with limited resources, it is unlikely that invasive plant managers will be able to monitor and treat this large number of novel species. Determining which species are likely to have the greatest impacts could inform further risk assessment and mitigate the greatest amount of potential damage. Here, we used the Environmental Impact Classification for Alien Taxa (EICAT) protocol to evaluate the potential impacts of 104 invasive plant species that are projected to establish in Delaware, Kentucky, Maryland, New Jersey, Ohio, Pennsylvania, Virginia, and/or West Virginia by midcentury with climate change. These species were identified using the Invasive Range Expanders Listing Tool to predict which invasive species are likely to shift their ranges into the target states by midcentury. We used Web of Science to search for studies on each species involving impacts to ecological or socioeconomic sectors. We scored ecological impacts on a scale of 1 ("minimal concern") to 4 ("major concern") and socioeconomic impacts as present or not present. We evaluated 674 papers and categorized the species into these categories: 32 high-impact species, 20 moderate-impact species, and 13 minor- or minimal-impact species. Two of the 32 high-impact species (panic veldtgrass [*Ehrharta erecta* Lam.] and Athel tamarisk [*Tamarix aphylla* (L.) Karst.]) pose a risk to all eight mid-Atlantic states. There were also 46 species that pose a risk to socioeconomic sectors, including agriculture, the economy, and human health. Twenty-four species were listed as data deficient (no data could be found on them). This study provides a comprehensive review of reported impacts of range-shifting invasive plants in the mid-Atlantic.

Introduction

Invasive plants that are likely to expand their ranges due to climate change (range-shifting invasive plants) are a top management concern (Beaury et al. 2020). In the United States, spatial models have projected future potential ranges for hundreds of invasive plants (Allen and Bradley 2016) and have used this information to identify lists of species that could expand into individual states by midcentury (https://www.eddmaps.org/rangeshiftlisting). However, given limited management resources, these lists of range-shifting species require further evaluation and prioritization before proactive monitoring for emerging invasive species can be implemented. The potential to cause ecological and socioeconomic impacts is one important criterion and is consistently used in state and federal risk assessments (Bacher et al. 2018 ; Blackburn et al. 2014; Hawkins et al. 2015). Thus, identifying high-impact, range-shifting species provides an important first step toward proactive monitoring and management of invasive plants in the context of climate change.

Based on projected changes in the spatial distributions of invasive species' niches due to climate change, the mid-Atlantic region of the eastern United States will remain a hot spot of plant invasion (Allen and Bradley 2016) with the potential addition of dozens of new species to each state (https://www.eddmaps.org/rangeshiftlisting). One proactive strategy for managing range-shifting invaders is early detection and rapid response (EDRR). EDRR is the process of monitoring for new invasive species (early detection) and eradicating new populations before they can spread (rapid response; (Reaser et al., 2020). Eradication of new invasive plants is only feasible when populations are small (Rejmánek and Pitcairn 2002). Thus, high-risk, range-shifting invasive plants should be a priority for EDRR, because they are not yet widespread and prevention/eradication is still possible.

Management Implications

Range-shifting invasive plants, while a threat to ecosystems and economies, also offer a novel opportunity for scientists and land managers to proactively identify and address invasives before they become widespread. Climate-driven projections of range shifts have already been created for many nonnative and invasive plants and, when combined with assessments of invader impacts, can be used to identify high-impact, range-shifting species. We combined the Invasive Range Expanders Listing Tool with ecological and socioeconomic impact assessments to identify 32 high-impact species that are projected to move into at least one of the eight study states. While some of the species listed are already present in parts of the mid-Atlantic region, many are not and offer opportunities for proactive management aimed at preventing the further spread of these species. Information about potential range and impact can inform state risk-assessment protocols, which lead to prohibited plant and/or seed lists in these states. Thus, the sale of high-impact invasives that are likely to emerge with climate change could be stopped before those species are widely introduced. Prohibiting high-impact, range-shifting species is most effective if multiple states join together to build consistent management practices. Thus, these results build upon previous impact assessments in northern and southern New England to comprehensively identify impactful invasive plants across the Northeast.

However, invasive species managers consistently report that they lack funding and personnel to effectively manage invasions (Beaury et al. 2020). Adding species to monitoring lists requires that managers spend time learning to identify those species and spend time searching for more species. Watch lists such as Western Pennsylvania Conservancy's Invader Watch List (https://waterlandlife.org/wildlife-pnhp/invasive-and-unwelcomed-species/invader-watch-list), which contains 13 invasive species, are tractable for management. In contrast, watch lists associated with climate change, such as those generated by the range-shift listing tool (https://www.eddmaps.org/rangeshiftlisting), are much lengthier and impractical for monitoring and management.

One way to prioritize invasive plants is through assessment of impacts. Preventing ecological and socioeconomic impacts is the primary reason for managing biological invasions. The potential to cause negative impacts is consistently used in the U.S. federal (Koop et al., 2012) and state (Buerger et al. 2016; Bradley et al. 2022) risk assessments that inform regulation and management. Although other state risk-assessment criteria often differ (e.g., Buerger et al. 2016; Bradley et al. 2022), information about impacts is universally useful for prioritization. Thus, by assessing potential impacts, we provide an important first step toward identifying species that states should assess further as well as information about impacts needed for state risk assessments (Kumschick et al. 2020).

