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Katherine E. Wyman-Grothem, United States Fish and Wildlife Service, 5600 American Boulevard West, Bloomington, Minnesota 55437

Theresa A. Thom[1], United States Fish and Wildlife Service, 911 NE 11th Avenue, Portland, Oregon 97232

and

Heidi L. Himes, United States Fish and Wildlife Service, 1101 Casey Road, Basom, New York 14013

Scanning the Horizon for Potential Nonnative Aquatic Plant and Algae Arrivals to the Pacific Northwest

Running footer: Aquatic Plant Horizon Scanning

3 tables, 2 figures, 2 supplemental tables (available online only)

[1]Author to whom correspondence should be addressed. Email: theresa_thom@fws.gov

Abstract

To date, the Pacific Northwestern United States has experienced fewer nonnative species introductions than other parts of the country, presenting an opportunity to minimize future harm from invasive species by investing in prevention efforts. Horizon scanning for potential future invasive species provides foundational data for developing efficient prevention and early detection strategies. We gathered more than twenty federal, state, tribal, local government, university, and industry partners to provide input on priority geography, introduction pathways, and taxa for a horizon scan focused on the Pacific Northwestern United States. The scope of this initial effort included submerged or floating aquatic plants and algae that could be introduced to the region via movement of recreational boats. Watercraft inspection data were combined with climate matching analyses to identify "top donor regions" from which submerged or floating aquatic plants were most likely to arrive. We identified five aquatic plants as posing high risk to the Pacific Northwest on the basis of climate match and prior history of invasiveness in other locations: Carolina mosquitofern (*Azolla caroliniana*), crested mosquitofern (*Azolla cristata*), Indian swampweed (*Hygrophila polysperma*), wingleaf primrose-willow (*Ludwigia decurrens*), and water spangles (*Salvinia minima*). Another 21 species pose uncertain risk given available information. These results can be used to inform regulatory actions, improve training, and refine detection tools and strategies on a local, regional, and national level. More broadly, this horizon scan provides a template for future horizon scanning for other geographies, pathways, and taxonomic groups.

Keywords: horizon scan; aquatic invasive species; invasive species prevention

Introduction

The Pacific Northwest region within the United States encompasses ecologically and culturally significant ecosystems including representation of almost every major physiographic region and biome classification found in the United States. This diverse landscape supports thousands of plants and animals including endemic, threatened, endangered, and imperiled species that are closely linked with the religions, cultures, identities, and economies of many Tribal Nations in the Pacific Northwest. However, introductions of nonnative species can alter the structure and function of these ecosystems and threaten the persistence of valued species (e.g., Sanderson et al. 2009, Kuehne et al. 2016).

For regions like the Pacific Northwest, which has experienced few nonnative aquatic species introductions relative to other regions of the conterminous United States (Mangiante et al. 2018), it is especially important to focus resources and attention on prevention of further introductions. Not only does this approach minimize damage to local ecosystems, but the financial costs of preventative actions are also much lower than addressing populations of nonnative species after they have established and caused impacts (Cuthbert et al. 2022).

Horizon scanning serves as the first step toward efficient and effective prevention of nonnative species introductions. Horizon scanning can be defined as the "systematic examination of future threats and opportunities" (Roy et al. 2014, NASEM 2020), with an emphasis on those threats and opportunities that are at the edge of current knowledge and planning. Even in the twenty-first century, approximately a quarter of nonnative species introductions involve species that have not been reported outside their native range previously (Seebens et al. 2018); horizon scanning can help managers plan for these less-anticipated risks. Horizon scanning is used to inform invasive species prevention efforts around the globe (e.g., Roy et al. 2019, Tsiamis et al. 2020, Kenis et al. 2022), and it is the foundation of current efforts by the US Fish and Wildlife Service and other US Federal agencies to develop a national early detection and rapid response framework for aquatic invasive species (AIS).

The objective of the effort presented here was to conduct a horizon scan for freshwater systems in the Pacific Northwestern United States, focused on taxonomic groups and transportation-related introduction pathways prioritized by regional AIS experts and stakeholders. Specifically, the project identified a list of species at risk of arriving in the region via focal pathways, establishing populations, and causing harm. On the guidance of regional AIS experts and stakeholders, this initial horizon scan focused on aquatic plant and algae taxa with potential for introduction via water-based recreational activities.

