Golden Mussel (*Limnoperna fortunei*)
Ecological Risk Screening Summary

U.S. Fish and Wildlife Service, November 2023
Revised, September 2024
Web Version, 11/8/2024

Organism Type: Mussel
Overall Risk Assessment Category: High

Photo: Boltovskoy. Licensed under CC BY-SA 4.0. Available: https://commons.wikimedia.org/wiki/File:Limnoperna_fortunei.jpg (November 2023).

1 Native Range and Status in the United States

Native Range

Boltovskoy et al. (2009) describes *L. fortunei* as native to China, Thailand, Korea, Laos, Cambodia, Vietnam, and Indonesia.

From Bogan (2012):

“Morton and Dinesen (2010) list the distribution of the species in China as: Yangtze basin - the lakes Dongting (Hunan Province), Yuangkian (Jiangsu Province), Chow-Wen-Miao, Chiang-Kia-Tsui, Jiangyin ('Siangyin'; Jiangsu Province) and Yoyang and adjacent rivers, and the Xiang River, near Changsha, Hunan Province). Also present in Thailand (Kwai River, Batambang, the mouth of the Kompong-Som River, the Mekong south of Nakon Ponom, the Maenam Mun River, the Lam Chi River, the Chao Phraya and Pasak rivers, the Tapi River, Tale Luang near Pattalung, Mekong branch at Muang Sene, Khong Island.”

“Brandt (1974) listed it [in Thailand] from Mekong River south of Nakon Panom, Maenam Mun River, Lam Chi River, Chao Phraya and the Pasak River. In many klongs and tributaries to the Chao Phraya River, in the Maeklong River, in the south it reaches the Tapi River and Tale Luang near Pattalung.”

Status in the United States

From California Department of Water Resources (2024):

“Golden Mussels (*Limnoperna fortunei*) were found at Rough & Ready Island near Stockton, California on October 17, 2024. […] This is the first-ever detection of the Golden Mussel in North America.”

California Department of Water Resources (2024) also listed a detection of *L. fortunei* at Turner Cut near Stockton, California.

No records of *Limnoperna fortunei* in trade in the United States were found.

Regulations

From Fusaro et al. (2023):

“Ohio lists *L. fortunei* as an injurious aquatic invasive species and therefore it is unlawful for any person to possess, import, or sell live individuals within the state. Dead golden mussels can only be possessed in Ohio if they are preserved in ethanol or formaldehyde, or eviscerated (internal organs removed) (OH ADM. Code, 1501:31-18-01). In Michigan, it is illegal to possess, import, sell, or offer to sell *L. fortunei* (NREPA Part 413 as amended, MCL 324.41302). Illinois lists *L. fortunei* as an injurious species as defined by 50 CFR 16.11-15. Therefore, *L. fortunei* cannot be possessed, propagated, bought, sold, bartered or offered to be bought, sold, bartered, transported, traded, transferred or loaned to any other person or institution unless a permit is first obtained from the Department of Natural Resources. Illinois also prohibits the release of any injurious species, including *L. fortunei* (17 ILL. ADM. CODE, Chapter 1, Sec. 805). It is prohibited to transport, possess, or introduce *L. fortunei* in Wisconsin (Wisconsin Chapter NR 40).”

Nevada (NVBWC 2022) classifies *L. fortunei* as invasive.
Texas (TPW 2022) classifies *L. fortunei* as an invasive, prohibited, and exotic species.

While effort was made to find all applicable regulations, this list may not be comprehensive.

Means of Introductions within the United States

From California Department of Fish and Wildlife (2024):

"These mussels were likely introduced to California by a ship traveling from an international port."

Remarks

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

According to the NIES (2023), *Limnoperna fortunei* is in the top 100 of Japan's worst invasive alien species.

From Fusaro et al. (2023):

"It is illegal to import, possess, deposit, release, transport, breed/grow, buy, sell, lease or trade [*Limnoperna*] *fortunei* in Ontario (Invasive Species Act 2015)."

From NIES (2020):

"Import, transport and keeping of genus *Limnoperna* are prohibited in Japan by the Invasive Alien Species Act."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From MolluscaBase (2023):

"Animalia (Kingdom) > Mollusca (Phylum) > Bivalvia (Class) > Autobranchia (Subclass) > Pteriomorphia (Infraclass) > Mytilida (Order) > Mytiloidea (Superfamily) > Mytilidae (Family) > Arcuatulinae (Subfamily) > *Limnoperna* (Genus) > *Limnoperna fortunei* (Species)"

According to MolluscaBase (2023), *Limnoperna fortunei* is the current valid name for this species.

Size, Weight, and Age Range

From GISD (2017):

"Trocophore is the first planktonic stage (hours). Several stages of free-swimming planktonic veliger (D-larvae about 7 days, between 80-146 um; veliconcha between 90-237 um and pediveliger or umbonate, more than 256 um). Then the larvae settle as plantigrade mussels, attach to substrate as juveniles. Maturity is reached at about 5.5mm in length. Golden mussels live about 3.2 years."

From Fusaro et al. (2023):

“Size: 20-30 mm, max 42-46 mm”

From Darrigran (2008):

“Its longevity is variable. In the natural environment of Bagliardi Beach, Argentina, longevity was recorded as 3.2 years (Maroñas et al., 2003). Boltovskoy and Cataldo (1999) estimated it as 3 years in Cuenca del Plata, Argentina. Iwasaki and Uryu (1998) suggested a longevity of 2 years in the Uji River, Japan, from 4 to 5 years in Korea and over 10 years in central China.”

Environment

From Palomaresea and Pauly (2024):

“Benthic; freshwater; depth range 2 - 19 m [Karateyev et al. 2010]”

From Darrigran (2008):

“*L. fortunei* inhabits rivers, streams, lakes, dams and estuaries. In Asia, it is found between 8-32°C, with confirmed occurrences up to 35°C. In South America, in a temperate area, *Limnoperna* populations can develop between 11 and 28ºC (approximately) (Darrigran et al., 2003). In a subtropical area, the reported temperatures are 17-29ºC (Mansur et al., 2004). It is intolerant to extended anaerobic conditions. Mansur et al. (2004) reported the pH tolerance range of 5.8-9.3. *L. fortunei* is a freshwater species that can inhabit brackish waters and maintain substantial populations in estuarine habitats. It is tolerant to polluted and contaminated waters with low calcium and pH levels.”

From Oliveira et al. (2006):

“In the Paraguay River, the population density of *L. fortunei* can be negatively impacted by periodic low levels of dissolved oxygen and decreases in pH to between 5 and 6. Such conditions are frequently present during the periodic flooding or inundation of this area. Under these conditions, a high mortality of *L. fortunei* was recorded in March of 2002, on both natural and artificial substrates.”

