U.S. Fish & Wildlife Service

Quagga Mussel (*Dreissena bugensis*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, February 2011
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1 Native Range and Status in the United States

Native Range

From Benson et al. (2019):

"*Dreissena rostriformis bugensis* is indigenous to the Dneiper River drainage of Ukraine and Ponto-Caspian Sea. It was discovered in the Bug River in 1890 by Andrusov, who named the species in 1897 (Mills et al. 1996)."

Status in the United States

Dreissena bugensis is listed as an injurious species by the U.S. Congress under the Lacey Act (18 U.S.C. 42(a)(1) under the names "*Dreissena rostriformis* or *Dreissena bugensis*" (U.S. Congress 2018). The importation of quagga mussels into the United States, any territory of the United States, the District of Columbia, the Commonwealth of Puerto Rico, or any possession of the United States, or any shipment between the continental United States, the District of Columbia, Hawaii, the Commonwealth of Puerto Rico, or any possession of the United States is prohibited.

According to Benson et al. (2019), nonindigenous occurrences of *Dreissena rostriformis bugensis* have been reported in the following States, with range of years and hydrologic units in parentheses:

- Arizona (2007-2017; Aqua Fria; Bill Williams; Havasu-Mohave Lakes; Imperial Reservoir; Lake Mead; Lower Colorado; Lower Lake Powell; Lower Salt; Middle Gila)
- California (2007-2018; Havasu-Mohave Lakes; Imperial Reservoir; Newport Bay; Salton Sea; San Diego; San Gabriel; San Luis Rey-Escondido; Santa Ana; Santa Clara; Santa Margarita; Southern Mojave; Whitewater River)
- Colorado (2007-2017; Blue; Colorado Headwaters; Middle South Platte-Sterling; South Platte Headwaters; Upper Arkansas)
- Illinois (2002-2013; Lake Michigan; Lower Illinois-Lake Chautauqua; Lower Ohio-Bay; Pike-Root)
- Indiana (2003-2003; Lake Michigan)
- Iowa (2006-2006; Coon-Yellow)
- Kentucky (2004-2005; Blue-Sinking; Lower Ohio-Bay; Middle Ohio-Laughery)
- Michigan (1997-2017; Betsie-Platte; Boardman-Charlevoix; Brule; Carp-Pine; Cedar-Ford; Cheboygan; Detroit; Fishdam-Sturgeon; Lake Erie; Lake Huron; Lake Michigan; Lake St. Clair; Muskegon; Pere Marquette-White)
- Minnesota (2004-2017; Beartrap-Nemadji; Buffalo-Whitewater; La Crosse-Pine; Lower St. Croix; Rush-Vermillion; St. Louis)
- Missouri (1995-1995; Peruque-Piasa)
- Montana (2016-2016; Marias)
- Nevada (2007-2011; Havasu-Mohave Lakes; Lake Mead; Lower Humboldt; Middle Carson)
- New York (1991-2018;Headwaters St. Lawrence River; Irondequoit-Ninemile; Lake Erie; Lake Ontario; Mohawk; Niagara; Oak Orchard-Twelvemile; Oneida; Raisin River-St. Lawrence River; Seneca)
- Ohio (1992-2013; Ashtabula-Chagrin; Lake Erie; Middle Ohio-Laughery)
- Pennsylvania (1994-2012; Lake Erie; Lehigh; Lower Susquehanna; Upper Juniata)
- South Dakota (2014-2014; Angostura Reservoir)
- Utah (2009-2014; Lower Green-Diamond; Provo; Upper Virgin)
- Wisconsin (2000-2017; Beartrap-Nemadji; Buffalo-Whitewater; Coon-Yellow; Duck-Pensaukee; Lake Michigan; Lake Superior; Manitowoc-Sheboygan; Rush-Vermillion)

From Benson et al. (2019):

"The quagga mussel may have arrived more recently than the zebra based on differences in size classes of initially discovered populations, and therefore it seems plausible that the quagga is still in the process of expanding its nonindigenous range (May and Marsden 1992, MacIsaac 1994). In the 1990s, the absence of quagga mussels from areas where zebra mussels were present may have been related to the timing and location of introduction rather than physiological tolerances (MacIsaac 1994). The quagga mussel is now well established in the lower Great Lakes and found in a few harbor and nearshore areas of Lake Superior.

Quagga mussels have displaced zebra mussels in all offshore areas of Lakes Michigan (Nalepa et al 2014 [personal communication, National Oceanic and Atmospheric Administration, Ann Arbor, MI]); Rowe et al. 2015a), Huron (Nalepa et al. 2018), and Ontario (Wilson et al. 2006; Birkett et al. 2015). There is a gradient of dreissenid domination in Lake Erie, with quagga mussels dominating eastern basins and the two species coexisting in the western basin (Patterson et al. 2005; Karatayev et al. 2014). A similar gradient was initially observed in southern Lake Ontario with quagga mussel dominating the west and zebra dominating the east (Mills et al. 1999), but the quagga mussel has since displaced zebra mussels in all offshore regions of Lake Ontario (Birkett et al. 2015). Coexistence is generally only found in shallow, productive systems such as Green Bay in Lake Michigan, Saginaw Bay in Lake Huron, and Western Lake Erie. There are multiple mechanisms by which quagga mussels displace zebra mussels, including differences in growth, reproduction, respiration, and development (Ram et al. 2012; Karateyev et al. 2015). Though zebra mussels have garnered the majority of public and research attention, quagga mussels have a more extensive distribution in the Great Lakes and their abundance far exceeds that of the zebra mussel peak (e.g., southern Lake Michigan, Nalepa et al. 2010)."

From CABI (2019):

"In 1989, *D. rostriformis bugensis* was first discovered in North America, at Port Colborne in Lake Erie (Mills et al., 1996). The most likely vector for this introduction was via ballast water of transoceanic ships carrying the mussel's larvae (Mills et al., 1994). The biochemical (Spidle et al., 1994) and genetic (May et al., 2006) comparative studies indicate that the Black Sea drainage was the most probable source of the North American population of *D. rostriformis bugensis*. By 1993, *D. rostriformis bugensis* was found in the Great Lakes from the central basin of Lake Erie to the St. Lawrence River at Quebec City (Mills et al., 1996). The first record of *D. rostriformis bugensis* outside the Great Lakes Basin was made in 1995 in the Mississippi River between St. Louis, Missouri and Atlon, Illinois (O'Neil, 1995). In 2005, the first mussels were sighted in Lake Superior (J Kelly, personal communication in Benson et al., 2008). By January 2007 the mussels were found in Lake Mead near Boulder City, Nevada (W Baldwin, personal communication in Benson et al., 2008), and in the lakes Havasu and Mohave on the California/Arizona border (R Aikens, personal communication in Benson et al., 2008). Late in 2007, *D. rostriformis bugensis* was found in six Californian reservoirs (D Norton, personal communication in Benson et al., 2008)."