Methods

We used a phased approach to identify species with potential to arrive, establish, and cause harm in the Pacific Northwest (Figure 1). In order to reduce bias toward familiar species already viewed as threats to the region, this approach emphasized systematic construction of a list of species with introduction potential; species were then prioritized and screened for establishment and harm potential. In Phase I, we assembled a group of AIS researchers and managers working in the Pacific Northwest and asked them to provide input on the scope and focus of the regional horizon scan based on their knowledge of the region and AIS threats. In Phase II, we identified the most likely geographic sources of organisms to the Pacific Northwest within the pathway and taxonomic scope selected by the advisory group. We used a climate matching tool to filter out source locations with low climatic similarity to the Pacific Northwest, and then generated a list of species within the taxonomic scope that were present in the remaining source locations but not in the Pacific Northwest. In Phase III, we prioritized the species list and selected a subset of species to screen for risk of establishment and harm if introduced now or in the future. Each of these phases is described in greater detail in the following sections.

Phase I: Scope Definition

We invited individuals representing federal, tribal, state, and local governments, industry, nongovernmental organizations, and universities to participate in the regional advisory group for the horizon scan. We extended invitations via announcements at regional meetings in fall 2020 and via targeted emails and conversations as needed to increase the breadth of organizational representation.

We held virtual meetings with the advisory group in November 2020 and January 2021 to determine the scope for the horizon scanning effort. Three aspects of scope were addressed through these meetings: the exact boundaries of the area to consider as the "target region" into which species could be introduced, introduction pathways on which to focus horizon scanning efforts, and taxonomic groups of particular concern. Based on limitations of the climate matching methodology (described below), we excluded taxonomic groups that were present only in marine environments. The first meeting of the advisory group introduced the horizon scanning effort and offered group members an opportunity to ask questions and begin discussing the aspects of scope. After the first meeting, we asked advisory group members to answer a series of questions on their priorities for the horizon scan. We used the aggregated responses to these questions to form an initial, informal proposal of scope. At the second meeting of the advisory group, the group heard, discussed, and amended the initial proposal. Finally, we circulated a written proposal reflecting the feedback from the second meeting to check for consensus on focal geography, introduction pathways, and taxonomic groups.

Phase II: Species List Generation

We began the process to generate a species list by assuming that the number of vectors originating at a source location is positively correlated with number of nonnative organisms introduced from that source location (supported by retrospective studies of invasion patterns; Ricciardi 2006, Keller et al. 2009). The states of Washington, Oregon, and Idaho provided annual data from 2018 through 2020 on number and source locations of vectors in the focal introduction pathway. We were unable to obtain similar data from Montana within the time frame of this project. Vector source locations were aggregated by state (within the United States) or country (outside the United States); these aggregate source locations are hereafter referred to as “donor regions.” Because effort to collect these data was not standardized across jurisdictions, we ranked donor regions according to vector volume within jurisdictions, and then we averaged the ranks across jurisdictions.

To focus on donor regions most likely to host nonnative species with potential for establishment in the Pacific Northwest, we estimated the climatic similarity between each donor region and the Pacific Northwest target region using the USFWS Risk Assessment Mapping Program version 3.1 (RAMP; Sanders et al. 2018, USFWS 2019). RAMP employs the CLIMATCH algorithm (Crombie et al. 2008) to calculate climate match based on WorldClim version 1.4 climate data (Hijmans et al. 2005). The CLIMATCH algorithm is simple, repeatable, and capable of predicting species establishment across a variety of taxa (Duncan et al. 2001; Baker and Bomford 2009; Bomford et al. 2009, 2010). All RAMP climate stations within the geographic boundaries of the donor region were used as source locations for that donor region. The target region for RAMP analysis included all RAMP climate stations within the geographic boundaries of the horizon scan target region. Donor regions for which > 5% of target climate stations scored 6 or higher out of 10 (indicating that establishment is more likely than not, a "medium" or "high" match; Bomford et al. 2010) were included in the next step of this phase.

We used species occurrence data from the Global Biodiversity Information Facility (GBIF.org 2021) and the US Geological Survey's BISON database (BISON 2021) to generate a list of species within the focal taxa present in each climate-matched donor region. Similarly, we generated a separate list of species within the focal taxa present in the target region (see Supplemental Table S1, available online only, for Digital Object Identifiers for all occurrence data downloads). Species names were verified with World Flora Online (2021) to remove synonyms and misspellings. To maintain focus on future threats to the Pacific Northwest as a whole, any species with known records of occurrence in the Pacific Northwest target region according to BISON (2021) were excluded from the final species list.