The Environmental Impact Classification for Alien Taxa (EICAT) enables a consistent categorization of the magnitude of ecological impacts (Blackburn et al. 2014). This tool is supported by the International Union for Conservation of Nature (IUCN) and has been used to evaluate and prioritize invasive birds (Evans et al. 2016; Lapin et al. 2021), mammals (Hagen and Kumschick 2018; Volery et al. 2021), and amphibians (Measey et al. 2020), as well as plants (Blackburn et al. 2014; Canavan et al. 2019; Coville et al. 2021; AC O'Uhuru, personal communication; Rockwell-Postel et al. 2020). Importantly, EICAT has been used in two previous studies to assess impacts of range-shifting plants in southern and northern New England (Coville et al. 2021; Rockwell-Postel et al. 2020). Thus, EICAT provides a consistent and repeatable metric of impact, and using this approach creates a uniform set of invasive plant impact assessments across the Northeast.

Here, we used the EICAT protocol to assess the potential ecological and socioeconomic impacts of 104 invasive plant species (chosen through the use of the Invasive Range Expanders Listing Tool) that have been projected to shift their ranges into the states of Delaware, Kentucky, Maryland, New Jersey, Ohio, Pennsylvania, Virginia, and/or West Virginia by midcentury with climate change. We use this information to identify high-impact species that could be priorities for monitoring and EDRR in the region. This study builds on previous EICAT assessments of range-shifting invasive plants into northern New England (Coville et al. 2021) and southern New England (Rockwell-Postel et al. 2020) to encompass the entire U.S. Northeast region.

Materials and Methods

We defined our mid-Atlantic study region as the states of Delaware, Kentucky, Maryland, Ohio, New Jersey, Pennsylvania, Virginia, and West Virginia. Our methods followed Rockwell-Postel et al. (2020), who performed impact assessments of invasive plants likely to expand into Connecticut, Massachusetts, New York, or Rhode Island, and Coville et al. (2021), who did the same for Maine, New Hampshire, and Vermont (Figure 1). To create a list of invasive plants with the potential to expand into the mid-Atlantic study region with climate change, we used the Invasive Range Expanders Listing Tool (https://www.eddmaps.org/rangeshiftlisting) based on Allen and Bradley 2016). On a state-by-state basis, this tool identifies invasive plants (species either listed as a noxious weed by one or more state or identified as invasive by the invasive plant atlas; https://www.invasiveplantatlas.org) that are not currently present in a state, but could establish there by midcentury given future climate conditions projected by 13 climate models. Following Rockwell-Postel et al. (2020) and Coville et al. (2021), we used the Invasive Range Expanders Listing Tool to create a list of range-shifting plants for each of the eight mid-Atlantic states. We selected all species identified as climatically suitable by at least 10 out of 13 climate models, assuming that consistent projections of multiple models indicate a higher likelihood of future habitat suitability. We did not include a distance criterion (i.e., we included species present anywhere in the United States, including Alaska and Hawaii), assuming that propagules can move quickly, particularly given that a large number of invasive plants remain available for sale (Beaury et al. 2021).

Of the evaluated species, *Magnifera indica* L. (mango), *Passiflora edulis* Sims (passionfruit), *Cucumis melo* L. (musk melon), and *Oryza sativa* L. (rice), are edible crop species in the United States and were excluded, assuming that cultivation is unlikely to stop. A number of the species likely to shift their range into one or more mid-Atlantic states with climate change also pose a risk to Northeast states and were already evaluated by Rockwell-Postel et al. (2020), Coville et al. (2021), and/or AC O'Uhuru (personal communication). We included these species in this assessment, but updated previous impact assessments to include any more recent impact studies. A full list of evaluated species is presented in Supplementary Appendix 1.

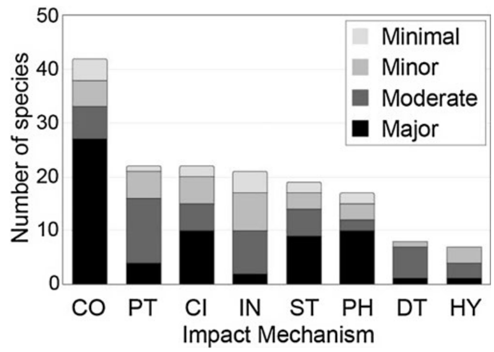

Figure 1. Impact level of target species by ecological impact mechanism. A total of 65 species had some ecological impact information reported in the scientific literature. CI, chemical impact; CO, competition; DT, disease transmission; HY, hybridization; IN, interaction with other invaders; PH, physical impact; PT, poisoning/toxicity; ST, structural impact.

Impact Assessment

Before searching for impact studies, we identified all synonyms for our target species using the Integrated Taxonomic Information System (https://www.itis.gov), which ensured that we captured all available papers, even if the taxonomy changed over time. We then searched the Web of Science Core Collection for the target species' name and all synonyms. We read titles and abstracts of all returned publications, looking for papers that described any negative ecological or socioeconomic impacts of the target invasive species. We did not include papers reporting positive impacts, as our goal was to inform proactive regulation and EDRR to high-impact invasive plants. Literature searches were conducted between September 2021 and July 2022.

