U.S. Fish & Wildlife Service

Mosquito Fern (*Azolla pinnata*)

Ecological Risk Screening Summary

U.S. Fish and Wildlife Service, November 2023
Revised, April 2024
Web Version, 3/11/2025

Organism Type: Fern
Overall Risk Assessment Category: High

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1 Native Range and Status in the United States

Native Range

From CABI (2023):

"*A. pinnata* is locally distributed in its native range of Africa and Madagascar, India, Southeast Asia, China and Japan, Malaysia and the Philippines, the New Guinea mainland and Australia (Croft, 1986)."

From WFO (2023):

"Widespread in tropical Africa as far south as South West [sic] Africa/Namibia, Botswana and Natal [KwaZulu-Natal, South Africa]."

GISD (2023) lists the following as the native range of *Azolla pinnata*: Africa, Australia, China, India, Japan, Madagascar, Malaysia, Papua New Guinea, Philippines, South East Asia, Vietnam.

Status in the United States

According to Pfingsten et al. (2023), nonindigenous occurrences of *Azolla pinnata* have been reported in the following U.S. states, with range of observation years, number of watersheds (8-digit hydrologic unit), and population status where reported (one or more watersheds) in parentheses:

- Arizona (2002; 2; Unknown)
- Florida (2007-2023; 7; Established)
- Hawaii (2017; 1; Established)
- Louisiana (2009; 1; Unknown)

From Pfingsten et al. (2023):

"Established in three drainages in Florida; status is unknown in Arizona and Louisiana."

"*Azolla pinnata* was discovered in nursery tanks in Idaho (Thomas Woolf, ID Dept. of Ag., pers. comm.) and North Carolina (Stratford Kay, NCSU, pers. comm.) and quickly removed. There are no established populations in waterbodies in those states."

From Kay and Hoyle (2001):

"In October of 1999, an odd-appearing mosquito fern was collected by S. H. Kay at a wetland nursery in Raleigh, NC. This mosquito fern was identified tentatively as *Azolla pinnata* R. Brown (a Federal Noxious Weed), and the identity was later confirmed (author's unpublished data). Both of these plants [*Salvinia molesta* and *Azolla pinnata*] have been listed for sale in catalogs and have been found in nurseries in several states."

Multiple international sources have listed *Azolla pinnata* for sale and provide shipping to the United States. *Azolla pinnata* is commonly misidentified as duckweed (*Lemnoideae* spp.) (Wisconsin Department of Natural Resources 2023), a plant species that is commonly found in the aquarium pond trade.

Fair Dinkum Seeds (2023) lists *Azolla pinnata* for sale at $20.00 for 30 grams or 1 ounce under the name "Water Fern Azolla Pinnata Duckweed Culture."

DMV Nursery and Gardens (2023) lists "*Azolla pinnata*" for $4.99 per 50 individual plants.

Regulations

A. pinnata is listed as a federal noxious weed (U.S. Department of Agriculture 2016).

A. pinnata is regulated at the state level in Idaho (IDDA 2022), Illinois (Illinois DNR 2015), Indiana (Indiana DNR 2022), Massachusetts (MDAR 2022), North Carolina (North Carolina DEQ 2022), Oklahoma (ODWC 2022), South Carolina (SCDNR 2010), West Virginia (WVDA 2022), and Wisconsin (Wisconsin DNR 2022). Please refer back to state agency regulatory documents for details on the regulations, including restrictions on activities involving this species. While effort was made to find all applicable regulations, this list may not be comprehensive. Notably, it does not include regulations that do not explicitly name this species or its genus or family, for example, when omitted from a list of authorized species with blanket regulation for all unnamed species.

Means of Introductions within the United States

From Pfingsten et al. (2023):

"The main pathway in the U.S. is hitchhiking with ornamental pond or aquarium plants (Kay and Hoyle 2001)."

Remarks

This ERSS was previously published in July 2021. Revisions were completed to incorporate new information and conform to updated standards.

Taxonomy of the *Azolla* genus is complicated and has undergone many revisions. The authority used for plant species in these screenings, World Flora Online, recognizes *Azolla pinnata* as a valid species with the following recognized subspecies: *A. pinnata* ssp. *africana*, *A. pinnata* ssp. *asiatica*, and *A. pinnata* ssp. *pinnata* (WFO 2023). These names were used to search for information for this screening.

From Pfingsten et al. (2023):

"The common name, mosquito fern, may originate from the use of *Azolla* as a measure to prevent mosquito reproduction in Europe and the United States by covering the water surface (Moore 1969)."

"**Look-a-likes:** *Azolla microphylla* (*A. caroliniana*) Mexcian mosquitofern, *A. pinnata* ssp. *africana*, and *A. pinnata* ssp. *asiatica*. *Azolla pinnata* differs from native *Azolla* species by the triangular leaf arrangement, and *A. pinnata* ssp. *pinnata* differs morphologically from other non-native subspecies of *Azolla pinnata* by having unicellular rhizome papillae and an elliptical dorsal lobe shape (Pereira et al. 2011, Madeira et al. 2013). *Azolla pinnata* populations in Florida were also determined to be genetically similar to *A. pinnata* ssp. *pinnata* populations in Australia (Madeira et al. 2013)."

From Gupta and Beentje (2018):

"There are three subordinate taxa of *Azolla pinnata* depending on the range of occurrence. *Azolla pinnata africana* is found Africa, *A pinnata asiatica* in Asia and *A pinnata pinnata* in Oceania."

From Wisconsin Department of Natural Resources (2023):

"Mosquito fern can often be mistaken for the similar-looking species duckweed (*Lemnoideae* spp.)"

From Center for Aquatic and Invasive Plants (2023):

"*Stenopelmus rufinasus*, a weevil native to Florida, is a specialist herbivore on North American mosquito ferns (*Azolla* spp.). This weevil has adopted *Azolla pinnata* as a source of food, which may prove useful as a control agent."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2023):

Kingdom Plantae
Subkingdom Viridiplantae
Infrakingdom Streptophyta
Superdivision Embryophyta
Division Tracheophyta
Subdivision Polypodiophytina
Class Polypodiopsida
Subclass Polypodiidae
Order Salviniales
Family Salviniaceae
Genus *Azolla* Lam.
Species *Azolla pinnata* R. Br.

According to WFO (2023), *Azolla pinnata* is the current valid name for this species.

Size, Weight, and Age Range

From WFO (2023):

"Stems densely pinnate, forming triangular outline for the whole plants, 1–3 cm long. Leaves less than 1 mm long […]. Roots up to 5 cm long, bearing root-hairs."

"Rhizome horizontal, minutely papillate, up to 20 x 0.2 mm; roots […] up to 35 mm long with long conspicuous root-cap. Upper leaf lobe ovate to broadly elliptic, up to 1.1 mm long […]."