Queries of GBIF and BISON databases were accomplished in Program R (R Core Team 2020) using the 'rgbif' (Chamberlain et al. 2021) and 'rbison' (Chamberlain 2020) packages, respectively. The packages 'stringr' (Wickham 2019) and 'dplyr' (Wickham et al. 2020) were used for data processing, and packages 'WorldFlora' (Kindt 2020) and 'taxizedb' (Chamberlain and Arendsee 2021) were used for taxonomic verification with World Flora Online (2021).

Phase III: Risk Screening

During the advisory group meetings, we asked for input on conditions and characteristics to use in prioritizing species for risk screening during Phase III. We obtained information on species occurrences, traits, and human uses from a variety of online databases (Winterton et al. 2018, CABI 2021, EPPO 2021, GBIF.org 2021, USGS 2021) for the species on our list from Phase II. We excluded any species found only in marine environments and then sorted the remaining species into priority tiers based on the advisory group's recommendations.

Individual species risk screening was conducted on a subset of priority species using the USFWS Ecological Risk Screening Summary (ERSS) tool (Marcot et al. 2019, USFWS 2020). The ERSS methodology classifies a species as high risk to the contiguous United States if it has a documented history of establishment and harm to native species, the ecosystem, human health, or the economy outside its native range and if the RAMP climate match of the species' current range to the contiguous United States shows > 5% of target climate stations scoring 6 or higher out of 10 (Bomford et al. 2010). Although it does not affect the overall risk screening outcome for the contiguous United States, the ERSS also reports the names of individual states where the threshold of > 5% of target climate stations scoring 6 or higher is met. ERSS reports are published online by the US Fish and Wildlife Service (USFWS 2023).

To estimate future establishment potential under a changing climate, ERSS climate change supplements were also written for the subset of priority species, following USFWS (2020). As with current climate matching, future climate matching was conducted with RAMP (Sanders et al. 2018, USFWS 2019). Six future climate scenarios were considered, representing all possible combinations of two time periods (years 2041–2060 ["2050"] and 2061–2080 ["2070"]) and three Representative Concentration Pathways (RCP2.6, RCP4.5, and RCP8.5; IPCC 2013). RAMP uses the Geophysical Fluid Dynamics Laboratory's coupled model (GFDL-CM3; Donner et al. 2011, Griffies et al. 2011) as the general circulation model for future climate predictions.

Results

Phase I: Scope Definition

A total of 35 individuals representing 24 entities (including federal, tribal, state, and local government, industry, and universities; listed in the Acknowledgments) participated in the advisory group to determine horizon scan scope. The advisory group reached consensus on a target region for this US-focused horizon scan that encompassed the states of Washington, Oregon, Idaho, and the portion of Montana within the Columbia River basin (Figure 2). As the focal pathway for the horizon scan, the group selected recreational boating; this pathway was a priority for over three quarters of advisory group members while the next most commonly prioritized pathway (commercial shipping) was mentioned by one third of the members. The taxonomic scope for the horizon scan included the following floating and submergent plant and algae families and genera: families Cabombaceae (watershields), Characeae (stoneworts), Hydrocharitaceae (tape-grasses and frogbits), Haloragaceae (watermilfoils), and Salviniaceae (water ferns); and genera *Ceratophyllum* (hornworts; family Ceratophyllaceae), *Hygrophila* (swampweeds; family Acanthaceae), and *Ludwigia* (water primroses; family Onagraceae). Reasons stated for the interest in aquatic plants and algae included historical impacts in the Pacific Northwest, potential for rapid spread, management challenges, and potential for causing large-scale ecosystem change.

Phase II: Species List Generation

Boat inspection data from 2018 through 2020 included over 90,000 inspections conducted in Idaho, over 33,000 inspections conducted in Oregon, and close to 14,000 inspections conducted in Washington. The top five donor regions were the same for all three jurisdictions: Montana (excluding the Columbia River basin), California, Utah, Arizona, and Wyoming (Table 1).

