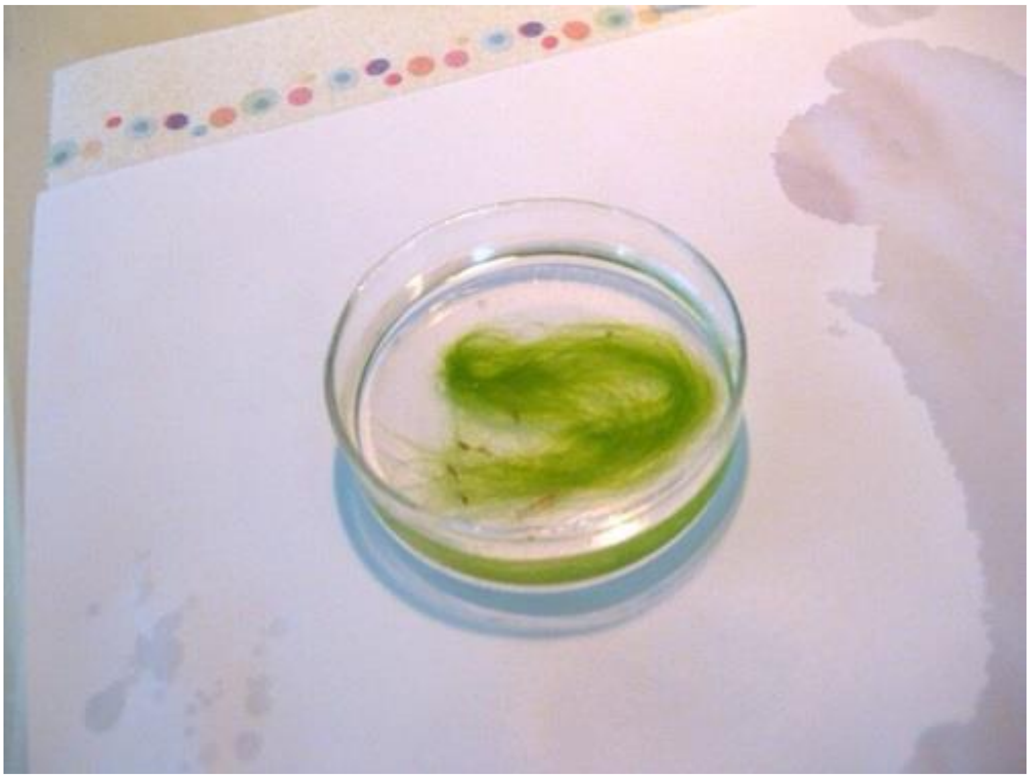
Grass Kelp (*Ulva flexuosa*)
Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, February 2014
Revised, March 2016, November 2017
Web Version, 12/12/2019



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1 Native Range and Status in the United States

Native Range

From Sturtevant et al. (2012):

"Unknown. This species is widespread. It occurs around the world in inland and/or coastal waters of Latin America and the Caribbean, Asia, Europe, Australia, the U.S.A., Mexico, and various islands in the Pacific Ocean (Kowalski 1975, Trono 1975, Webber 1975, Riouall 1976, Sivalingam 1977, Morton 1978, Vaughan 1978, Bird and McIntosh 1979, Lobel and Ogden 1981, Kies and Dworsky 1982, Rodriguez de Rios and Lobo 1984, Grant and Prasad 1985, Guner et al. 1985, Ho 1987, Hadi et al. 1989, Khotimchenko 1993, Beach et al. 1995, Martinez-Murillo and Aladro-Lubel 1996, Magnusson 1997, Schories et al. 1997, Fernandez et al. 1998, Woolcott and King 1999, Hodgson and McDermid 2000, Tabudravu et al. 2002, Matik-Skoko et al. 2004, Lourenco et al. 2006, Sahoo et al. 2006).

Ulva flexuosa is considered a cosmopolitan species that has a worldwide distribution (Lougheed and Stevenson 2004)."

From Mareš et al. (2011):

"Most importantly, we were able to identify all studied populations from European inland waters as *U. flexuosa*. This result was strongly supported by both morphological and molecular approaches. We consequently could confirm previous observations exclusively based on morphology by Wærn (1952), Bliding (1963), Marvan et al. (1997), Lederer et al. (1998), Sitkowska (1999), Skácelová (2004), Messyasz and Rybak (2009), and Kaštovský et al. (2010), who reported *U. flexuosa* from the Czech Republic, Poland, and Sweden. For comparison, we sampled some of the important localities noted by these authors, for example, the river Saxån in Sweden, where Bliding collected original material for his monograph, or the classical Czech site in the Soos salt marsh, from which *Ulva* has been reported since the 19th century (Hansgirg 1892, Brabez 1941). Further evidence was gained by the examination of herbarium specimens. Historical collections from the Czech Republic, Hungary, and Romania starting in the 1930s (originally classified as *U. intestinalis*) demonstrably belonged to the same taxon as our recent samples, which was proved by analysis of both morphological and molecular data. Using *rbc*L sequencing, […]"

"Based on our results, *U. flexuosa* should not be considered as alien or invasive in inland European waters. There is now convincing evidence that the species has occurred in this area at least since collection of the type specimen of *U. flexuosa* subsp. *pilifera* (Kützing 1856). Our observations of eight historic specimens (two from Hungary, one from Romania, and five from the Czech Republic) indicate that many previous reports of freshwater *U. intestinalis* should be regarded as *U. flexuosa* in a modern systematic view, as was already proposed by Wærn (1952), Bliding (1963), and Kaštovský et al. (2010). As our data set is limited, we cannot exclude the possible occurrence of other taxa, but we believe that *U. flexuosa* is most likely the prevailing species of Ulva in European freshwaters."

