Feathered Mosquitofern (*Azolla pinnata*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, September 2015
Revised, January 2018
Web Version, 7/26/2021

Organism Type: Plant
Overall Risk Assessment Category: Uncertain

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Available: https://commons.wikimedia.org/wiki/File:Azolla_pinnata3.jpg.

1 Native Range and Status in the United States

Native Range

From World Flora Online (2021):

"Widespread in tropical Africa as far south as South West Africa/Namibia, Botswana and Natal."

According to GISD (2021), *Azolla pinnata* is native to Africa, Australia, China, India, Japan, Madagascar, Malaysia, Papua New Guinea, Philippines, South East Asia, and Viet Nam.

From Pfingsten et al. (2018):

"Native Range [of *Azolla pinnata* ssp. *pinnata*]: Australia (Saunders and Fowler 1992; Madeira et al. 2013)."

Status in the United States

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"Nonindigenous Occurrences: Distribution by states' drainages and/or counties:
Arizona - private residence in Aqua Fria drainage, and a creek in Tucson in Rillito drainage (Thomas and Guertin 2007)
Florida - Everglades (Center for Invasive Species and Ecosystem Health 2015), Florida Southeast Coast (Kunzer et al. 2009), and Lower Ochlockonee (Anderson 2001) drainages
Louisiana - Fort Jackson in East Central Louisiana Coastal drainage (Madsen 2010)"

"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."

According to the USDA, NRCS (2018) *Azolla pinnata* is listed as a Class A noxious weed in Alabama, North Carolina, and Vermont, a quarantine species in California and Oregon, prohibited in Massachusetts, and an invasive aquatic plant and plant pest in South Carolina. *Azolla pinnata* is on the Federal Noxious Weeds list (USDA, NRCS 2018).

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tentatively as *Azolla pinnata* R. Brown (a Federal Noxious Weed), and the identity was later confirmed (author's unpublished data).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."

Means of Introductions in the United States

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

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

Remarks

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 one recognized subspecies, *A. pinnata* ssp. *africana*. Other authors and sources have suggested possible additional subspecies, *A. pinnata* ssp. *asiatica* and *A. pinnata* ssp. *pinnata*, but they are not recognized by World Flora Online. Neither does World Flora Online attribute those subspecies to another valid species, so the decision was made to include that information in this screening. Where information pertaining to *Azolla pinnata* was reported using a subspecies name this has been clearly indicated.

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"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)."

From Gupta and Beentje (2017):

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

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

According to World Flora Online (2021), *Azolla pinnata* is the valid name for this species.

From ITIS (2015):

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

Size, Weight, and Age Range

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

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

Environment

From CABI (2018):

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

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"It tolerates salt concentrations up to 30 mM, but can be preincubated in lower concentrations to increase salinity tolerance up to as high as 60 mM (Rai and Rai 1999)."

Climate

From Gupta and Beentje (2017):

"It is fairly common in tropical regions of the world."

Gupta and Beentje (2017) list a lower elevation limit of 1m and an upper elevation limit of 1800m.

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

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

From CABI (2018):

"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 (2018) 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.

Distribution Outside the United States

Native

According to GISD (2021), *Azolla pinnata* is native to Africa, Australia, China, India, Japan, Madagascar, Malaysia, Papua New Guinea, Philippines, South East Asia, and Viet Nam.

From Pfingsten et al. (2018):

"Native Range [of *Azolla pinnata* ssp. *pinnata*]: Australia (Saunders and Fowler 1992; Madeira et al. 2013)."

Introduced

GISD (2021) lists *Azolla pinnata* as introduced, invasive, and established in New Zealand.

FAO (2018) 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).

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

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), […]"

Means of Introduction Outside the United States

From CABI (2018):

"Introductions to new countries are assumed to have been through horticultural or ornamental trade with the aquarium industry."

"There is a low risk of spread to non-tropical and sub-tropical areas, and spread between waterbodies within natural areas appears to be regulated by deliberate introduction by man for agricultural purposes. Once in a waterbody, vegetative fragments and spores can spread easily downstream, and be carried with floodwaters to colonize new areas."

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"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)."