From Pfingsten et al. (2023):

"**Size:** 1.5-2.5 cm long, 1-1.5 cm wide (Sweet and Hills 1971)"

Environment

From Pfingsten et al (2023):

"It tolerates salt concentrations up to 30 m*M* [millimolar], but can be preincubated in lower concentrations to increase salinity tolerance up to as high as 60 m*M* (Rai and Rai 1999)."

From CABI (2023):

"[…] Nitrogen levels are relatively unimportant for growth of *Azolla*, although growth rates are higher in eutrophic conditions."

From de Silva et al. (2022):

"The growth conditions that achieved the highest growth rate of 0.321 day^{-1} were high light intensity, 90% humidity, nitrogen, and pH control. A higher light intensity resulted in higher growth rates. The presence or absence of nitrogen generally produced similar growth rates. The pH control had the greatest effect at high humidity and reduced algae formation, thus improving the health of the plants and increasing the growth rate. Overall, the study concluded that higher humidity values increased the plant growth rate but needed to be used in conjunction with pH control."

From Wisconsin Department of Natural Resources (2023):

"It has been found that decreasing the amount of phosphorous in the affected waterbody will limit the growth potential of mosquito fern. An abundance of phosphorous, an essential mineral for the growth of mosquito fern, can enter a waterbody in several ways but typically is contributed via run-off from agricultural areas."

Climate

From Pfingsten et al. (2023):

"*Azolla pinnata* grows optimally between 29-33ºC, although only subspecies *asiatica* was studied (Watan[a]be and Berja 1983)."

From Gupta and Beentje (2018):

"This species is fairly common in tropical regions of the world."

Gupta and Beentje (2018) list a lower elevation limit of 0m and an upper elevation limit of 1800m.

From CABI (2023):

“In New Guinea the altitudinal distribution falls into two disjunct ranges: lowland populations at 3-60 m altitude; and highland populations at 1000-3000 m altitude. However, there is no obvious difference between plants from the highlands and those from the lowlands (Croft, 1986).”

CABI (2023) lists the absolute minimum air temperature as 4°C, the mean annual air temperature with a lower limit of 14°C and upper limit of 23°C, the mean maximum air temperature of the hottest month with a lower limit of 14°C and upper limit of 35°C, and the mean minimum air temperature of the coldest month with a lower limit of 12°C and upper limit of 29°C.

From Wisconsin Department of Natural Resources (2023):

“Mosquito fern cannot survive prolonged periods of freezing temperatures, so typically perennial growths of mosquito fern occur in regions protected from protracted freezing.”

Distribution Outside the United States

Native

From CABI (2023):

“*A. pinnata* is locally distributed in its native range of Africa and Madagascar, India, Southeast Asia, China and Japan, Malaysia and the Philippines, the New Guinea mainland and Australia (Croft, 1986).”

From WFO (2023):

“Widespread in tropical Africa as far south as South West [sic] Africa/Namibia, Botswana and Natal [KwaZulu-Natal, South Africa].”

GISD (2023) lists the following as the native range to *Azolla pinnata*: Africa, Australia, China, India, Japan, Madagascar, Malaysia, Papua New Guinea, Philippines, South East Asia, Vietnam.

Introduced

According to CABI (2023), *Azolla pinnata* is introduced and invasive in New Zealand.

FAO (2023) lists *Azolla pinnata* as introduced and established in the Cook Islands as well as New Zealand.

Azolla pinnata is listed as introduced and now rare or extirpated in the Marshall Islands (Vander Velde 2003 in PIER 2011). It is listed as introduced, invasive, and naturalized in Singapore (Chong et al. 2009 in PIER 2011).

From Lumpkin and Plucknett (1980):

"In the 19th century, it [*Azolla filiculoides*] was reintroduced into western Europe, along with *A. caroliniana* and *A. pinnata* […] (Saccardo, 1892; Marsh, 1914; Chevalier, 1926; Sculthorpe, 1967) […]"

No further information was found on the status of *Azolla pinnata* in Europe.

According to Fabricante and de Siqueira Filho (2012), *Azolla pinnata* has been recorded as a present exotic species in Brazil.

Means of Introduction Outside the United States

From Pfingsten et al. (2023):

"In other countries [other than the Unites States] it has also been introduced by farmers to help fertilize rice fields and control mosquito populations (Moore 1969; Lumpkin and Pucknett 1980; Holm et al. 1997)."

From Lumpkin and Plucknett (1980):

"In the 19th century, it [*Azolla filiculoides*] was reintroduced into western Europe, along with *A. caroliniana* and *A. pinnata*, as an ornamental (Saccardo, 1892; Marsh, 1914; Chevalier, 1926; Sculthorpe, 1967) […]"

Short Description

From WFO (2023):

"Stems densely pinnate, forming triangular outline for the whole plants, 1–3 cm long. Leaves less than 1 mm long, purplish to reddish in old ones; upper surface densely papillose, with semitransparent cartilaginous membrane at margin. Roots up to 5 cm long, bearing root-hairs."

"Rhizome horizontal, minutely papillate, up to 20 x 0.2 mm; roots in fascicles of 2-3, hairy, up to 35 mm long with long conspicuous root-cap. Upper leaf lobe ovate to broadly elliptic, up to 1.1 mm long, papillate chlorophyllous central portion surrounded by hyaline border; lower leaf lobe similar in size but hyaline. Megasporocarps with prominent dark apex and containing a single granular megaspore surmounted by numerous massulae. Microsporocarps borne singly or subtended by a megasporocarp, only partly covered by a hyaline lower leaflet, spherical, with minute dark apex and containing numerous long-stalked microsporangia; massulae with few or no weak outgrowths."

From Pfingsten et al. (2023):

"**Stem/Rhizoids:** *Azolla pinnata* is a free floating aquatic plant typically found in clusters or in large mats (Bodle 2008). Each plant is 1-2.5 cm in diameter with a feathered triangular shape; midsection is typically straight with pinnately arranged side branches that are longer towards their base (Sweet and Hills 1971; Saunders and Fowler 1992)."

“**Leaves:** Each leaf is 1-2 mm long and overlap in a two-ranked pattern (Pereira et al. 2011).”

“Color ranges from green to maroon-red. Red hues form when anthocyanin is produced as a reaction to unfavorable pH, temperature, moisture or nutrient availability (Holm *et al.* 1997).”

Biology

From Pfingsten et al. (2023):

“Plants reproduce vegetatively and sexually. Vegetative fragments form when the main axis deteriorates and lateral branches break free (Rao 1935; Shen 1960; Lumpkin 1983). When reproducing sexually, round sporocarps (1-1.5 mm in diameter) form on the underside of the leaves (Rao 1935; Shen 1960; Lumpkin 1983).”