Status in the United States

From Sturtevant et al. (2012):

"*Ulva flexuosa* was recorded for the first time in 2003 in Muskegon Lake, Michigan, where the Muskegon River empties into Lake Michigan. Within the same drainage, it has also been recorded from White Lake and Mona Lake (Lougheed 2005, Lougheed and Stevenson 2004)."

"The Great Lakes range of *U. flexuosa* is currently limited to Muskegon, Mona and White Lake. However, as it is able to form blooms in Muskegon Lake—which has a lower conductivity than Lake Erie—there is potential for it to thrive in other locations in the Great Lakes (Lougheed and Stevenson 2004)."

"Established where recorded."

Means of Introductions in the United States

From Sturtevant et al. (2012):

"*Ulva flexuosa* was very likely transported to the Great Lakes basin in ballast water or on ship hulls (Lougheed and Stevenson 2004)."

Remarks

Various sources list *Ulva flexuosa* (e.g., Guiry in World Register of Marine Species) or *Enteromorpha flexuosa* (e.g., ITIS) as the senior synonym. *Ulva and Enteromorpha* have been treated as separate genera in the past, however, genetic analysis suggests that they are congeneric and as *Ulva* was the first name used in the literature, *Enteromorpha* should be reduced to a synonym status (Shimada et al. 2003). Taxonomy at the Family level and above is the same for both genera. This ERSS follows current scientific understanding that *Ulva flexuosa* is the valid name for this species and *Enteromorpha flexuosa* is a synonym. Information searches were conducted using both names. There are multiple subspecies known, the specific number of which depends on the source being referenced (e.g., 5 subspecies given by Guiry (2015), 2 subspecies given in ITIS, 4 subspecies and 4 varieties in GBIF Secretariat (2019)).

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From Guiry (2015):

"*Ulva flexuosa* Wulfen, 1803"

"Classification: Biota > Plantae (Kingdom) > Viridaeplantae (Subkingdom) > Chlorophyta (Phylum) > Ulvophyceae (Class) > Ulvales (Order) > Ulvaceae (Family) > *Ulva* (Genus) > *Ulva flexuosa* (Species)"

"Status accepted"

"Synonymised names […] *Enteromorpha flexuos*a (Wulfen) J.Agardh, 1883"

Size, Weight, and Age Range

From Sturtevant et al. (2012):

"Size: < 30 cm long and 0.5-1.0 cm in diameter (Sahoo et al. 2003)"

From Hill (2001):

"*E. flexuosa* grows to 20 cm but generally tends to be smaller."

Environment

From Sturtevant et al. (2012):

"*Ulva flexuosa* is primarily a marine species but can tolerate freshwater conditions and is considered euryhaline. It is fast growing and prefers littoral zones with some wave action. In the Lake Michigan watershed, it occurs in mesotrophic to eutrophic aquatic habitats. Its establishment could have been spurred by increased salt concentrations from industrial sources and de-icing salts since the 1850s, as well as a lack of native grazing pressure."

"*Ulva flexuosa* is known from diverse habitats around the world and has been recorded in salinities ranging from 0.5–34‰."

From Hill (2001):

"Optimum reproduction temperature is under 30° C (Mairh, Pandey and Tewari 1986) in waters with a pH of approximately 8.2."

From Mareš et al. (2011):

"Our chemical analyses from several sampling localities indicate that *U. flexuosa* prefers environments with a higher content of dissolved ions (especially chloride and sulfate) than normally present in average freshwater (Wetzel 2001)."

Climate/Range

From Hill (2001):

"Growth of this species in outdoor ponds in India (Mairh, Pandey and Tewari 1986) showed that *E. flexuosa* was able to sustain growth in water temperatures as high as 30° C. Favorable growth was maintained at temperatures ranging from 15.5 - 30° C.

At 33° C, bleaching of a few branches begins to occur, and above this temperature, adverse effects on growth increase as more and more branches become bleached."

Distribution Outside the United States

Native

From Sturtevant et al. (2012):

"Unknown. This species is widespread. It occurs around the world in inland and/or coastal waters of Latin America and the Caribbean, Asia, Europe, Australia, the U.S.A., Mexico, and various islands in the Pacific Ocean (Kowalski 1975, Trono 1975, Webber 1975, Riouall 1976, Sivalingam 1977, Morton 1978, Vaughan 1978, Bird and McIntosh 1979, Lobel and Ogden 1981, Kies and Dworsky 1982, Rodriguez de Rios and Lobo 1984, Grant and Prasad 1985, Guner et al. 1985, Ho 1987, Hadi et al. 1989, Khotimchenko 1993, Beach et al. 1995, Martinez-Murillo and Aladro-Lubel 1996, Magnusson 1997, Schories et al. 1997, Fernandez et al. 1998, Woolcott and King 1999, Hodgson and McDermid 2000, Tabudravu et al. 2002, Matik-Skoko et al. 2004, Lourenco et al. 2006, Sahoo et al. 2006).