From Fusaro et al. (2023):

“The mussel can survive (90%) up to a salinity shock of 2 ppt for periods of at least 10 days (Angonesi et al. 2008). *Limnoperna fortunei* had 41% survival in 800mOsm (seawater ~1000mOsm) water (Deaton et al. 1989).”

“This species overwinters in South Korea, with water temperature as low as 0°C (Oliveira et al. 2010). In Japan, minimum temperature in a reservoir with mussels was 4.2°C (Nakano et al. 2011). Experimental research supports the 5°C threshold for prolonged exposure (Oliveira et al. 2010).”

From Fusaro et al. (2024):

"Experiments to examine *L. fortunei* overwintering survival found that populations at the northern invasion front can survive 6 days, 41 days, and 108 days at <1°C, <2°C, and <5°C respectively. Overall survival was 27% at these temperatures. An accompanying species distribution model implies suitable habitats at higher latitudes than previously considered (Xia et al. 2021)."

Climate

According to Darrigran (2008), *Limnoperna fortunei* tolerates tropical wet and dry savanna climates and prefers warm temperate climates with dry winters. The mean annual air temperature range for *L. fortunei* is 8–33˚C. Latitude/altitude range is 16°N to 35°S.

Distribution Outside the United States

Native

Boltovskoy et al. (2009) describes *L. fortunei* as native to China, Thailand, Korea, Laos, Cambodia, Vietnam, and Indonesia.

From Bogan (2012):

"Morton and Dinesen (2010) list the distribution of the species in China as: Yangtze basin - the lakes Dongting (Hunan Province), Yuangkian (Jiangsu Province), Chow-Wen-Miao, Chiang-Kia-Tsui, Jiangyin ('Siangyin'; Jiangsu Province) and Yoyang and adjacent rivers, and the Xiang River, near Changsha, Hunan Province). Also present in Thailand (Kwai River, Batambang, the mouth of the Kompong-Som River, the Mekong south of Nakon Ponom, the Maenam Mun River, the Lam Chi River, the Chao Phraya and Pasak rivers, the Tapi River, Tale Luang near Pattalung, Mekong branch at Muang Sene, Khong Island."

"Brandt (1974) listed it [in Thailand] from Mekong River south of Nakon Panom, Maenam Mun River, Lam Chi River, Chao Phraya and the Pasak River. In many klongs and tributaries to the Chao Phraya River, in the Maeklong River, in the south it reaches the Tapi River and Tale Luang near Pattalung."

Introduced

According to GISD (2023), *L. fortunei* has been introduced and established in the following South American countries with specific locations in parentheses: Argentina (Buenos Aires, Chaco, Corrientes, Distrito Federal, Entre Rios, Formosa, Misiones, Santa Fe), Brazil (Mato Grosso do Sul, Parana, Rio Grande do Sul), Paraguay (Alto Paraguay, Alto Parana, Central, Concepcion, Itapua, Misiones, Neembucu, Presidente Hayes, San Pedro), and Uruguay (Canelones, Colonia, Durazno, Montevideo, Rio Negro, Salto, San Jose, Soriano).

From NIES (2023):

"[Range in Japan] Tonegawa River System (Chiba and Ibaraki Prefs.), Lake Oshio (Gumma Pref.), Tenryu River (Shizuoka Pref.), Uregawa River (Aichi Pref.), Kisogawa River System (Gifu and Aichi Prefs.), and Lake Biwa-Yodogawa River System (Shiga, Kyoto, and Osaka Prefs.)."

From Boltovskoy et al. (2009):

"[…] introduced into Hong Kong and […] Taiwan, Japan, and Argentina […]."

In addition to areas listed above, Bogan (2012) list *Limnoperna fortunei* as introduced in the Plurinational States of Bolivia.

Means of Introduction Outside the United States

From Darrigran (2008):

"Morton (1975) first recorded it in Hong Kong where it had been introduced from China via supplied potable water. The species has been recorded in Taiwan, fouling potable water supply systems (Tan et al.,1987). In Japan, *L. fortunei* was first recorded in the ancient Lake Biwa in 1991 (Kimura, 1994) and has subsequently invaded associated potable water treatment systems (Nakai, 1995)."

"Darrigran and Pastorino (1995) proposed the non-intentional introduction of *L. fortunei* into the Río de la Plata in 1991, through ballast water of ocean vessels. At that time an increase of trade between Argentina and two countries that *L. fortunei* inhabits occurred. In Guaíba Basin [Brazil], it was also probably introduced via ballast water (Mansur et al., 1999) and in the Itaipu reservoir (Zanella and Marenda, 2002) probably via boats used for sport."

"In South America, the identified vectors are commercial and sport ships and boats, live bait, nets, and buoys that spread the species through the basin. Other vectors are the trucks that transport sand from an invaded beach to other areas (Darrigran, 2002; Belz, 2006). Magara et al. (2001) proposed that *L. fortunei* arrived in Japan before 1987 possibly with the Asian clam imported as food from mainland China."

From Boltovskoy et al. (2006):

"Along the Paraná-Paraguay waterway, which hosts intense boat traffic, *L. fortunei* has moved upstream at an average rate of of 250 km per year. In contrast, along the Uruguay river, where boat traffic is restricted to the lowermost 200 km section, upstream colonization is almost 10-times slower. This suggests that attachment to vessels is by far the most important dispersion mechanism."

Short Description

From Darrigran (2008):

"Adult *L. fortunei* are sessile and are generally found in clumps on hard substrates."

"The shells of adult *L. fortunei* are equivalve and heteromyarian. It is dark-brown above the umbonal keel and paler yellow-brown below. This is caused by the nacre of the interior of the shell being purple above and white below the keel. The presence of a nacreous layer in *L. fortunei* removes this genus from all contact with Dreissenacea."

"The outer periostracal layer of the shell is smooth and shiny, and thick where it curls inwards at the shell margin. The umbones are very nearly terminal and the dorsal ligamental margin is straight or, at most, only slightly curved. The ventral margin of the shell is the most variable feature and in different specimens varied between the two extremes of being either straight or distinctly arcuate. There are no hinge teeth or byssal notches."

"The shells are yellow-brown. In clear water, for example in northern Argentina, they look golden; so it is called the 'golden mussel'."

Biology

From Fusaro et al. (2024):

"*Limnoperna fortunei* requires external fertilization to reproduce and is considered a dioecious spawner with an equal ratio of males to females (Darrigran 2022). After fertilization, the oocyte develops into the first trochophore stage after six hours."

"*L. fortunei* can reach densities of 5000-250,000 individuals/m^2 on hard substrate, and 90-2000 individuals/m^2 on soft substrate (Frau et al. 2012). Analysis of a *L. fortunei* population in Brazil found a high annual growth rate (K = 1.22) and estimated that 62.920 juveniles/m^2 will be recruited annually (Ayroza et al. 2021). *L. fortunei* spawns continually in suitable conditions, as opposed to batch spawning that is observed in similar species (i.e. zebra mussel) (Boltovskoy et al. 2006)."

