Golden mussel (*Limnoperna fortunei*)
Aquatic Invasive Species
Risk Screening Summary
Washington Department of Fish and Wildlife

Golden mussel (*Limnoperna fortunei*) – Aquatic Invasive Species Risk Screening Summary

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Cover photo is of golden mussel shells collected in October 2024 at a water quality station at Rough and Ready Island near Stockton in San Joaquin County, California, USA. Cover photo by Elizabeth Wells, Ph. D., California Department of Water Resources.

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Acknowledgement

The United States Fish and Wildlife Service's (USFWS) Ecological Risk Screening procedure was adapted for use in the development of the Aquatic Invasive Species Risk Screening Summary.

Aquatic Invasive Species Risk Screening Summary

The Aquatic Invasive Species Risk Screening Summary evaluates a species' potential invasiveness in Washington.

Three criteria determine the species potential invasiveness:

1. The species has a history of invasion in other locations. Invasion requires documentation of establishment and spread of populations, as well as negative ecological or economic impacts.
2. The potential for the transport of the species into and within Washington.
3. Conditions in Washington are suitable for the survival and reproduction of the species.

These summaries provide an initial process to determine which species are more likely (**high risk**), about as likely as not (**moderate risk**), and less likely (**low risk**) to arrive, survive, reproduce, spread, and have a detrimental impact in Washington. Species for which there is insufficient information to make such a determination are classified as **uncertain risk**.

This summary does not identify locations in Washington where an aquatic invasive species is most likely to become established or address monitoring or mitigation strategies.

This summary is a partial review of the species summarized. The following resources may provide additional information:

- Centre for Agriculture and Biosciences International (CABI) Compendium: https://www.cabidigitallibrary.org/journal/cabicompendium
- Global Biodiversity Information Facility (GBIF): https://www.gbif.org/
- National Estuarine and Marine Exotic Species Information System (NEMESIS): https://invasions.si.edu/nemesis/
- United States Geological Survey (USGS) Nonindigenous Aquatic Species List: https://nas.er.usgs.gov/queries/SpSimpleSearch.aspx
- United States Fish and Wildlife Service (USFWS) Ecological Risk Screening Summaries https://www.fws.gov/library/categories/ecological-risk-screening

Taxonomy

Information from Bánki and others. (2024).

Taxonomic Tree

Domain: Eukaryota
Kingdom: Metazoa
Phylum: Mollusca
Class: Bivalvia
Subclass: Pteriomorphia
Order: Mytiloida
Family: Mytilidae
Genus: *Limnoperna*
Species: *Limnoperna fortunei (Dunker, 1857)*

Synonyms and Other Name(s)

Volsella fortunei (Dunker, 1857)
Limnoperna coreana (Park & Choi, 2008)
Limnoperna lacustris (E. von Martens, 1875)
Modiola lacustris (E. von Martens, 1875)
Mytilus martensi (Neumayer, 1898)
Modiola cambodjensis (Clessin, 1889)

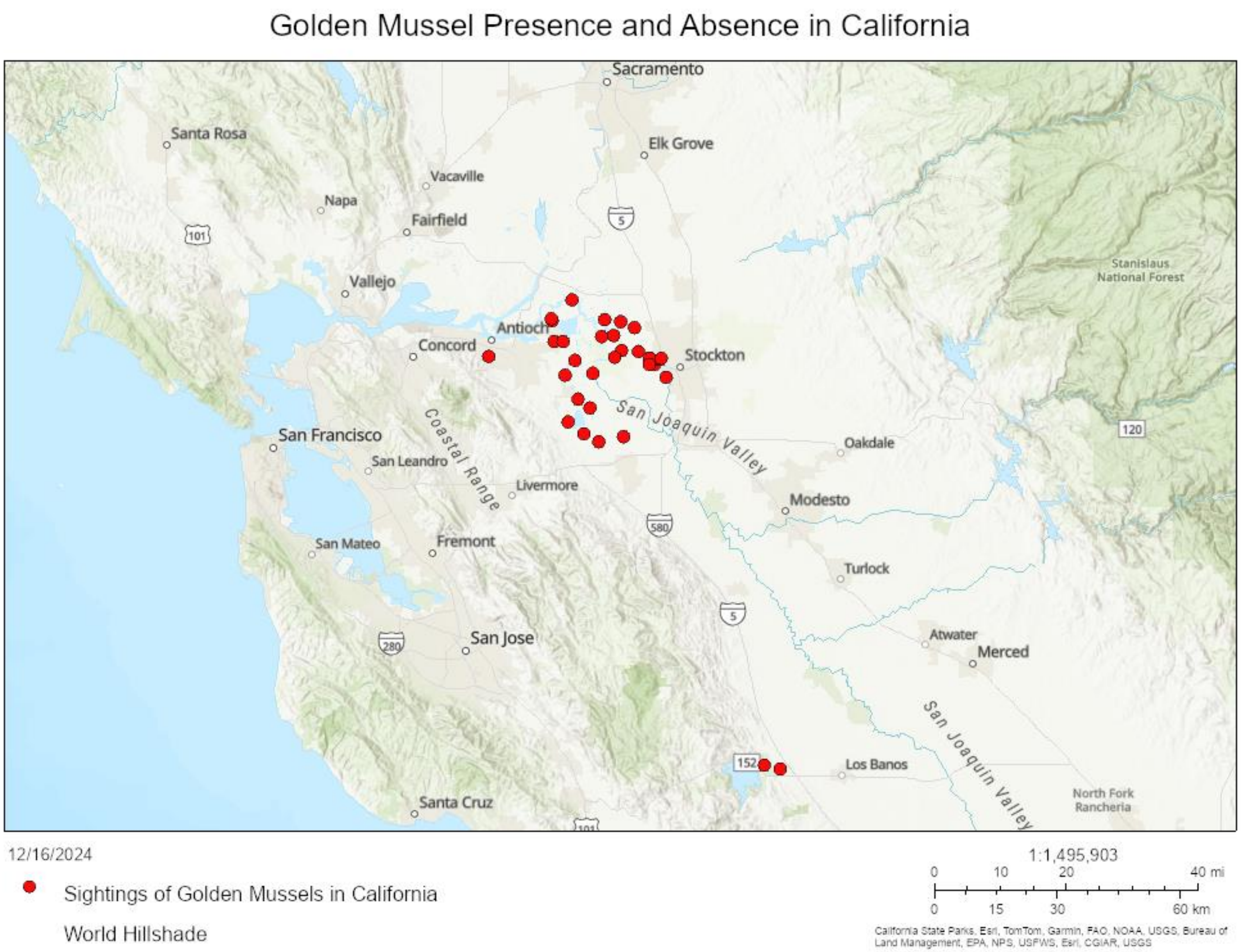
Common Name(s)

Golden mussel

Context for Risk Summary

On November 6, 2024, California Department of Fish and Wildlife announced the discovery of golden mussels (*Limnoperna fortune*) in the Port of Stockton by California Department of Water resources staff while conducting routine operations. This is a rapidly developing situation and reports continue to come in and are being followed up on. These mussels were likely introduced to California by a ship traveling from an international port. This discovery is the first known occurrence of golden mussels in North America. Delineation is ongoing, with 30 known locations as of December 16, 2024 (Figure 1). Additional validated sightings will be made available on a map at the following website: Golden Mussel Sightings in California.

Figure 1. Sightings of Golden Mussels in California as of December 16, 2024.



Species Overview

Status in Washington

Classification under Washington Administrative Code (WAC) Chapter 220-640

L. fortunei is not listed as a Prohibited or Regulated type A or B aquatic invasive species under Washington Administrative Code (WAC) Chapter 220-640. Therefore, *L. fortunei* is classified as a Regulated Type C species under WAC 220-640-080. Per Revised Code of Washington (RCW) 77.135, Regulated Type C species may not be introduced on or into a water body or property without department authorization, a permit, or as otherwise provided by rule.

Distribution in Washington

As of 12/16/2024, there have been no recorded detections of *L. fortunei* in Washington.