Means of Introductions in the United States

From Benson et al. (2019):

"The introduction of *D. r. bugensis* into the Great Lakes appears to be the result of ballast water discharge from transoceanic ships that were carrying veligers, juveniles, or adult mussels. The genus *Dreissena* is highly polymorphic and prolific, with high potential for rapid adaptation attributed to its rapid expansion and colonization (Mills et al. 1996). Still, there are other factors that can aid in the spread of this species across North American waters. Th[e]se factors include larval drift in river systems or fishing and boating activities that allow for overland transport or movement between water basins."

From GISD (2019):

"A study conducted by Ricciardi and colleagues (1995) revealed that under temperate summer conditions adult *D. bugensis* may survive on overland transport (e.g. small trailer-boats) for up to 5 days. Veligers can be transported in fish and bait wells as well as in cooling ports of inboard and outboard motors. Most or all the introductions of quagga mussels beyond the 100th Meridian in North America are purported to be via trailered boats (Mackie & Claudi 2009). Its release into Great Lakes waters is linked to discharge of ship ballast water (Mills et al., 1999)."

From CABI (2019):

"The spread of *D. rostriformis bugensis* between water basins in the USA was facilitated by overland transportation of recreational boats (Benson et al., 2008), and the presence of many artificial waterways for drinking water and irrigation also exacerbates the spread of *D. rostriformis bugensis* veligers (Wong and Gerstenberger, 2011)."

"Natural downstream dispersal of *D. rostriformis bugensis* at the planktonic stage poses a high risk of introduction for waterbodies interconnected by natural (rivers, streams) or man-made (canals) waterways, and is an equally important pathway in Europe and North America (Orlova et al., 2005)."

Remarks

From Benson et al. (2019):

"Hybridization between the two introduced dreissenid species was an initial concern. Zebra x quagga mussel hybrids were created by pooling gametes collected after exposure to serotonin in the laboratory, indicating that interspecies fertilization may be feasible (Mills et al. 1996). However, there is evidence for species-specific sperm attractants suggesting that interspecific fertilization may be rare in nature. Thus, if hybridization does occur, these hybrids will constitute a very small proportion of the dreissenid community (Mills et al. 1996).

Redear sunfish (*Lepomis microlophus*) have been shown in experimental enclosers in Sweetwater Reservoir, CA to feed upon and control population sizes of quagga mussels (Wong et al. 2013)."

Literature research was conducted for the valid name, *Dreissena bugensis* and the synonym, *D. rostriformis bugensis.* There is no single consensus in the scientific literature as a whole as to which name is correct for this species. *D. bugensis* was used as the valid name in developing this ERSS as the taxonomic authorities used in the ERSS process all agreed that it was the valid name and *D. rostriformis bugensis* was a synonym. The SOP for the ERSS process can be found online (https://www.fws.gov/fisheries/ANS/species_erss.html).

A previous version of this ERSS was published in 2015. Revisions were done to incorporate new information and to bring the document in line with current standards.

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2019):

"Kingdom Animalia
Subkingdom Bilateria
Infrakingdom Protostomia
Superphylum Lophozoa
Phylum Mollusca
Class Bivalvia
Subclass Heterodonta
Order Veneroida
Superfamily Dreissenoidea
Family Dreissenidae
Genus *Dreissena*
Species *Dreissena bugensis* Andrusov, 1897"

"**Taxonomic Status:**
Current Standing: valid"

Size, Weight, and Age Range

From Benson et al. (2019):

"Size: Reaching sizes up to 4 cm"

From GISD (2019):

"Because they are long-lived […]"

No further information was available on the exact age range of *Dreissena bugensis*.

Environment

From Benson et al. (2019):

"Quagga mussels inhabit freshwater rivers, lakes, and reservoirs. In North American populations, they are not known to tolerate salinities greater than 5 ppt (Spidle et al. 1995). Water temperatures of 28°C begin to cause significant mortality, and 32-35°C are considered lethal for dreissenid species (Antonov and Shkorbatov 1990, as cited in Mills 1996). The depth at which the mussels live varies depending on water temperature. They are not generally found in lakes near shore in shallow water due to wave action. The quagga mussel can inhabit both hard and soft substrates, including sand and mud, down to depths of 130 m and possibly deeper. The maximum density of quagga mussels in Lake Michigan is at 31-90 m (Rowe et al. 2015a)."

"The ability to colonize different substratas could suggest that *D. rostriformis bugensis* is not limited to deeper water habitats and that it may inhabit a wider range of water depths where they have been found at depths up to 130 m in the Great Lakes (Mills et al. 1996, Claxton and Mackie 1998)."

From GISD (2019):

"*D. bugensis* typically occur in fresh water but thrive in salinities up to 1‰ and can reproduce in salinities below 3‰. Salinities exceeding 6‰ cause mortality (Ussery & McMahon 1995; Wright et al. 1996)."

Distribution Outside the United States

Native

From Benson et al. (2019):

"*Dreissena rostriformis bugensis* is indigenous to the Dneiper River drainage of Ukraine and Ponto-Caspian Sea. It was discovered in the Bug River in 1890 by Andrusov, who named the species in 1897 (Mills et al. 1996)."

Introduced

From CABI (2019):

"The expansion of its range in Europe began only after 1940 and likely was associated with construction of interbasin canals and creation of impoundments along the large European rivers (see Orlova et al., 2005). In the mid-1980s, *D. rostriformis bugensis* was introduced into North America, presumably through discharge of ballast water from transoceanic ships (Mills et al., 1994). […] This species was identified as the top ranking invasive species threat to the UK in a study of almost 600 non-native species (Roy et al., 2014); it was discovered for the first time in Surrey in October 2014."

"The quagga mussel, *D. rostriformis bugensis*, originates from the estuarine region of the rivers Southern Bug and Dnieper, Ukraine. The mussels began their range extension within Europe only after 1940, when the first reservoirs were constructed on the Dnieper River. Between the

1940s and 1990s, they had spread in the following main directions (reviewed in Mills et al., 1996; Orlova et al., 2004, 2005; Son, 2007):

- north along the cascades of reservoirs on the Dnieper River;
- east through the Don River system and then north along the reservoirs on the Volga River;
- northwest through the Dniester River.

Until 2005, the westernmost European records of *D. rostriformis bugensis* were from the Danube River within Romania (Micu and Telembici, 2004; Popa and Popa, 2006). In 2006, however, *D. rostriformis bugensis* was discovered as far westward of its native area as in Rhine River Delta, the Netherlands (Molloy et al., 2007), the Dutch Haringvliet (Schonenberg and Gittenberger, 2008) and also in the Main River, Germany (Van der Velde and Platvoet, 2007). […]. In October 2014, it was reported for the first time from the UK, in Wraysbury Reservoir and the Wraysbury River, near Egham, Surrey (BBC, 2014; NNSS, 2014)."