We assessed negative ecological impacts of the target range-shifting invasive plant species using the EICAT protocol (Blackburn et al. 2014; Hawkins et al. 2015). JDS received training for the EICAT protocol before conducting impact assessments. EICAT training was conducted in association with another project (AC O'Uhuru, personal communication) and involved three reviewers who evaluated the same species and discussed differences in scoring to improve consistency and conform to updated EICAT protocols (Volery et al. 2020). While reviewer biases are likely to remain, all species were scored by a single reviewer, which should make the data set internally consistent. Additionally, we report scoring criteria and include the text associated with the scoring in data-sheet appendices so invasive plant scientists and managers can use the original data to draw their own conclusions.

Ecological impacts were scored on a scale from 1 to 4 with the following criteria:

1 = minimal concern, or having discernible impacts but none affecting the fitness of individual species;
2 = minor, defined as reducing the fitness of individuals but not the population;
3 = moderate, or causing a reduction in the population of one native species; and
4 = major, or having a negative impact on native community composition (a decline in species richness or diversity).

Following Rockwell-Postel et al. (2020), we did not include the EICAT score of 5 (massive, or the irreversible extirpation of a native species), because plants are not yet known to cause extinctions. We categorized the reported impacts into one of nine impact-mechanism categories associated with invasive plants: competition, hybridization, disease transmission, parasitism, poisoning/toxicity, biofouling, physical impact, chemical impact, structural impact, and interaction with other aliens (Hawkins et al., 2015). A single paper could include multiple impact scores for multiple impact mechanisms. Following the EICAT protocol, we selected the maximum scores overall and across each impact mechanism to compare the magnitude of reported ecological impacts across invasive plant taxa.

In addition to the EICAT evaluation, negative socioeconomic impacts of target species (impacts relating to agriculture, economics, or human health) were recorded. While there is a Socio-Economic Impact Classification for Alien Taxa (SEICAT; Bacher et al., 2018), the SEICAT protocol focuses on abandonment of activity, whereas most socioeconomic impact papers in our study focus on costs (e.g., loss of crop yield). Therefore, following Rockwell-Postel et al. (2020), we recorded negative socioeconomic impacts as "present." We recorded socioeconomic impacts for the same impact-mechanism categories described previously for the EICAT assessment. Socioeconomic impacts fell into one of three categories: affecting human health (not associated with crop losses), affecting economics (not associated with crop losses), and affecting agriculture (negative effects on crops).

For each species, we created a data sheet with all reported ecological and socioeconomic impacts and impact mechanisms. Data sheets also included citation information (first author, year of publication, journal, DOI, full citation), a description of the impact, and a quote of relevant supporting text from the publication. We also recorded other criteria that could inform end users' interpretation of potential risk to a given ecosystem or species. The affected system categorizes whether the impacts are reported in an ecological, agricultural, economic, or human health system. When the affected system was an ecosystem, we further classified the habitat code being affected using the IUCN Habitat(s) Classification Scheme (https://www.iucnredlist.org/resources/habitat-classification-scheme). The affected species, or species impacted by the invasive, was recorded for studies where individual native species were reported. The affected taxon categorizes the affected species as a plant, vertebrate, invertebrate, or other. The extent (in hectares), plot size (m^2), and number of plots in the study were all recorded where available to inform end-user confidence in the study results. Country was based on the location reported in each study. Finally, we recorded whether the study site was managed (meaning the invasive species was being managed before the impact assessment) and the type of study (field, lab, field and lab, review, or other).

Results and Discussion

We evaluated the impacts of 104 invasive plants with the potential to shift their range into the mid-Atlantic states with climate change. We found 674 papers describing ecological or socioeconomic impacts. Numbers of impact papers per species ranged from 0 (for 24 data-deficient species) to 58 for Chinese fir [*Cunninghamia lanceolata* (Lamb.) Hook.]. The majority of impact papers focused on ecological impacts, with 431 ecological impact papers compared with 250 socioeconomic impact papers. Seven papers reported both ecological and socioeconomic impacts.

Of the 104 target species, 65 (60%) had one or more studies reporting a negative ecological impact. We identified 32 species with major impacts, 20 species with moderate impacts, and 13 species with minor or minimal impacts (Table 1). The most frequently reported ecological impact was competition (reported

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Table 1. List of species with ecological impacts and the mechanism of impact.