From Darrigran (2008):

"It is dioecious and reaches sexual maturity in the first year of its life span. Spawning occurs at temperatures of 16-28°C. After spawning and fertilization, the trocophore is the first planktonic stage. Several stages of free-swimming planktonic veliger (D-larvae about 7 days, between 80 and 146 mm; veliconcha between 90 and 237 mm and pediveliger or umbonate, more than 256 mm). Then the larvae settle as plantigrade mussels and attach to the substrate as juveniles. These larvae are free-swimming and planktonic and live in the water column. These stages of the mussel's life cycle are the most vulnerable to environmental fluctuations."

"The larvae settle to the bottom and securely attach to a hard substrate by byssal threads, which are secreted from a gland at the base of the mussel's muscular foot."

"*L. fortunei* are epifaunal, unlike most other South American native freshwater bivalves, and not overly selective, therefore they colonize almost any solid, submerged surface such as buoys, water intake pipes, rocks, rooted aquatic plants, boat hulls, and the shells of other molluscs. Its eurioic status allows a quick and effective distribution in water bodies. The juveniles differentiate into males and females; with lengths of 5 mm in the spring and 9 mm in the summer, and can reach sexual maturity after 6 mm total length (Darrigran et al., 2003)."

From Fusaro et al. (2023):

"Consumes a variety of phytoplankton and zooplankton (Rojas Molina et al. 2010, Rojas Molina [et al.] 2012, Frau et al. 2013). Adults do well despite low food availability (Oliveira et al. 2011)."

Human Uses

From GISD (2023):

"No uses are known for this species in its native area. It has potential as a bioacumulator of xenobiotics and for water clarifying."

From Darrigran (2008):

"No productive benefit (economic, social or environmental) is known for *L. fortunei* invasion (Darrigran, 2002)."

Diseases

No information was found associating *Limnoperna fortunei* with any diseases listed by the World Organisation of Animal Health (2023).

From Darrigran (2008):

"Associations between *L. fortunei* and other species have not been described. In South America, there are no records of *L. fortunei* as a vector of symbiotic organisms (commensals or parasites)."

According to MolluscaBase (2023), *Limnoperna fortunei* is a host of the endoparasite *Parabucephalopsis parasiluri*.

According to Poelen et al. (2014), *Limnoperna fortunei* hosts the pathogen Golden Marseillevirus.

Threat to Humans

From Wang et al. (2021):

"The concentration of NH3 released during the corruption of *Limnoperna fortunei* can reach the level of health and safety threat to workers at the earliest day out of water, and the accumulated concentration of NH3 far exceeds the exposure limit (30 mg/m3) with the increase in the time out of water of *Limnoperna fortunei*. The influence of H2S and CH4 concentration on workers is still within an acceptable level."

3 Impacts of Introductions

The following details documented, ***actual*** impacts of introduction for *L. fortunei*

From Fusaro et al. (2023):

"*Limnoperna fortunei* is an ecosystem engineer that significantly alters invaded habitats by altering habitat complexity, sedimentation, and accelerating eutrophication (Burlakova et al. 2012, Tokumon et al. 2018, Gattas et al. 2020). *L. fortunei* reach large densities (5000-250,000 individuals/m^2 on hard substrate, and 90-2000 individuals/m^2 on soft substrate; Frau et al. 2012) shifting productivity in the nutrient cycle from the pelagic zone to the benthic zone. This species filters water quickly, clarifying water causing a reduction in primary production occurring within the water column. […] *L. fortunei* bioaccumulates heavy metals and pesticides and may facilitate the transfer of these substances to existing fauna (Besen and Marengoni 2021, Sene et al. 2021)."

"*Limnoperna fortunei* has been shown to physically foul living unionids and naiads through settlement on their shells. This impairs movement and restricts their ability to open their valves, thus depriving them of food and oxygen (Darrigan and Damborenea 2005, Weigand 2019). This species also significantly impacts benthic fauna, with changes in invertebrate and plankton abundance well-documented (Rojas Molina et al. 2012, Frau et al. 2012, Bertao et al. 2021, Silva et al. 2021)"

"*Limnoperna fortunei* can clog/foul water intake sieves and filters, pipes, heat exchangers, and condensers. This species has become a common difficulty for industrial and power plants that use raw water, chiefly for cooling purposes (Cataldo et al. 2003, Goto 2002, Boltovskoy et al. 2009). Their biofouling leads to increased abrasive wear and significant economic costs for their cleaning and maintenance (Yao et al. 2017, de Castro et al. 2019, Boltovskoy et al. 2022). *L. fortunei* biofouls 38% of the hydropower plants in Brazil and is responsible for estimated annual losses of 120 million dollars (US$) (SPIC Brasil 2021)."

"*Limnoperna fortunei* modifies nutrient concentrations and proportions, and promotes aggregation of solitary *Microcystis* spp. cells into colonies; both these effects can favor blooms of this often noxious cyanobacteria (Cataldo et al. 2012). Gazulha et al. (2012) found that while single cells of cyanobacteria were accepted, filamentous and colonial cyanobacteria were rejected as pseudofeces. *L. fortunei* has been shown to increase the growth of *Microcystis* spp. through the alteration of P:N ratios, selective grazing, competitor exclusion, and increasing nutrient supply (Boltovskoy et al. 2017, Silva and Giani 2018, Gangi et al. 2020)."

From Darrigran (2008):

"Freshwater macrofouling is a new economic/environmental problem for South America. Until the beginning of the 1990s, macrofouling in the neotropical region occurred only in marine and mixohaline waters. Since the introduction of *L. fortunei*, macrofouling also extended to freshwaters in Argentina, Brazil, Paraguay and Uruguay (Darrigran and Damborenea, 2005). This kind of problem (freshwater macrofouling) is caused by the appearance of larvae or juveniles of *L. fortunei*. It impacts the sources of water supply of many water-treatment plants, industrial refrigeration systems, and power stations. Among the usual problems involved, the following are the most significant: pipe obstruction; reduction in flow velocity in pipes due to friction loss (turbulent flows); accumulation of empty valves and pollution of water ways by massive mortality; filter occlusion; and increase in the corrosion of surfaces due to mussel infestation. This new economical and environmental problem for the neotropical regions produces unexpected expenses, for example, due to system shutdowns, the need for chemical or mechanical cleaning, and pipe and filter replacement."

"The large biomass associated with high densities of *L. fortunei* impacts on aquatic food chains. Several species of native fish consume *L. fortunei* (López Armengol and Casciotta, 1998; Montalto et al., 1999) and it has become the main food source for *Leporinus obtusidens* (Anostomidea) in the Río de la Plata (Penchaszadeh et al., 2000)."