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"Based on our results, *U. flexuosa* should not be considered as alien or invasive in inland European waters. There is now convincing evidence that the species has occurred in this area at least since collection of the type specimen of *U. flexuosa* subsp. *pilifera* (Kützing 1856). Our observations of eight historic specimens (two from Hungary, one from Romania, and five from the Czech Republic) indicate that many previous reports of freshwater *U. intestinalis* should be regarded as *U. flexuosa* in a modern systematic view, as was already proposed by Wærn (1952), Bliding (1963), and Kaštovský et al. (2010). As our data set is limited, we cannot exclude the possible occurrence of other taxa, but we believe that *U. flexuosa* is most likely the prevailing species of Ulva in European freshwaters."

Introduced

The native, and therefore also the invasive, range of *Ulva flexuosa* is uncertain (Sturtevant et al. 2012).

From Heesch et al. (2009):

"Based on the criteria used in this study, we have concluded that of the 19 species of *Ulva*, at least four are probable introductions [to New Zealand] (*U. armoricana*, *U. californica*, *U. flexuosa* and *U. lactuca*)."

Kirkendale et al. (2013) lists *Ulva flexuosa* as possibly introduced to Australia based on a lack of genetic diversity in the samples collected from Australia.

Means of Introduction Outside the United States

Information on the specific means of introduction for *Ulva flexuosa* outside the United States could not be found.

From Hill (2001):

"The ecological success of *E. flexuosa* and other pioneering species is in part attributed to the readily available pool of motile unicells that are able to rapidly colonize new areas. The chance for successful settlement of these cells is greatly enhanced because gametes and zoospores of this species remain viable for 10 or more days due to their ability to photosynthesize, often achieving photosynthetic rates approaching those of the adult thalli (Beach et al. 1989)."

Short Description

From Sturtevant et al. (2012):

"*Ulva flexuosa* has a smooth, tubular thallus that is linear and uniform in width, with numerous branches in the lower third. It can have one to several fronds. *Ulva flexuosa* ranges from translucent dark to light green, with chloroplasts taking up part to most of the outer region of its cells. It has a very small rhizoidal region (Woolcott and King 1999). In general, its subspecies are differentiated by their degree of branching: *U. flexuosa* subsp. *flexuosa* tends to be unbranched, while *Ulva flexuosa* subsp. *paradoxa* has branched filaments and is typically more slender (Sahoo et al. 2003). Additional characteristics are summarized below.

Ulva flexuosa subsp. *flexuosa* is yellow-green with tubular fronds, cylindrical stalks, and a blade expanding above the stalk which ends in a rounded tip. It is attached to the substrate by a small, round basal disc (Sahoo et al. 2003). *Ulva flexuosa* subsp. *flexuosa* has sparse branching, one to two pyrenoids (for carbon dioxide fixation), and quadrangular or rectangular cells arranged in approximately regular rows (Mareš et al. 2011).

Ulva flexuosa subsp. *paradoxa* has an intensely branched stalk with rectangular cells arranged in long rows. These rows are somewhat unordered in the central parts of broader thalli, thinning to a single row of cells at the ends of branchlets (Mareš et al. 2011)."

Biology

From Sturtevant et al. (2012):

"To reproduce, dioecious gametophytes produce male and female gametes that have two flagellae, while sporophytes produce zoospores with four flagellae (Koeman and van den Hoek 1984). Zoospores can be stored in the dark for over 50 days and still germinate with a 35% survival rate, suggesting that transport in ballast water is possible (Beach et al. 1995, Kolwalkar et al. 2007). Swarmers may be released with increasing exposure at night and greater desiccation, whereas vegetative growth may typically occur with shorter exposure times (Mairh et al. 1985)."

"In Muskegon Lake [Michigan], the two subspecies co-occur in littoral zone macrophyte beds, although *U. flexuosa* subsp. *paradoxa* has been recorded to comprise 61% of the macroalgae present by biovolume and *U. flexuosa* subsp. *flexuosa* only 31%. In White Lake [Michigan], *Ulva* sp. has been known to comprise 5% of the macroalgae present, and in Mona Lake [Michigan], 20% (Lougheed and Stevenson 2004)."

"It has been recorded in tidal pools, on mudflats, in sea dikes, in polyhaline man-made waters, in oligohaline ponds, in drainage ditches, on rocks, and in warm calm waters below low tide (Kapraun 1970, Koeman and van den Hoek 1984, Hadi et al. 1989, Sahoo et al. 2003)."

From Hill (2001):

"*E. flexuosa* is highly fecund (Beach et al. 1989), with propagule release via both mitotic spores and meiotic gametes occurring on a daily basis in the lower latitudes. Release of reproductive cells (spores and gametes) into the intertidal zone is driven by tidal and lunar rhythms (Smith 1947, Christie and Evans 1962, Beach et al. 1995). Spores and gametes of this species are photosynthetically competent upon release into the water column, with unicells remaining motile for up to 11 days. Both gametes and zoospores have higher cellular respiration rates when compared to parental tissues, presumably due to their motility. Additionally, the photosynthetic rate for gametes and zoospores of *E. flexuosa* and several other pioneering species is substantially higher than photosynthetic rates observed in the reproductive cells of later successional genera such as the kelps (Phaeophyta). Thus, motility coupled with photosynthetic ability increase the ecological success in settlement and recruitment of this species."

Human Uses

From Hill (2001):

"*E. flexuosa* has some commercial importance due to its antibacterial activity against *Mycobacterium tuberculosis* (Mairh, Pandey and Tewari 1986). This algal species has also been investigated for its potential value as a bioindicator of trace metal pollution in coastal waters (Sivalingam 1978)."