Scientific Name	Common Name	Max. EICAT score[a]	Mechanism of impact[b]									No. of impact papers
			CO	HY	DT	PT	PH	CI	ST	IN	UN	
Aegilops triuncialis	Barbed goatgrass	4	4	N/A	N/A	N/A	N/A	4	4	4	N/A	10
Arctotheca calendula	Capeweed	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Ardisia elliptica	Shoebutton	4	4	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	3
Arundo donax	Giant reed	4	4	N/A	N/A	N/A	4	3	4	3	N/A	34
Avena barbata	Slender oat	4	4	3	N/A	4	2	2	N/A	1	N/A	22
Carduus pycnocephalus	Italian plumeless thistle	4	Present	Present	N/A	N/A	N/A	4	N/A	4	N/A	2
Carex kobomugi	Japanese sedge	4	4	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	7
Carthamus lanatus	Woolly distaff thistle	4	4	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	2
Cenchrus setaceus (*Pennisetum setaceum*	Crimson fountaingrass	4	4	N/A	N/A	N/A	4	4	4	Present	N/A	10
Cortaderia selloana	Uruguayan pampas grass	4	4	N/A	N/A	2	4	3	N/A	N/A	N/A	14
Cunninghamia lanceolata	Chinese fir	4	4	N/A	N/A	3	3	3	N/A	N/A	N/A	52
Cyperus entrerianus	Woodrush flatsedge	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Ehrharta erecta	Panic veldtgrass	4	4	N/A	N/A	N/A	N/A	3	N/A	3	N/A	2
Genista monspessulana	French broom	4	4	4	N/A	4	4	4	N/A	N/A	N/A	13
Hemarthria altissima	Limpograss	4	4	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	4
Hypochaeris glabra	Smooth cat's ear	4	1	N/A	4	N/A	N/A	N/A	N/A	N/A	Present	3
Lantana montevidensis	Trailing shrubverbena	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Ligustrum lucidum	Glossy privet	4	4	N/A	N/A	N/A	4	4	4	N/A	N/A	20
Macrothelypteris torresiana	Swordfern	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2
Melia azedarach	Chinaberrytree	4	4	N/A	N/A	2	N/A	N/A	N/A	3	N/A	8
Miscanthus sacchariflorus	Amur silvergrass	4	4	3	N/A	N/A	N/A	N/A	N/A	Present	N/A	4
Olea europaea ssp. *cuspidata*	African olive	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Phalaris minor	Littleseed canarygrass	4	Present	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	2
Pyracantha angustifolia	Narrowleaf firethorn	4	3	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	3
Rosa bracteata	Macartney rose	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Tamarix aphylla	Athel tamarisk	4	4	N/A	N/A	4	4	4	4	N/A	N/A	8
Tamarix chinensis	five-stamen tamarisk	4	4	3	N/A	4	4	3	4	2	N/A	30
Tamarix ramosissima	salt cedar	4	4	N/A	N/A	N/A	4	4	4	N/A	4	5
Tradescantia fluminensis	small-leaf spiderwort	4	4	N/A	N/A	N/A	N/A	4	4	N/A	N/A	14
Triadica sebifera	Chinese tallow	4	4	N/A	N/A	Present	N/A	N/A	N/A	N/A	N/A	2
Tripidium ravennae ssp. *ravennae*	Ravennagrass	4	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Vitex rotundifolia	Roundleaf chastetree	4	N/A	N/A	N/A	N/A	4	4	N/A	N/A	N/A	4
Araujia sericifera	White bladderflower	3	N/A	N/A	N/A	N/A	N/A	N/A	2	3	N/A	2
Asclepias curassavica	Bloodflower	3	N/A	2	3	3	N/A	N/A	3	1	N/A	12
Bellardia trixago	Mediterranean lineseed	3	N/A	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	1
Brachypodium distachyon	Purple false brome	3	N/A	N/A	3	N/A	2	2	N/A	N/A	N/A	4
Casuarina cunninghamiana	River sheoak	3	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A	N/A	1
Cestrum diurnum	Day jessamine	3	N/A	N/A	N/A	3	N/A	N/A	N/A	2	N/A	2

(*Continued*)

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Table 1. (*Continued*)

Scientific Name	Common Name	Max. EICAT score[a]	Mechanism of impact[b]									No. of impact papers
			CO	HY	DT	PT	PH	CI	ST	IN	UN	
Conyza bonariensis	Asthmaweed	3	N/A	N/A	N/A	3	N/A	N/A	3	N/A	N/A	5
Dalbergia sissoo	Indian rosewood	3	3	N/A	N/A	2	N/A	2	N/A	N/A	N/A	8
Hedera helix spp. canariensis	Algerian ivy	3	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Hypericum calycinum	Aaron's beard	3	2	N/A	2	3	N/A	N/A	N/A	N/A	N/A	3
Lagerstroemia indica	Crapemyrtle	3	1	2	3	N/A	N/A	N/A	3	2	N/A	15
Ligustrum japonicum	Japanese privet	3	N/A	N/A	3	N/A	1	N/A	2	N/A	N/A	9
Mahonia bealei	Beale's barberry	3	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Nandina domestica	Sacred bamboo	3	2	N/A	3	N/A	N/A	N/A	N/A	N/A	N/A	3
Paspalum urvillei	Vasey's grass	3	N/A	N/A	3	N/A	N/A	N/A	N/A	3	N/A	5
Peganum harmala	Harmal peganum	3	2	N/A	N/A	3	N/A	1	N/A	N/A	N/A	8
Persea americana	Avocado	3	3	N/A	N/A	N/A	2	2	3	3	N/A	15
Senna occidentalis	Septicweed	3	N/A	N/A	N/A	3	N/A	N/A	N/A	3	N/A	7
Sesbania punicea	Rattlebox	3	N/A	N/A	N/A	3	N/A	N/A	1	3	N/A	3
Spartium junceum	Spanish broom	3	3	N/A	N/A	3	3	2	N/A	2	N/A	8
Buddleja lindleyana	Lindley's butterflybush	2	N/A	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2
Centaurea melitensis	Maltese star-thistle	2	2	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A	2
Crotalaria spectabilis	Showy rattlebox	2	1	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A	4
Hibiscus tiliaceus	Sea hibiscus	2	N/A	N/A	N/A	N/A	N/A	N/A	2	2	N/A	4
Phyllostachys aurea	Golden bamboo	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A	1
Pseudognaphalium luteoalbum	Jersey cudweed	2	2	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A	2
Alysicarpus vaginalis	White moneywort	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Carduus tenuiflorus	Winged plumeless thistle	1	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	1
Crotalaria pallida	Smooth rattlebox	1	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	1
Elaeagnus pungens	thorny olive	1	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	1
Firmiana simplex	Chinese parasoltree	1	N/A	N/A	1	N/A	N/A	N/A	N/A	1	N/A	2
Rumex stenophyllus	Narrowleaf dock	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	1
Sacciolepis indica	Glenwoodgrass	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1