Existing Risk Screening Summary and Assessments

Golden Mussel (*Limnoperna fortunei*) Ecological Risk Screening Summary. (USFWS 2024) https://www.fws.gov/media/ecological-risk-screening-summary-golden-mussel-limnoperna-fortunei-high-risk

A risk assessment of the golden mussel, *Limnoperna fortunei* (Dunker, 1857) for Ontario, Canada. (Mackie and Brinsmead 2017) https://www.reabic.net/journals/mbi/2017/3/MBI_2017_Mackie_Brinsmead.pdf

Distribution

Native Range

L. fortunei is native to Southeast Asia, specifically lakes and rivers of China. This species also occurs naturally in Laos, Cambodia, Vietnam, Korea, Indonesia and Thailand (Ricciardi 1998).

Ecology

Mackie and Brinsmead (2017)

"The golden mussel, *Limnoperna fortunei* (Dunker, 1857) is a mytilid mussel related to the marine Blue Mussel (*Mytilus edulis;* Linaeus, 1758) and has the same invasive characteristics as freshwater dreissenids. Like zebra (*Dreissena polymorpha;* Pallas, 1771) and quagga mussels (*Dreissena bugensis;* Andrusov, 1897) they secrete byssal threads and attach to solid substrates and foul any suitable natural or man-made surface causing macrofouling problems in industrial installations (Mackie and Claudi, 2010 [2009])."

CABI (2024)

"*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 28°C (approximately) (Darrigran et al., 2003). In a subtropical area, the reported temperatures are 17-29°C (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."

"*L. fortunei* filters a wide range of particles, such as algae, zooplankton and organic matter. The larval stages feed on bacteria."

Record of Invasion Outside of Washington

Introduced Range

Invasive populations of *L. fortunei* have been found in Japan, Hong Kong, Taiwan, Brazil, Argentina, Bolivia, Uruguay, Paraguay and the United States (GBIF Secretariat 2024; Figure 2). Georeferenced records of *L. fortunei* presence can be at the following website: GBIF Golden Mussel Records.

Figure 2. Global distribution (native and non-native detections) of golden mussel (Limnoperna fortunei) as of December 16, 2024.

Image by GBIF Secretariat, 2024

Presence in the United States

Specimens of *L. fortunei* were found in Merced and San Joaquin counties in California in October 2024 (USGS 2024; Figure 3), with additional detections occurring thereafter. Validated records can be found at the following website: USGS Golden Mussel Map and Specimen Records.

Figure 3. Distribution of the golden mussel (Limnoperna fortunei) in the United States as of December 16, 2024.

Image by USGS 2024.

Ecological Impacts

CABI (2024)

"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 canaliculata* (Gastropoda, Ampullariidae) and *Aegla platensis* (Anomura, Aeglidae), as well as on the introduced *Corbicula fluminea* (Bivalvia, Corbiculidae) (Darrigran et al., 2000; Darrigran, 2002)."

"However, many other aspects of the biology of *L. fortunei* are poorly understood (Sylvester et al., 2005), including its filtering capacity. Because of its high density in the Plata basin, *L. fortunei* could increase water clarity in a manner similar to that caused by *Dreissena polymorpha* in North America (Darrigran and Damborenea, 2005).”

“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).”

Economic Impacts

Darrigran and Damborenea (2005)

“Freshwater macrofouling, caused by *L. fortunei*, is a novel economic problem in South America. Previously, macrofouling was only a problem in coastal and estuarine localities. Now, however, major industries in Argentina, Brazil, Uruguay, and Paraguay are faced with problems including reduction of water-pipe diameter, blockage of pipelines, decrease of water velocity, accumulation of empty shells [of *L. fortunei*], contamination of water by dead mussels, and blockage of filters by larvae and juveniles and their settlement in different parts of the processing plants (Darrigran 2000). These problems have been recorded in numerous installations, including water purifying plants, hydroelectric plants, thermal plants, freezing plants, and oil factories. As a consequence, costs rise because of shutdowns caused by pipeline obstructions and the need for periodic mechanical or chemical cleaning as well as the replacement of pipes and filters. Most information on this issue is contained in technical reports that are not widely available.”

CABI (2024)

“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.”

Summary

Populations of *L. fortunei* have become established in locations outside their native range, most recently in California. The ecological and economic impacts of *L. fortunei* are similar to those from quagga (*Dreissena bugensis*) and zebra (*Dreissena polymorpha)* mussels. Ecological impacts include competition with and displacement of native species and alteration of food webs. Economic impacts result primarily from mussels attaching to hard substrates, which fouls boats and docks, clogs water intake pipes, and requires a significant allocation of resources for maintenance efforts.

Potential for Transport into and Within Washington

Means of Introduction and Spread

Darrigran and Pastorino (1995)

"As the country with the steepest increment in imports is Hong Kong (more than fivefold times) and the presence of *Limnoperna fortunei* is confirmed (Morton, 1987), it seems to be the source of the Argentinian population of this species. Although it is not used as food, it may have been transported in tanks containing untreated fresh water."

Magara and others. (2001)

"The aquatic nuisance mussel, *Limnoperna fortunei*, arrived in Japan before 1987 possibly with the Asian clam imported as food from mainland China. Now the mussel's distribution has spread to two river systems in central Japan."

Darrigran (2002)

"Darrigran and Pastorino (1995) described the transport and release of this species into South America as a non-intentional introduction through ballast waters of ocean vessels."

"*Limnoperna fortunei* has an epifaunal mode of life, attaching to a wide variety of hard substrates, both natural (from trunks and aquatic plants to compact silt, sand) and artificial (docks, tubes, walls, etc.)."

Boltovskoy and others. (2006)

"Along the Paraná-Paraguay waterway, which hosts intense boat traffic, *L. fortunei* has moved upstream at an average rate 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."

Mackie and Brinsmead (2017)

"The arrival of golden mussel by overland transport is considered low because either the distance traveled overland (i.e. from west coast to Great Lakes) is too great for survival of propagules, or because there are few ballast water discharge events from ships arriving at Atlantic Ocean ports. However, some caution is warranted because the probability of dispersal of zebra mussels into western United States was assessed as a low probability event, but we now know this prediction was incorrect."

CABI (2024)

"The natural dispersal of *L. fortunei* is passive, and occurs as veliger larvae that are passively transported from colonized areas through connected streams. The natural dispersal is downstream and dependent on water currents."

"In Guaíba Basin, 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."

Desiccation Tolerance

Zhang and others. (2022)

"Montalto & Ezcurra de Drago (2003) had conducted laboratory and outdoor experiments to analyse the tolerance of L. fortunei to desiccation. They found that *L. fortunei* is tolerant to desiccation, and the tolerance increases with mussel size. In the laboratory tests, small (up to 6 mm) mussels died after 72 h of exposure to desiccation conditions, medium-sized (6–15 mm) ones for 192 h, and maximum-sized (15–27) adults for 276 h. In the outdoor experiments, small, medium-sized, and maximum-sized mussels died at 72, 96, and 108 h, respectively."

Potential for Overland Transport to Washington

Watercraft Inspections from waterbodies positive for Golden Mussels in California.

In 2024 (January 1 – December 16), there have been 53 aquatic conveyances, such as recreational watercraft, intercepted at Watercraft Inspection and Decontamination (WID) stations in Washington from known positive waterbodies in California (San Joaquin delta, Sacramento-San Juaquin Delta, Sacramento Delta, Delta Marina, central delta, California Delta, Brentwood delta, Bethel Island (delta), San Francisco Bay, San Francisco Bay (Pacific Ocean), San Francisco Bay- San Francisco, San Pablo Bay). These inspections were predominately commercially transported vessels and a significant number of kayaks (Table 1). In 2023, 24 watercraft were intercepted and inspected from these same waters (Table 2). None were found to be mussel fouled. WID inspection activity from California has been limited by identified expansion needs of WID station accessibility in Southwest Washington.

Annual WID inspections in Washington generally exceed 50,000 watercraft. The inspection of watercraft from positive waterbodies in California make up a small portion of watercraft movement in the state. However, if the establishment of golden mussel, *L. fortunei* becomes more prolific in California, the occurrence of mussel fouled vessels is expected to increase. If the watercraft identified from this and previous years were to have been found carrying golden mussels, it would have significantly increased the number of mussel fouled boats intercepted at Washington's WID Stations.