Twelve of the top 15 donor regions met the climate match threshold with the Pacific Northwest. Within the focal taxa, 123 species were reported in at least one climate-matched donor region but not in the target region: 54 species in family Characeae, 27 species in genus *Ludwigia*, 13 species each in families Hydrocharitaceae and Haloragaceae, 8 species in family Salviniaceae, 4 species in family Cabombaceae, 3 species in genus *Hygrophila*, and one species in genus *Ceratophyllum* (Supplemental Table S2, available online only).

Phase III: Risk Screening

ERSS reports already existed for 7 of the 123 species on the species list from Phase II. To select species for new risk screening from the remaining 116 species on the list, the advisory group prioritized those that had past history of introduction, were present in one or more trade pathways (separate from presence in the recreational boating pathway), or had a broad geographic range. Based on these factors, 20 species were prioritized for new risk screening: 13 species on the basis of both known history of introduction and known trade history, 6 species on the basis of a known history of introduction and presence on at least 4 continents, and one species on the basis of known history of introduction, presence on 3 continents, and special interest expressed by members of the advisory group. Therefore, the results discussed below reflect findings from 27 ERSS reports, 20 of which were written as part of this horizon scan and 7 of which were written previously but are still applicable.

Risk screening identified 6 species posing high risk to the contiguous United States within the focal aquatic plant and algae families due to climate match and history of invasiveness. Five of these species (Carolina mosquitofern [*Azolla caroliniana*], crested mosquitofern [*A. cristata*], Indian swampweed [*Hygrophila polysperma*], wingleaf primrose-willow [*Ludwigia decurrens*], and water spangles [*Salvinia minima*]) showed a current climate match to one or more states within the Pacific Northwest United States target region (Table 2). Under future climate projections, suitable climate was predicted to expand to additional states for wingleaf primrose-willow and water spangles. Although the ERSS for forked fanwort (*Cabomba furcata*) showed high risk to the contiguous United States as a whole, the species had a low climate match to the Pacific Northwestern United States under both current conditions and future projections. Twenty-one species had uncertain overall risk classifications due to lack of documented introductions or impacts of introduction (Table 3). For 11 species, current climate conditions were predicted to be suitable for establishment within one or more states within the target region. Climate conditions were predicted to become suitable for establishment of 3 additional species by 2080 under one or more future climate scenarios.

Discussion

Horizon scanning for future nonnative aquatic plant and algae threats to the Pacific Northwestern United States via the recreational boating pathway identified 5 species with documented history of invasiveness (nonnative establishment and harm) and medium or high climate match within the region (Table 2). An additional 14 nonnative aquatic plant species without documented history of invasiveness were predicted to have suitable climate match to the region currently or under future climate scenarios (Table 3). Recreational boats, as potential vectors for the introduction of these nonnative aquatic plant species, were most likely to come from surrounding states, all of which have portions that were well-matched climatically with portions of the Pacific Northwestern United States (Table 1).

Of the high-risk species identified through this process, water spangles poses perhaps the most immediate risk to the Pacific Northwestern United States. The species is established in five drainages in southern California (USGS 2021), its small size facilitates inadvertent spread, multiple introduction pathways exist, and it can have a significant impact on the structure and function of aquatic habitats (Jacono et al. 2001, Stallings et al. 2015). The other species with high-risk ERSS outcomes are less concerning when considering only the recreational boating introduction pathway, but each is also present in at least two other introduction pathways (Table 2). Wingleaf primrose-willow is the only other high-risk species known to be currently established in one of the top five donor regions of recreational boats arriving in the Pacific Northwestern United States. It has not yet been reported from the recreational boating pathway, but the potential for its seeds to be spread via equipment used in rice agriculture (Chandrasena 1988) suggests that spread is possible via vehicles used in infested waters. The remaining high-risk species (Carolina mosquitofern, crested mosquitofern, and Indian swampweed) are not currently established in the western United States (with the possible exception of the mosquitoferns which are extremely difficult to identify; Madeira et al. 2016) and thus are less likely to enter the Pacific Northwest in the near future via overland transport of recreational boats. However, their presence in ornamental trade provides another primary introduction pathway into the region or into one of the top donor regions, at which point recreational boats could play a role in their spread.