[a]EICAT, Environmental Impact Classification for Alien Taxa protocol.
[b]CI, chemical impact; CO, competition; DT, disease transmission; HY, hybridization; IN, interaction with other invaders; PH, physical impact; PT, poisoning/toxicity; ST, structural impact; UN, unknown.

in 41 of 65 species, 63%), with poisoning/toxicity (22 of 65, 34%) and chemical impact (22 of 65, 34%) also common (Figure 1). The least frequently reported ecological impacts were hybridization (7 of 65, 10.8%) and disease transmission (9 of 65, 13.8%). Although hybridization and disease transmission impacts were rarely reported, the species displaying these impacts tended to receive a higher score on EICAT assessments, with four out of seven hybridization-reporting species receiving a score of 3 or higher, and seven out of nine disease transmission–reporting species receiving a score of 3 or higher (Figure 1). These higher proportions suggest that novel species with the potential to hybridize or transmit disease could cause greater ecological impacts compared with other species and thus should be of particular interest to land managers.

Many of the species with reported ecological impacts also had reported socioeconomic impacts (31 of 65 species, 48%). An additional 15 species had no reported ecological impact, but did have socioeconomic impacts. Of the 46 species with socioeconomic impacts (Table 2), agricultural impacts were most common (43 of 46 species, 94%), while economics were the least common (8 of 46 species, 17%) (Figure 2). Of the 32 species with major ecological impacts, 18 also had reported socioeconomic impact(s).

Mid-Atlantic states were vulnerable to between 7 and 13 of the 32 species with major ecological impact (Figures 3 and 4): Delaware = 13, Kentucky = 10, Maryland = 12, New Jersey = 13, Ohio = 10, Pennsylvania = 7, Virginia = 11, and West Virginia = 10. All mid-Atlantic states were vulnerable to two major-impact species: *E. erecta* and *T. aphylla*. In addition, all mid-

Table 2. List of species with socioeconomic impacts and the mechanism of impact.