From Sturtevant et al. (2012):

"*Ulva flexuosa* is used as a bioindicator for metal contamination, including lead and iron (Ho 1987, Tabudravu et al. 2002). *Ulva flexuosa* was also found to be an economically efficient species for bioabsorption in industrial settings. It could be used as an eco-friendly alternative for wastewater treatment in dye manufacturing, tannery, textile, and cosmetic industries (Silvasamy et al. 2012)."

Diseases

Information on potential diseases of *Ulva flexuosa* was not found.

Threat to Humans

From Sturtevant et al. (2012):

"*Ulva flexuosa* is known to foul a variety of permanent man-made structures and boats. This can lead to expensive repairs of fouled boat motors. There are even reports of it growing on boats treated with antifouling paint (Kolwalker et al. 2007, Lougheed and Stevenson 2004)."

3 Impacts of Introductions

Ulva flexuosa was unknown within the Great Lakes basin before it was discovered in 2003 (Sturtevant et al. 2012). It is therefore considered to be introduced to the basin.

From Lougheed and Stevenson (2004):

"In addition, *Enteromorpha* [*Ulva flexuosa*] appears to be a poor host for epiphytic algal growth [...]. Epiphytic diatom densities were significantly lower [...] on both subspecies of *Enteromorpha* [*U. flexuosa*] (3.5 ± 1.5 and 1.9 ± 1.0 cells mm^{-2}) than on *Cladophora* (1,286 ± 319 cells mm^{-2}) and *Oedogonium* (677 ± 280 cells mm^{-2}). Epiphytic diatom growth on *Zygnema* and *Spirogyra* was close to zero, and was not significantly difference from that observed on *Enteromorpha* [*U. flexuosa*]. These results concur with those of Lowe *et al.* (1982) who found that epiphyte density on *Cladophora* (1,320 cell mm^{-2}) was 1,000-fold higher than on the mucilaginous-coated cell walls of the exotic alga *Bangia atropurpurea*. This is a concern in systems where *Enteromorpha* [*U. flexuosa*] is dominant and epiphytic diatoms may be important components of the food web."

Other reports of impacts from blooms of *Ulva flexuosa* were from areas that may comprise the native range of the species and so were not included here.

4 Global Distribution

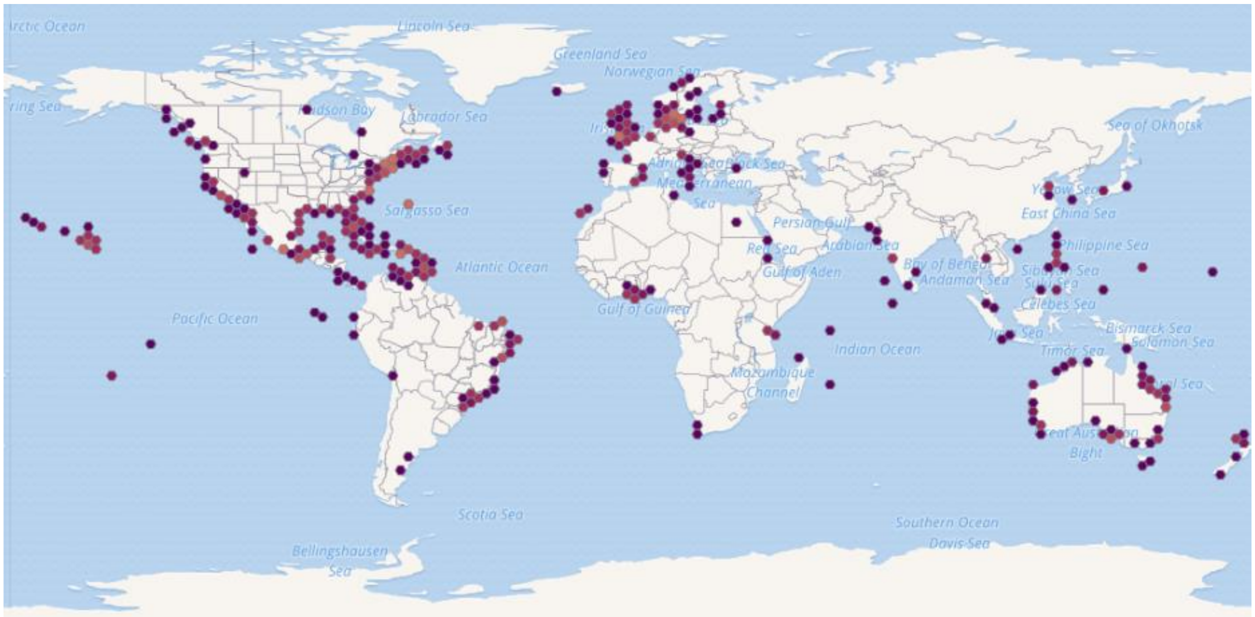

Figure 1. Known global distribution of *Ulva flexuosa*. Map from GBIF Secretariat (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

Additional observations from Czech Republic, Finland, Germany, Hungary, Italy, Norway, Poland, Romania, Scotland, Slovakia, and Sweden are given in Mareš et al. (2011).