"The impact caused by *L. fortunei* it is not restricted to the economic aspect. Darrigran et al. (1998) showed that since the introduction of *L. fortunei* at Bagliardi Beach, two gastropods commonly found have been displaced: one of them, *Chilina fluminea*, is no longer found; whereas the other, *Gundlachia concentrica*, is becoming rare. In contrast, several benthic species, uncommon or absent before the occurrence of *L. fortunei* in this microenvironment, are now present, including the Annelids: Oligochaeta (eight species), Aphanoneura (one species) and Hirudinea (eight species). In addition, several species of crustaceans and insects never cited at the invaded areas are now present (Darrigran et al., 1998)."

"The most direct and severe ecological impact has been the epizoic colonization of native naiads (Hyriidae and Mycetopodidae) by *L. fortunei,* similar to the impact of *D. polymorpha* on native bivalves in North America (Ricciardi et al., 1997). The displacement of the native naiads resulted from their inability to open and shut their valves because of the byssally-attached mussels on their shells. The quantitative impact of *L. fortunei* on native naiads in South America is unknown. *L. fortunei* also settles on other native fauna, such as *Pomacea canaliculate* (Gastropoda, Ampullariidae) and *Aegla platensis* (Anomura, Aeglidae), as well as on the introduced *Corbicula fluminea* (Bivalvia, Corbiculidae) (Darrigran et al., 2000; Darrigran, 2002)."

From Oliveira et al. (2006):

"Despite low densities, *L. fortunei* can colonize water cooling systems of boats, obstructing water circulation and causing motor overheating. Accumulation in water supply equipment, such as pumps and pipes has also been observed."

From Boltovskoy et al. (2009):

"On the basis of diver-collected bottom samples, we estimated the overall density of this mussel in a reservoir (Embalse de Río Tercero, Argentina), where *Limnoperna* is present since 1998 and analyzed changes in several water-column properties before and after the invasion. The 47 km^2

reservoir hosts around 45 billion mussels; at these densities, a volume equivalent to that of this water body can potentially be filtered by the bivalves every 2–3 days. Data collected regularly since 1996 indicate that after the invasion water transparency increased, and suspended matter, chlorophyll *a*, and primary production decreased significantly, with strong changes occurring in the area with highest mussel densities. Our results indicate that the ecosystem-wide impacts of *Limnoperna* are generally comparable to those described in Europe and North America for another invasive mussel—*Dreissena polymorpha*."

From Boltovskoy and Correa (2015):

"*Limnoperna* modifies nutrient concentrations and decreases concentrations of particulate organic matter in the water column (including phytoplankton and zooplankton), thus enhancing light penetration and stimulating growth of periphyton and macrophytes. […] *Limnoperna* beds significantly enhance the numbers, biomass, and diversity of practically all accompanying invertebrates. The mussel's planktonic larvae represent an important food item for the larvae of 18 fish species, while juveniles and adults are consumed by at least 50 fish species. *Limnoperna* is the first and only abundant benthic filter-feeding animal in South American continental waters."

The following details theorized, ***potential*** impacts of introduction for *L. fortunei.*

From Cataldo et al. (2012):

"In order to evaluate the effects of the golden mussel *Limnoperna fortunei* on phytoplankton density and composition and nutrient recycling we conducted a 24 h filtration experiment in Río Tercero Reservoir (Argentina) using four 400 L mesocosms, two of them stocked with 1700-1800 adult mussels each, and two controls (without mussels). Nutrient concentrations and phytoplankton composition and density were evaluated at 0, 3, 6, 12, and 24 h. Estimated filtration rates were 1.48-3.14 mL mg DW-1 h-1. Grazing pressure by the mussel was not associated with algal taxonomy or cell size. After 24 h, *L. fortunei* removed 84% of the particulate nitrogen, and 49% of the particulate phosphorus. Nutrient regeneration was very significant as well: ammonium was produced at a rate of 3 µM NH3g DW-1 h-1, whereas production of phosphates was 0.42 µM PO4g DW-1 h-1. It is concluded that the impact of *L. fortunei* on phytoplankton and nutrient cycling can be as significant as that reported for another invasive bivalve - the zebra mussel *Dreissena polymorpha* in Europe and North America, but the overall effect of this impact on the biota may differ strongly under different environmental settings."

From Boltovskoy et al. (2006):

"Observations of the negative impacts of *L. fortunei* include reports from southern Brazil and Japan. In the area of Guaíba lake (southern Brazil), Mansur et al. (2003) reported that the mussel attaches to at least 6 species of molluscs, including 2 unionids, in numbers of up to ca. 300 *L. fortunei* per host. In several cases this over growth may hinder the host's normal displacement and valve mobility. The same authors also suggested that *L. fortunei*'s settlements on the roots of the reed *Scirpus californicus*, an emergent helophyte, may be 'suffocating' the plants and be responsible for the thinning of reed populations. Howewer [sic], this effect is unlikely because the roots of *Scirpus* must be adapted to the very low oxygen environment characteristic of shallow areas with very abundant organic debris. Furthermore, filtering bivalves are known to enhance water oxygenation, rather than the opposite (e.g. Karatayev et al. 1997)."

"Another potential threat posed by this invader was reported by Ogawa et al. (2004). The authors identified widespread parasitic infections by bucephalid trematodes in several cyprinid fishes from the Uji river, suggesting that the infections started with the accidental introduction of infested first intermediate hosts – *Limnoperna fortunei*."

"Among the potentially positive impacts, enhancement of the diversity and abundance of most other benthic organisms (Darrigran et al. 1998), and consumption by fish have been mentioned. Trophic interactions with fish are of particular interest because the mussel represents a novel resource available at an unprecedented scale. At least 16 species have been recorded in the Paraná and Río de la Plata rivers that actively consume *L. fortunei* (Montalto et al. 1999; Ferriz et al. 2000; Penchaszadeh et al. 2000; Cataldo et al. 2002). Some of the commercially most valuable species, like *Pterodoras granulosus* and *Leporinus obtusidens*, have been observed to feed preferentially on *L. fortunei*: up to 100% of the specimens retrieved in the summer have their guts filled predominantly or exclusively with remains of this mollusc (Ferriz et al. 2000; Penchaszadeh et al. 2000; Cataldo et al. 2002)."

From Fusaro et al. (2023):

"*L. fortunei* bioaccumulates heavy metals and pesticides and may facilitate the transfer of these substances to existing fauna (Besen and Marengoni 2021, Sene et al. 2021)."

"The current solutions implemented in the Great Lakes to control dreissenid mussels are expected to be effective against *Limnoperna fortunei*. As such, there are many control measures in place to mitigate socio-economic impact from golden mussel invasion. The potential for increased impacts exists if *L. fortunei* is resistant to existing control measures or able to occupy areas where dreissenids are excluded due to their increased physiological tolerances."