Management agencies may also want to consider potential prevention measures for several of the species classified as uncertain risk (Table 3). The risk screening tool we used in Phase III demands robust documentation of impacts to classify a species as high risk rather than uncertain

(USFWS 2020), but risk tolerance varies. For example, the breadth and severity of potential impacts of starry stonewort (*Nitellopsis obtusa*) has led to significant investments in research and control in the North American Great Lakes region despite limited peer-reviewed findings of impacts (Larkin et al. 2018, Kipp et al. 2022).

This work does not address all potential threats from the recreational boating pathway. In line with the definition of horizon scanning (Roy et al. 2014, NASEM 2020), we targeted the edge of current awareness by focusing on species not yet detected in the Pacific Northwest. We assumed that management agencies have a baseline awareness of reported detections. However, we acknowledge that species already present within the Pacific Northwest may be repeatedly transported into the region on recreational boats in addition to spreading within the region. Potential next steps for AIS managers, policy-makers, and researchers in the Pacific Northwest include developing and improving training resources, refining detection tools and strategies, considering the appropriateness of policy restrictions, and conducting further risk analysis. This horizon scanning process identified several species that may pose a risk for invasion, although additional information is needed. As lack of information does not denote absence of threat, these species should undergo more thorough assessments and potentially receive research priority to address data gaps, develop early detection strategies, and inform policy. The standardized horizon scanning process described here can be repeated for additional taxa, pathways, or geographic regions as a foundational step toward preventing impacts of new invasive species to the unique habitats within the Pacific Northwest and elsewhere.

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Figure Captions

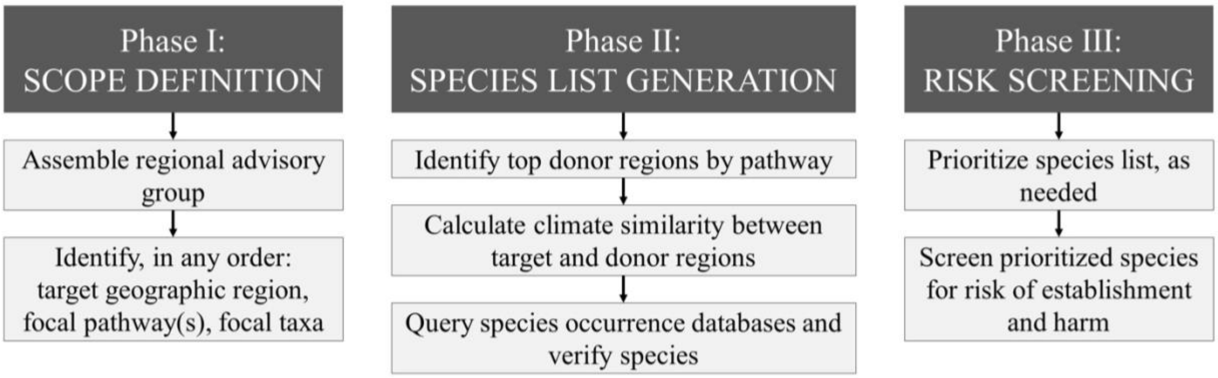

Figure 1. Diagram of the process used to identify nonnative aquatic species with potential for introduction, establishment, and harm in the Pacific Northwest.