Short Description

From GISD (2021):

"Plants small, 1.5 - 2.5cm long, with a more or less straight main axis with pinnately arranged side **branches**, progressively longer towards the base, thus roughly triangular in shape, the basal branches themselves becoming pinnate and eventually fragmenting as the main axis decomposes to form new plants. Roots with fine lateral rootlets, having a feathery appearance in the water. **Leaves** minute, 1 -2mm long, overlapping in 2 ranks, upper lobe green, brown green or reddish, lower lobe translucent brown; minute, short, plae, +/- cylindrical unicellular hairs often present on the upper lobes. When fertile, round **sporocarps** 1 - 1.5mm wide can be seen on the under side [sic] at the bases of the side branches. The leaves often have a maroon-red tinge and the water can appear to be covered by red velvet from the distance. The upper surface of the leaves are totally water-repellant, and if completely submerged the plants quickly refloat with the right side up."

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"*Azolla microphylla* (*A. caroliniana*) Mexcian mosquitofern, *A. pinnata* ssp. *africana*, and *A. pinnata* ssp. *asiatica*. *Azolla pinnata* differs from native [to the United States] *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)."

"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 CABI (2018):

"Known chromosome counts for the genus *Azolla* are centred around n=22, with many variations. This probably indicates that a tetraploid n=22 was the original count, deriving from n=11. *A. pinnata* has been reported as n=22 (tropical Africa), n=33 (Asia) and n=44 (Australia) (Knouse, 1997)."

"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*.”

From Pfingsten et al. (2018):

“Upper lobes of *A. pinnata*'s leaves are host to a cyanobacteria symbiont that fixes atmospheric nitrogen (Strasburger 1873; Moore 1969; Wagner 1997).”

Human Uses

From GISD (2021):

“*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 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 The Azolla Foundation (2015):

“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 Gupta and Beentje (2017):

“The plants are antiseptic and its pastes are applied externally as poultice on wounds.”

From CABI (2018):

"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)."

Any species of *Azolla* is required to have a certificate attached during importation to Japan to verify their type (Ministry of the Environment 2020).

From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"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)."

Diseases

From CABI (2018):

"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 a [sic] 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 on threats to humans from *Azolla pinnata* was found.

3 Impacts of Introductions

From GISD (2021):

"It [*Azolla pinnata*] forms dense mats that choke out other species. *A. pinnata* is on the US noxious weed list."

"*Azolla pinnata* has replaced a native floating fern, *Azolla rubra*, over most of northern New Zealand (Owen, 1997)."

From Esler (1988):

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

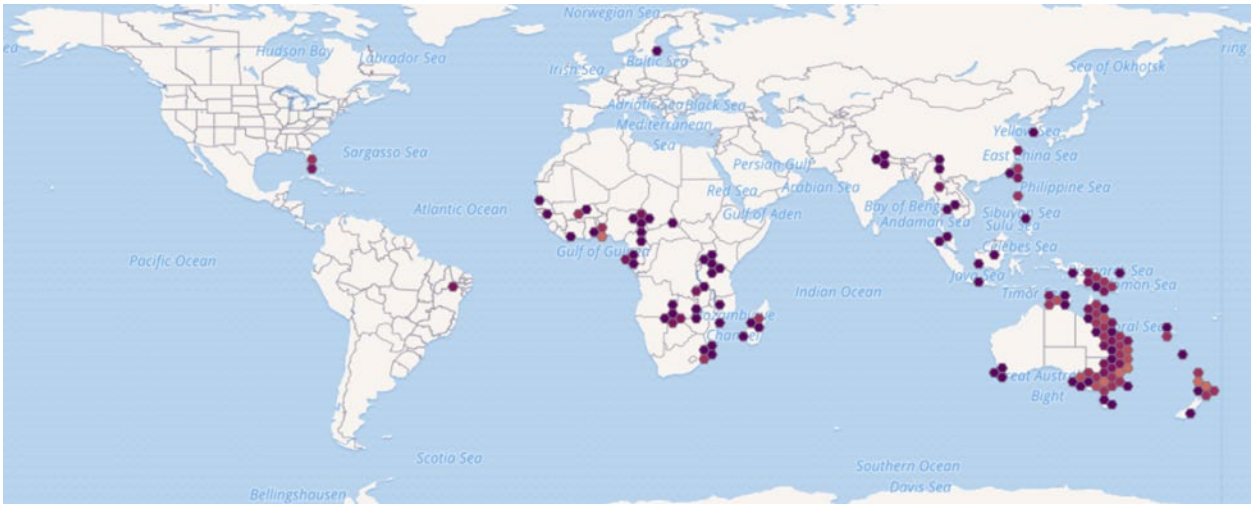
Some information regarding the impacts of the genus was available.
From Pfingsten et al. (2018; under the name *Azolla pinnata* ssp. *pinnata*):

"*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)."