This mussel is currently regulated in Illinois, Michigan, Nevada, Ohio, Texas, and Wisconsin. Further details of regulations can be found in Section 1 of this ERSS.

4 History of Invasiveness

The History of Invasiveness for *Limnoperna fortunei* is classified as High. *Limnoperna fortunei* has been introduced and become established in several countries outside of its native range. Impacts of these introductions have been well documented. *L. fortunei* has been shown to displace and alter diets of other organisms. *L. fortunei* has also been reported to cause macrofouling and water clarity alterations. Colonization of native bivalve shells impacts the native bivalve's ability to open the shell, leading to starvation and suffocation. It has also been introduced in California.

5 Global Distribution

Figure 1. Known global distribution of *Limnoperna fortunei*. Observations are reported from China, Japan, Republic of Korea, Taiwan, Thailand, Vietnam, Cambodia, Lao People's Democratic Republic, Brazil, Uruguay, Bolivia, Paraguay, and Argentina. Map from GBIF Secretariat (2023).

Populations of *L. fortunei* are also reported from Indonesia (Fusaro et al. 2023) but no geospatial data was found in the literature search. The point in the Atlantic Ocean off the United States Atlantic coast does not represent an established population and was removed for climate matching (Section 7).

6 Distribution Within the United States

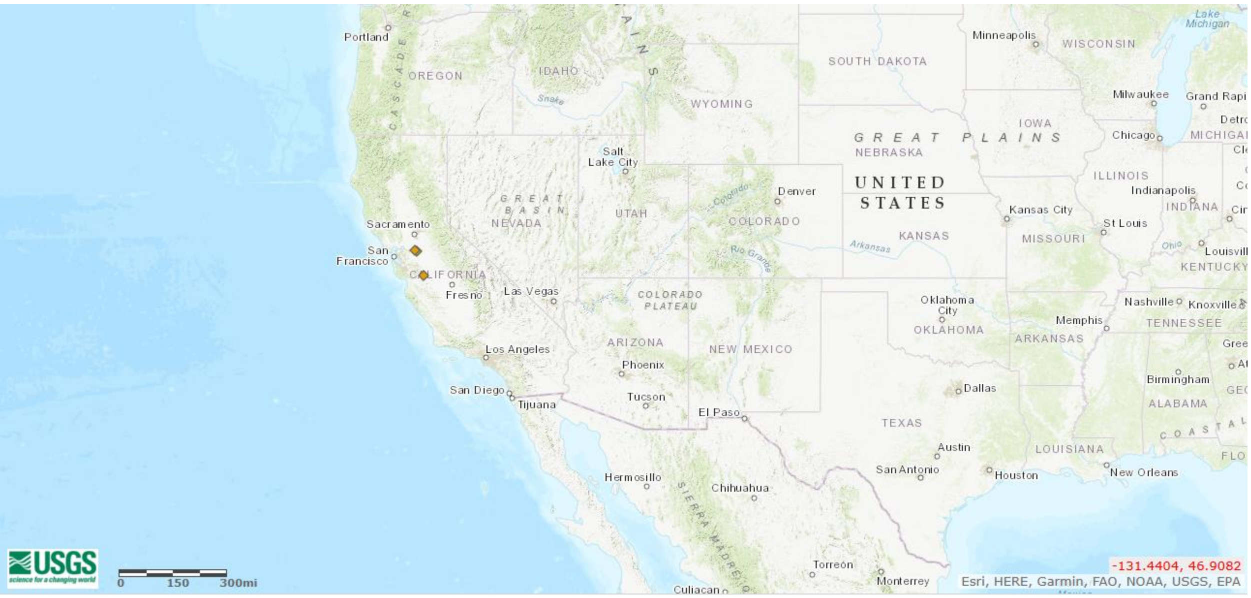

Figure 2. Reported distribution of scientific name in the United States. Map from Fusaro et al. (2024). Observations are reported from California. At the time of this screening there was no information regarding possible establishment so the location was not used to select source points for the climate match. If this occurrence is determined at a future date to be an established population, then the climate match around that area would likely increase. The climate match to other areas of the contiguous United States may be affected as well.

7 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Limnoperna fortunei* to the contiguous United States was medium across much of the eastern and central portions of the contiguous United States. Areas of low match were recorded along the northern west coast, west of the Rocky Mountains and small areas in the northern Northeast. Areas of high match were found in the north central region to the east of the Rocky Mountains and west of the Great Lakes as well as the southeast region up the Mid-Atlantic Coast. The overall Climate 6 score (Sanders et al. 2023; 16 climate variables; Euclidean distance) for the contiguous United States was 0.634, indicating that Yes, there is establishment concern for this species. The Climate 6 score is calculated as: (count of target points with scores ≥ 6)/(count of all target points). Establishment concern is warranted for Climate 6 scores greater than or equal to 0.002 based on an analysis of the establishment success of 356 nonnative aquatic species introduced to the United States (USFWS 2024). If the detection in California is determined at a future date to be an established population, then the climate match around that area would likely increase. The climate match to other areas of the contiguous United States may be affected as well.