Table 1. Washington Watercraft Inspection Information for 2024 (January 1 – December 16) on vessels from *Limnoperna fortunei* positive waterbodies in California.

Date Inspected	Inspection Station	*L. fortunei* Positive waterbody	Vessel Type	Vessel Count	Clean Drain Dry	Decontamination Required
1/22/2024	Pasco	CA - San Francisco Bay (Pacific Ocean)	Kayak/Canoe	2	Yes	No
3/12/2024	Ridgefield	CA - San Francisco Bay (Pacific Ocean)	Commercial - Used	1	No	No
3/14/2024	Spokane	CA - California Delta	Kayak/Canoe	2	Yes	No
3/16/2024	Pasco	CA - California Delta	Fishing Boat	1	Yes	No
3/18/2024	Clarkston	CA - San Francisco Bay (Pacific Ocean)	Commercial - Used	1	Yes	No
4/17/2024	Pasco	CA - Sacramento Delta	Fishing Boat	1	Yes	No
5/1/2024	Cle Elum Eastbound	CA - San Francisco Bay (Pacific Ocean)	Commercial - Used	24	Yes	No
5/1/2024	Cle Elum Eastbound	CA - San Francisco Bay (Pacific Ocean)	Commercial - Used	1	Yes	No
5/24/2024	Pasco	CA - San Francisco Bay (Pacific Ocean)	Fishing Boat	1	Yes	No
6/8/2024	Pasco	CA - California Delta	Fishing Boat	1	Yes	No
6/22/2024	Pasco	CA - San Francisco Bay (Pacific Ocean)	Pontoon	1	Yes	No
6/28/2024	Cle Elum Eastbound	CA - California Delta	Ski Boat	1	Yes	No
7/7/2024	Cle Elum Eastbound	CA - San Francisco Bay (Pacific Ocean)	Ski Boat	1	Yes	No
7/25/2024	Cle Elum Eastbound	CA - Sacramento Delta	Kayak/Canoe	1	Yes	No
7/28/2024	Pasco	CA - Bethel Island (delta)	Ski Boat	1	Yes	No
8/13/2024	Pasco	CA - California Delta	Ski Boat	1	Yes	No
10/5/2024	Pasco	CA - San Francisco Bay (Pacific Ocean)	Kayak/Canoe	12	Yes	No

In total, 53 vessels from L. fortunei positive waterbodies in California stopped at Washington Watercraft Inspection and Decontamination Stations. Of these vessels, the majority (52) underwent Clean, Drain, Dry procedures and no vessels underwent decontamination procedures at the inspection station.

Table 2. Washington Watercraft Inspection and De Information for 2023 (January 1 – December 31) on vessels from *Limnoperna fortunei* positive waterbodies in California.

Date Inspected	Inspection Station	*L. fortunei* Positive waterbody	Vessel Type	Vessel Count	Clean Drain Dry	Decontamination Required
3/30/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Pontoon	1	Yes	No
4/9/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	PWC	1	Yes	No
4/16/2023	Pasco	CA - Sacramento Delta	Fishing Boat	1	Yes	No
4/29/2023	Pasco	CA - California Delta	Fishing Boat	1	Yes	No
5/5/2023	Pasco	CA - California Delta	Fishing Boat	1	Yes	No
5/25/2023	Pasco	CA - California Delta	Ski Boat	1	Yes	No
6/1/2023	Pasco	CA - California Delta	Ski Boat	1	Yes	No
6/12/2023	Pasco	CA - Sacramento Delta	Fishing Boat	1	Yes	No
6/28/2023	Pasco	CA - California Delta	Ski Boat	1	Yes	No
7/16/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Sailboat	1	Yes	No
7/17/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Kayak/Canoe	1	Yes	No
7/17/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Paddleboard	1	Yes	No
7/22/2023	Pasco	CA - California Delta	Cabin Cruiser	1	Yes	No
7/28/2023	Cle Elum Eastbound	CA - Sacramento Delta	Ski Boat	1	Yes	No
8/27/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Sailboat	1	Yes	No
10/15/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Barge/Dock	1	Yes	No
10/17/2023	Spokane	CA - Sacramento Delta	Fishing Boat	1	Yes	No
11/14/2023	Pasco	CA - Sacramento Delta	Fishing Boat	1	Yes	No
11/27/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Ski Boat	1	Yes	No
11/28/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Fishing Boat	1	Yes	No
12/22/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Kayak/Canoe	2	Yes	No
12/22/2023	Pasco	CA - San Francisco Bay (Pacific Ocean)	Fishing Boat	1	Yes	No
12/27/2023	Clarkston	CA - San Francisco Bay (Pacific Ocean)	Fishing Boat	1	Yes	No

In total, 24 vessels from L. fortunei positive waterbodies in California stopped at Washington Watercraft Inspection Stations. All vessels underwent Clean, Drain, Dry procedures and no vessels underwent decontamination procedures at the inspection station.

Potential for Maritime Transport to Washington

Ballast Water and Biofouling Overview

Washington state RCW Chapter 77.120 enables the Washington Department of Fish and Wildlife (WDFW) to regulate operations for vessels 300 gross tons and greater for the prevention of release of invasive species from ballast water and biofouling (or hull fouling) - marine growth, including plants, algae, and animals that accumulate on the wetted surfaces of a vessel. Fouling organisms may include invasive species and may spread by larval release or fragmentation from a fouled surface. Ballast water is essential to the safe operation of large oceangoing vessels that carry cargo between the world's ports. Water is typically pumped into ballast tanks at one port when cargo is offloaded and then pumped back out to another port when new cargo is loaded. Ballast water helps vessels maintain stability and maneuverability and can also harbor invasive species including the larvae of *L. fortunei* (Darrigran and Pastorino 1995, Uliano-Silva and others 2013, CABI 2024).

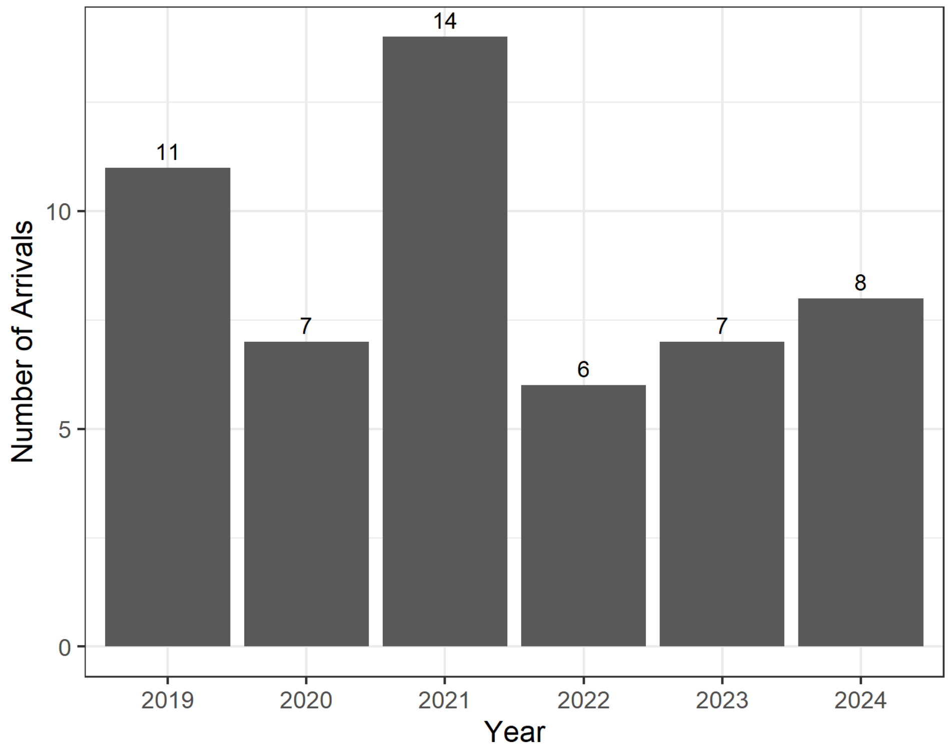
Required operations and reporting schedules are listed in WAC Chapter 220-650. In general, vessels arriving to Washington that intend to discharge ballast water must either conduct an open-ocean ballast water exchange at least 50 Nautical Miles (for coastal voyages) or 200 NM (for transoceanic voyages) from any shoreline or must treat all ballast water with a U.S. Coast Guard (USCG) Type Approved Ballast Water Management System (BWMS) that has been installed onboard. The process of BWMS type approval in the United States includes the issuance of a USCG Type Approval Certificate that includes specific installation and operational limitations that must be met for the BWMS to be operated legally in U.S. waters. Vessels are also required to clean and maintain their hulls for the prevention of biofouling accumulation in accordance with laws protecting water quality and must receive prior written approval from the Washington Department of Ecology and WDFW prior to conducting any in-water cleaning operation that could dislodge fouling organisms.