5 Distribution Within the United States

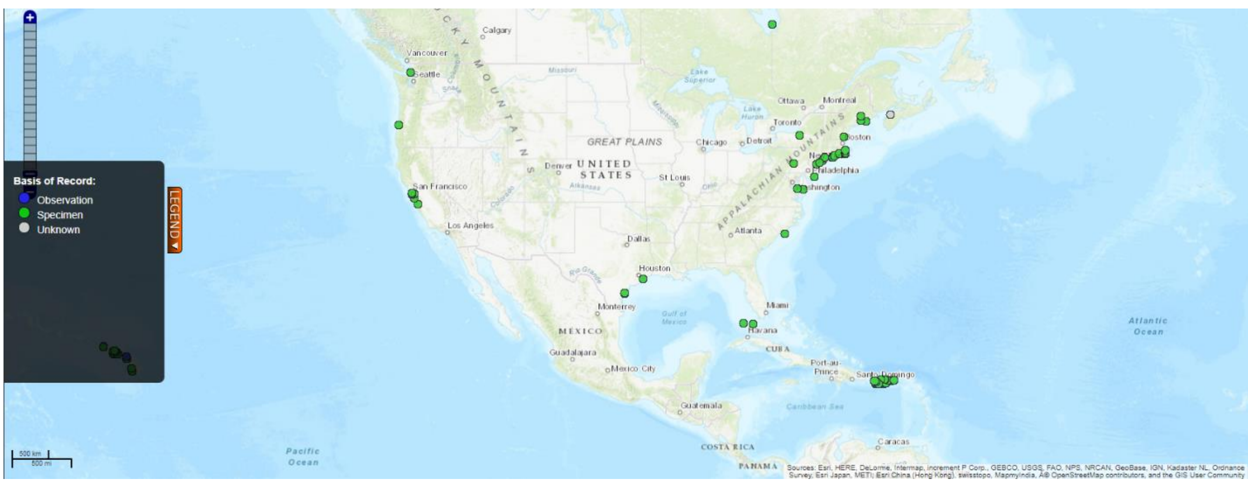

Figure 2. Known distribution of *Ulva flexuosa* in the United States. Map from BISON (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

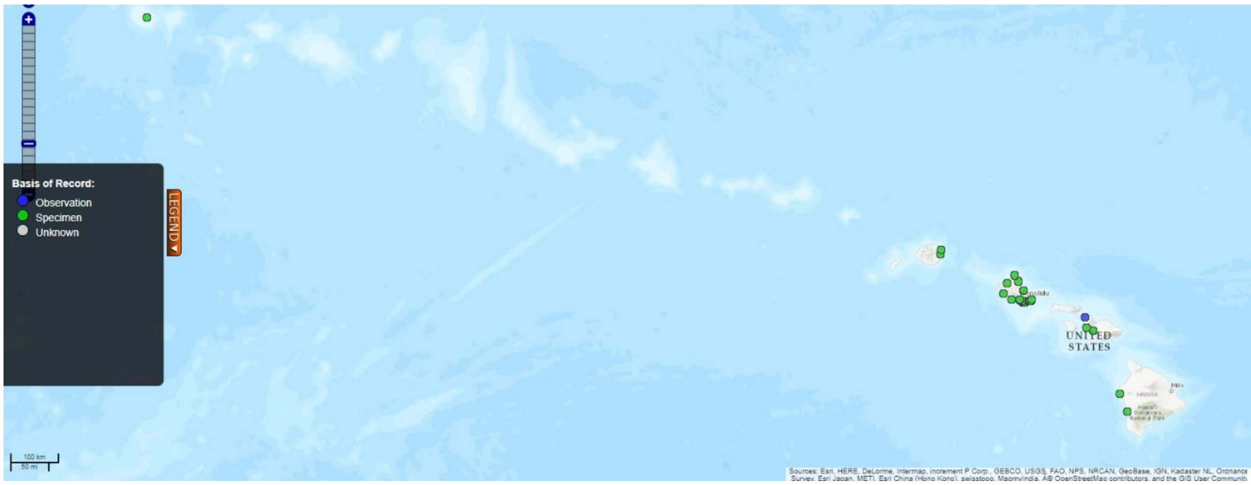

Figure 3. Known distribution of *Ulva flexuosa* in Hawaii. Map from BISON (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

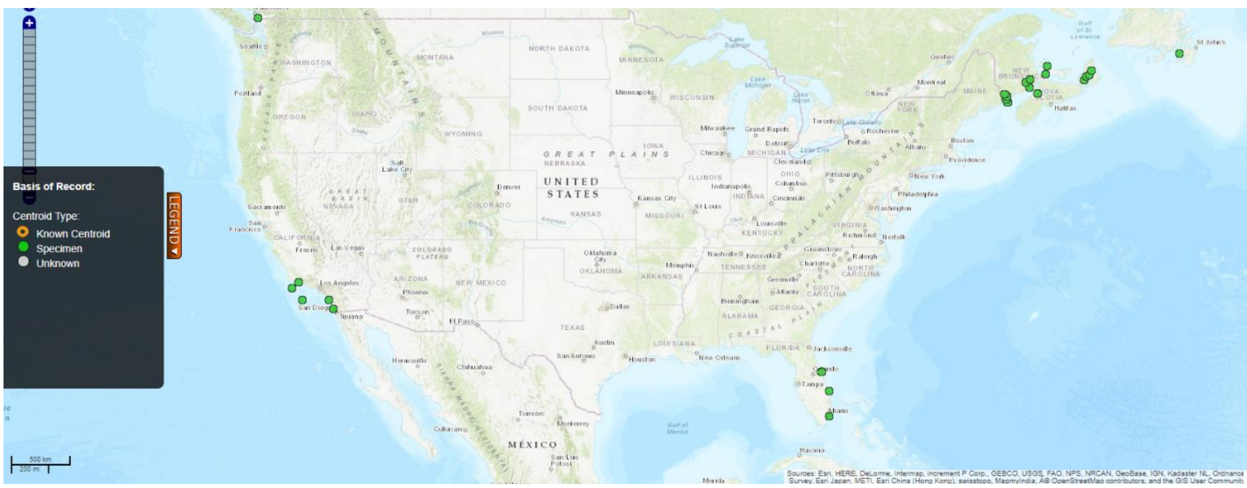

Figure 4. Additional known distribution of *Ulva flexuosa* (listed under the synonym *Enteromorpha flexuosa*) in the United States. Map from BISON (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