4 History of Invasiveness

The history of invasiveness for *Azolla pinnata* is classified as Data Deficient. In the United States, it has been introduced to several States and established in Florida. Globally, it has been reported as introduced and established beyond its native range in New Zealand, the Cook Islands, Singapore, and Brazil. It has also been introduced in western Europe and the Marshall Islands but the current status of the species in those locations was unclear. *A. pinnata* is in trade internationally within the agricultural, horticultural, and aquarium industries but quantities and duration of trade were not found. According to the USDA, NRCS (2018) *A. pinnata* is listed as a Class A noxious weed in Alabama, North Carolina, and Vermont; a quarantine species in California and Oregon; prohibited in Massachusetts; and an invasive aquatic plant and plant pest in South Carolina. *A. pinnata* is on the Federal Noxious Weeds list (USDA, NRCS 2018). Adverse impacts were reported in summary form in the publications cited in Section 3. When resources were cited in those publications, they either could not be found or did not contain the information indicated in the summary specific to *A. pinnata*. Therefore, while some indication of adverse impacts is available, additional documentation is needed to confirm the impacts are attributable to *A. pinnata*.

5 Global Distribution



6 Distribution Within the United States

7 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Azolla pinnata* was high along the southern Atlantic Coast through Florida (where it has established) and along the Gulf Coast. It was also high in southern and central Texas extending up into Oklahoma and Kansas. Small areas of high match were also found in the southwest and Pacific Coast. The climate match was low in the northern New England and New York, most of the Midwest and Northern Great Plains, and small pockets of the Pacific Northwest. The climate match was medium everywhere else. The Climate 6 score (Sanders et al. 2014; 16 climate variables; Euclidean distance) for the contiguous United States was 0.173, high. (Scores of 0.103 or greater are classified as high.) The following States had high individual climate scores: Alabama, Arizona, Arkansas, California, Florida, Georgia, Louisiana, Massachusetts, North Carolina, Oklahoma, South Carolina, Texas, Virginia, Washington, and West Virginia.