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

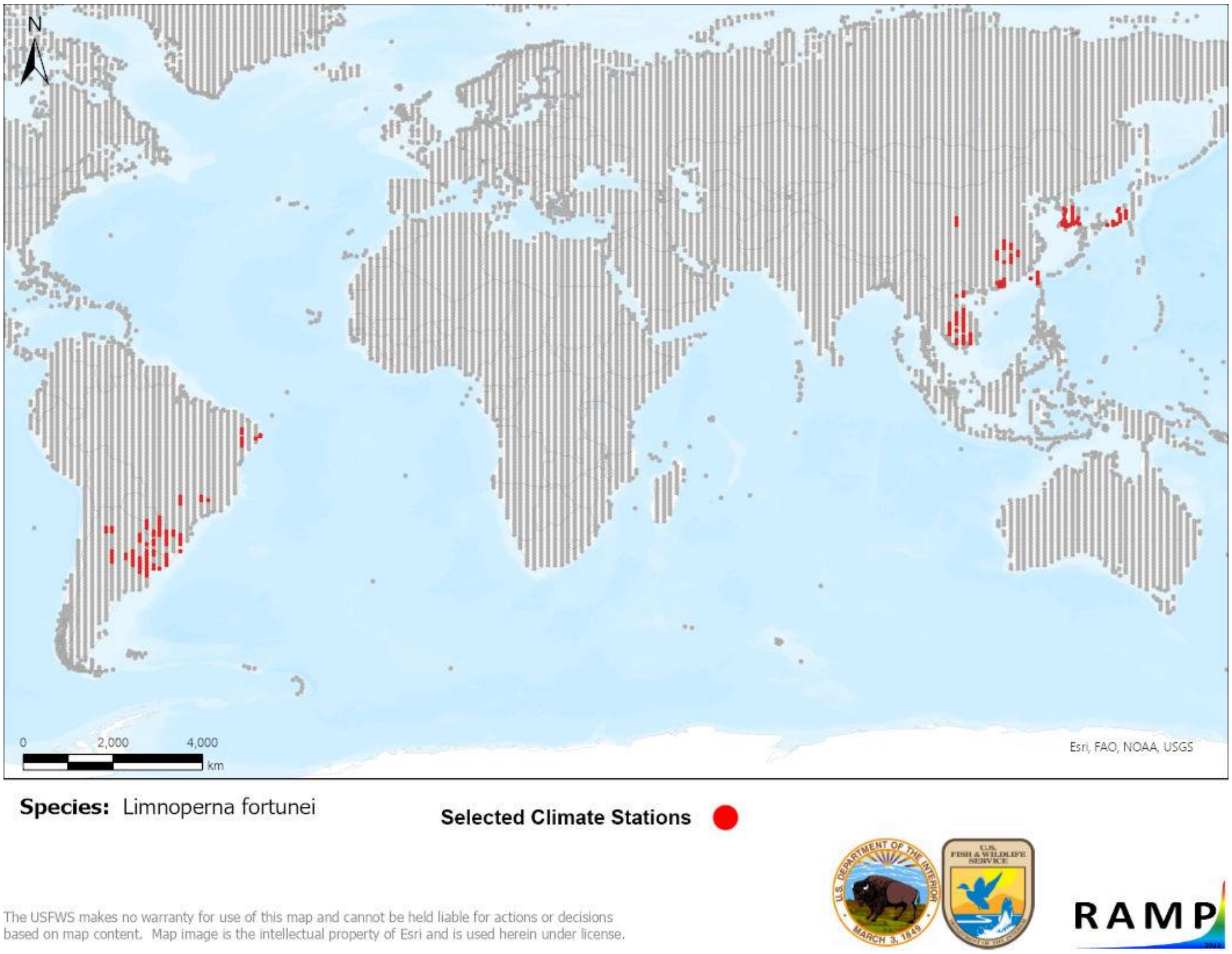

Figure 3. RAMP (Sanders et al. 2023) source map showing weather stations throughout the world selected as source locations (red; China, Taiwan, Republic of Korea, Japan, Thailand, Vietnam, Cambodia, Lao People's Democratic Republic, Brazil, Uruguay, Bolivia, Paraguay, and Argentina) and non-source locations (gray) for *Limnoperna fortunei* climate matching. Source locations from GBIF Secretariat (2023). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

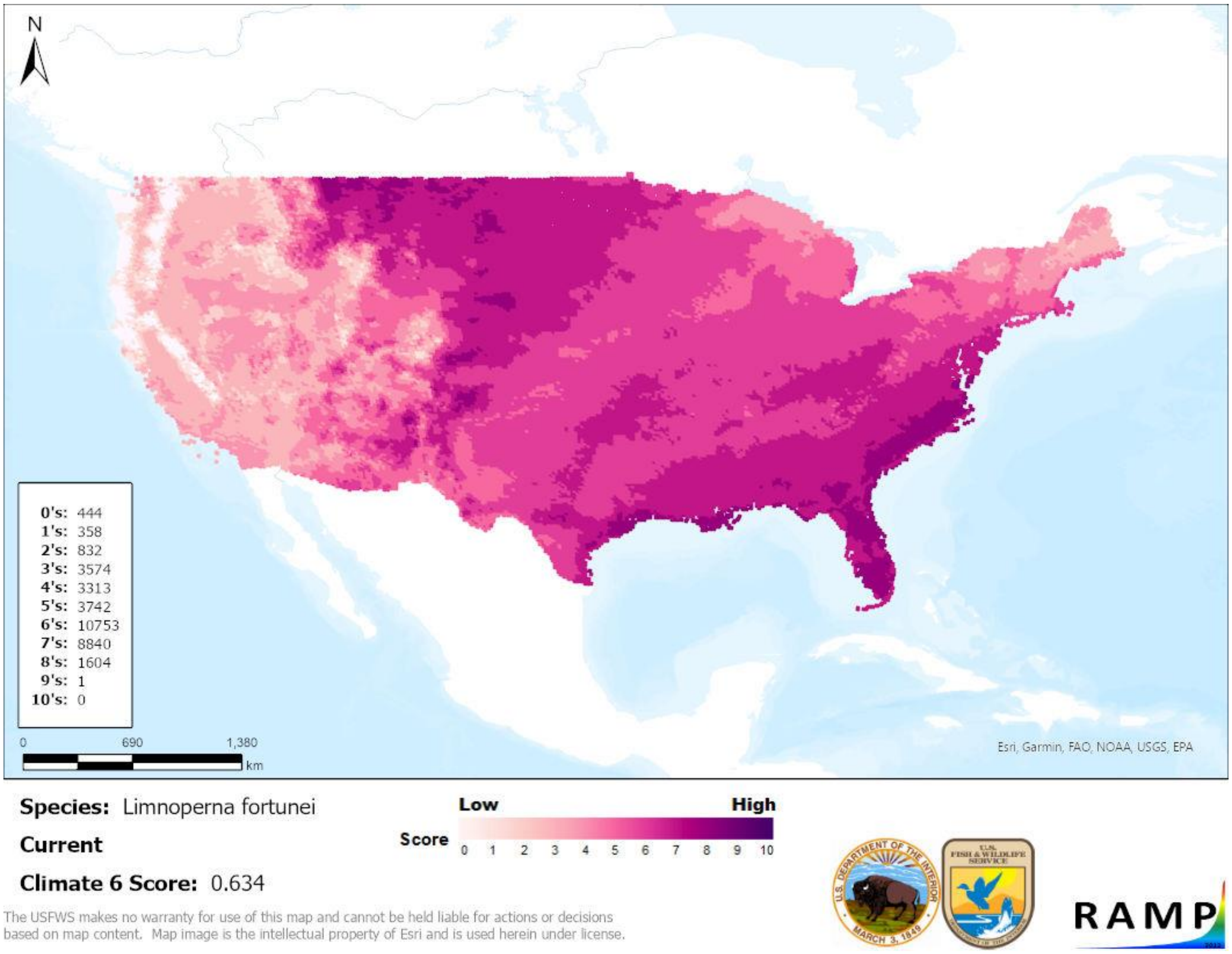

Figure 4. Map of RAMP (Sanders et al. 2023) climate matches for *Limnoperna fortunei* in the contiguous United States based on source locations reported by GBIF Secretariat (2023). Counts of climate match scores are tabulated on the left. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

8 Certainty of Assessment

The Certainty of Assessment for *Limnoperna fortunei* is classified as High. Information regarding the distribution and the history of invasiveness of *Limnoperna fortunei* is readily available. The available data from peer-reviewed sources documents mostly negative impacts where the species has been introduced. Populations of *L. fortunei* are reported from Indonesia, but no geospatial data was found in the literature search. It is not thought that the lack of geospatial data for the species' distribution in Indonesia is enough to impact the interpretation of the climate matching analysis.