Scientific Name	Common Name	Mechanism of impact[a]									No. of impact papers
		CO	HY	DT	PT	PH	CI	ST	IN	UN	
Aegilops triuncialis	Barbed goatgrass	A	N/A	N/A	N/A	N/A	N/A	A	N/A	N/A	2
Araujia sericifera	White bladderflower	N/A	N/A	A	H	N/A	N/A	N/A	N/A	N/A	2
Arctotheca calendula	Capeweed	A/E	N/A	A	N/A	N/A	N/A	N/A	N/A	A	7
Asclepias curassavica	Bloodflower	N/A	N/A	A	H	N/A	N/A	N/A	N/A	N/A	2
Avena barbata	Slender oat	A	N/A	A/H	N/A	N/A	N/A	N/A	N/A	N/A	7
Brachypodium distachyon	Purple false brome	N/A	N/A	A	H	N/A	N/A	N/A	N/A	N/A	5
Canna indica	Indian shot	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	1
Carduus pycnocephalus	Italian plumeless thistle	A/E	A	N/A	N/A	N/A	N/A	N/A	N/A	A	6
Carthamus lanatus	Woolly distaff thistle	N/A	N/A	N/A	N/A	N/A	N/A	A	A	N/A	2
Cenchrus setaceus	Birdwood grass	N/A	N/A	N/A	N/A	E	N/A	N/A	E/H	N/A	3
Cestrum diurnum	Day jessamine	N/A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	3
Commelina benghalensis	Jio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	A	8
Conyza bonariensis	Asthmaweed	A	N/A	A	N/A	N/A	N/A	N/A	A	N/A	10
Cortaderia selloana	Uruguayan pampas grass	N/A	N/A	N/A	A/H	N/A	N/A	N/A	A	N/A	3
Crotalaria spectabilis	Showy rattlebox	A	N/A	A	A	N/A	N/A	N/A	A	N/A	13
Cunninghamia lanceolata	Chinese fir	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	N/A	6
Cyperus entrerianus	Woodrush flatsedge	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2
Dactyloctenium aegyptium	Egyptian grass	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3
Dalbergia sissoo	Indian rosewood	A	N/A	N/A	A/H	N/A	A	N/A	N/A	N/A	8
Digitaria violascens	Violet crabgrass	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	A	4
Hemarthria altissima	Limpgrass	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	1
Hibiscus tiliaceus	Sea hibiscus	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	2
Hypochaeris glabra	Smooth cat's ear	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	2
Ipomoea carnea ssp. *fistulosa*	Gloria de la manana	N/A	N/A	N/A	A/E	N/A	N/A	N/A	N/A	N/A	4
Lantana montevidensis	Trailing shrubverbana	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
Melia azedarach	Chinaberrytree	A	N/A	N/A	A/H	N/A	N/A	N/A	N/A	N/A	4
Melilotus indicus	Annual yellow sweetclover	A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	6
Miscanthus sacchariflorus	Amur silvergrass	N/A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	1
Nerium oleander	Oleander	N/A	N/A	A	A/H	N/A	N/A	N/A	N/A	N/A	29
Orobanche ramosa	Hemp broomrape	A/E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5
Peganum harmala	Harmal peganum	A	N/A	N/A	A/H	N/A	H	N/A	N/A	N/A	11
Persea americana	Avocado	N/A	A	A/H	H	N/A	A	N/A	A	N/A	19
Phalaris minor	Littleseed canarygrass	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6
Phyllostachys aurea	Golden bamboo	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	A	2
Rosa bracteata	Macartney rose	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4
Rottboellia cochinchinensis	itchgrass	A	N/A	A	N/A	N/A	N/A	N/A	A	A	7
Senna occidentalis	Septicweed	A	N/A	A	A/H	N/A	H	N/A	A	N/A	27
Sesbania punicea	Rattlebox	N/A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	1
Solanum pseudocapsicum	Jerusalem cherry	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	A	2
Solanum viarum	Tropical soda apple	A/E	N/A	A	N/A	N/A	N/A	N/A	A	N/A	4
Spartium junceum	Spanish broom	N/A	N/A	N/A	H	N/A	N/A	N/A	A	N/A	3
Striga asiatica	Asiatic witchweed	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	5
Tamarix ramosissima	Saltcedar	N/A	N/A	N/A	N/A	E	N/A	N/A	N/A	N/A	1
Triadica sebifera	Chinese tallow	N/A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	1
Urochloa ramosa	Dixie signalgrass	N/A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	1
Verbena bonariensis	Purpletop verbain	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	1
Youngia japonica	Oriental false hawksbeard	A/E	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	3

[a]CI, chemical impact; CO, competition; DT, disease transmission; HY, hybridization; IN, interaction with other invaders; PH, physical impact; PT, poisoning/toxicity; ST, structural impact; UN, unknown

Atlantic states were also vulnerable to two species with socioeconomic impacts: *Araujia sericifera* Brot. (white bladderflower) and *Asclepias curassavica* L. (bloodflower). A summary table of impacts and impact mechanisms for all mid-Atlantic range-shifting species can be found in Supplementary Appendix 1. Full impact reports for individual species can be found in Salva and Bradley (2023). While we present state-level lists, we encourage practitioners to consider the longer regional list of high-impact species. Species are excluded from the Range Shift Listing Tool if they are present in the state, but practitioners might want to include range-shifting species with small within-state populations. EDDMapS is a useful tool for assessing current species distributions as well as projected range shifts at the county level based on Allen and Bradley 2016).

While EICAT is a well-used approach for invasive species impact assessment (e.g., Blackburn et al. 2014; Canavan et al. 2019; Coville et al. 2021; Evans et al. 2016; Hagen and Kumschick 2018; Lapin et al. 2021; Measey et al. 2020; AC O'Uhuru, personal communication; Rockwell-Postel et al. 2020; Volery et al. 2021), it is one of many such assessments (e.g., Bernardo-Madrid et al. 2022). EICAT performs well in comparison to other impact and risk assessments in terms of consistency of scoring between reviewers (Bernardo-Madrid et al. 2022). However, practitioners should still use caution when interpreting impact scores and double check the source papers listed in individual species reports (Supplementary Appendix 2).

With limited resources for monitoring and treatment, invasive plant managers must constantly prioritize species. Focusing on

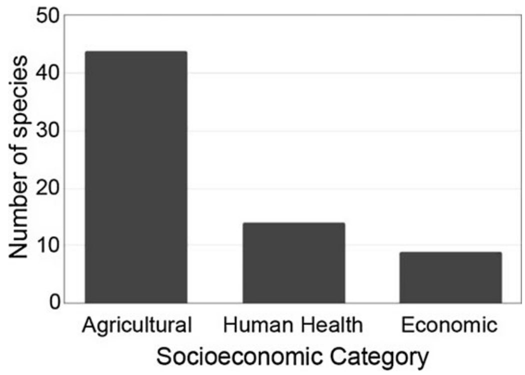

Figure 2. Impact level of target species by socioeconomic category. A total of 46 species had some socioeconomic impact information reported in the scientific literature.