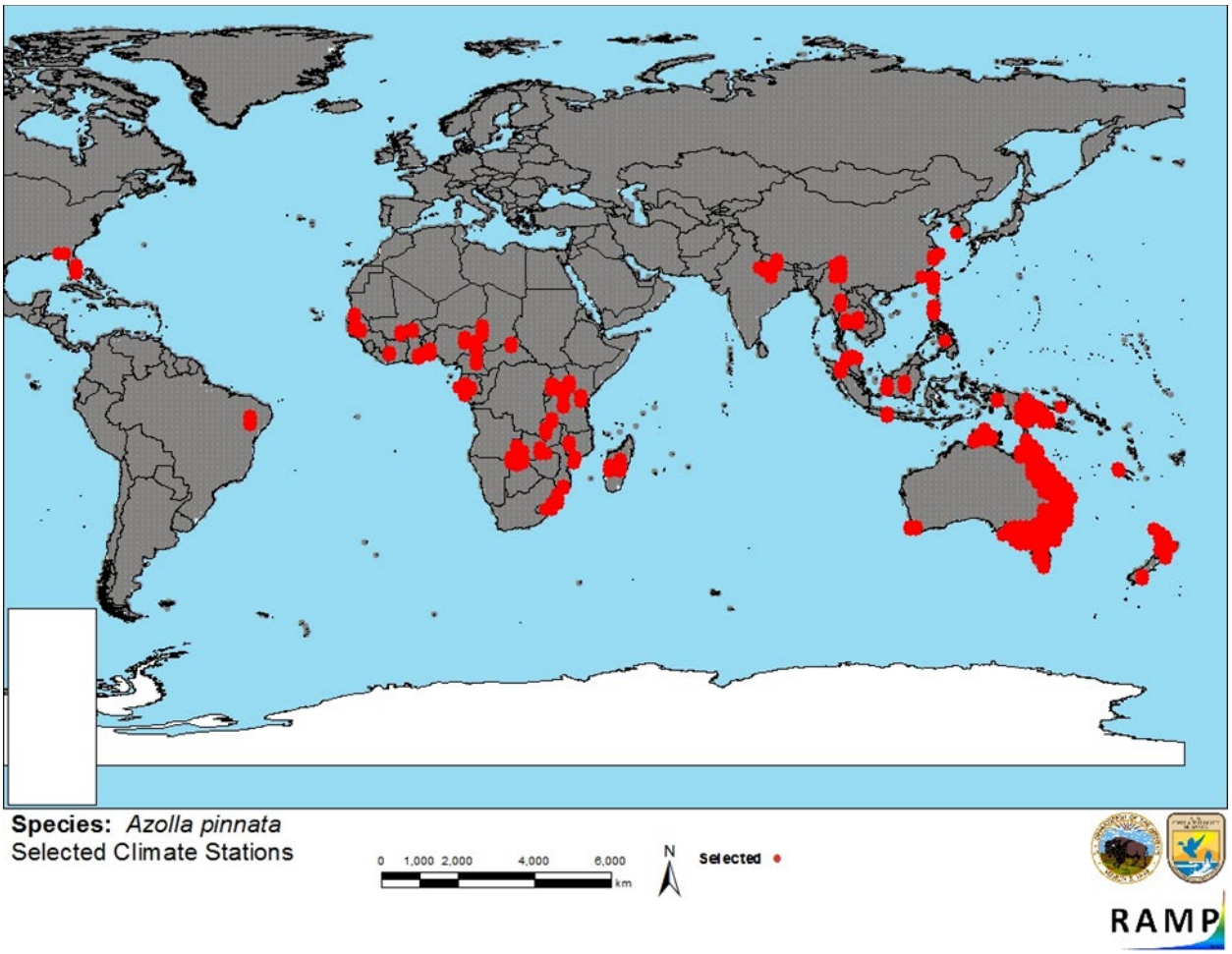


Figure 3. RAMP (Sanders et al. 2014) source map showing weather stations in the southeastern United States, Brazil, Sub-Saharan Africa, Madagascar, India, Southeast Asia, Australia, and New Zealand selected as source locations (red) and non-source locations (gray) for *Azolla pinnata* climate matching. Source locations from GBIF Secretariat (2018) and Pfingsten et al. (2018). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