"*D. rostriformis bugensis* was first discovered in the Southern Bug River part of the Dnieper-Bug Liman near the Nikolaev City, Ukraine (Andrusov, 1890 in Mills et al., 1996). Although there was extensive ship traffic between the native area of *D. rostriformis bugensis* and other European regions, this mussel remained restricted to the Dnieper-Bug Liman and the lower parts of the Southern Bug and Ingulets rivers until the middle of the twentieth century. […]. In correspondence with this hypothesis, the first observation of *D. rostriformis bugensis* outside its native area was reported in 1941, soon after construction of the first reservoir on the Dnieper River (Dnieper Reservoir). Between the 1950s and 1970s, *D. rostriformis bugensis* eventually moved upstream and colonised the whole cascade of reservoirs built on the Dnieper. By 1990-1992, the mussel had spread to the Pripyat River Delta, which is currently its northernmost range within the Dnieper River basin (Mills et al., 1996; Orlova et al., 2005).

In 1980, *D. rostriformis bugensis* was recorded for the first time east of its native area, i.e. in the lower stretch of the Don River in Russia, […]. In 1996, it was found in the middle part of that river (Zhulidov et al., 2005). Construction of the Volga-Don Canal (1948-1952) and extensive ship traffic along it allowed mussels to penetrate into the next large Russian river – the Volga, which drains into the Caspian Sea. Until recently, the initial finding of *D. rostriformis bugensis* in the Volga River system was believed to have occurred in 1992 (Antonov, 1993; Orlova et al., 2004; 2005). However, Zhulidov et al. (2005) re-examined their own archived dreissenid specimens collected between 1979 and 1996 and revealed that *D. rostriformis bugensis* were present in the Volga River system near the Akhtyubinsk City as early as 1981. Between 1994 and 1997, the species was found in the Volga Delta and in the shallows of the Caspian Sea. In 1997, *D. rostriformis bugensis* was recorded in the upper part of the Volga River. By 2000, the mussels colonised seven of the nine large reservoirs of the Volga cascade (Orlova et al., 2004). Around 2001, *D. rostriformis bugensis* penetrated through the shipping canal from the Volga River into the Moscow River (Lvova, 2004).

The first record of *D. rostriformis bugensis* west of its native range was in 1988 from the Dniester Reservoir, Ukraine (Shevtsova, 2000), and by 2001 the mussel was already common in the lower part of this river, including the Dniester Estuary (Prof. T. A. Kharchenko, personal communication in Orlova et al., 2005). In 2005, *D. rostriformis bugensis* were observed also in the Moldavian part of the Dniester (Son, 2007). Further spread of *D. rostriformis bugensis* west of its native area was evidenced by two records from the Lower Danube River made in 2004 (Micu and Telembici, 2004) and 2005 (Popa and Popa, 2006) in Romania. The creation of irrigation and shipping canals and ship traffic are considered the main causes for *D. rostriformis bugensis* invasion into the Dniester and Danube Basins (Kharchenko, 1995; Son, 2007). The westernmost European populations of *D. rostriformis bugensis* were revealed in 2006 in the Rhine River Delta, the Netherlands (Molloy et al., 2007), and in 2007 in the Main River, Germany (Van der Velde and Platvoet, 2007). A later paper by Schonenberg and Gittenberger (2008) reports quagga mussel in the Dutch Haringvliet which is now recognised as the westernmost record of this species in Europe[…]. As Van der Velde and Platvoet (2007) did not find *D. rostriformis bugensis* in the canal itself, it is likely that population *of D. rostriformis bugensis* in the Netherlands arose as a result of a single long-distance transfer of the propagules from the lower Danube River. After having been identified as the top ranking invasive species threatening to invade the UK (Roy et al., 2014) this mussel was found in Wraysbury Reservoir and the Wraysbury River, a tributary of the River Colne in the Thames catchment, near Egham, Surrey in October 2014."

From Waerzyniak-Wydrowska et al. (2019):

"In the Szczecin Lagoon (a southern Baltic coastal lagoon), the quagga was recorded for the first time in 2014 and found to co-occur with the zebra mussel, a long-time resident of the Lagoon."

In addition to the areas list previously, CABI (2019) lists *Dreissena bugensis* as introduced in Moldova.

Means of Introduction Outside the United States

From GISD (2019):

"A study conducted by Ricciardi and colleagues (1995) revealed that under temperate summer conditions adult *D. bugensis* may survive on overland transport (e.g. small trailer-boats) for up to 5 days. Veligers can be transported in fish and bait wells as well as in cooling ports of inboard and outboard motors. Most or all the introductions of quagga mussels beyond the 100th Meridian in North America are purported to be via trailered boats (Mackie & Claudi 2009)."

From CABI (2019):

"The expansion of its range in Europe began only after 1940 and likely was associated with construction of interbasin canals and creation of impoundments along the large European rivers (see Orlova et al., 2005). In the mid-1980s, *D. rostriformis bugensis* was introduced into North America, presumably through discharge of ballast water from transoceanic ships (Mills et al., 1994)."

“The spread of *D. rostriformis bugensis* within mainland Europe was facilitated by creation of river impoundments, by construction of interbasin canals and by shipping (see Orlova et al., 2004; 2005).”

“Molloy et al. (2007) suspected that the source of the introduction of *D. rostriformis bugensis* into Western Europe was the Main-Danube Canal re-opened after reconstruction in 1992.”

“Natural downstream dispersal of *D. rostriformis bugensis* at the planktonic stage poses a high risk of introduction for waterbodies interconnected by natural (rivers, streams) or man-made (canals) waterways, and is an equally important pathway in Europe and North America (Orlova et al., 2005).”

Short Description

From Benson et al. (2019):

“*Dreissena rostriformis bugensis* is a small freshwater bivalve mollusk that exhibits many different morphs, though there are several diagnostic features that aid in identification. The quagga mussel has a rounded angle, or carina, between the ventral and dorsal surfaces (May and Marsden 1992). The quagga also has a convex ventral side that can sometimes be distinguished by placing shells on their ventral side: a quagga mussel will topple over, whereas a zebra mussel will not (Claudi and Mackie 1994). Overall, quaggas are rounder in shape and have a small byssal groove on the ventral side near the hinge (Claudi and Mackie 1994). Color patterns vary widely with black, cream, or white bands; a distinct quagga morph has been found that is pale or completely white in Lake Erie (Marsden et al. 1996). They usually have dark concentric rings on the shell and are paler in color near the hinge. If quaggas are viewed from the front or from the ventral side, the valves are clearly asymmetrical (Domm et al. 1993). Considerable phenotypic plasticity of all morphological characteristics is known in dreissenid species and this may be a result of environmental factors, meaning the same genotype may express different phenotypes in response to environmental conditions (Claxton et al. 1998). Due to this phenotypic plasticity, visual identification is not always an acceptable means of differentiating between quagga and zebra mussels (Kerambrun et al. 2018, Beggel et al. 2015). Thus, different methods of genetic comparison have been developed (e.g. May and Marsden 1992; Brown and Stepien 2010; Ram et al. 2012).”