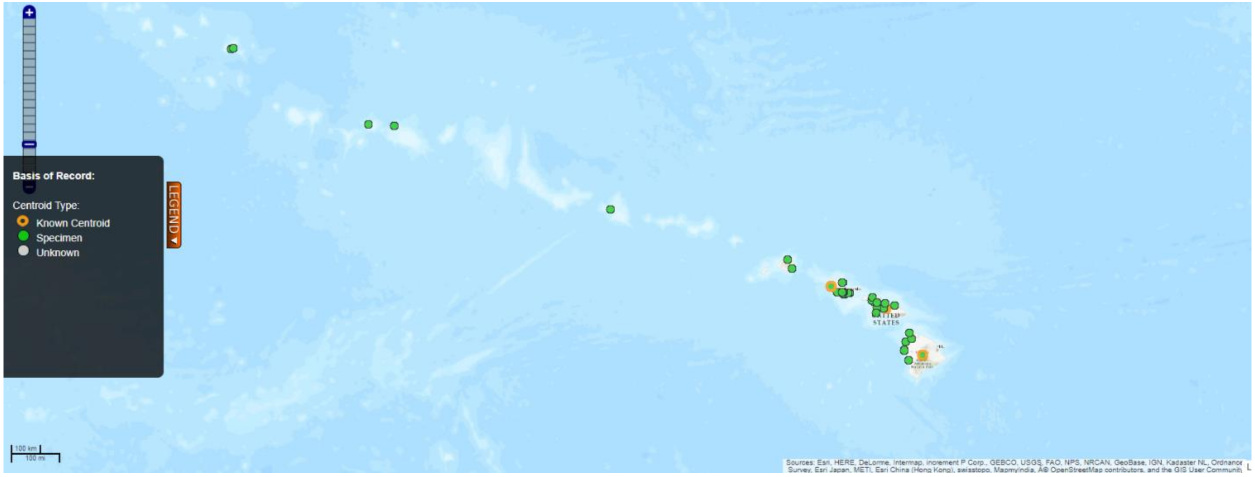

Figure 5. Additional known distribution of *Ulva flexuosa* (listed under the synonym *Enteromorpha flexuosa*) in Hawaii. Map from BISON (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

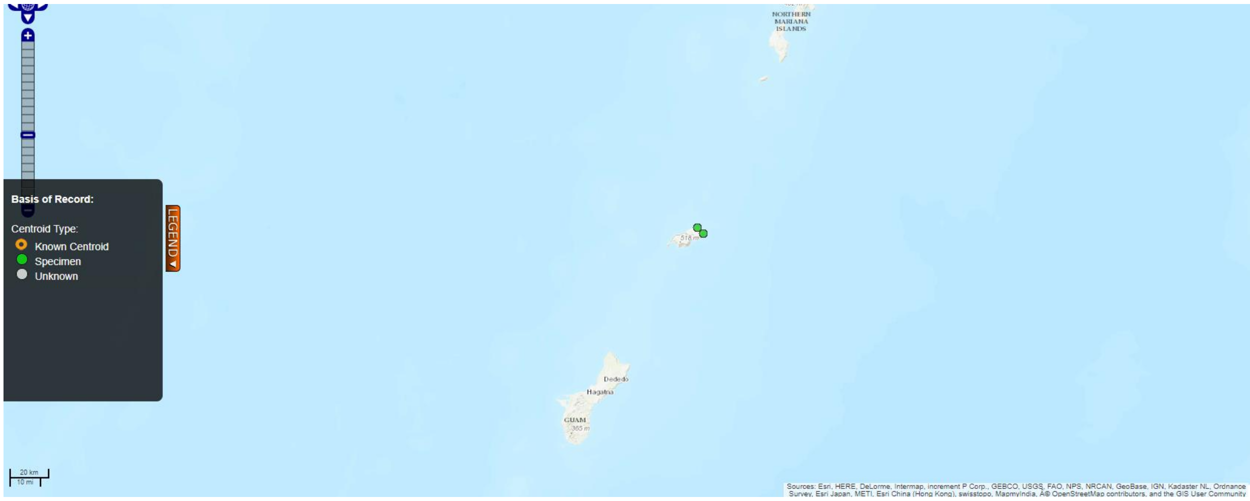

Figure 6. Known distribution of *Ulva flexuosa* (listed under the synonym *Enteromorpha flexuosa*) in the Northern Mariana Islands. Map from BISON (2019). Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

Figure 7. Known distribution of *Ulva flexuosa* in the Great Lakes Basin. Map from Sturtevant et al. (2012).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Ulva flexuosa* was high along the Atlantic, Pacific, and Gulf coasts, where the species thought to be native, and in the Great Lakes region, where *U. flexuosa* is introduced. There were patches of high match inland in the west, where the species is not known to be present. The climate match was medium for the rest of the contiguous United States, except in scattered locations throughout the west and in a portion of the Plains States bordering Canada, where the match was low. The Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for the contiguous United States was 0.756, high. (Scores of 0.103 or greater are classified as high.) All States had high individual Climate 6 scores except North Dakota and South Dakota, which had medium scores.