Limnoperna fortunei and commercial vessels in Washington

The detection of *L. fortunei* in Stockton, California is of concern partly because Washington receives vessels and ballast water discharges from Stockton and the nearby freshwater ports of Antioch and Pittsburgh (no ballast discharged during the focal period was sourced from Antioch). The freshwater ports of Longview, Kalama, and Vancouver, Washington on the lower Columbia River are particularly vulnerable as these fully freshwater ports may present an environmental match for *L. fortunei.* According to the WDFW vessel records, vessels may take as little as two days between taking on ballast in Stockton and arriving in freshwater ports on the Columbia River. Shorter voyages are associated with greater risk that organisms such as *L. fortunei* larvae could survive in ballast tanks should they escape mortality from exchange or treatment.

Washington received a total of 53 regulated arrivals from Stockton and adjacent ports from 2019 – present (Figure 4). While this does not necessarily indicate that all these vessels were carrying ballast water from the Stockton area, vessels from these ports may also carry *L. fortunei* on exposed portions of their hulls if antifouling coatings have been compromised. Arrivals to Washington from Stockton and adjacent ports represented 0.7% of all arrivals to Washington waters in this evaluation period.

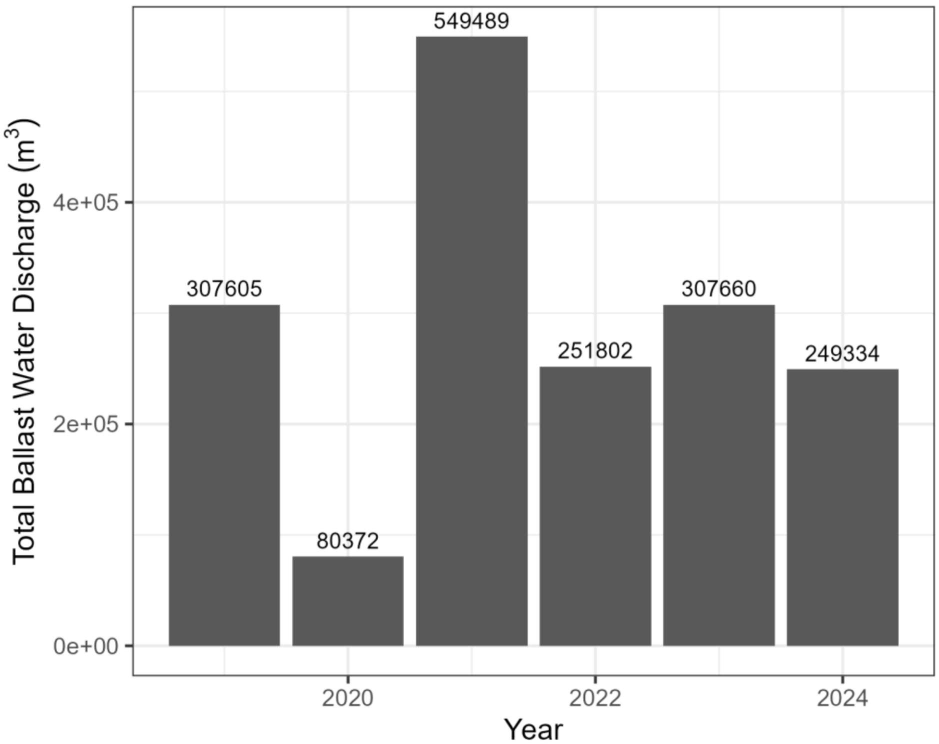
Figure 4. Regulated commercial vessel arrivals to Washington ports and/or places from 2019 – present.



Note that only the first 3 quarters of 2024 are accounted for in the WDFW database, so 2024 arrivals will likely be higher.

Total vessel arrivals from infested waters in California does not, in isolation, represent the risk of *L. fortunei* release in ballast water. Some vessel arrivals were not associated with ballast discharge, and others were carrying ballast sourced at ports not known to harbor *L. fortunei*. From 2019-present, at least 1,746,262 metric tons of ballast water containing some water sourced in the Stockton area were released to Washington ports (Figure 5), or ~1.8% of total ballast water released by volume in Washington over the study period. Ballast water could still represent a high-risk pathway for invasion by *L. fortunei* to Washington, however, given the nature of commercial vessel traffic from affected regions.

Figure 5. Ballast water discharged to Washington from 2019-present that contained at least some water sourced in Stockton, Antioch, and Pittsburg, CA.



This includes ballast water released from vessels that listed a source as Stockton, Pittsburgh, or Antioch in addition to vessels that did not specify a source location.

Summary

Numerous vectors exist for the potential transport of *L. fortunei* into and within Washington. Larvae of *L. fortunei* travel via natural currents (once established), contaminated water (e.g., freshwater ballast, aquaculture). Adult mussels attach to hard substrates including recreational vessels and gear and may be transported via aquatic or overland routes. While desiccation may reduce survival rates of adult *L. fortunei*, adults can survive for several days out of water. WDFW's Watercraft Inspection and Decontamination Stations encountered 53 vessels from *L. fortunei* positive waterbodies in California from January 1- November 26, 2024 (Table 1). WDFW concluded that from 2019-present, 1,746,262 metric tons of ballast water containing water from the Stockton area (where *L. fortunei* are present) were released to Washington ports (Figure 5).

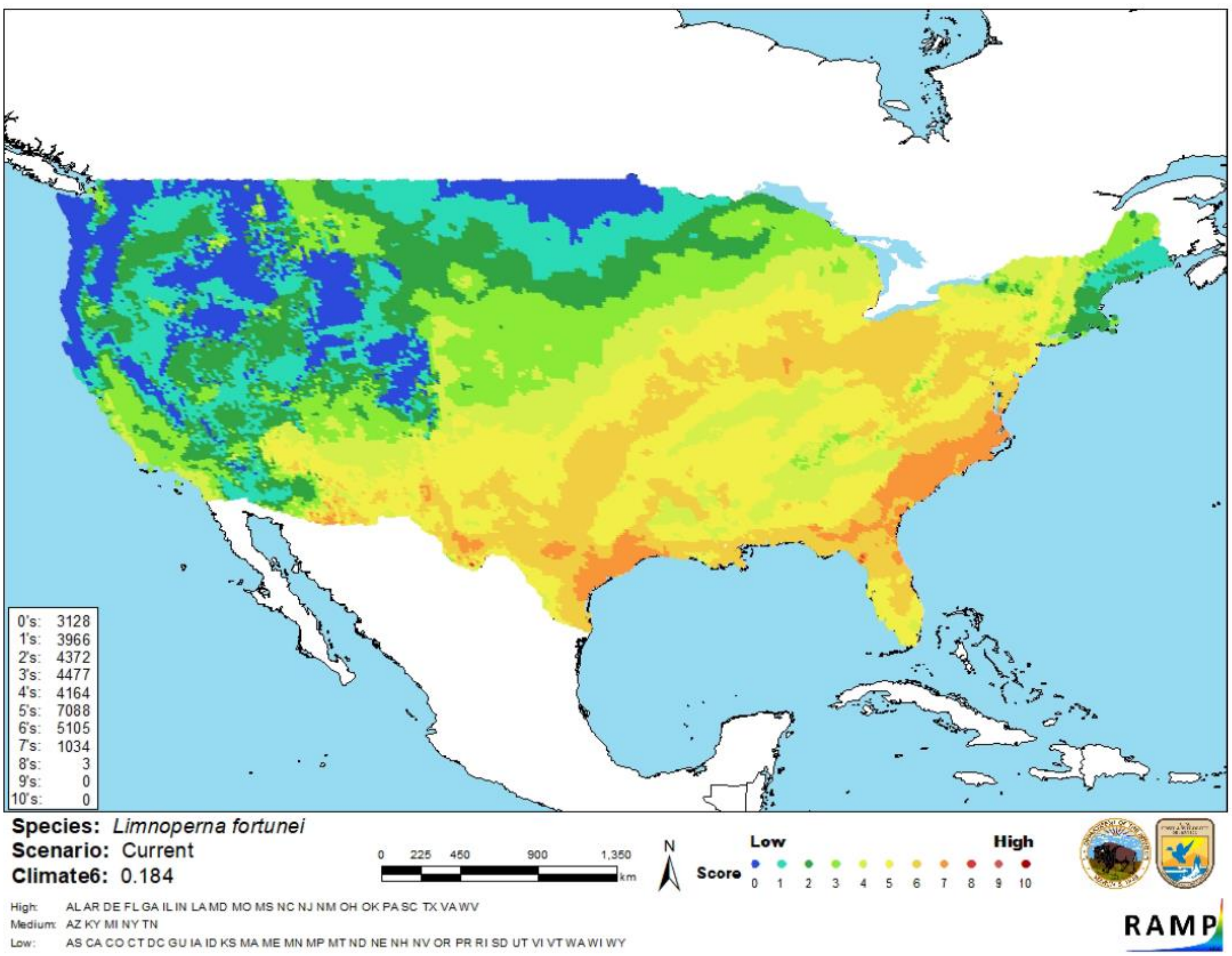
Conditions in Washington Suitable for Survival and Reproduction