From GISD (2019):

“*Dreissena bugensis* commonly has alternating light and dark brown stripes, but can also be solid light brown or dark brown. It has two smooth shells that are shaped like the letter “D”. These mussels are usually less than 2 inches in length. In new populations, most mussels are young and therefore very small (under ¼ -inch long) (California Department of Fish and Game 2008). […].

There are two phenotypes of *D. bugensis* that have been reported in the Great Lakes: the "epilimnetic" form, which has a high flat shell, and the "profunda" form, which has an elongate modioliform shell and has invaded soft sediments in the hypolimnion. The epilimnetic form uses its byssal threads to attach to objects and particles and form druses or colonies. The profunda

morph can form colonies and attach to objects with its byssal threads or it can partially bury itself in soft sediments and extend its very long incurrent siphon above itself to bring in suspended food particles (Vanderploeg et al. 2002)."

Biology

From Benson et al. (2019):

"They are not generally found in lakes near shore in shallow water due to wave action. […]. The maximum density of quagga mussels in Lake Michigan is at 31-90 m (Rowe et al. 2015a)."

"*Dreissena rostriformis bugensis* lacks the keeled shape that allows *D. polymorpha* to attach so tenaciously to hard substrata; though, *D. rostriformis bugensis* is able to colonize hard and soft substrata (Mills et al. 1996). The ability to colonize different substratas could suggest that *D. rostriformis bugensis* is not limited to deeper water habitats and that it may inhabit a wider range of water depths where they have been found at depths up to 130 m in the Great Lakes (Mills et al. 1996, Claxton and Mackie 1998)."

From GISD (2019):

"After fertilisation veligers (pelagic microscopic larvae) develop within a few days and soon acquire minute bivalve shells. Free-swimming veligers drift with the currents for three to four weeks, feeding using their hair-like cilia while trying to locate suitable substrata to settle and secure byssal threads. Mortality in this transitional stage from planktonic veliger to settled juveniles may exceed 99% (Stanczykowska 1977, in Bially & MacIsaac 2000). Macrophytes, mussel colonies and pebbles were found to be more suitable substrates for settling than gravel, sand or mud (Lewandowski 1982, in Bially & MacIsaac 2000"

"*D. bugensis* is a prolific breeder. It is dioecious and exhibits external fertilisation. A fully mature female mussel is capable of producing up to one million eggs per season (Richerson 2002; D'Itri 1996)."

"*D. bugensis* are filter feeders which use cilia to pull water into their shell cavity from where it passes through an incurrent siphon. Desirable particulate matter is removed in the siphon. Each adult mussel is capable of filtering one or more liters of water each day, removing phytoplankton, zooplankton, algae and even their own veligers (larvae) (Snyder et al. 1997). Any undesirable particulate matter is bound with mucus, known as pseudofeces, and ejected out the incurrent siphon. The particle-free water is then discharged out the excurrent siphon (Richerson 2002, D'Itri 1996, Nalepa & Schloesser 1993)."

From Jones and Ricciardi (2005):

"Twenty sites along the St. Lawrence River were sampled to determine if the distribution and abundance of invasive mussels (zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena bugensis*)) are explained by physicochemical variables. Calcium concentration, substrate size, and depth independently explained significant proportions of variation in biomass for both species. Zebra mussel populations occurred at calcium levels as low as 8 mg Ca·L–1,

but quagga mussels were absent below 12 mg Ca·L–1, suggesting that they have higher calcium requirements. Both species increased in biomass with increasing substrate size but displayed contrasting patterns with depth."

Human Uses

From GISD (2019):

"Because they are long-lived and sessile, quagga mussels can be used as bioindicators of hazardous substances such as radionuclides (Lubianov 1972, in Orlova 2009)."

From CABI (2019):

"*D. rostriformis bugensis* do not possess any economic value and social benefits; however, its use as a biomonitor of metal contamination has been investigated by Johns (2011)."

Diseases

No records of OIE-reportable diseases (OIE 2019) were found for *Dreissena bugensis*.

From CABI (2019):

"More than 40 taxa are known to date to be associated with the mantle cavity and/or visceral mass of *D. polymorpha* (Molloy et al., 1997; Karatayev et al., 2000; Mastitsky, 2004; Mastitsky and Gagarin, 2004; Mastitsky and Samoilenko, 2005). The endosymbionts of *D. rostriformis bugensis* are not so diverse though this may be a reflection of less research work made on *D. rostriformis bugensis*.

Most of the organisms that occur within dreissenids, e.g. nematodes, chironomid larvae, and oligochaetes, are likely to inadvertently penetrate into the mantle cavity by being sucked in through the inhalant siphon of a mussel (e.g. Mastitsky and Gagarin, 2004; Mastitsky and Samoilenko, 2005). Some species, however, are true parasites able to cause negative impact on *Dreissena*. The most severe parasitic disease is likely to be caused by the trematode *Bucephalus polymorphus*, which can substantially destruct the gonads of a mussel host (Molloy et al., 1997; Laruelle et al., 2002). However, this and other trematodes parasitizing dreissenids cannot be used for biological control as they pose a risk for non-target species, i.e. fish and waterfowl that serve as hosts to adult stages of parasites (Molloy, 1998).

Evidence suggests that *D. rostriformis bugensis* is less susceptible to infections by parasites and commensals than its congener, *D. polymorpha*. For example, a 2-year study of the dynamics of infection by the ciliate *Conchophthirus acuminatus* in dreissenids from the Dnieper River, Ukraine has demonstrated a much lower infection rate in *D. rostriformis bugensis* than in *D. polymorpha* (Karatayev et al., 2000). Similarly, 4 taxa of pathogenic helminths were found in *D. polymorpha* from the Rybinsk Reservoir (Volga River Basin), Russia, while no helminth infection was registered in sympatric *D. rostriformis bugensis* (Tyutin, 2005)."

Threat to Humans

From CABI (2019):

"Due to sharp razor-like edges of their shells, dreisseinds often cause cuts and lacerations to [beach] bathers. These wounds then become subjected to a wide range of infections, e.g. Wiel's disease, caused by the bacterium *Leptospira interogans* (Minchin et al., 2002). Along shorelines, decaying mussels produce an extremely foul smell, which incombination with the hazards of cuts in barefoot swimmers and beachcombers may prohibit recreational activities (ZMIS, 2002)."