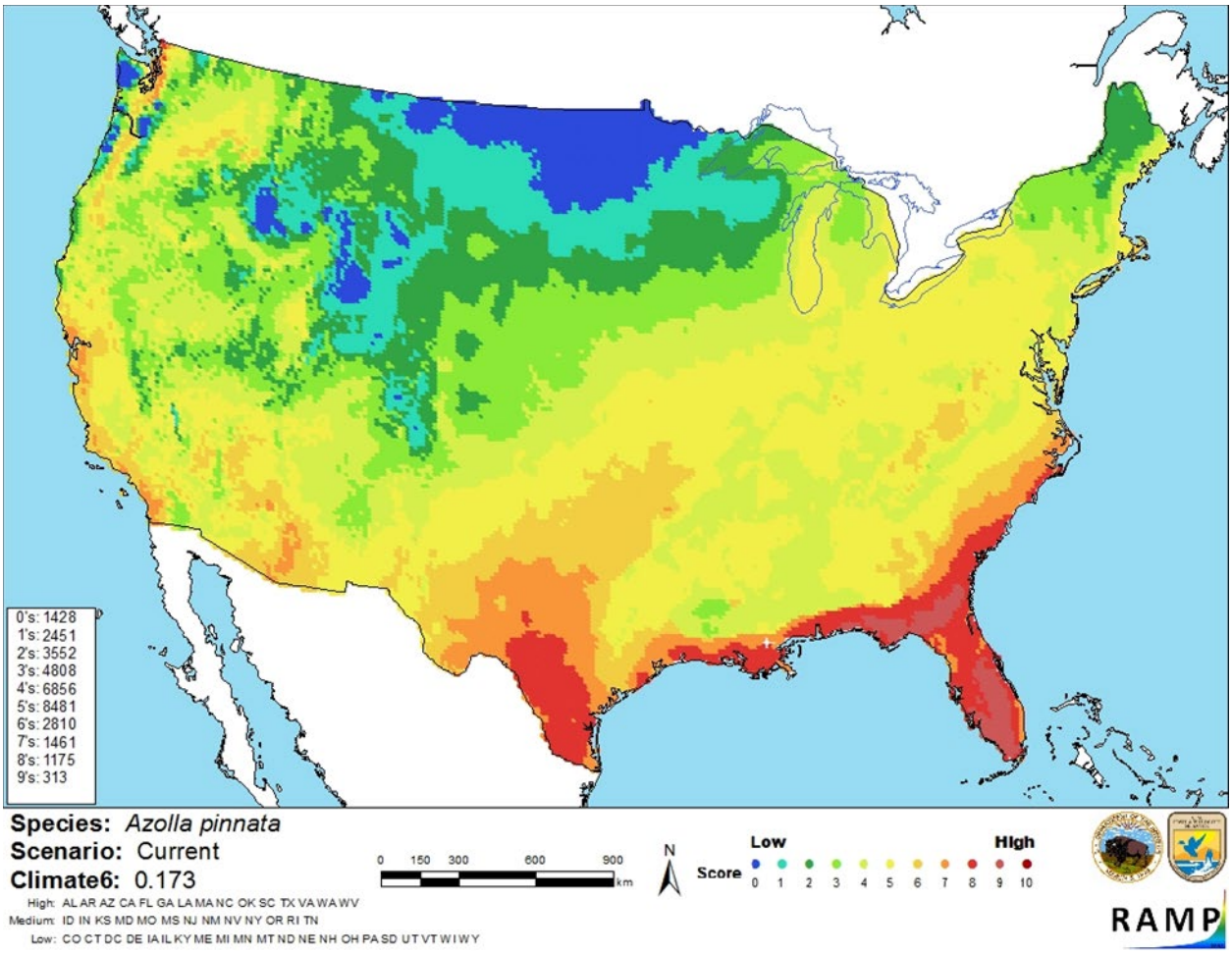


Figure 4. Map of RAMP (Sanders et al. 2014) climate matches for *Azolla pinnata* in the contiguous United States based on source locations reported by GBIF Secretariat (2018) and Pfingsten et al. (2018). Counts of climate match scores are tabulated on the left. 0/Blue = Lowest match, 10/Red = Highest match.

The High, Medium, and Low Climate match Categories are based on the following table:

Climate 6: (Count of target points with climate scores 6-10)/ (Count of all target points)	Overall Climate Match Category
0.000≤X≤0.005	Low
0.005<X<0.103	Medium
≥0.103	High

8 Certainty of Assessment

Certainty of assessment for *Azolla pinnata* is low. Adequate quality information was available for the biology and ecology of this species. However, there is still debate about the taxonomy of this species and its subspecies, reducing certainty about the distribution of the species. The uncertainty in the taxonomy and range decreases the certainty in the interpretation of the climate

match. Records of introductions resulting in established populations were available. Information on impacts of introductions was found, however it was not substantiated by peer reviewed resources.

9 Risk Assessment

Summary of Risk to the Contiguous United States

Feathered mosquitofern (*Azolla pinnata*) is a species of freshwater aquatic fern native to Africa, and possibly Asia and Oceania. *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 controls 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 the Marshall Islands and western Europe. The history of invasiveness for *Azolla pinnata* is classified as Data Deficient. Adverse impacts such as chocking and displacing native aquatic vegetation and altering habitat for wildlife, were reported in summary form in general databases but when resources were cited, they either could not be found or did not contain the information indicated by the database specific to *A. pinnata*. Therefore, while some indication of adverse impacts is available, additional documentation is needed to confirm the impacts are attributable to *A. pinnata*. The climate match was high with the areas of highest match along the southern Atlantic and Gulf Coasts. It is already established in Florida. The certainty of assessment is low due to the taxonomic issues within the *Azolla* genus, the resulting uncertainty in the distribution information, and lack of scientifically defensible impact information. The overall risk assessment category is Uncertain.

Assessment Elements

- **History of Invasiveness (Sec. 4): Data Deficient**
- **Overall Climate Match Category (Sec. 7): High**
- **Certainty of Assessment (Sec. 8): Low**
- **Remarks, Important additional information:** The taxonomy of the *Azolla* genus is unresolved.
- **Overall Risk Assessment Category: Uncertain**

10 Literature Cited

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 11.