Climate Matching

USFWS (2024)

“The climate match for *Limnoperna fortunei* was high throughout the east, southeast, and central area of the contiguous United States. The west and most of the northern area of the country was low. The overall Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for the contiguous United States was 0.184, high (scores of 0.103 and greater are classified as high). The following States had high individual Climate 6 scores: Alabama, Arkansas, Delaware, Florida, Georgia, Illinois, Indiana, Louisiana, Maryland, Missouri, Mississippi, North Carolina, New Jersey, New Mexico, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas, Virginia, and West Virginia. States with medium individual climate scores included Arizona, Kentucky, Michigan, New York, and Tennessee. All other States had low individual climate scores.”

Figure 6. Map of Risk Assessment Mapping Program (RAMP) (Sanders and others 2018) climate matches for *Limnoperna fortunei* in the contiguous United States.



Based on source locations reported by GBIF Secretariat (2020). Counts of climate match scores are tabulated on the left. 0/Blue = Lowest match, 10/Red = Highest match. Image taken from USFWS (2024). Washington is listed as a Low climate match for L. fortunei.

Overlapping Distribution with Established Invasive Species

Mackie and Brinsmead (2017)

"However, a good surrogate of survey effort is demonstrated in determining the distribution of the Asian clam, *Corbicula fluminea* (O. F. Müller, 1774), which is often associated with the golden mussel (Morton 1996 [1997]; Darrigran and Pastorino 1995, 2004; Magara et al. 2001; Darrigran and Damborenea 2006; Darrigran et al. 2012). Figure 4 [not included in this risk summary] shows the global distribution of the Asian clam up to 2015 (Gama et al. 2016). Its isolated occurrence in Ontario is probably due to its broader tolerance of low temperatures than golden mussel, and despite this, Asian clam has not become widespread in Ontario."

Water Quality

Calcium

Karatayev and others. (2015)

"The calcium limits for both species of Dreissena are substantially higher than those for *L. fortunei*. Calcium is generally scarce in South American floodplain rivers colonized by the golden mussel (3-9 mg/L; Maglianesi 1973, Bonetto et al. 1998), and values as low as 1 mg/L of Ca and pH<6 have been reported from some areas successfully colonized by *L. fortunei*, such as the Upper Paraguay River (Oliveira et al. 2011)."

Figure 7. Mean calcium concentrations in rivers on different continents (Wetzel 1975) and minimum calcium requirements for *Dreissena polymorpha* and *Limnoperna fortunei*.

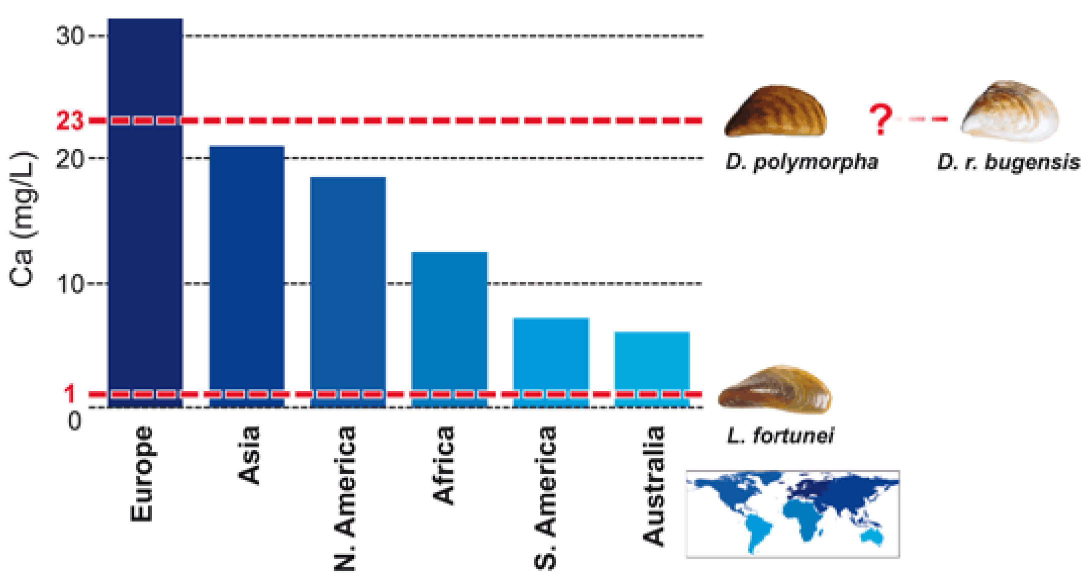


Image from Karatayev and others. (2015).

Salinity

Karatayev and others. (2015)

"In Europe and North America, *D. polymorpha* can form stable populations at salinities below 6 ‰, which is only slightly higher than the limit for quagga mussels (Table 2). For L. fortunei, constant salinities around 2 ‰ are the upper limit for extended survival (Huang et al. 1981; Angonesi et al. 2008; Barbosa and Melo 2009; Sylvester et al. 2013). However, at intermittent saltwater-freshwater conditions, such as those normally present in tidal estuaries, golden mussels can tolerate short periods (hours) of salinities up to 23 ‰ without significant mortality (Sylvester et al. 2013; see Chapter "Chemical Strategies for the Control of the Golden Mussel (*Limnoperna fortunei*) in Industrial Facilities" in this volume). This suggests that tests at constant salinity underestimate the tolerance of this species, and probably other freshwater molluscs, to saltwater exposure. Because estuarine ports represent ~ 70 % of nonmarine ports globally, they constitute major donor and recipient hotspots for the spread of nonnative species into continental aquatic ecosystems via shipping. It is probable that the tolerance of *L. fortunei* to estuarine conditions contributes to this species' success as an invader (Sylvester et al. 2013)."

Temperature

Oliveira and others. (2010)

"In contrast to Ca concentrations and the $SI_{calcite}$, which do not appear limiting to the establishment of L. fortunei in the major North American rivers, seasonally low water temperatures may present a limitation in northern regions. Winter water temperatures in the North American rivers range between 0 and 5°C in the upper Mississippi and its tributary the Missouri River (Figure 7[not included in this risk summary]). This low temperature can last for about 3 months in those rivers. In the Ohio River, the main eastern tributary of the Mississippi, minimum water temperatures are slightly higher than 5°C (Figure 8[not included in this risk summary]). The Colorado and Rio Grande rivers showed higher mean minimum temperatures, above 8°C during the winter season."