3 Impacts of Introductions

From Benson et al. (2019):

"Quaggas are prodigious water filterers, removing substantial amounts of phytoplankton and suspended particulate from the water. As such, their impacts are similar to those of the zebra mussel. By removing the phytoplankton, quaggas in turn decrease the food source for zooplankton, therefore altering the food web. Impacts associated with the filtration of water include increases in water transparency, decreases in mean chlorophyll a concentrations, and accumulation of pseudofeces (Claxton et al. 1998). Water clarity increases light penetration causing a proliferation of aquatic plants that can change species dominance and alter the entire ecosystem. The pseudofeces that is produced from filtering the water accumulates and creates a foul environment. As the waste particles decompose, oxygen is used up, and the pH becomes very acidic and toxic byproducts are produced. In addition, quagga mussels accumulate organic pollutants within their tissues to levels more than 300,000 times greater than concentrations in the environment and these pollutants are found in their pseudofeces, which can be passed up the food chain, therefore increasing wildlife exposure to organic pollutants (Snyder et al. 1997). Macksasitorn et al. (2015) found that mussel tissue polychlorinated biphenyl (PCB) concentration was positively related to sediment PCB levels, suggesting that quagga (and zebra) mussels might provide an entry point for PCBs into near-shore benthic trophic webs.

Dreissena species ability to rapidly colonize hard surfaces causes serious economic problems. These major biofouling organisms can clog water intake structures, such as pipes and screens, therefore reducing pumping capabilities for power and water treatment plants, costing industries, companies, and communities. Recreation-based industries and activities have also been impacted; docks, breakwalls, buoys, boats, and beaches have all been heavily colonized. Quaggas are able to colonize both hard and soft substrata so their negative impacts on native freshwater mussels, invertebrates, industries and recreation are unclear. Many of the potential impacts of *Dreissena* are unclear due to the limited time scale of North American colonization. Nonetheless, it is clear that the genus *Dreissena* is highly polymorphic and has a high potential for rapid adaptation to extreme environmental conditions by the evolution of allelic frequencies and combinations, possibly leading to significant long-term impacts on North American waters (Mills et al. 1996). *Dreissena rostriformis bugensis* lacks the keeled shape that allows *D. polymorpha* to attach so tenaciously to hard substrata; though, *D. rostriformis bugensis* is able to colonize hard and soft substrata (Mills et al. 1996). The ability to colonize different substratas could suggest that *D. rostriformis bugensis* is not limited to deeper water habitats and that it may

inhabit a wider range of water depths where they have been found at depths up to 130 m in the Great Lakes (Mills et al. 1996, Claxton and Mackie 1998)."

From GISD (2019):

"Nutrient loading and species introductions are thought to be two of the major environmental problems currently facing freshwater ecosystems (Richter et al. 1997, Hall et al. 2003 in Haynes et al. 2005), and both of these anthropogenic factors are of concern in the Great Lakes, USA (Haynes et al. 2005)."

"*D. bugensis* causes changes in the structural characteristics of zooplankton including total abundance, biomass and species composition. Specifically, there is an inverse relationship between zooplankton abundance/biomass and density of *Dreissena* mussels (Grigorovich & Shevtsova, 1995). *Dreissena* infestations have caused upwards of 95% reduction in unionid numbers and extirpated eight species of unionids in some areas of the Great Lakes (Schloesser et al. 1998; Schloesser & Masteller 1999). Individuals attach themselves to the shells of other mussels, forming encrusting mats many shells thick (10-30mm)."

"*Dreissena* negatively affects benthic invertebrate communities, especially filter-feeding or deep-dwelling invertebrates that rely on detrital rain (Dermott and Munawar 1993, Strayer et al. 1998, Johannsson et al. 2000, in Haynes et al. 2005). Predicting benthic invertebrate community response to a change in nutrient levels is very difficult, and the potential synergistic effects of nutrient alterations and exotics such as *Dreissena* are complex (Haynes et al. 2005)."

"Thick encrustations of mussels form on man-made structures or within raw water systems, impacting on operation and efficiency. *D. bugensis* can have major detrimental impacts on recreational and commercial shipping/boating as well as on water-using industries, potable water treatment plants and electric power stations (Ussery & McMahon, 1995)."

"In both North America and its original range in Europe, *D. bugensis* is replacing zebra mussel (*D. polymorpha*) populations (Domske & Oneill 2003; Diggins et al. 2004). Some industries build intake structures at depths too low for *D. polymorpha* to grow in; however, *D. bugensis* is able to colonise surfaces at greater depths, rendering these new structures vulnerable to mussel colonisation (Mills et al., 1999; and Richerson and Maynard, 2004)."

From CABI (2019):

"The invasion of *D. rostriformis bugensis* into numerous European and North American waterbodies has resulted in a number of adverse impacts, both environmental and economic. Due to their ability to colonise hard surfaces, these mussels become a major fouling problem for raw water-dependent infrastructures, causing damage and increased operating expenses. The mussels invade and clog water-intake pipes and water filtration systems of the municipalities and electric generating plants, fire prevention systems, navigation dams, docks, buoys, hulls of the commercial and recreational vessels, etc. (Molloy, 1998). In the USA alone, the estimated costs associated with *Dreissena* total about 1 billion dollars per year (Pimentel et al., 2005)."

“Dreissenid mussels, including *D. rostriformis bugensis*, are typical “ecological engineers”, i.e. species that “directly or indirectly control the availability of resources to other organisms by causing physical state changes in biotic or abiotic material” (Jones et al., 1994; 1997). Much more information on ecological impacts is available for *D. polymorpha* than for *D. rostriformis bugensis*. However, similar life histories and ecological niches of these two species imply their impacts to be also very similar.”

“As suspension feeders that attach to hard substrates and form large populations, dreissenids are functionally different from most benthic freshwater invertebrates. Due to filtration of large volumes of water, they transfer energy and matter from the water column to the benthos, providing a strong direct link between planktonic and benthic components of the ecosystem (benthic-pelagic coupling, or “benthification”), and thus induce significant alterations in the processes of invaded ecosystems (see Karatayev et al., 1997; 2002, 2007; Idrisi et al., 2001; Vanderploeg et al., 2002; Mills et al., 2003; Burlakova et al., 2005).”

“The filtering activity of *Dreissena* leads to increased water transparency and light penetration, decreased concentrations of seston and organic matter, decreased biochemical oxygen demand, and increased concentrations of ammonia, nitrates, and phosphates (see Karatayev et al., 1997, 2002; Vanderploeg et al., 2002; Burlakova et al., 2005). As *D. rostriformis bugensis* has higher filtration rate than *D. polymorpha* (Diggins, 2001), the former are likely to have greater environmental impacts associated with filtration than the latter. At the same time, *D. rostriformis bugensis* excretes less ammonia and phosphates than its congener (Conroy et al., 2005).