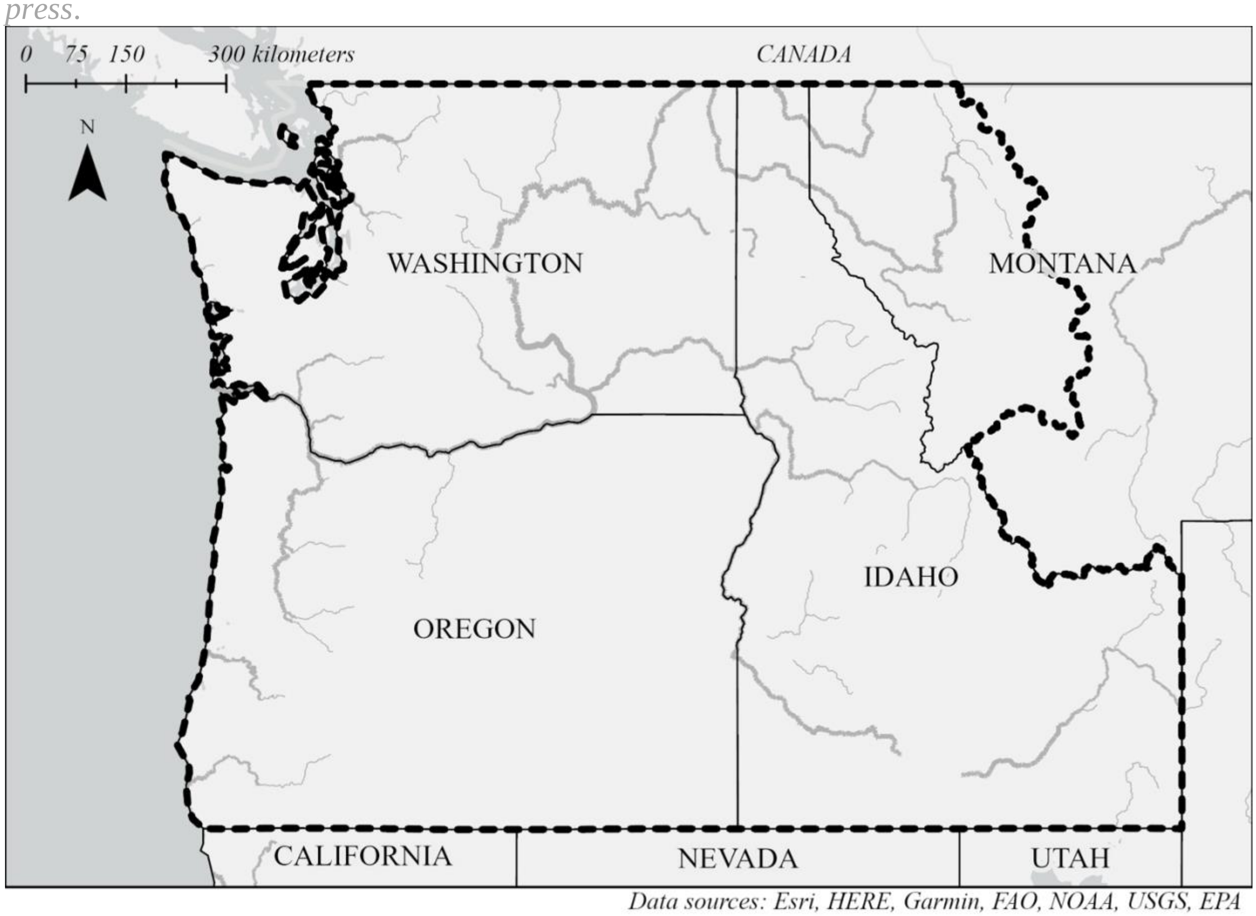

Figure 2. Map of the Pacific Northwest region of the contiguous United States showing the geographic scope of the regional horizon scan (black dotted line; Washington, Oregon, Idaho, and the Columbia River basin within Montana). Gray lines indicate the locations of major US rivers. Map created in ArcGIS Pro version 2.9.9 (Esri, Redlands, CA).

TABLE 1. Top 15 source jurisdictions of recreational boats traveling into the Pacific Northwest and their degree of climatic similarity to the Pacific Northwest. Ranks were determined by ranking source jurisdictions individually for three states in the target region (Washington, Oregon, and Idaho) according to number of arriving boats recorded in 2018–2020, and then averaging ranks across the three states. The climate match category was determined based on the Climate 6 score, which is calculated as the proportion of target points in the climate matching analysis that score at least 6 out of 10 for climatic similarity to the climate within the source jurisdiction. Scores ≤ 0.005 were classified as low; scores > 0.005 and < 0.103 were classified as medium; scores ≥ 0.103 were classified as high.

Rank	Source jurisdiction	Climate 6 score	Climate match category
1	Montana[1]	0.096	Medium
2	California	0.688	High
3	Utah	0.749	High
4	Arizona	0.654	High
5	Wyoming	0.320	High
6	Colorado	0.219	High
7	British Columbia	0.755	High
8	Nevada	0.649	High
9	Minnesota	0.000	Low
10	Florida	0.000	Low
11	Michigan	0.028	Medium

12	Alberta	0.094	Medium
13	Texas	0.000	Low
14	Wisconsin	0.014	Medium
15	Mexico	0.072	Medium

[1]Excludes portion of Montana located within the Columbia River basin. This portion of Montana was included in the target region of introduction for the horizon scan.