"Our thermal tolerance assays using specimens of L. fortunei from the tropical Paraguay River provide an indication of how this species responds to low temperatures. Adult mussels survived up to 15 days at water temperatures of 0-1°C, although they were inactive during that time (Figure 9[not included in this risk summary]). Survival at 5-7°C was <50% during the first 20 days, with a maximum survival of about 38 days. At temperatures above 10°C mussels were active, and about 80% of them survived for the entire 30 days of the experiment. These data lend support to a threshold of ~5°C for protracted exposure of L. fortunei to low winter temperatures (i.e., weeks to months)."

Karatayev and others. (2015)

"While on the basis of these data, it is tempting to speculate that low winter temperatures are unlikely to be a deterrent for the spread of *L. fortunei* into cooler waterbodies, minimum survival temperature may not be a good indicator of the mussel's ability to maintain self-sustaining populations. Reproductive cycles (as evidenced by the presence of larvae in the water column) clearly show that temperature is the dominant factor for spawning (see Chapter "Reproductive Output and Seasonality of Limnoperna fortunei" in this volume). The shorter the periods of high temperature, the shorter is the spawning season. Thus, while in the Upper Paraná River, where water temperatures range around 18 to > 30 °C, larvae are produced for 9–10 months each year, in Japan, at ~ 7–25 °C, larval output is restricted to 1–2 months, and in Korea, at 0–30 °C, reproduction is restricted to around 20 days (Choi and Shin 1985; Nakano et al. 2010a; Hamada 2011; Mata 2011; see Fig. 2, 3 and 10 in Chapter "Reproductive output and Seasonality of Limnoperna fortunei" in this volume). Interestingly, in all of these waterbodies, summer water temperatures are high. Even Paldang Reservoir, which freezes in the winter, reaches ~ 30 °C in the summer (Choi and Shin 1985). This suggests that the magnitude and duration of warm summer temperatures determine whether self-sustaining populations are possible, rather than minimum winter values. Data at hand indicate that the lowest temperatures at which *L. fortunei* spawns are around 15–18 °C (see Chapter "Reproductive Output and Seasonality of *Limnoperna fortunei*" in this volume), which suggests that waterbodies whose temperature is always below these values are unlikely to be colonized by this mussel. Therefore, Andean Patagonian lakes located south of ~ 38 °S, most of which do not freeze but never reach temperatures above 13–15 °C (Baigun and Marinone 1995; Díaz et al. 2000) are most probably not at risk of colonization by *L. fortunei*. In contrast, the North American Great Lakes, which may freeze in the winter, but usually have 3–4 month periods when water temperatures are above 16 °C (except Lake Superior; National Oceanic and Atmospheric Administration, NOAA 2014), are probably suitable for colonization by *L. fortunei*."

Xia and others. (2021)

"These findings provide direct evidence that golden mussels can tolerate chronic exposure to low water temperature in situ. Using a population from the Paraguay River (Brazil), Oliveira et al. (2010) found that golden mussels reached 100% mortality after 38 days at 5– 7°C and suggested that 5°C was a critical lower threshold for extended (i.e. weeks to months) survival in winter. This threshold (5°C) was subsequently used to estimate their distribution (Mackie & Brinsmead, 2017; Oliveira et al., 2010). In our study, however, golden mussels from both sites lived for more than 2,580 hr (~108 days) in water <5°C, and some individuals survived near- freezing conditions in situ, indicating greater cold tolerance. Though the underlying mechanisms (e.g. genetic or physiological plasticity) for such enhanced cold tolerance remains unstudied, our study suggests a higher latitude distributional range than previous predictions based on the proposed cold limit (Mackie & Brinsmead, 2017; Oliveira et al., 2010). For example, the upper Mississippi River was suggested as unsuitable for golden mussels because of extended low water temperature (i.e. <5°C for ~3– 4 months) (Oliveira et al., 2010), while our findings provide direct evidence that they can survive such chronic exposure to low water temperatures (i.e. 108 days in Shisanling Reservoir versus ~3– 4 months in the upper Mississippi River). If our assessments are broadly applicable, they indicate that many other water bodies are potentially vulnerable to the establishment of golden mussels associated with inland water diversion projects (e.g. South to North Water Diversion Project in China) or other invasion routes that enhance the transfer propagules (Zhan et al., 2015). Our SDMs suggest that the southern margin of the Laurentian Great Lakes is susceptible to invasion by the golden mussel (see later Discussion), while previous studies provided contrasting predictions. For example, Mackie and Brinsmead (2017) predicted that the probability of survival and establishment of golden mussels in Ontario, Canada, was low because of intolerance to cold winter. However, Kramer et al. (2017) reported possible support for reproduction of the species in Lake Erie and southern Lake Michigan by considering habitat- specific water temperatures. According to our in situ results, the former study might underestimate the cold tolerance of the species by taking the 5°C as a cold limit."

Zhang and others. (2022)

"*L. fortunei* exhibit extensive tolerance to many environmental factors. However, the low water temperature can affect reproduction, filtration rate, growth rate, and overwintering survival rate, which is expected to limit the distribution of mussels at high latitudes (Ricciardi 1998; Tagliarolo et al. 2016; Zhao et al. 2019). Oliveira et al. (2010) found that L. fortunei reached 100% mortality after 38 days at 5–7 °C, and suggested that 5 °C was a critical lower threshold for extended survival in winter. However, Xia et al. (2021) recently claimed that golden mussels from both sites lived for more than 108 days in water <5 °C, and some individuals survived near-freezing conditions in situ, indicating greater cold tolerance. Their findings suggest enhanced cold tolerance of L. fortunei and wider potential distribution than currently exists."

Water temperature suitability in Washington

An assessment of water temperatures at various locations in Washington was performed to determine suitability for *L. fortunei* survival and reproduction. Water temperature data was collected from the Washington State Department for Ecology's Environmental Information Management System Freshwater Information Network. Locations were selected for analysis if there were sufficient records to calculate the monthly mean, maximum, and minimum water temperature for all 12 months of the year. See Appendix Table 4 for all sites and years included.

Monthly mean, minimum, and maximum water temperatures for each location were calculated and compared with known temperature tolerances for *L. fortunei.* These tolerances were:

- Upper temperature limit for adult survival (°C): 35 (Oliveira and others. 2011)
- Lower temperature limit for reproduction (°C): 16-17 (Cataldo and Boltovskoy 2000)
- Lower temperature limit for adult survival (°C): 0 - 5 (Xia and others. 2021)
    - The lower temperature limit for adult survival of *L fortunei* varies across populations, with mussels from the Paraguay River, Brazil reaching 100% mortality after 38 days at 5-7°C (Oliveira and others. 2010) and mussels in Shisanling Reservoir, China surviving over 108 days in < 5°C water (Xia and others. 2021).

A location was considered suitable for *L. fortunei* if the mean monthly temperature remained > 5°C and was > 17°C for at least two consecutive months. Both criteria are conservative estimates (erring on *L. fortunei* being less likely to establish) given the range of tolerances observed for *L. fortunei.* For example, *L. fortunei* can survive for extended periods at temperatures < 5°C (Xia and others. 2021) and in temperate climates produces larvae for only 1 month or less each year (Choi and Shin 1985, Nakano and others. 2010).

Mean monthly water temperature was examined for 46 locations (Figure 8; Appendix Table 4). While only 11 locations met all criteria to be considered suitable for *L fortunei*, 12 locations met the criteria for survival (remain > 5°C), and 13 locations met the criteria for reproduction (> 17°C for at least two consecutive months). Only 10 sites failed to meet either of the criteria.

Consideration should be given to the variability of temperature at all assessed locations. Minimum and maximum monthly water temperatures across all locations often exceeded or fell short of the criteria chosen for this assessment. This natural variability in water temperatures across years suggests that conditions may fluctuate between favorable or unfavorable for *L. fortunei* survival and reproduction in most locations.

Environmental Tolerances of *L. fortunei* compared to Dreissenid mussels

Dreissena polymorpha (zebra mussel) and *Dreissena bugensis* (quagga mussel) are both Prohibited level 1 species listed under WAC 22-640-030. Species listed as Prohibited level 1 “pose a high invasive risk and are a priority for prevention and expedited rapid response management actions” under RWC 77.135.030. WDFW monitors for both species of *Dreissena* at locations at risk of invasion throughout the state.