Large aggregations of *Dreissena* alter the physical three-dimensional structure of benthic habitats and provide shelter and food for other invertebrates. Shells of the dead mussels often form reef-like structures that also become inhabited by various invertebrate species (see Karatayev et al., 1997; 2002; 2005; […]).”

“Invasion of *Dreissena* results in decreased phytoplankton density and chlorophyll concentrations (see Karatayev et al., 1997; 2002, 2007; Idrisi et al., 2001; Vanderploeg et al., 2002; Mills et al., 2003; Burlakova et al., 2005). However, the increased nutrients flux from the mussels in combination with selective grazing can facilitate certain algal species, for example, cyanobacteria that cause water blooms (Vanderploeg et al., 2001; Pillsbury et al., 2002, Raikow et al., 2004).”

“Zooplankton abundance usually declines after invasion of *Dreissena*. This decrease may result from competition for food (phytoplankton, planktonic bacteria, and other suspended particles), direct filtering of small-sized zooplankton, or from more complex interactions, such as increased predation of zooplankton by fish (see Karatayev et al., 1997; 2002; 2007; Kryuchkova and Derengovskaya, 2000; Wong et al., 2003; Kissman et al., 2010).”

“Increased water transparency and light penetration caused by filtering activity of *Dreissena* allows submerged macrophytes and periphyton algae to grow deeper and, thus, cover larger portions of the bottom of a waterbody. This effect has a positive feedback as macrophyte beds can further be used by the mussels as a substrate for attachment (see Karatayev et al., 1997; 2002; 2005; Vanderploeg et al., 2002).”

"The impact of *Dreissena* on fish communities may be both positive and negative, as well as direct and indirect, depending on the feeding mode of the fish. The mussels can quickly become a major diet component of molluscivorous fish in recently invaded waterbodies. At least 38 fish species, including some well-known invaders, like round goby (*Neogobius melanostomus*), were field-documented to consume attached dreissenids. Many species also consume veligers of *Dreissena*, which can comprise over 70% of the zooplankton density in summer period (Molloy et al., 1997). Indirect positive impact of *Dreissena* on benthic feeding fish can result from an increased abundance of native benthic macroinvertebrates associated with the mussels' aggregations (see Karatayev et al., 1997; 2002; […]). Indirect negative impacts on planktivorous fish may result from decreased density and biomass of zooplankton organisms in *Dreissena*-invaded waterbodies."

"*D. rostriformis bugensis* serve as a host to about 20 taxa of parasites and commensals, including ciliates, trematodes, nematodes, oligochaetes, chironomids and mites […]. Among these are helminths whose adult stages parasitize in fish (the trematode *Bucephalus polymorphus*) and waterfowl (the trematodes of the family Echinostomatidae) (Chernogorenko and Boshko, 1992; Yurishinets, 1999). Therefore, invasion by *D. rostriformis bugensis* may, at least theoretically, lead to worsening of the parasitological situation in a waterbody."

"Although most studies conducted in Europe and North America demonstrated positive effects of dreissenid mussels on native benthic species (e.g. amphipods, isopods, leeches, turbellarians, hydrozoans, oligochaetes and chironomids), some natives are negatively affected. The unionid mussels are of special concern in this respect (Schloesser and Nalepa, 1994; Karatayev et al., 1997; Schloesser et al., 1998; Ricciardi et al., 1998; Burlakova et al., 2000). When attached to the shells of unionids, dreissenid mussels impede their burrowing and moving through the sediments. Extra weight of the unionids can also result in their burial in soft sediments. More importantly, attached *Dreissena* prevent unionids from opening their valves for respiration, feeding and reproduction, and also prevent closing of the valves. The most severe mass mortalities of native unionids occur during the initial stages of colonisation of a waterbody, when dreissenid populations are rapidly growing. With time, however, this negative impact becomes weaker, making possible the co-existence of *Dreissena* and unionids (Karatayev et al., 1997; Burlakova et al., 2000).

Introduction and subsequent proliferation of *D. rostriformis bugensis* and *D. polymorpha* in the Laurentian Great Lakes have coincided with dramatic declines in density and biomass of the burrowing amphipods *Diporeia hoyi*, which had supplied about 20% of the fisheries energy budget in the region (Dermott and Munawar, 1993; Dermott, 2001; Lozano et al., 2001; Dermott et al., 2005; Nalepa et al., 2006). Reasons for the negative response of *Diporeia* to these mussels are not clear. One possible explanation is that dreissenids are outcompeting Diporeia for available algal food (Dermott and Munawar, 1993; Dermott, 2001; Lozano et al., 2001). Evidence suggests, however, that the reason is more complex because the amphipods have completely disappeared even from those localities where dreissenids are rare or absent and food is abundant (Nalepa et al., 2006). A recent study by Dermott et al. (2005) has demonstrated that feeding of *Diporeia* on pseudofaeces of *D. rostriformis bugensis* results in a significant mortality in the amphipods. The exact mechanism of low survival of *Diporeia* in this experiment is

unknown but might be related to the nutritional quality of pseudofaeces or associated waste metabolites."

"*D. rostriformis bugensis* can negatively affect recreational activities of humans in different ways. In recreational boats, for instance, they can attach to the water intake slots of coolant pipes, leading to damage of the engine from overheating. Hulls' fouling can increase fuel consumption because of greater drag (Minchin et al., 2002).

Dreissenid mussels may colonise fishing nets and navigational buoys making them useless because of the added weight that drags them under the water (ZMIS, 2002).

Due to sharp razor-like edges of their shells, dreisseinds often cause cuts and lacerations to bathers. These wounds then become subjected to a wide range of infections, e.g. Wiel's disease, caused by the bacterium *Leptospira interogans* (Minchin et al., 2002). Along shorelines, decaying mussels produce an extremely foul smell, which incombination with the hazards of cuts in barefoot swimmers and beachcombers may prohibit recreational activities (ZMIS, 2002)."

From Fahenstiel et al. (2010):

"The dominance of non-indigenous invertebrates in both the pelagic and benthic regions of Lake Michigan also has implications for future fisheries management. While *Dreissena* influence on fish populations is less clear than for phytoplankton, present fish production in Lake Michigan is likely affected by *Dreissena* populations. For example, the condition of two abundant planktivores, alewife *Alosa pseudoharengus* and lake whitefish *Coregonus clupeaformis*, has declined since dreissenids became abundant (Pothoven et al., 2001; Madenjian et al., 2006). Moreover, *Mysis relicta* density is now low at a time of low fish predation (Pothoven et al., 2010), and the question of whether *Mysis* populations are sustainable with increased fish predation has implications for future fisheries. A major consideration in the post-*Dreissena* period is whether present fisheries management goals based on a pelagic dominated system and historical food webs are realistic and sustainable.