TABLE 2. Aquatic plant species from the Pacific Northwest horizon scan species list classified as high risk to the contiguous United States, using the US Fish and Wildlife Service's Ecological Risk Screening Summary tool. For all species in this table, there is documentation of harm caused by establishment of the species outside its native range, and the certainty of the assessment is classified as "high." Individual state climate match classification as medium or high was calculated with the Risk Assessment Mapping Program (Sanders et al. 2018) and indicates that, with respect to climate, establishment is more likely than not (Bomford et al. 2010, USFWS 2019). State abbreviations in brackets indicate that the climate match was not classified as medium or high under current conditions but was predicted to become medium or high under at least some future climate scenarios (see Methods for further information). Introduction pathway abbreviations: ag = agricultural trade or practices, fl = natural spread via flooding, or = ornamental trade, sh = commercial shipping, wi = natural spread via wildlife.

Species	Medium or high climate match	Recreational boating pathway	Other known pathways
Azolla caroliniana (Carolina mosquitofern)	ID, MT, OR, WA	Yes	ag, or
Azolla cristata (crested mosquitofern)	ID, MT, OR, WA	Yes	ag, fl, or, wi
Cabomba furcata (forked fanwort)	None	No	fl, or
Hygrophila polysperma (Indian swampweed)	WA	Yes	or, wi

Ludwigia decurrens (wingleaf primrose-willow	OR, WA [ID, MT]	No	ag, fl
Salvinia minima (water spangles)	OR, WA [ID, MT]	Yes	fl, or, sh

TABLE 3. Aquatic plant species from the Pacific Northwest horizon scan species list classified as uncertain risk to the contiguous United States, using the US Fish and Wildlife Service's Ecological Risk Screening Summary tool. Individual state climate match classification as medium or high was calculated with the Risk Assessment Mapping Program (Sanders et al. 2018) and indicates that, with respect to climate, establishment is more likely than not (Bomford et al. 2010, USFWS 2019). State abbreviations in brackets indicate that the climate match was not classified as medium or high under current conditions but was predicted to become medium or high under at least some future climate scenarios (see Methods for further information).

Species	Nonnative establishment	Medium or high climate match	Certainty
Azolla pinnata (feathered mosquitofern)	Yes	ID, OR, WA [MT]	Medium
Cabomba aquatica (giant cabomba)	Yes	None	Low
Cabomba haynesii (fishgrass)	No	None	Low
Elodea callitrichoides (South American waterweed)	Yes	WA	Low
Hygrophila costata (lake hygrophila)	Yes	[MT]	Low
Limnobium spongia (American spongeplant)	No	None	Low
Ludwigia adscendens (water primrose)	Yes	[MT]	Low
Ludwigia erecta (yerba de jicotea)	Yes	[ID, OR, WA]	Low
Ludwigia helminthorrhiza	Yes	None	Low
Ludwigia perennis	No	ID, OR, WA [MT]	Low

Ludwigia repens (creeping primrose-willow)	Yes	ID, MT, OR, WA	Low
Ludwigia sedioides (mosaic plant)	Yes	None	Low
Ludwigia suffruticosa (shrubby primrose willow)	No	None	Low
Myriophyllum pinnatum (cutleaf watermilfoil)	Yes	ID, MT, OR, WA	Low
Najas graminea (ricefield waternymph)	Yes	OR, WA [ID, MT]	Low
Nitellopsis obtusa (starry stonewort)	Yes	ID, MT, WA	Low
Ottelia alismoides (ducklettuce)	Yes	MT [ID]	Low
Salvinia auriculata (eared watermoss)	Yes	None	Low
Salvinia natans (floating watermoss)	Yes	ID, MT, OR, WA	Low
Stratiotes aloides (water soldiers)	Yes	ID, MT, OR, WA	Low
Vallisneria spiralis (tape grass)	Yes	ID, MT, OR, WA	Low

TABLE S1. Digital Object Identifiers (DOI) for occurrence datasets downloaded from GBIF.org (2021) via Program R (R Core Team 2020) and the 'rgbif' package (Chamberlain et al. 2021) and used in horizon scanning for potential nonnative aquatic plant and algae arrivals to the Pacific Northwest. All datasets were downloaded between 16 and 17 February 2021.