L. fortunei has similar physiological tolerances to *D. polymorpha* and *D. bugensis* (Table 3) and should be capable of establishment and reproduction in the same waterbodies. The calcium requirements and dissolved oxygen requirements for *L. fortunei* are significantly less than those of dreissenid mussels (1mg/L and 23–2824mg/L). The lower temperature tolerances are similar for all three species, though this may vary depend on *L. fortunei’s* point of origin (Xia and others. 2021). While *L. fortunei* requires substantially warmer water temperatures for reproduction (°C) compared *D. bugensis*, *L. fortunei* and *D. polymorpha* have similar water temperature requirements.

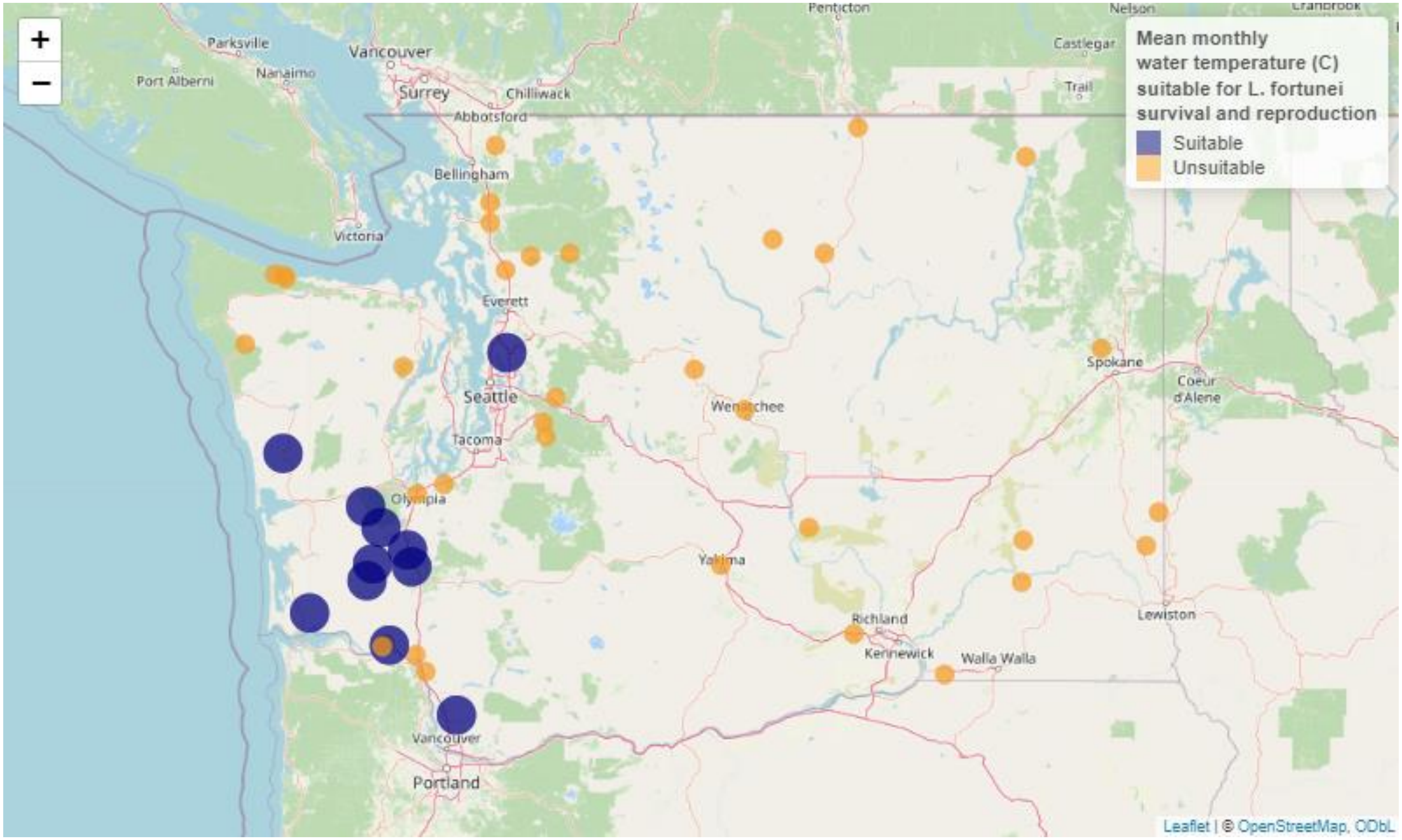
Summary

Washington is a low climate match for *L. fortunei* based on the analysis performed by USWFW (2020; Figure 6), though the lack of geospatial data for *L. fortunei* populations in several countries (Democratic People’s Republic of Korea, Republic of Korea, Indonesia, Taiwan, Indonesia, Bolivia, and Paraguay) may reduce certainty of this conclusion. If the analysis by USFWS (2020) is accurate, environmental conditions may at least serve as a partial barrier to the establishment of *L fortunei*. Mackie & Brinsmead (2017) highlight the common association of *L. fortunei* with the Asian clam, *Corbicula fluminea*, an established invasive species in Washington. While the presence of *C. fluminea* does not guarantee environmental conditions are suitable for *L. fortunei*, it may suggest locations of increased establishment risk.

Water temperatures in Washington appear suitable for the establishment and reproduction of *L. fortunei* in at least some locations. Of the 46 sites examined, 11 had average monthly temperatures that did not dip below 5°C (suggesting suitability for adult survival) and exceeded 17°C for at least two consecutive months (suggesting suitability for reproductive success). While the analysis does not definitively determine if *L. fortunei* would or would not establish and reproduce if introduced to any of these locations, it does suggest some habitats in Washington are suitable for *L. fortunei.*

The physiological tolerances of *L. fortunei, D. polymorpha* and *D. bugensis* are similar among all three species (Table 3). Since it has been determined *D. polymorpha* and *D. bugensis* pose a high invasive risk and could become established in Washington, it is reasonable to assume that *L. fortunei* has a similar potential for establishment.

Figure 8. Map of locations assessed for water temperature suitability for *Limnoperna fortunei* survival and reproduction.



Location was considered suitable for *L. fortunei* if the mean monthly temperature remained > 5°C and was > 17°C for at least two consecutive months. Of the 46 locations examined, 11 were determined to be suitable for the establishment and reproduction of *L. fortunei.*

Table 3. Environmental limits for *Limnoperna fortunei*, *Dreissena polymorpha*, and *Dreissena rostriformis bugensis*. Modified from Karatayev et al.(2015)

Factors	*L. fortunei*	*D. polymorpha*	*D. r. bugensis*
Upper salinity limit (‰)	Continuous: 2[1,2] Discontinuous, punctuated by periods of fresh water: up to 23[2]	6[3]	3.5[4]
Lower temperature limit for adult survival (°C)	0[5, 6]	0[7]	0[8]
Upper temperature limit (°C)	35[9]	32–33[3, 10, 11, 12]	31[3,11]
Lower temperature limit for reproduction (°C)	15–17[13, 14, 15, 16]	12–15[3, 17, 18, 19, 20, 21]	5–7[22, 23]
Lower pH limit	< 6.0[9]	7.3–7.5[17, 24, 25, 26]	No data
Lower calcium limit (mg/L)	1[9]	23–28[24,25]	No data
Lower oxygen limit at 20 °C (mg/L)	0.5[27]	1.8–2.4[28, 29]	1.5[29]
Tolerance to pollution	High[27, 30, 31, 32, 33]	Medium[25, 34, 35]	No data
Distribution within a waterbody	Littoral, sublittoral[36, 37]	Littoral, sublittoral[3, 27, 38]	Littoral, sublittoral, and profundal[23, 39, 40, 41, 42]
Substrate type	Natural or artificial hard substrata, aquatic macrophytes, avoids soft silt[27, 36, 43]	Natural or artificial hard substrata, avoids soft silt[3, 44, 45]	Natural or artificial hard substrata and soft silt[23, 42, 44]

Values given are those that allow for survival of adult individuals, but not necessarily reproduction or survival of larvae (unless otherwise noted).