9 Risk Assessment

Summary of Risk to the Contiguous United States

Limnoperna fortunei, the golden mussel, is a mussel native to China and Southeast Asia. *L. fortunei* is a unionid mussel that has a broad tolerance of water conditions and can become very dense in some areas. It has been introduced to other countries in Southeast Asia as well as South America where it has become established. Negative impacts, such as macrofouling, water clarity alteration, displacement and diet alteration of other species have been reported from these areas. Within the United States, *L. fortunei* has been found in California. Regulations for this species exist in Illinois, Michigan, Nevada, Ohio, Texas, and Wisconsin. The history of invasiveness for *L. fortunei* is classified as High due to the records of established nonnative populations and documented negative impacts. The climate matching analysis for the contiguous United States indicates establishment concern for this species. The highest matches were recorded in the southeast up to the Mid-Atlantic region as well as the north central Midwest region. West of the Rocky Mountains and the northeast recorded the lowest matches. The Certainty of Assessment for this ERSS is classified as High due to the quality of information available. The Overall Risk Assessment Category for *Limnoperna fortunei* in the contiguous United States is High.

Assessment Elements

- **History of Invasiveness (see Section 4): High**
- **Establishment Concern (see Section 7): Yes**
- **Certainty of Assessment (see Section 8): High**
- **Remarks, Important additional information:** No additional remarks.
- **Overall Risk Assessment Category: High**

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Appendix

Summary of Future Climate Matching Analysis

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

Under the future climate scenarios (figure A1), on average, high climate match for *Limnoperna fortunei* was projected to occur in the Southern Atlantic Coast region of the contiguous United States. Small areas of high match were also found in the Northern Plains, Colorado Plateau, and Great Basin under some scenarios. Areas of high match decreased between time step 2055 and time step 2085. Areas of low climate match were projected to occur in the Great Basin, Northern Pacific Coast, and Western Mountains regions. The Climate 6 scores for the individual future scenario models (figure A2) ranged from a low of 0.243 (model: UKESM1-0-LL, SSP5, 2085) to a high of 0.614 (model: IPSL-CM6A-LR, SSP3, 2055). All future scenario Climate 6 scores were above the Establishment Concern threshold, indicating that Yes, there is establishment concern for this species under future scenarios. The Climate 6 score for the current climate match (0.634, figure 4) falls above the range of scores for future projections. The time step and climate scenario with the most change relative to current conditions was SSP5, 2085, the most extreme climate change scenario. Under one or more time step and climate scenarios, areas within the Northeast saw a large increase in the climate match relative to current conditions. Additionally, areas within the Colorado Plateau, Great Lakes, and Western Mountains saw a moderate increase in the climate match relative to current conditions. Under one or more time step and climate scenarios, areas within the Northern Plains saw a large decrease in the climate match relative to current conditions. Additionally, areas within the Colorado Plateau, Great Basin, Gulf Coast, Mid-Atlantic, Southeast, Southern Atlantic Coast, Southern Florida, Southern Plains, and Western Mountains saw a moderate decrease in the climate match relative to current conditions. Additional, very small areas of large or moderate change may be visible on the maps (figure A3).

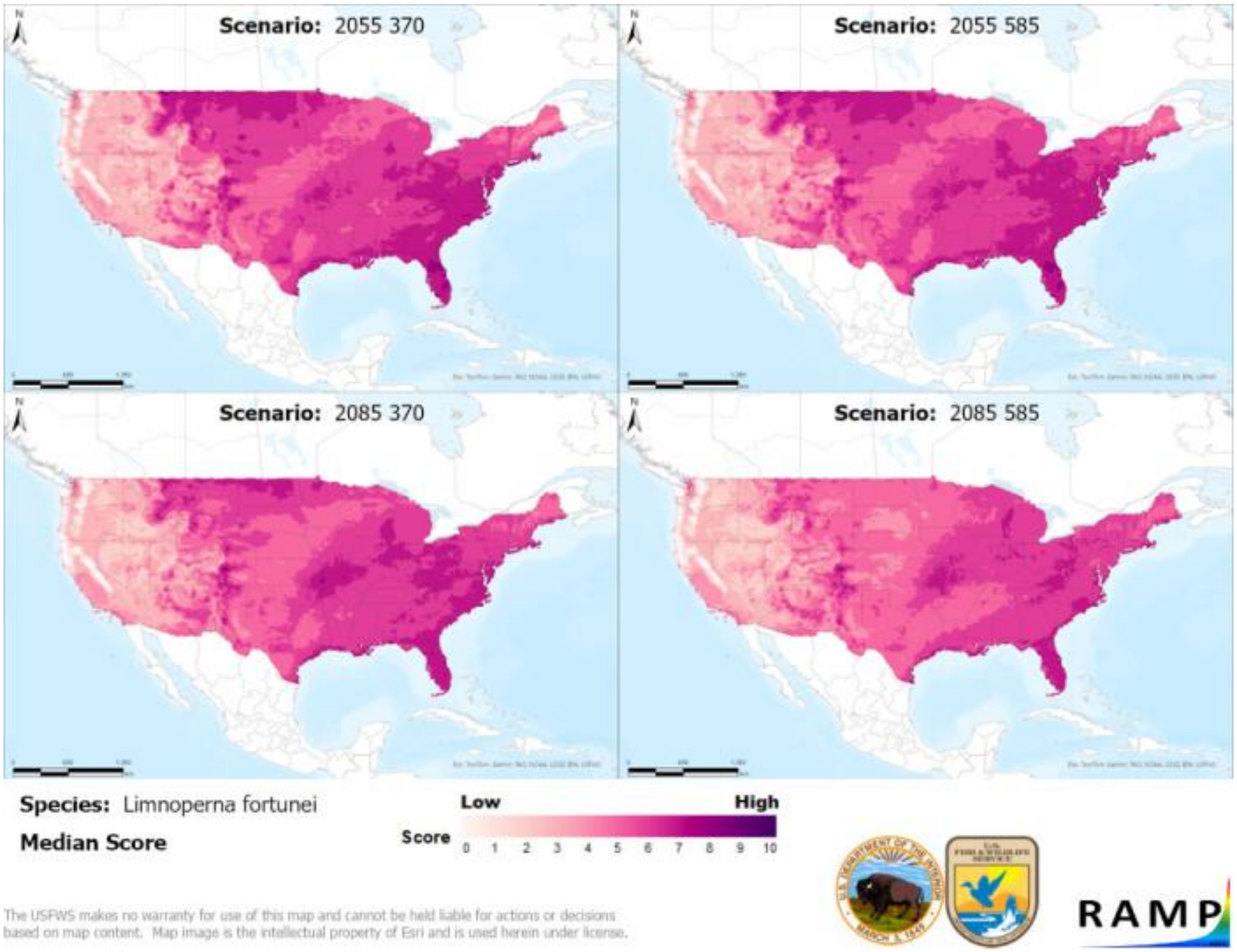

Figure A1. Maps of median RAMP (Sanders et al. 2023) climate matches projected under potential future climate conditions using five global climate models for *Limnoperna fortunei* in the contiguous United States. Climate matching is based on source locations reported by GBIF Secretariat (2023). Shared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