“Upper lobes of *A. pinnata*'s leaves are host to a cyanobacteria symbiont that fixes atmospheric nitrogen (Strasburger 1873; Moore 1969; Wagner 1997). It is sometimes introduced by rice farmers as a natural fertilizer for this reason (Lumpkin and Plucknett 1980). Typical habitats are wind-protected, slow-moving waters, such as ponds, small lakes, swamps, wetlands or drainage canals (Svenson 1944).”

From CABI (2023):

“Growth occurs all year round in tropical and sub-tropical areas. Reproduction by spores is often triggered by crowding, as is a change to red coloration, although there is no definitive link between sporulation and colour change. Fronds divide vegetatively, with doubling possible every 3 days, leading to very rapid growth rates and colonization of new lakes and ponds. Development of the red coloration of *A. pinnata* is also promoted by phosphorus starvation (Nirmala Gunapala and Amarasiri, 1983). The upper surfaces of the leaves are totally water repellent and, if completely submerged, the plants quickly refloat with the right side up (Croft, 1986). Deoxyanthocyanins are present in *A. pinnata* and act as a feeding deterrent to molluscs (Cohen et al., 2002a).”

“Vegetative reproduction is by fragmentation of the fronds. Sexual reproduction leads to the formation of spores that are released into the water. *Azolla* is heterosporous, a clear adaptation to an aquatic environment. Sporangia are borne in sporocarps, usually paired micro- and megasporocarps, borne in the axils of the submerged lobes, basally on the branches, quite enclosed by a thin indusium. The microsporocarp is large, globose, containing several to many globose microsporangia, each containing 32-64 microspores. The megasporocarp is smaller, containing a single megasporangium with a single megaspore. Spores are globose, trilete, smooth to variously pitted or sculptured. Microspores are imbedded in the outer edge of several mucilaginous masses (massulae) in the microsporangium, the massulae bearing several to many, hooked (glochidiate) or non-hooked, septate or non-septate processes on one or all sides. Megaspores have three or nine apical massulae or 'floats'.”

"A feature of the genus is the symbiotic association of the cyanobacterium *Anabaena azollae*. This alga lives endophytically in the inter-cellular spaces of basal leaves of *Azolla*. Atmospheric nitrogen is fixed by heterocysts in the algal cell, and transferred as ammonia to *Azolla*."

Human Uses

From Pfingsten et al. (2023):

"*Azolla* is commonly used as a fertilizer in rice paddies and forage for livestock in southeast Asia (Moore 1969; Lumpkin and Plucknet 1980)."

"In other countries [other than the United States] it has also been introduced by farmers to help fertilize rice fields and control mosquito populations (Moore 1969; Lumpkin and Pucknett 1980; Holm et al. 1997)."

From GISD (2023):

"*Azolla* is useful as a 'soybean plant in rice field', because it can assimilate atmospheric nitrogen gas owing to the nitrogen fixation by cyanobacteria (blue green alga) living in the cavities located at the lower side of upper (dorsal) lobes of leaf. (Duke [no date])"

From Azolla Foundation (2022):

"Unlike almost all other plants, *Azolla* is able to get its nitrogen fertilizer directly from the atmosphere. That means that it is able to produce biofertilizer, livestock feed, food and biofuel exactly where they are needed and, at the same time, draw down large amounts of CO2 from the atmosphere, thus helping to reduce the threat of climate change."

From Rai (2007):

"*Azolla pinnata* strain can be cultivated on secondary-treated sewage effluents during all the seasons, and the biomass produced can be safely used. This strain is thus useful in treating municipal wastewater, which may be used for irrigation, and the biomass produced can be used as biofertilizer or green manure after mild acid wash."

From Gupta and Beentje (2018):

"These plants are antiseptic and its pastes are applied externally as poultice on wounds. It is useful in rice fields for its capacity to fix nitrogen and suppress other aquatic plants."

From CABI (2023):

"It is used as an ornamental pond and aquarium plant. Broiler chicken diets have been supplemented with up to 5% *A. pinnata* resulting in improved live weight, production number, protein efficiency and feed conversion ratios (Basak et al., 2002). *A. pinnata* was assessed as a promising additive to abalone feed by Reyes and Fermin (2003). Dried, powdered *A. pinnata* has also been used to supplement carp diets (Basudha and Vishwanath, 1997). *A. pinnata* has been

investigated for use in the decontamination of land in India (Kaur, 2001). Bacterial flocs produced on decaying *A. pinnata* enhanced degradation of diesel in experimental microcosms by up to 100% (Cohen et al., 2002b).There is some evidence to suggest that extracts of *A. pinnata* have inhibitory effects on root-knot nematodes (Thakar et al., 1988; Patel et al., 1994, Malek et al., 1996; Ramakrishnan et al. 1996; Hossain et al. 2002,), on Cucumber green mottle mosaic virus (Tewari et al., 2001) and on the mollusc *Biomphalaria alexandrina* (Abdel-Hafez, 1997; Zidan et al., 1998)."

Diseases

From CABI (2023):

"Dath and Singh (1998) reported that *A. pinnata* was very susceptible to the fungus *Rhizoctonia solani* [*Thanatephorus cucumeris*], and Shahjahan et al. (1980) reported inhibition of growth of *A. pinnata* by *Sclerotium rolfsii* [*Corticium rolfsii*] and *Rhizoctonia* sp. These fungal pathogens are opportunists and also[…] attack a range of crop plants. Fannah (1987) reported a completed life cycle of *Elophila africalis* on *A. pinnata* in Sierra Leone which was followed up by Roberts et al. (1998)."

Poelen et al. (2014) lists *Azolla pinnata* as a host of *Trichormus azollae*.

Threat to Humans

No information was found on threats to humans from *Azolla pinnata*.

3 Impacts of Introductions

From GISD (2023):

"*Azolla pinnata* can spread very quickly forming dense vegetative masses on areas of still water. This in turn limits light available to other aquatic plants and oxygen used by other aquatic life. It forms dense mats that choke out other species. [… *Azolla pinnata*] has replaced a native floating fern, *Azolla rubra*, over most of northern New Zealand."

From Ocampo-Ariza et al. (2018):

"Where the ranges of the two *Azolla* species [native *A. rubra* and introduced *A. pinnata*] overlap, there is often an abrupt transition from *A. rubra* domination during winter and spring to *A. pinnata* domination over summer; whereas *A. rubra* dominates all year long in water systems in which *A. pinnata* is absent. This suggests that *A. pinnata* is competitively replacing the native species (Owen 1996; Popay et al. 2010), but direct tests of this hypothesis are lacking. We therefore performed a competition experiment between *A. pinnata* and *A. rubra* under natural weather conditions to compare the growth rate of the plants alone and with competition with the congener (as a "resident" at higher abundance). […] Our results show that *A. pinnata* had a positive growth rate when growing in the presence of *A. rubra* as a resident […], while *A. rubra* could not grow in the presence of *A. pinnata* as a resident."