Plant taxon	Country	DOI
Cabombaceae	Canada	10.15468/dl.8cwhmu
	Mexico	10.15468/dl.tu2ed2
	US	10.15468/dl.77eexz
Ceratophyllum	Canada	10.15468/dl.jfeqzj
	Mexico	10.15468/dl.spwcf8
	US	10.15468/dl.vcp6as
Characeae	Canada	10.15468/dl.9cjzjy
	Mexico	10.15468/dl.7jw6fw
	US	10.15468/dl.m67d9n
Haloragaceae	Canada	10.15468/dl.2nte6q
	Mexico	10.15468/dl.nd4af8
	US	10.15468/dl.x7adus
Hydrocharitaceae	Canada	10.15468/dl.cqxjxp
	Mexico	10.15468/dl.wy4zcu
	US	10.15468/dl.5tngze
Hygrophila	Canada	10.15468/dl.38jfcz

	Mexico	10.15468/dl.fcnmqf
	US	10.15468/dl.hr2rdk
Ludwigia	Canada	10.15468/dl.3a2bjr
	Mexico	10.15468/dl.65cvnb
	US	10.15468/dl.yaj553
Salviniaceae	Canada	10.15468/dl.wrbrmt
	Mexico	10.15468/dl.p6mzjp
	US	10.15468/dl.yar3zj

TABLE S2. Full list of species reported from climate-matched donor regions (based on volume of recreational boat traffic) but not from the Pacific Northwestern United States, obtained through the horizon scanning process. Species occurrence data from GBIF.org (2021; Supplemental Table S1) and BISON (2021). Accepted species names verified with World Flora Online (2021).

Family	Species
Acanthaceae[1]	*Hygrophila costata, H. polysperma, H. ringens*
Cabombaceae	*Cabomba aquatica, C. furcata, C. haynesii, C. paliformis*
Ceratophyllaceae[2]	*Ceratophyllum muricatum*
Characeae	*Chara aculeolata, C. carmenensis, C. diaphana, C. drouetii, C. elegans, C. fibrosa, C. filiformis, C. foetida, C. foliolosa, C. formosa, C. gymnopus, C. haitensis, C. hirta, C. hornemannii, C. inconstans, C. intermedia, C. kenoyeri, C. leptospora, C. longifolia, C. morongii, C. nitelloides, C. papulosa, C. polyacantha, C. sanctae-margaritae, C. schweinitzii, C. sejuncta, C. verrucosa, C. virgata, C. zeylanica, Lychnothamnus barbatus, Nitella acuminata, N. asagrayana, N. axillaris, N. californica, N. cernua, N. furcata, N. glaziovii, N. greenii, N. hyalina, N. intermedia, N. megacarpa, N. macrocarpa, N. minuta, N. obtusa, N. opaca, N. praelonga, N. subglomerata, N. tenuissima, N. translucens, Nitellopsis obtusa, Tolypella canadensis, T. intertexta, T. intricata, T. nidifica*

Haloragaceae	*Haloragis erecta, Myriophyllum alterniflorum, M. farwellii, M. humile, M. magdalense, M. mexicanum, M. pinnatum, M. propinquum, M. sibiricum, M. tenellum, Proserpinaca intermedia, P. palustris, P. pectinata*
Hydrocharitaceae	*Elodea callitrichoides, Enhalus acoroides, Halophila decipiens, H. engelmannii, Limnobium spongia, Najas arguta, N. gracillima, N. graminea, N. wrightiana, Ottelia alismoides, Stratiotes aloides, Thalassia testudinum, Vallisneria spiralis*
Onagraceae[3]	*Ludwigia adscendens, L. affinis, L. alternifolia, L. apetala, L. bonariensis, L. brenanii, L. decurrens, L. erecta, L. foliobracteolata, L. helminthorrhiza, L. hyssopifolia, L. inclinata, L. leptocarpa, L. linearis, L. linifolia, L. natans, L. nervosa, L. perennis, L. polycarpa, L. prostrata, L. repens, L. rigida, L. sedioides, L. stricta, L. suffruticosa, L. tepicana, L. torulosa*
Salviniaceae	*Azolla caroliniana, A. cristata, A. pinnata, Salvinia adnata, S. auriculata, S. minima, S. natans, S. sprucei*

[1]Genus *Hygrophila* only.

[2]Genus *Ceratophyllum* only.

[3]Genus *Ludwigia* only.

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