Based on the long-term observations and experiments presented in the papers of this issue, it is apparent that recent, unprecedented changes in the lower food web of southern Lake Michigan can be attributed to the increased abundance and spatial expansion of *D. r. bugensis*. Many observed changes were similar to those resulting from the initial expansion of *D. polymorpha* in the shallow nearshore regions of the Great Lakes (i.e., decreased chlorophyll and primary production, increased water clarity, decoupling of chlorophyll from nutrient loads, etc.). Yet given the habitat, the observed changes are unique in that they demonstrate a strong vertical connection between mussel filtering activities and the extensive pelagic environment found in deep, offshore regions during a major portion of the year. Direct and indirect impacts were far-reaching, as evidenced by the loss of the spring diatom bloom and the decline of *Mysis*. Changes in the pelagic food web are relatively recent, and the long term, more permanent state may be quite different as the mussel population stabilizes and likely declines and the pelagic system adjusts accordingly. Presently, the *D. r. bugensis* population in southern Lake Michigan continues to rapidly expand at depths N50 m, even though potential food resources have declined to historically low levels."

4 Global Distribution

Figure 1. Known global distribution of *Dreissena bugensis*. Map from GBIF Secretariat (2019).

5 Distribution Within the United States

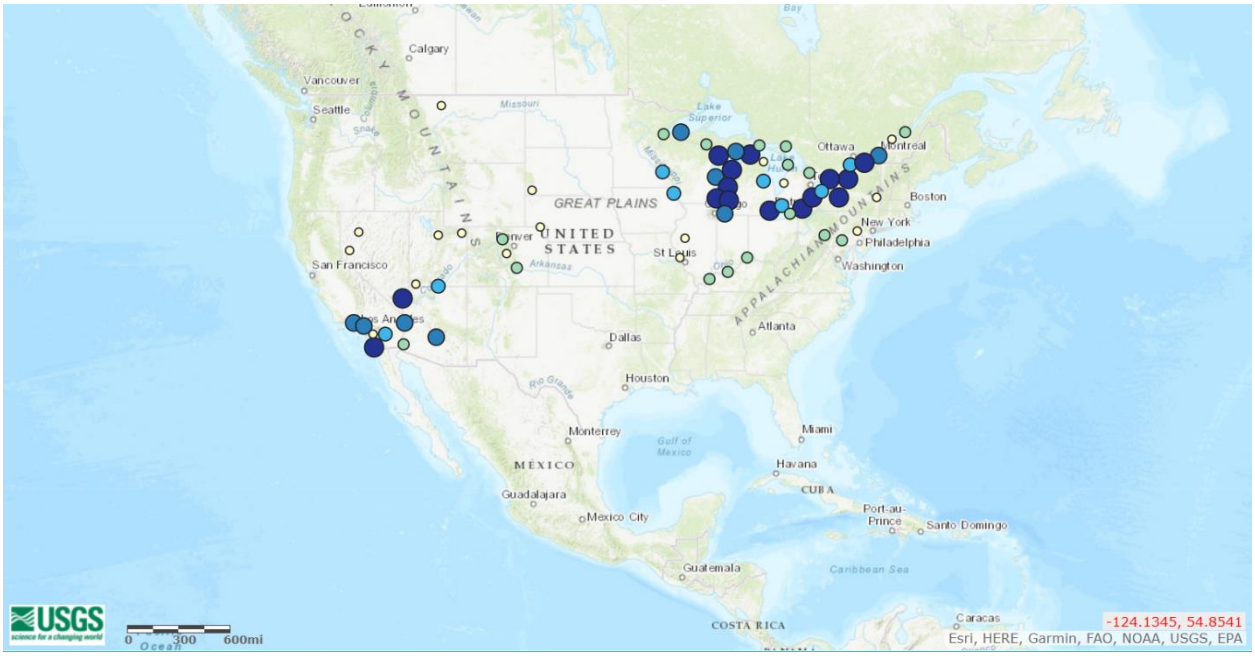

Figure 2. Known distribution of *Dreissena bugensis* in the United States. Map from Benson et al. (2019).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Dreissena bugensis* was high throughout the majority of the contiguous United States with small areas of low match in southern Florida, western Washington, and Oregon. The Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for the contiguous United States was 0.838, high (scores 0.103 and greater are classified as high). All States had high individual Climate 6 scores except for Florida, which had a low score.