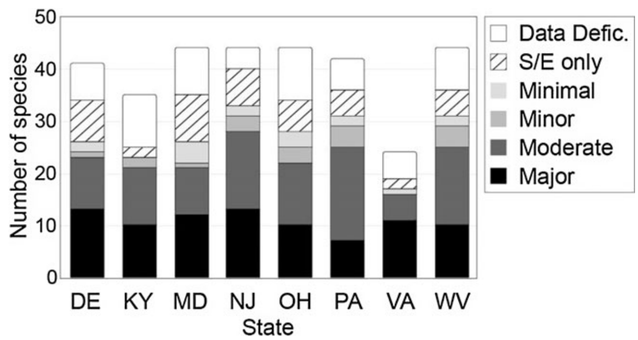

Figure 3. Impact level of target species by state. Gray bars indicate species with different levels of ecological impact (from major to minimal). Diagonal hash bars indicate species with socioeconomic impacts only (S/E only). White bars indicate species with no impact information in the scientific literature (data deficient).

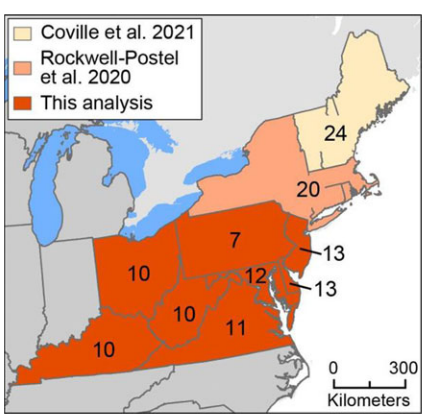

Figure 4. Numbers of range-shifting invasive plants with "major" ecological impacts expanding into mid-Atlantic states. Total numbers of major impact species for southern and northern New England regions from Rockwell-Postel et al. (2020) and Coville et al. (2021), respectively, are also presented.

range-shifting invasive plants for EDRR is an opportunity to prevent invasions before they begin - some of the highest return on investment in management (Keller et al. 2007). However, with hundreds of potentially invasive species shifting their ranges across the eastern United States (Allen and Bradley 2016), it is imperative that we focus our efforts on the species likely to cause the most ecological and/or socioeconomic harm. Species with listed impacts of 4 or higher should be prioritized for further risk assessment and preventative management. Species that are commonly available for sale as ornamentals (Beaury et al. 2021) could be proactively regulated before they are widely available commercially in the state. High-priority species could also be placed on watch lists for monitoring and EDRR when new populations are detected in states. Species with lower impact scores should not necessarily be interpreted as low impact, as invasion science has well-known biases in how impact is studied (Hulme et al. 2013). However, with limited resources, further evaluation of species known to harm ecological communities and/economies should be a priority. The evaluated list of range-shifting species was based on a climate change scenario (RCP 4.5) that related to a 0.5 to 1.5°C temperature increase by 2100 (IPCC 2022). Depending on human actions, actual climate change by midcentury could be higher or lower than this range, which would affect the list of range-shifting species. Thus, our analysis could underestimate numbers of high-impact, range-shifting species if climate change trajectories continue to follow some of the more dire projections. Additionally, the negative impacts reported in our literature review come from studies around the world, and impacts will vary depending on the recipient ecosystem. Practitioners should consider ecosystems where impacts were observed (Supplementary Appendix 2) when evaluating risk to a particular management area. For both recipient ecosystem type and level of overall impact score, lack of information should not be interpreted as lack of impact.

After assessing the impacts of these species, we created lists of all high-impact species for each state (Table 3). These species have documented negative impacts on communities of native species and thus likely present a significant threat to taxa within the mid-Atlantic. For instance, *Tamarix aphylla* (Athel tamarisk) produces several community-level impacts of high concern, such as increasing the potential and severity of flooding and fire events (Di Tomaso 1998), affecting the richness and diversity of fungal operational taxonomic units (Raghavendra et al. 2017), negatively affecting wildlife habitat (Di Tomaso 1998), salinizing soils (Shamir and Steinberger 2007; Walker et al. 2006), and reducing native vegetation (Di Tomaso 1998). *Tamarix aphylla* is also projected to expand its range into all eight study states within the next 40 yr. As such, it is a serious threat to biodiversity in the mid-Atlantic and should be a primary target for preventative management. A second species, *E. erecta*, also has community-level impacts and is projected to shift its range into all eight states in the study area over the next 40 yr. *Ehrharta erecta* was shown to decrease the ground cover of native plants in its invaded ranges as well as affecting nitrogen availability (Bidwell et al. 2006) and acting as a host plant for other invasive species (van der Linde et al. 2016). The recorded impacts for *T. aphylla* fall under the mechanism categories of competition, physical impact, structural impact, chemical impact, and poisoning/toxicity. The recorded impacts of *E. erecta* comprise chemical impact, competition, and interaction mechanisms. These mechanisms are widely represented in our data, and therefore these species generally represent the mechanisms seen in other range-shifting invaders.

Impact mechanisms identified in this study were similar to those reported in previous studies. Rockwell-Postel et al. (2020) also identified competition, poisoning/toxicity, and interaction with other alien species as common impact mechanisms. Similarly, Coville et al. (2021) identified competition and physical impacts as the most common mechanisms. The combined results clearly illustrate that competition between invasive plants and native

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Table 3. List of 32 species with recorded high impacts and states they have the potential to expand into by 2050 with climate change (according to the Range Shift Listing Tool, https://www.eddmaps.org/rangeshiftlisting).