From Pfingsten et al. (2023):

"*Azolla* spreads rapidly via vegetative reproduction and quickly covers water surfaces (Moore 1969). It forms dense surface mats, which interfere with boating, fishing and recreational activities as well as degrade water quality by reducing oxygen levels and limiting light to native plants (Lumpkin and Plucknett 1980; Kay and Hoyle 2001; Pemberton and Bodle 2009)."

From Esler (1988):

"*Azolla pinnata* and purple-backed duckweed (*Spirodela punctata*) contribute little obstruction or aesthetic detraction, but impair wildlife habitats."

From Wisconsin Department of Natural Resources (2023):

"Native plant richness and abundance decrease in the presence of mosquito fern; zooplankton and phytoplankton reduce significantly. As a result, fish production decreases due to the lack of habitat and break in the food chain."

"Although in its native range mosquito fern provides habitat for wildlife and fish, the habitat it provides [in the introduced range] is one of lesser quality than that it replaces."

"This leads to decreased dissolved oxygen concentration and light penetration, decreased pH levels and nutrient richness and lower water quality."

A. pinnata is on the Federal Noxious Weeds list (U.S. Department of Agriculture 2010) and is regulated in the following states: Idaho (IDDA 2022), North Carolina (North Carolina DEQ 2022), Oklahoma (ODWC 2022), West Virginia (WVDA 2022), Illinois (Illinois DNR 2015), Indiana (Indiana DNR 2022), Massachusetts (MDAR 2022), Wisconsin (Wisconsin DNR 2022), and South Carolina (SCDNR 2010). See section 1.

4 History of Invasiveness

The history of invasiveness for *Azolla pinnata* is classified as High. In the United States, *Azolla pinnata* has been established in Florida and Hawaii and introduced to Arizona, Louisiana, Idaho, North Carolina. Globally, it has been established outside of its native range in New Zealand, Singapore, Brazil, and the Cook Islands. *A. pinnata* has also been introduced into the Marshall Islands and western Europe, where its current status is unclear. There is evidence of *A. pinnata* within the agricultural, horticultural, and aquarium trade in the United States and internationally, but quantities and duration of trade were not found. *A. pinnata* is misidentified and sold in conjunction with duckweed (*Lemnoideae* spp.), which is commonly found in similar trade industries. *A. pinnata* is on the Federal Noxious Weeds list (U.S. Department of Agriculture 2010) and is currently regulated in numerous U.S. states. Adverse impacts have been reported, including competitive exclusion of a native fern, reduced water quality, and interference with water access.

5 Global Distribution

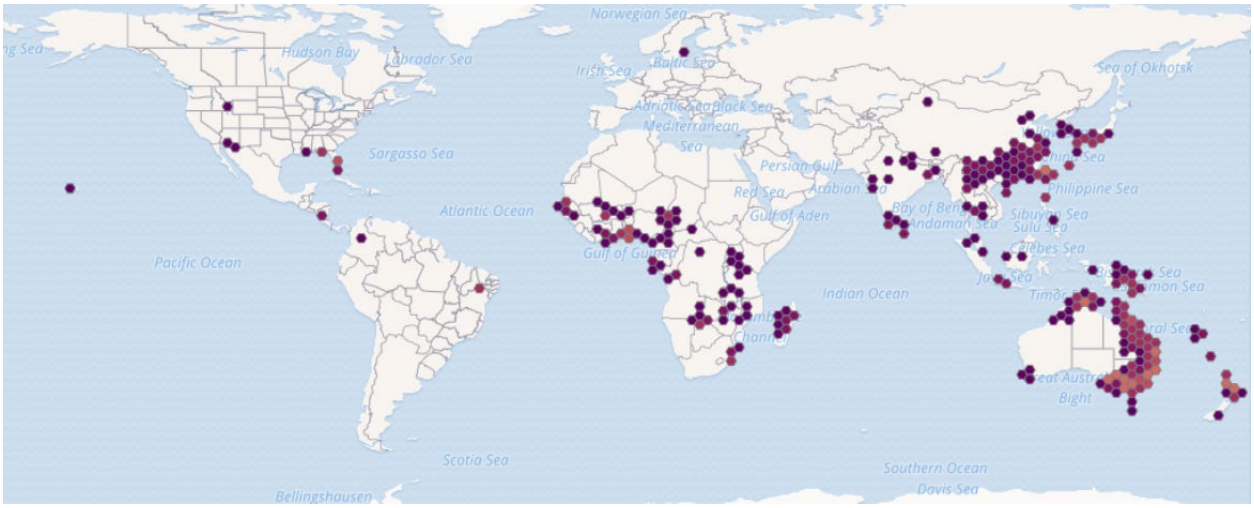

Figure 1. Reported global distribution of *Azolla pinnata*. Map from GBIF Secretariat (2023). Observations are reported from western, central, and southern Africa, Madagascar, India, Sri Lanka, China, Japan, South Korea, Nepal, Bangladesh, Thailand, Cambodia, Malaysia, the Philippines, New Guinea, Australia, New Zealand, Sweden, United States, Hawaii, Colombia, Brazil, and Costa Rica. According to Pfingsten et al. (2023), establishment of *Azolla pinnata* in Arizona and Louisiana is uncertain, so these reported occurrences were excluded from the source points used in the climate matching analysis. Observations in Idaho, Sweden, and northwest China were excluded because they each represent a contained or preserved specimen. Observations in Costa Rica and Colombia may have been confused with *Azolla filiculoides*, a related species native to North and South America. No information was found to confirm occurrences of *Azolla pinnata* in these two countries and they were therefore excluded from the climate matching analysis.