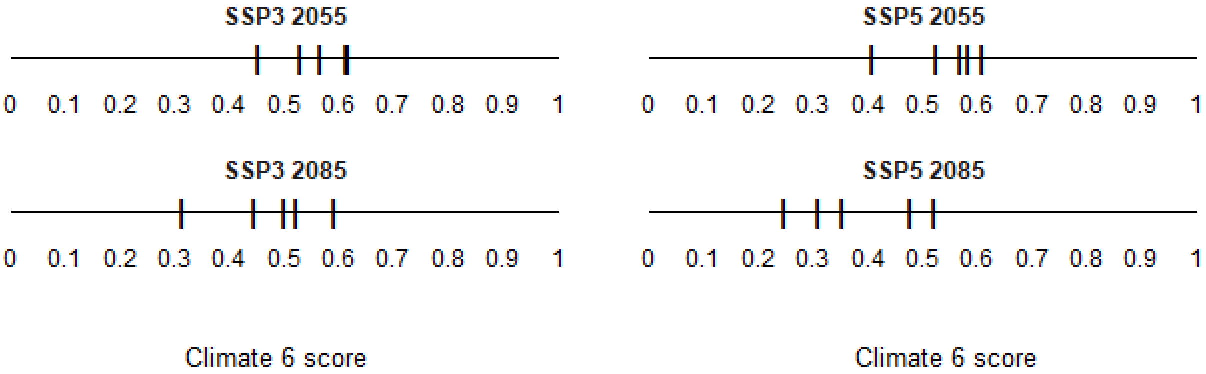

Figure A2. Comparison of projected future Climate 6 scores for *Limnoperna fortunei* in the contiguous United States for each of five global climate models under four combinations of Shared Socioeconomic Pathway (SSP) and time step. SSPs used (from left to right): SSP3, SSP5 (Karger et al. 2017, 2018;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

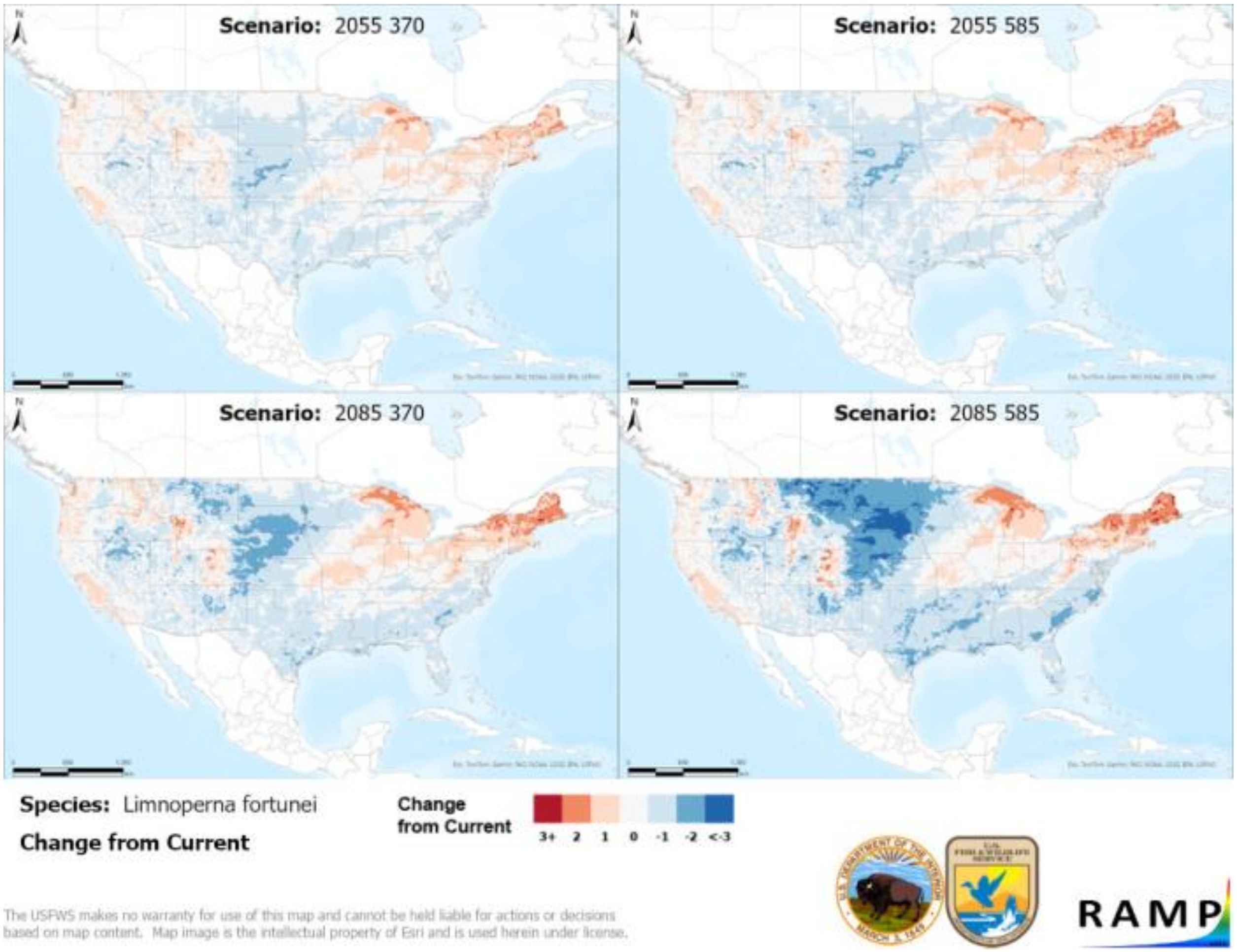

Figure A3. RAMP (Sanders et al. 2023) maps of the contiguous United States showing the difference between the current climate match target point score (figure 4) and the median target point score for future climate scenarios (figure A1) for *Limnoperna fortunei* based on source locations reported by GBIF Secretariat (2023). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. Shades of blue indicate a lower target point score under future scenarios than under current conditions. Shades of red indicate a higher target point score under future scenarios than under current conditions. Darker shades indicate greater change.

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