[CABI] CABI International. 2018. *Azolla pinnata* (mosquito fern). CABI Invasive Species Compendium. Wallingford, United Kingdom: CAB International. Available: https://www.cabi.org/isc/datasheet/8120 (January 2018).

Esler AE. 1988. The naturalisation of plants in urban Auckland, New Zealand 6. Alien plants as weeds. New Zealand Journal of Botany 26:585–618.

Fabricante JR, de Siqueira Filho JA. 2012. Exotic and invasive plants of the Caatingas of the São Francisco River. Pages 368–393 in Siqueira Filho JA. Flora of the Caatingas of the São Francisco River. 1st edition. Rio de Janeiro, Brazil: Andreak Jakobsson Estúdio.

[FAO] Fisheries and Agriculture Organization of the United Nations. 2018. Database on introductions of aquatic species. Rome: FAO. Available: http://www.fao.org/fishery/introsp/search/en (January 2018).

GBIF Secretariat. 2018. GBIF backbone taxonomy: *Azolla pinnata* R. Br. Copenhagen: Global Biodiversity Information Facility. Available: https://www.gbif.org/species/2650106 (January 2018).

[GISD] Global Invasive Species Database. 2018. Species profile: *Azolla pinnata*. Gland, Switzerland: Invasive Species Specialist Group. Available: http://www.iucngisd.org/gisd/speciesname/Azolla+pinnata (January 2018).

Gupta AK, Beentje HJ. 2017. *Azolla pinnata*. The IUCN Red List of Threatened Species 2017: e.T168790A84276316. Available: http://www.iucnredlist.org/details/full/168790/0 (January 2018).

[ITIS] Integrated Taxonomic Information System. 2015. *Azolla pinnata* R. Br. Reston, Virginia: Integrated Taxonomic Information System. Available: http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=181820 (April 2015).

Kay SH, Hoyle ST. 2001. Mail order, the internet, and invasive aquatic weeds. Journal of Aquatic Plant Management 39:88–91.

Lumpkin TA, Plucknett DL. 1980. *Azolla*: botany, physiology, and use as a green manure. Economic Botany 34(2):111–153.

Ministry of the Environment. 2020. List of Regulated Living Organisms under the Invasive Species Act. Japan: Ministry of the Environment.

Nel JL, Richardson DM, Rouget M, Mgidi TN, Mdzeke N, Le Maitre DC, van Wilgen BW, Schonegevel L, Henderson L, Neser S. 2004. A proposed classification of invasive alien plant species in South Africa: towards prioritizing species and areas for management action. South African Journal of Science 100:53–64.

[PIER] Pacific Island Ecosystems at Risk. 2011. *Azolla pinnata.* Available: http://www.hear.org/pier/species/azolla_pinnata.htm (January 2018).

Pfingsten IA, Thayer DD, Howard V. 2018. *Azolla pinnata* R. Brown. Gainesville, Florida: U.S. Geological Survey, Nonindigenous Aquatic Species Database. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2745 (January 2018).

Poelen JH, Simons JD, Mungall CJ. 2014. Global Biotic Interactions: an open infrastructure to share and analyze species-interaction datasets. Ecological Informatics 24:148–159.

Rai PK. 2007. Wastewater management through biomass of *Azolla pinnata*: an eco-sustainable approach. AMBIO 36(5):426–428.

Sanders S, Castiglione C, Hoff M. 2014. Risk Assessment Mapping Program: RAMP. Version 2.81. U.S. Fish and Wildlife Service.

The Azolla Foundation. 2015. Available: http://theazollafoundation.org/azolla/the-azolla-anabaena-symbiosis-2/ (June 2015).

USDA, NRCS. 2018. *Azolla pinnata*. The PLANTS database. Greensboro, North Carolina: National Plant Data Team. Available: https://plants.usda.gov/core/profile?symbol=AZPI (January 2018).

World Flora Online. 2021. World Flora Online – a project of the World Flora Online Consortium. Available: www.worldfloraonline.org (July 2021).