6 Distribution Within the United States

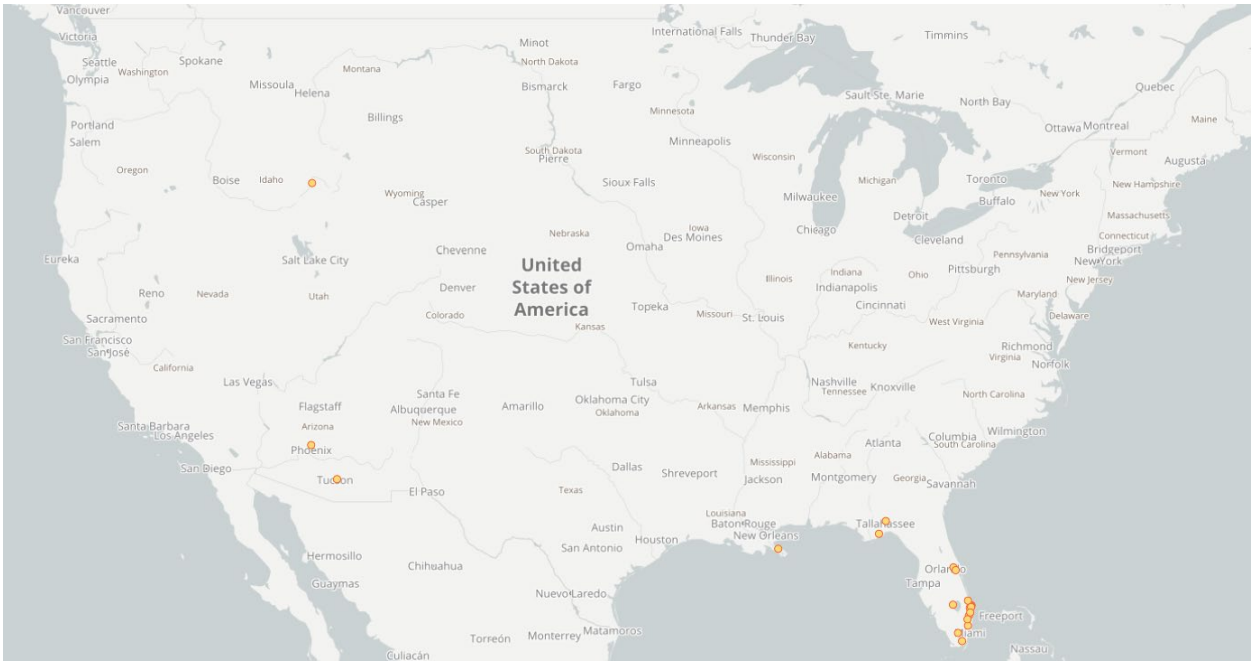

Figure 2. Reported distribution of *Azolla pinnata* in the United States. Map from GBIF-US (2023). Observations are reported from Florida, southern Louisiana, southern Arizona, and southern Idaho. The observation in Idaho is from a nursery and does not represent an established population. Establishment status of *Azolla pinnata* in Arizona and Louisiana is uncertain (Pfingsten et al. 2023). The occurrences in Idaho, Arizona, and Lousiana were therefore excluded from the selection of source points for the climate matching analysis.

Figure 3. Reported distribution of *Azolla pinnata* in Hawaii. Map from GBIF-US (2023). Observations are reported from northern Maui.

7 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Azolla pinnata* was high along the southern Atlantic coast from North Carolina to Florida (where it has established) and along the Gulf Coast. It was also high in southern and central Texas extending up into the Southern Plains (primarily Oklahoma and Kansas). There were small patches of high match in coastal Maine and Massachusetts as well as in southern Arizona and the Pacific Northwest. The climate match was medium to low across much of the northern United States and in parts of northern Louisiana, northern Mississippi, Colorado, Wyoming, and the Pacific Northwest. The climate match was medium in the remaining areas of the contiguous United States. The overall Climate 6 score (Sanders et al. 2023; 16 climate variables; Euclidean distance) for the contiguous United States was 0.707, indicating that Yes, there is establishment concern for this species. The Climate 6 score is calculated as: (count of target points with scores ≥ 6)/(count of all target points). Establishment concern is warranted for Climate 6 scores greater than or equal to 0.002 based on an analysis of the establishment success of 356 nonnative aquatic species introduced to the United States (USFWS 2024).

Projected climate matches in the contiguous United States under future climate scenarios are available for *Azolla pinnata* (see Appendix). These projected climate matches are provided as additional context for the reader; future climate scenarios are not factored into the Overall Risk Assessment Category.