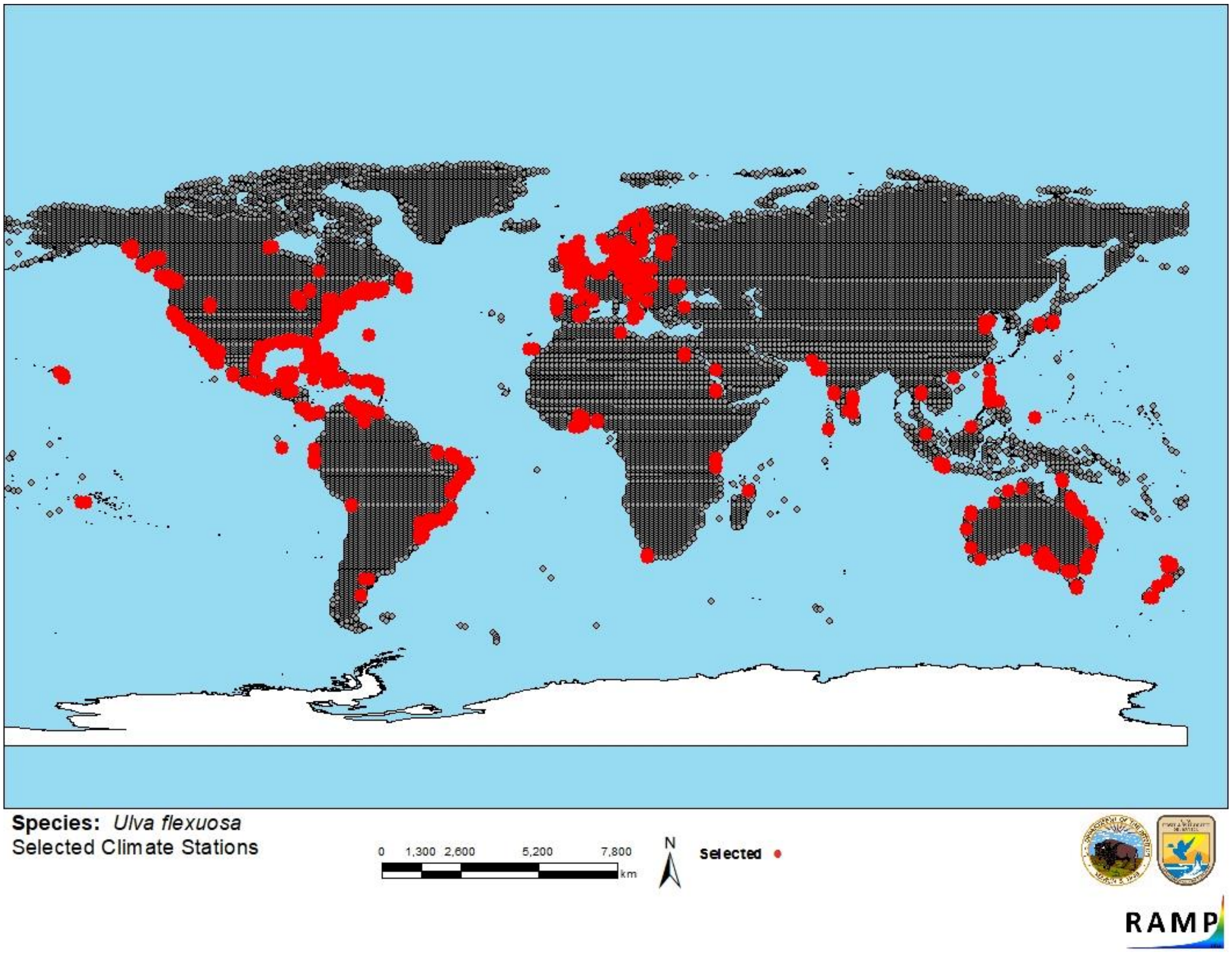

Figure 8. RAMP (Sanders et al. 2018) source map showing weather stations selected as source locations (red) and non-source locations (gray) for *Ulva flexuosa* climate matching. Source locations from Mareš et al. (2011), Sturtevant et al. (2012), BISON (2019) and GBIF Secretariat (2019). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves. Because the climate matching analysis (section 6) is not valid for marine waters, no marine occurrences were used in the climate matching analysis. Points that look to be in marine locations were verified to be located on islands.