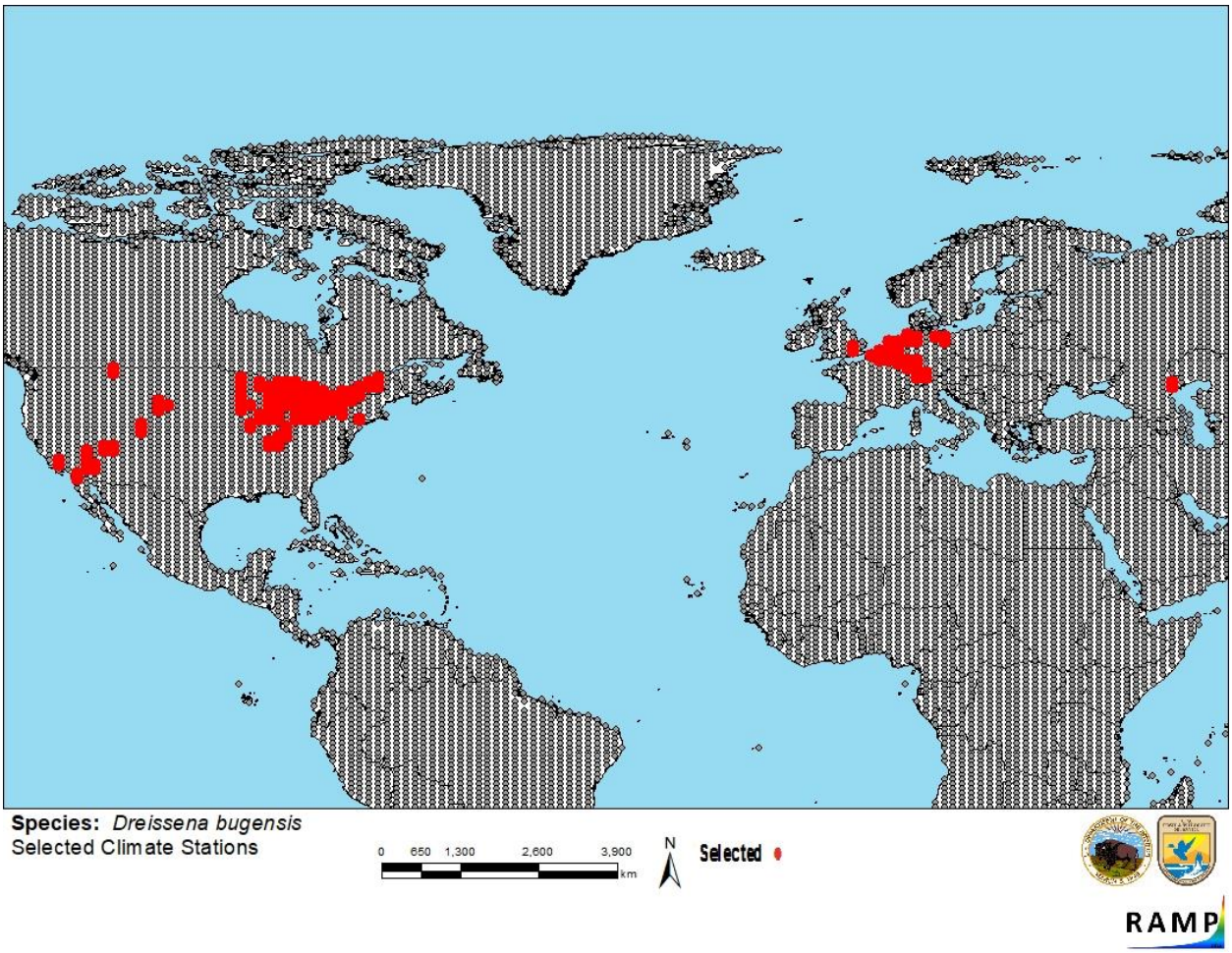

Figure 3. RAMP (Sanders et al. 2018) source map showing weather stations throughout the world selected as source locations (red; North America, Europe, and Russia) and non-source locations (gray) for *Dreissena bugensis* climate matching. Source locations from GBIF Secretariat (2019). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

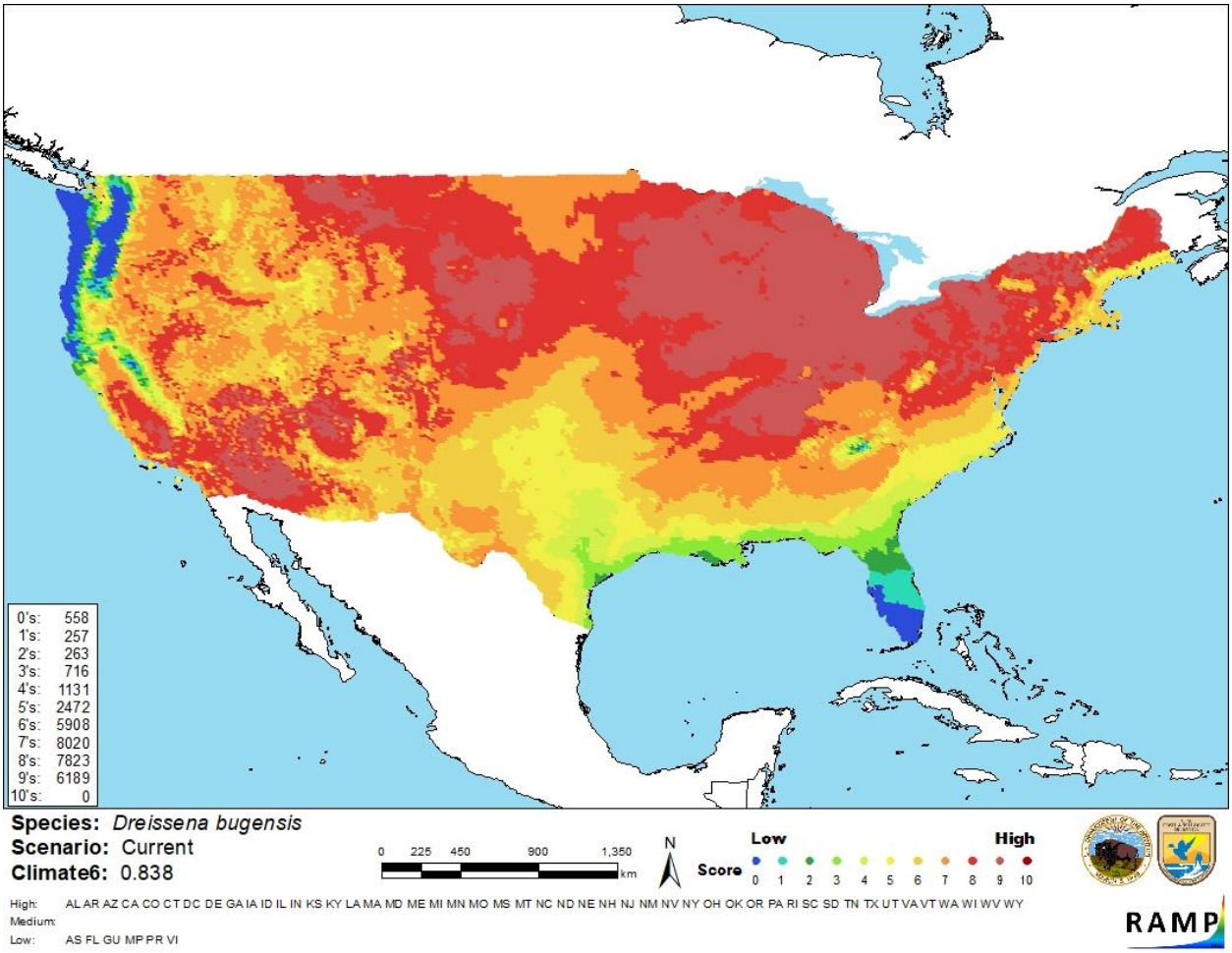

Figure 4. Map of RAMP (Sanders et al. 2018) climate matches for *Dreissena bugensis* in the contiguous United States based on source locations reported by GBIF Secretariat (2019). 0 = Lowest match, 10 = Highest match.

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 biology and ecology of *Dreissena bugensis* are well-known. Negative impacts from introductions and spread of this species are adequately documented in the scientific literature. No further information is needed to evaluate the negative impacts the species is having where introduced. Certainty of this assessment is high.

8 Risk Assessment

Summary of Risk to the Contiguous United States

The quagga mussel (*Dreissena bugensis*) is bivalve native to the Dneiper River drainage of Ukraine and Ponto-Caspian Sea. Establishment and impacts in the United States are occurring. Spreading of this nonindigenous species is likely between watersheds, where transportation of boats and other watercraft is common. *D. bugensis* can profoundly modify ecosystem characteristics through cascading effects of its water filtration behavior. Thick encrustations of mussels form on artificial structures or within raw water systems, interfering with operation and decreasing efficiency. *D. bugensis* can have major detrimental impacts on recreational and commercial shipping and boating as well as on water-using industries, potable water treatment plants, and electric power stations. Major injuries have been reported for native species in the Great Lakes, such as the extirpation of eight unionid species in some areas. The climate score was categorically high for the contiguous United States with all States having an individually high climate score except for Florida. The certainty of this assessment is high. Overall risk assessment for *Dreissena bugensis* 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: This species is listed as an injurious species in the United States (U.S. Congress 2018).**
- **Overall Risk Assessment Category: High**

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