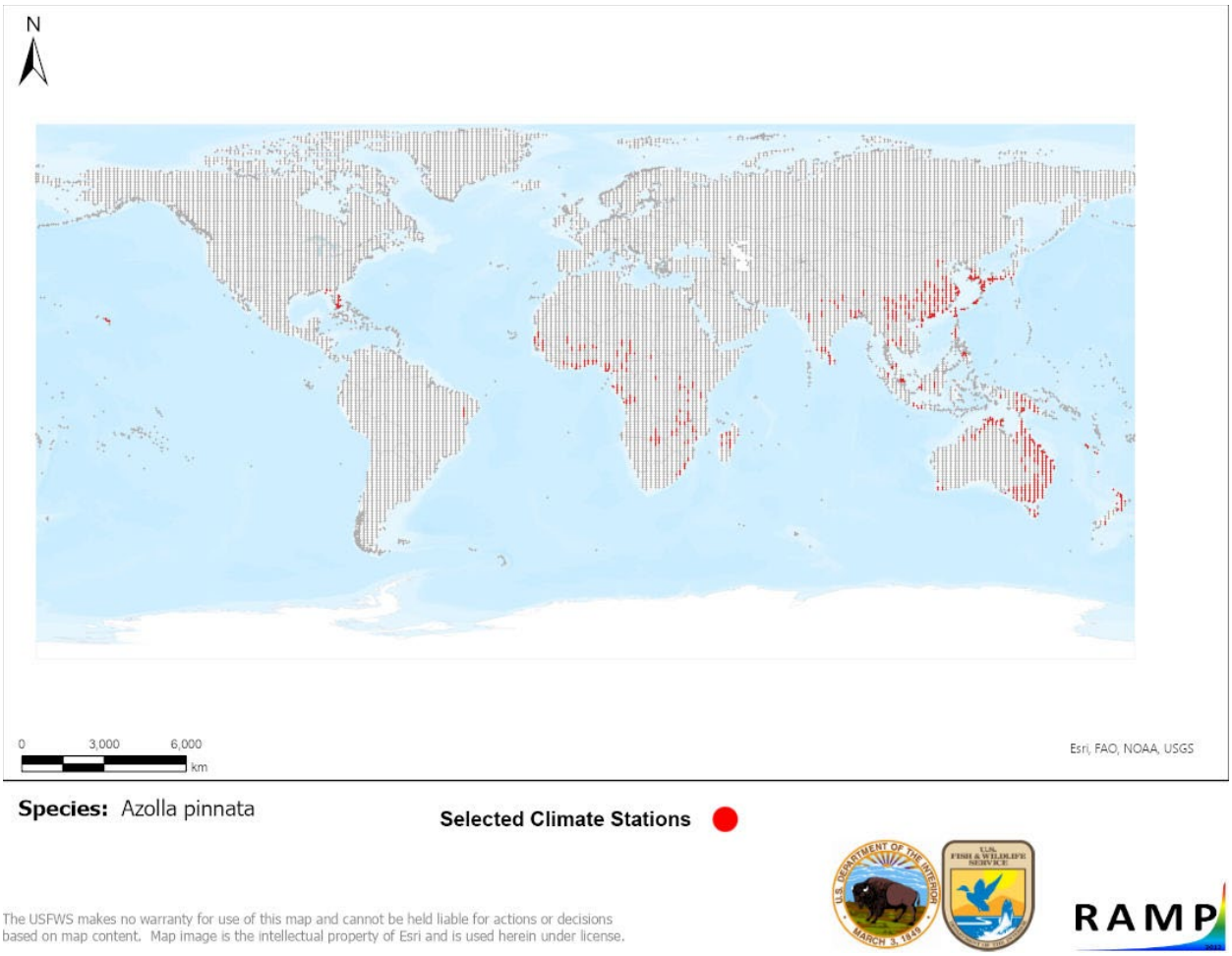

Figure 4. RAMP (Sanders et al. 2023) source map showing weather stations in North America, South America, Africa, Asia, Oceania, and Australia selected as source locations (red; United States, Brazil, Senegal, Guinea-Bissau, Ivory Coast, Mali, Ghana, Togo, Benin, Burkina Faso, Niger, Nigeria, Cameroon, Chad, Central African Republic, Gabon, Democratic Republic of the Congo, Kenya, Tanzania, Malawi, Zambia, Mozambique, Madagascar, South Africa, Namibia, Botswana, India, Sri Lanka, Nepal, Bangladesh, Thailand, Cambodia, Malaysia, China, Cambodia, South Korea, Japan, Taiwan, Philippines, Indonesia, Australia, New Zealand, Papua New Guinea, New Caledonia) and non-source locations (gray) for *Azolla pinnata* climate matching. Source locations from GBIF Secretariat (2023). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

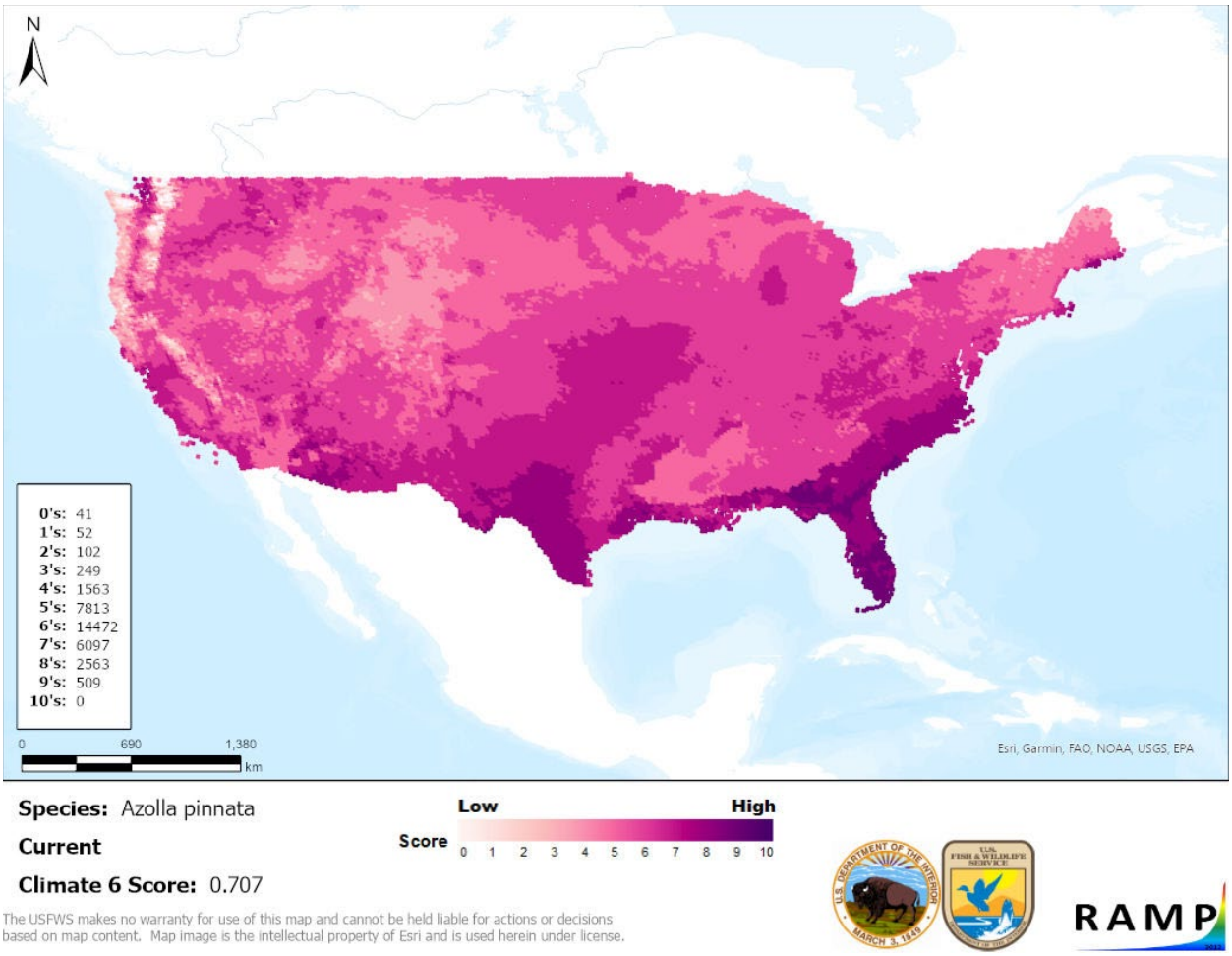

Figure 5. Map of RAMP (Sanders et al. 2023) climate matches for *Azolla pinnata* in the contiguous United States based on source locations reported by GBIF Secretariat (2023). Counts of climate match scores are tabulated on the left. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

8 Certainty of Assessment

The Certainty of Assessment for *Azolla pinnata* is classified as Low. Adequate information was available on the biology and ecology of this species. There is some uncertainty in the distribution information from the potential to misidentify *Azolla pinnata* as *Lemnoideae* spp. and other species of *Azolla*, which decreases the certainty in the interpretation of the climate match results. Records of introductions resulting in established populations were available. Information on impacts of introductions was found, however much of it was not substantiated by peer-reviewed sources.