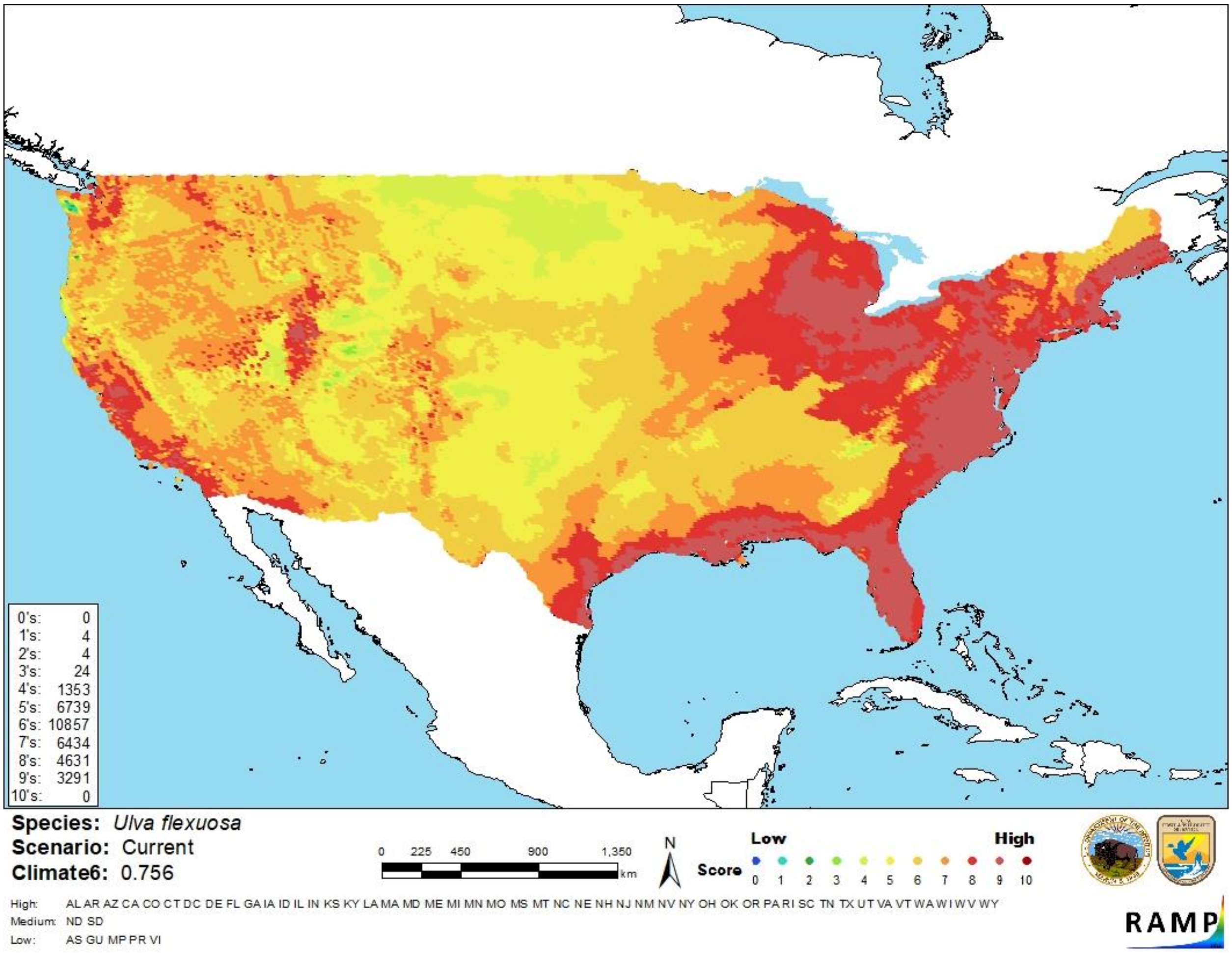

Figure 9. Map of RAMP (Sanders et al. 2018) climate matches for *Ulva flexuosa* in the contiguous United States based on source locations reported by Mareš et al. (2011), Sturtevant et al. (2012), BISON (2019), and GBIF Secretariat (2019). 0 = Lowest match, 10 = Highest match.

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

Climate 6: Proportion of (Sum of Climate Scores 6-10) / (Sum of total Climate Scores)	Climate Match Category
0.000≤X≤0.005	Low
0.005<X<0.103	Medium
≥0.103	High

7 Certainty of Assessment

The certainty of assessment is high. *Ulva flexuosa* is globally distributed. A potentially long history of invasiveness is the reason for the cryptogenic classification of this organism. A record of known introduction and establishment was found with documentation of a negative impact from peer-review literature. There is sufficient information on *U. flexuosa* to satisfy the elements of this assessment.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Ulva flexuosa is a cryptogenic aquatic macroalgae that is globally distributed. *U. flexuosa* primarily a marine and coastal species but it is tolerant to freshwater conditions and a variety of climates. It has uses as a bioindicator of contamination, antibacterial materials, and bioremediation. The history of invasiveness is high. It has been reported in Lake Michigan starting in 2003, with no previous records in the Great Lakes basin, with negative impacts to abundance of epiphytic diatoms. The climate match with the contiguous United States is high. The climate match was high in coastal areas where this species is possibly native and in the Great Lakes basin where it has been introduced. It was also high in parts of the west that do not have any reports of this species' presence. The certainty of assessment is high. The overall risk assessment category is high.

Assessment Elements

- **History of Invasiveness (Sec. 3): High**
- **Climate Match (Sec. 6): High**
- **Certainty of Assessment (Sec. 7): High**
- **Remarks/Important additional information** Referred to in the literature frequently as the synonym *Enteromorpha flexuosa*. There are many subspecies and varieties.
- **Overall Risk Assessment Category: High**

9 References

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 10.

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Sturtevant, R. A., M. M. McCarthy, and A. Fusaro. 2012. *Ulva* (*Enteromorpha*) *flexuosa* subsp. *flexuosa* and *flexuosa* subsp. *paradoxa*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, Michigan. Available: http://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?SpeciesID=2726. (February 2014).

10 References Quoted But Not Accessed

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.

Beach, et al. 1989. [Source material did not give full citation for this reference.]

Beach, K. S., C. M. Smith, T. Michael, and H. W. Shin. 1995. Photosynthesis in reproductive unicells of *Ulva fasciata* and *Enteromorpha flexuosa*: implications for ecological success. Marine Ecology Progress Series 125(1–3):229–237.

Bliding, C. 1963. A critical survey of European taxa in Ulvales. Part I: Capsosiphon, Percursaria, Blidingia, Enteromorpha. Opera Botanica 8:1–160.

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