11 Literature Cited in Quoted Material

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

Abdel-Hafez AM, Zidan ZH, Abdel-Megeed MI, El-Emam MA, FM Ragab, El-Deeb FA. 1997. Effect of the plant *Azolla pinnata* on survival, growth rate, fecundity and hatchability of egg-masses of *Biomphalaria alexandrina* snails. Journal of the Egyptian Society of Parasitology 27(3):825–841.

Anderson LC, curator. 2001. Herbarium specimen voucher data, Florida State University Herbarium (FSU). Tallahassee: Florida State University.

Basak B, Pramanik AH, Rahman MS. 2002. Azolla (*Azolla pinnata*) as a feed ingredient in broiler ration. International Journal of Poultry Science 1:29–34.

Basudha C, Vishwanath W. 1997. Formulated feed based on aquatic weed *Azolla* and fish meal for rearing medium carp *Osteobrama belangeri* (Valenciennes). Journal of Aquaculture in the Tropics 12(3):155–164.

Center for Invasive Species and Ecosystem Health. 2015. EDDMapS: early detection and distribution mapping system. Tifton: The University of Georgia. Available: http://www.eddmaps.org.

Chevalier A. 1926. La culture des *Azolla* pour la nourriture des animaux de basse-cour et comme engrais vert pour les rizieres. Rev. Journal d'Agriculture Tropicale et de Botanique Appliquée 6:356–360.

Chong KY, Tan HTW, Corlett RT. 2009. A checklist of the total vascular plant flora of Singapore: native, naturalised and cultivated species. Singapore: National University of Singapore, Raffles Museum of Biodiversity Research.

Cohen MF, Meziane T, Tsuchiya M, Yamasaki H. 2002a. Feeding deterrence of *Azolla* in relation to deoxyanthocyanin and fatty acid composition. Aquatic Botany 74(2):181–187.

Cohen MF, Williams J, Yamasaki H. 2002b. Biodegradation of diesel fuel by an *Azolla*-derived bacterial consortium. Journal of Environmental Science and Health. Part A, Toxic/Hazardous Substances & Environmental Engineering 37(9):1593–1606.

Croft JR. 1986. The aquatic pteridophytes of New Guinea. Australian National Herbarium, Centre for Plant Biodiversity Research. Available: http://www.anbg.gov.au/projects/fern/aquatic/.

Dath AP, Singh DP. 1998. Effect of rice *Rhizoctonia solani* Kuhn infection on the biomass of different *Azolla* species. Oryza 35(2):186–187.

Duke JA. No date. Innovative biological technologies for lesser developed countries. Available: http://ota.fas.org/reports/8512.pdf (October 2003).

Fannah SJ. 1987. *Elophila* sp.? *africalis* Hampson (Lepidoptera: Pyralidae): a new pest of *azolla* in Sierra Leone. International Rice Research Newsletter 12(3):30.

Holm L, Doll J, Holm E, Pancho J, Herberger J. 1997. World weeds: natural histories and distribution. New York: Wiley & Sons.

Hossain M, Ahmad MU, Ahmed N, Hossain MA, Alim MA. 2002. A study on control of root knot nematode (*Meloidogyne javanica*) of wheat. Indian Agriculturist 46:121–128.

Kaur H. 2001. Biomass production of *Azolla pinnata* R. BR. in contaminated soils of Punjab (India). Florida: 5th International Biomass Conference of the Americas.

Knouse JA. 1997. Genus *Azolla*: the mosquito ferns. Available: http://www.jaknouse.athens.oh.us/ferns/g_azol.html#top.

Kunzer JM, Wunderlin RP, Anderson LC, Burkhalter JR. 2009. New and noteworthy plants from Florida. Journal of the Botanical Research Institute of Texas 3:331–337.

Madeira PT, Center TD, Coetzee JA, Pemberton RW, Purcell MF, Hill MP. 2013. Identity and origins of introduced and native *Azolla* species in Florida. Aquatic Botany 111:9–15.

Madsen JD. 2010. Invasive plant atlas of the MidSouth. Starkville: Mississippi State University, Geosystems Research Institute.

Malek MA, Ahmed MU, Ansari TH. 1996. Effect of soil amendment with azolla (*Azolla pinnata*) on control of root-knot of brinjal. Bangladesh Journal of Plant Pathology 12(1/2):59–60.

Marsh AS. 1914. *Azol*[*l*]*a* in Britain and in Europe. Journal of Botany 52:209–213.