9 Risk Assessment

Summary of Risk to the Contiguous United States

Azolla pinnata, Mosquito Fern, is a freshwater aquatic plant that is native to Africa and Madagascar, India, Southeast Asia, China, Japan, Oceania, and Australia. *Azolla* species in

general, and *A. pinnata* in particular, are used in farming as a green fertilizer, in aquariums, as animal feed, in traditional medicines, and as population control for mosquitos. *A. pinnata* has been introduced and become established in Florida, Brazil, New Zealand, the Cook Islands, and Singapore. It has been introduced but the status is currently unknown in Arizona, Louisiana, the Marshall Islands, and western Europe. The History of Invasiveness for *Azolla pinnata* is classified as High. Adverse impacts were reported, such as choking and displacing native aquatic vegetation, altering habitat for wildlife, reducing water quality, and disrupting water access. The climate matching analysis for the contiguous United States indicates establishment concern for this species. The climate match was high along the southern Atlantic and Gulf Coasts, as well as southern to central Texas extending to the Midwest. The Certainty of Assessment is Low due to the uncertainty in the distribution and the limited amount of scientifically defensible impact information. The Overall Risk Assessment Category is High.

Assessment Elements

- **History of Invasiveness (see section 4): High**
- **Establishment Concern (see section 7): Yes**
- **Certainty of Assessment (see section 8): Low**
- **Remarks, Important additional information: World Flora Online, recognizes *Azolla pinnata* as a valid species with the following recognized subspecies: *A. pinnata* ssp. *africana*, *A. pinnata* ssp. *asiatica*, *A. pinnata* ssp. *pinnata*.**
- **Overall Risk Assessment Category: High**

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Appendix

Summary of Future Climate Matching Analysis

Future climate projections represent two Shared Socioeconomic Pathways (SSP) developed by the Intergovernmental Panel on Climate Change (IPCC 2021): SSP5, in which emissions triple by the end of the century; and SSP3, in which emissions double by the end of the century. Future climate matches were based on source locations reported by GBIF Secretariat (2023).

Under the future climate scenarios (figure A1), on average, high climate match for *Azolla pinnata* was projected to occur in the Gulf Coast, Mid-Atlantic, Southern Atlantic Coast, and Southern Florida regions of the contiguous United States. Another area of high match was present in western Texas under all scenarios. The Climate 6 scores for the individual future scenario models (figure A2) ranged from a low of 0.495 (model: MPI-ESM1-2-HR, SSP5, 2085) to a high of 0.775 (model: MRI-ESM2-0, SSP5, 2055). All future scenario Climate 6 scores were above the Establishment Concern threshold, indicating that Yes, there is establishment concern for this species under future climate scenarios. The Climate 6 score for the current climate match (0.707, figure 5) falls within the range of scores for future projections. The time step and climate scenario with the most change relative to current conditions was SSP5, 2085, the most extreme climate change scenario (figure A3). Under one or more time step and climate scenarios, areas within the Appalachian Range, Colorado Plateau, Great Lakes, Mid-Atlantic, Northeast, and Northern Pacific Coast saw a moderate increase in the climate match relative to current conditions. No large increases were observed regardless of time step and climate scenarios. Under one or more time step and climate scenarios, areas within the Southwest saw a large decrease in the climate match relative to current conditions. Additionally, areas within the Appalachian Range, California, Gulf Coast, Northern Pacific Coast, Northern Plains, Southeast, Southern Atlantic Coast, Southern Florida, and Western Mountains saw a moderate decrease in the climate match relative to current conditions. Although moderate, these decreases were most prominent in the later, year 2085 scenarios. Additional, very small areas of large or moderate change may be visible on the maps (figure A3).

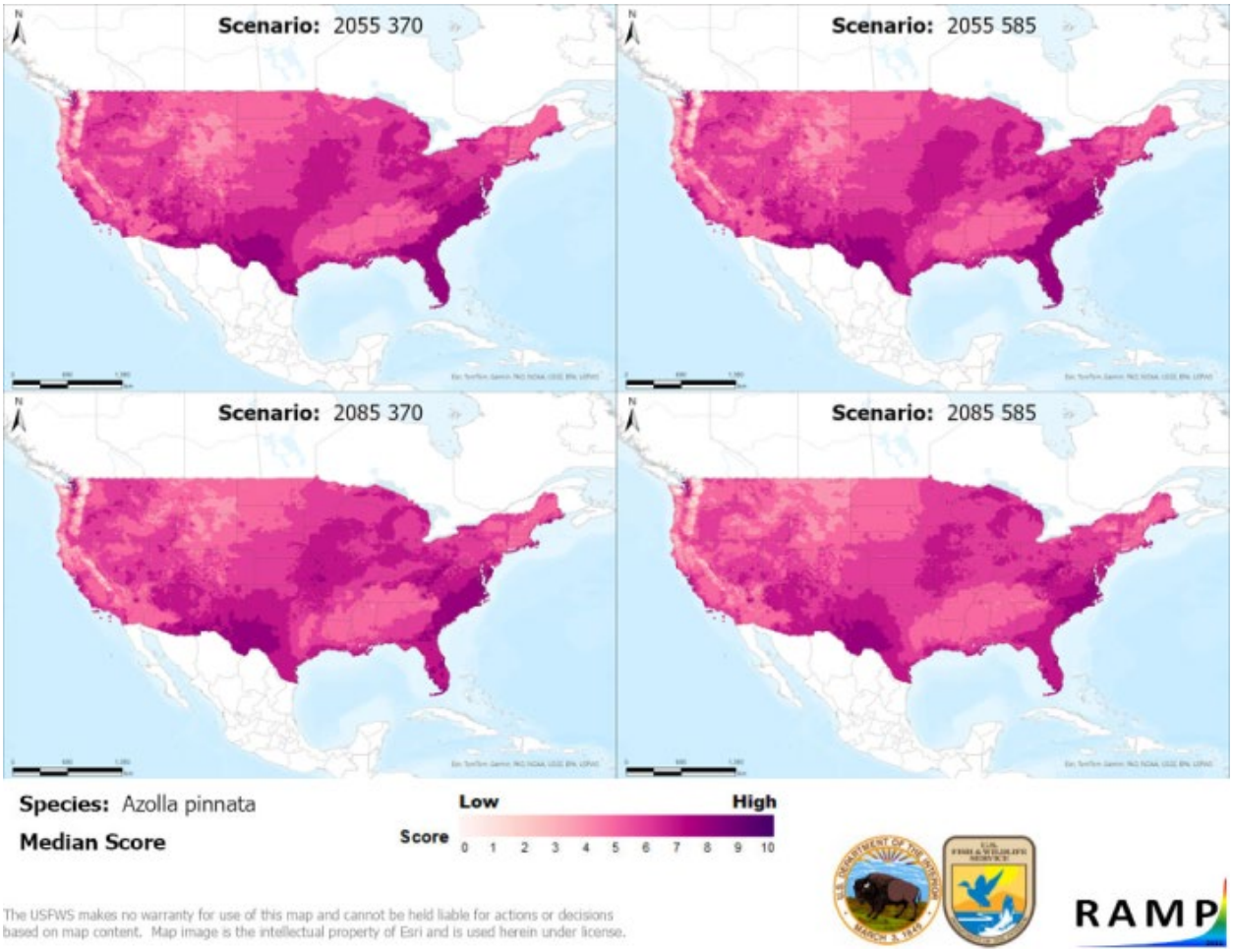

Figure A1. Maps of median RAMP (Sanders et al. 2023) climate matches projected under potential future climate conditions using five global climate models for *Azolla pinnata* in the contiguous United States. Climate matching is based on source locations reported by GBIF Secretariat (2023). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