Scientific name	Common name	Growth habit	Socioeconomic impacts?	No. impact papers	Maximum EICAT score[a]	No. of socioeconomic impact papers	No. of ecological impact papers	Threatened states
Aegilops triuncialis	Barb goatgrass	Graminoid	Y	12	4	2	10	OH
Arctotheca calendula	Capeweed	Forb/herb	Y	9	4	7	4	VA
Ardisia elliptica	Shoebutton ardisia	Shrub, tree	N	3	4	0	3	NJ, PA, VA, WV, MD, KY, OH
Arundo donax	Giant reed	Graminoid, shrub, subshrub	N	36	4	2	34	NJ, PA, OH
Avena barbata	Slender oat	Graminoid	Y	29	4	7	22	NJ, DE
Carduus pycnocephalus	Italian plumeless thistle	Forb/herb	Y	10	4	6	2	NJ, DE
Carex kobomugi	Japanese sedge	Graminoid	N	7	4	0	7	WV
Carthamus lanatus	Woolly distaff thistle	Forb/herb	Y	3	4	2	2	NJ
Cenchrus setaceus	Crimson fountaingrass	Graminoid	Y	12	4	3	10	NJ, PA, WV, DE, KY, OH
Cortaderia selloana	Uruguayan pampas grass	Graminoid	Y	17	4	3	14	NJ, DE
Cunninghamia lanceolata	Chinese fir	Tree	Y	58	4	6	52	WV, OH
Cyperus entrerianus	Deeprooted sedge	Graminoid	Y	6	4	2	4	VA, KY
Ehrharta erecta	Panic veldtgrass	Graminoid	N	2	4	0	2	NJ, PA, VA, WV, DE, MD, KY, OH
Genista monspessulana	French broom	Shrub	N	21	4	0	13	PA, OH
Hemarthria altissima	Limpograss	Graminoid	Y	5	4	1	4	WV, KY
Hypochaeris glabra	Smooth cat's ear	Forb/herb	Y	5	4	2	3	NJ
Lantana montevidensis	Weeping lantana	Shrub, subshrub	Y	4	4	1	4	VA
Ligustrum lucidum	Glossy privet	Shrub, tree	N	20	4	0	20	DE, MD, KY
Macrothelypteris torresiana	Swordfern	Forb/herb	N	2	4	0	2	VA
Melia azedarach	Chinaberry	Shrub, tree	Y	12	4	4	8	NJ, WV, DE, MD
Miscanthus sacchariflorus	Amur silvergrass	Graminoid	Y	5	4	1	4	VA, WV, DE, MD, KY, OH
Olea europaea ssp. *cuspidata*	African olive	Shrub, tree	N	1	4	0	1	MD
Phalaris minor	Littleseed canarygrass	Graminoid	Y	8	4	6	2	MD
Pyracantha angustifolia	Narrowleaf firethorn	Shrub	N	3	4	0	3	MD
Rosa bracteata	Macartney rose	Subshrub, vine	Y	5	4	4	1	DE, MD, KY
Tamarix aphylla	Athel tamarisk	Shrub, tree	N	8	4	0	8	NJ, PA, VA, WV, DE, MD, KY, OH
Tamarix chinensis	Fivestamen tamarisk	Shrub, tree	N	30	4	0	30	NJ, DE
Tamarix ramosissima	Saltcedar	Shrub, tree	Y	5	4	1	5	NJ, DE
Tradescantia fluminensis	White-flowered spiderwort	Forb/herb	N	17	4	0	14	VA
Triadica sebifera	Chinese tallowtree	Tree	Y	3	4	1	2	VA
Tripidium ravennae ssp. *ravennae*	Ravennagrass	Graminoid	N	1	4	0	1	VA, WV, MD, OH
Vitex rotundifolia	Beach vitex	Shrub	N	4	4	0	4	PA, DE, MD, KY

[a]EICAT, Environmental Impact Classification for Alien Taxa protocol.

plants is the most commonly studied impact mechanism in invasion science. This is likely due to a combination of both the common presence of competitive impacts as well as the relative feasibility of studying competitive impacts versus, for example, impacts stemming from changes caused by the invader to the physical environment. Thus, managers should interpret absence of an impact mechanism as lack of study/investigation of a potential impact rather than lack of impact.

The proportion of species with major ecological impacts in this study (32 of 104, 31%) was comparable to what was reported by Coville et al. (2021) (24 of 87 species, 28%) but higher than what was reported by Rockwell-Postel et al. (2020) (15 of 100 species, 15%). Although the mid-Atlantic has fewer range-shifting species than New England relative to its land area, the proportion of high-impact species is equivalent or higher than in the more northern regions. This suggests that proactively regulating and monitoring for range-shifting species could be particularly effective in mid-Atlantic states.

In conclusion, the 32 species with reported community-level ecological impacts are of the highest concern for EDRR, and predicting their presence will allow managers to most efficiently combat the threat of invasives while preserving as many resources as possible. Because resources are scarce for land managers (Beaury et al. 2020), prioritizing the most impactful species for management will allow said resources to be used most effectively. With proactive management, these species may be prevented from spreading into the focal states, and the creation of this list of high-impact species can provide a strong example for the creation of invasive species watch lists by future land managers and researchers.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/inp.2023.24

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