Moore AW. 1969. *Azolla*: biology and agronomic significance. Botanical Review 35:17–34.

Nirmala Gunapala [no initials], Amarasiri SL. 1983. Effect of addition of phosphorus on the growth of *Azolla*. Tropical Agriculturist 139:85–95.

Owen. 1997. [Source material did not provide full citation.]

Patel HR, Patel DJ, Patel CC, Thakar NA. 1994. Effectivity of *Clerodendron inerme* L., *Catharanthus roseus* (L.) G. Don. and *Azolla pinnata* R. Br. for management of root-knot nematodes in okra. Pakistan Journal of Nematology 12:95–98.

Pemberton RW, Bodle JM. 2009. Native North American azolla weevil, *Stenopelmus rufinasus* (Coleoptera: Curculionidae), uses the invasive old world *Azolla pinnata* as a host plant. Florida Entomologist 92:153–155.

Pereira AL, Martins M, Oliveira MM, Carrapiço F. 2011. Morphological and genetic diversity of the family Azollaceae inferred from vegetative characters and RAPD markers. Plant Systematics and Evolution 297:213–226.

Rai V, Rai AK. 1999. Growth behaviour of *Azolla pinnata* at various salinity levels and induction of high salt tolerance. Plant and Soil 206:79–84.

Ramakrishnan S, Gunasekaran CR, Vadivelu S. 1996. Effect of bio-fertilizers *Azolla* and *Azospirillum* on root-knot nematode, Meloidogyne incognita and plant growth of okra. Indian Journal of Nematology 26(2):127–130.

Reyes OS, Fermin AC. 2003. Terrestrial leaf meals or freshwater aquatic fern as potential feed ingredients for farmed abalone *Haliotis asinina* (Linnaeus 1758). Aquaculture Research 34(8):593–599.

Roberts JMF, Hance T, Cvan H. 1998. Fecundity and ovipositional preference of *Elophila africalis* on *Azolla*: test for host plant susceptibility. Journal of African Zoology 112(3):215–222.

Saccardo PA. 1892. De diffusione *Azollae carolinianae* per Europam. Hedwigia 31:217–218.

Saunders RMK, Fowler K. 1992. A morphological taxonomic revision of *Azolla* Lam. section *Rhizosperma* (Mey.) Mett. (Azollaceae). Botanical Journal of the Linnean Society 109(3):329–357.

Sculthorpe CD. 1967. The biology of aquatic vascular plants. New York: St. Martin's Press.

Shahjahan AKM, Miah SA, Nahar MA, Majid MA. 1980. Fungi attack *Azolla* in Bangladesh. International Rice Research Newsletter 5:17–18.

Strasburger E. 1873. Ueber *Azolla*. Jena, Germany: Hermann Davis.

Sweet A, Hills LV. 1971. A study of *Azolla pinnata* R. Brown. American Fern Journal 61:1–13.

Tewari JP, Singh K, Srivastava P. 2001. Inhibition of cucumber green mottle mosaic virus by extract of some ferns. Journal of Living World 8:28–32.

Thakar NA, Patel CC, Patel HR. 1988. Effect of extracts of *Azolla pinnata* on egg hatching of root knot nematodes *Meloidogyne incognita* and *M. javanica*. Madras Agricultural Journal 75(7-8):297–299.

Thomas KA, Guertin P. 2007. Southwest exotic mapping program 2007: occurrence summary and maps of select invasive non-native plants in Arizona. Tucson, Arizona: U.S. Geological Survey. Open-File Report 2007-1277.

Vander Velde N. 2003. The vascular plants of Majuro Atoll, Republic of the Marshall Islands. Atoll Research Bulletin 503:1–141.

Wagner GM. 1997. *Azolla*: a review of its biology and utilization. Botanical Review 63:1–26.

Watanabe I, Berja NS. 1983. The growth of four species of *Azolla* as affected by temperature. Aquatic Botany 15:175–185.

Zidan ZH, Abdel-Hafez AM, Abdel-Megeed MI, El-Emam MA, Ragab FM, El-Deeb FA. 1998. Susceptibility of *Biomphalaria alexandrina* to the plant *Azolla pinnata* and some herbicides in relation to infection with *Schistosoma mansoni miracidia*. Journal of the Egyptian Society of Parasitology 28:89–100.