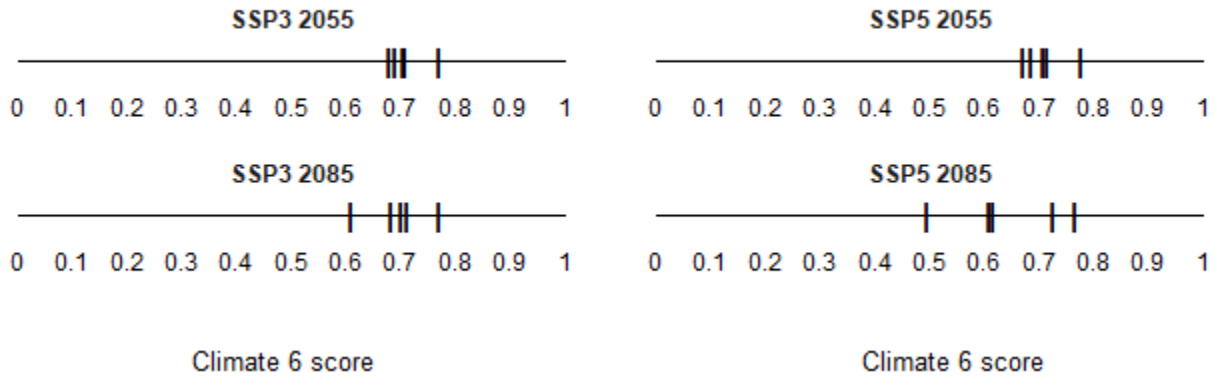

Figure A2. Comparison of projected future Climate 6 scores for *Azolla pinnata* in the contiguous United States for each of five global climate models under four combinations of Shared Socioeconomic Pathway (SSP) and time step. SSPs used (from left to right): SSP3, SSP5 (Karger et al. 2017, 2018; IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0.

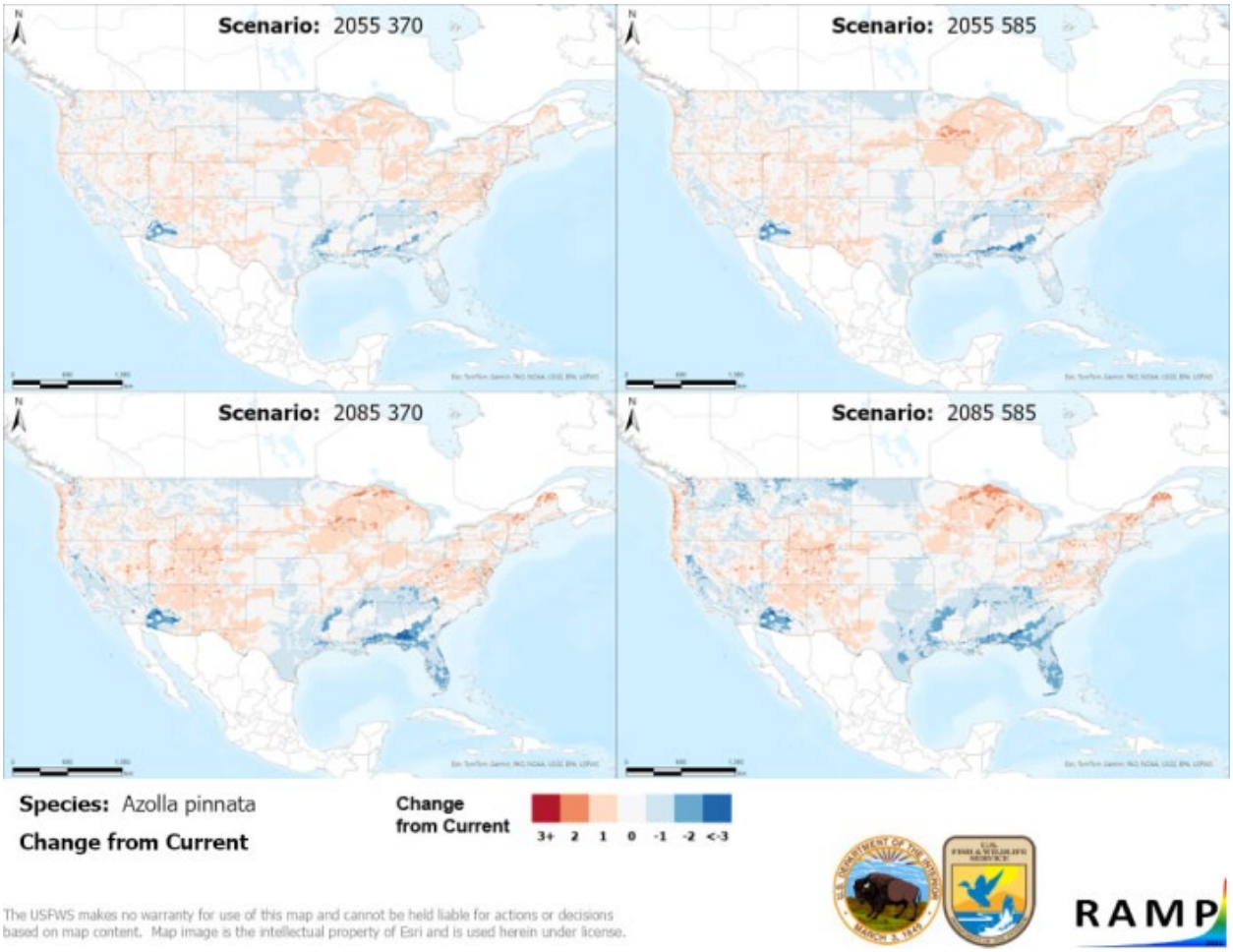

Figure A3. RAMP (Sanders et al. 2023) maps of the contiguous United States showing the difference between the current climate match target point score (figure 5) and the median target point score for future climate scenarios (figure A1) for *Azolla pinnata* based on source locations reported by GBIF Secretariat (2023). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. Shades of blue indicate a lower target point score under future scenarios than under current conditions. Shades of red indicate a higher target point score under future scenarios than under current conditions. Darker shades indicate greater change.

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