Citations: [1]Angonesi and others. 2008,[2]Sylvester and others. 2013,[3]Karatayev and others. 1998, [4]Lyakhnovich and others. 1994, [5]Choi and Kim 1985, [6]Choi and Shin 1985, [7]Luferov 1965, [8]Orlova 1987, [9]Oliveira and others. 2011, [10]Karatayev 2006, [11]Karatayev 2007, [12]Allen and others. 1999, [13]Morton 1977, [14]Cataldo and Boltovskoy 2000, [15]Nakano and others.

2010b, [16]Brugnoli and others. 2011, [17]Sprung 1987, [18]Borcherding 1991, [19]Lvova and others. 1994, [20]Pollux and others. 2010, [21]Garton and others. 2014, [22]Roe and MacIsaac 1997, [23]Nalepa 2010a, [24]Ramcharan and others. 1992, [25]Burlakova 1998, [26]Hallstan and others. 2010, [27]Boltovskoy and others. 2006, [28]Spiridonov 1972, [29]Shkorbatov and others. 1994, [30]Villar and others. 1999, [31]Mariano and others. 2006, [32]Bonel and others. 2013, [33]Young and others. 2014, [34]bij de Vaate and others. 1992, [35]Jantz and Neumann 1992, [36]Boltovskoy and others. 2009, [37]Karatayev and others. 2010, [38]Karatayev and others. 2013, [39]Patterson and others. 2005, [40]Watkins and others. 2007, [41]Nalepa and others. 2010a, [42]Karatayev and others. 2015, [43]Rojas Molina 2010, [44]Karatayev and others. 2014, [45]Burlakova and others. 2006

Certainty of Assessment

Information regarding *L. fortunei*'s distribution, ecology, and invasiveness is readily available from a variety of peer-reviewed sources. Overall, the certainty about this assessment is high.

Risk Summary

Risk Criteria

Three criteria determine the species potential invasiveness:

1. The species has a history of invasion in other locations. Invasion requires documentation of establishment and spread of populations, as well as negative ecological and economic impacts.
2. The potential for the transport of the species into and within Washington.
3. Conditions in Washington are suitable for the survival and reproduction of the species.

Risk Levels

High risk: Species that are considered high risk meet all three risk criteria.

Moderate risk: Species that are considered high risk meet two of the risk criteria.

Low risk: Species that are considered high risk meet one or less of the risk criteria.

Uncertain risk: Species that are considered uncertain risk are considered uncertain risk are those where there is insufficient information available to confidently address one or more of the risk criteria.

Summary

History of invasion by the species in other locations

The golden mussel, *Limnoperna fortunei*, is a well-documented aquatic invasive species throughout Eastern Asia and South America. The establishment of *L. fortunei* in these regions has resulted in ecological and economic impacts like those caused by zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*). For example, a 2018 report estimated that golden mussels were creating over $120 million in impacts to the Brazilian electricity sector (Rebelo and others. 2018).

Potential for the transport of the species into and within Washington

Given the recent detections in California, populations of *L. fortunei* are far closer to Washington, increasing the risk of introduction. Overland transport (e.g., aquaculture, recreational vessels) and marine transport (e.g., freshwater or brackish ballast) have led to the spread of *L. fortunei* from established populations. WDFW records show potential pathways already exist for *L. fortunei* transport from newly discovered populations in California via overland transport of aquatic vehicles and ballast water transport.

Conditions in Washington are suitable for the survival and reproduction of the species

Climatic conditions in Washington are a low match with regions where *L. fortunei* is established and may serve as at least a partial buffer to establishment. However, *L. fortunei* is commonly associated with the Asian clam, *Corbicula fluminea*, an established invasive species in Washington. While the presence of *C. fluminea* does not guarantee environmental conditions are suitable for *L. fortunei*, it may suggest locations of increased establishment risk.

Water temperatures in Washington appear suitable for the establishment and reproduction of *L. fortunei* in at least some locations. While the analysis does not definitively determine if *L fortunei* would or would not establish and reproduce if introduced to any of these locations, it does suggest some habitats in Washington are suitable for *L. fortunei.* However, minimum and maximum monthly water temperatures for each location imply that water temperatures may fluctuate between favorable or unfavorable conditions *for L. fortunei* survival and reproduction.

The physiological tolerances of *L. fortunei, D. polymorpha* and *D. bugensis* are similar among all three species. Since it has been determined *D. polymorpha* and *D. bugensis* pose a high invasive risk and could become established in Washington, it is reasonable to assume that *L. fortunei* has a similar potential for establishment.

Conclusion

Based on this risk screen, WDFW concludes there is a high risk of *L. fortunei* establishment, reproduction, and impact should it be introduced to the waters of Washington.

WDFW has determined that *L. fortune*i, poses a high invasive risk and should be a priority for prevention and expedited rapid response management actions.

WDFW recommends that *L. fortunei* be classified as Prohibited Level 1 Aquatic Invasive Species, similarly to *D. Polymorpha* and *D. bugensis,* meaning it may not be possessed, introduced on or into a water body or property, or trafficked, without department authorization, a permit, or as otherwise provided by rule.

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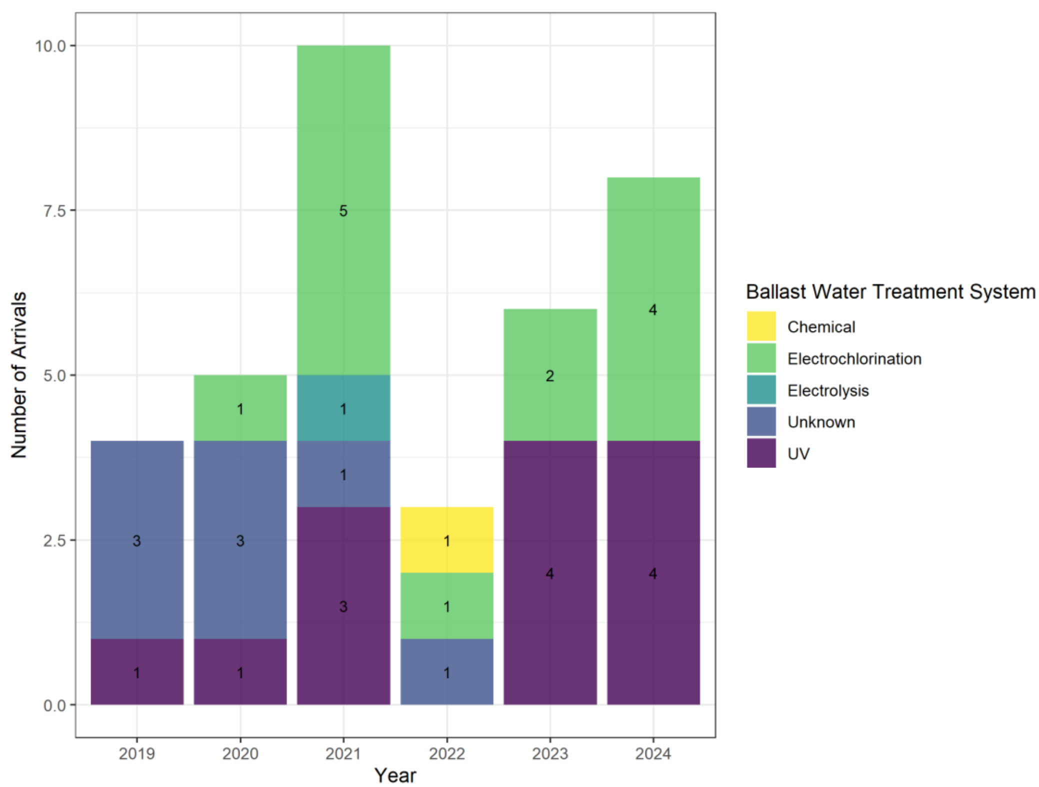
Appendix

Additional Ballast Water Information

Vessels discharging ballast water sourced in the Stockton area from 2019-present primarily treated their ballast with USCG approved ballast water treatment systems that utilize either ultraviolet light or electrochlorination/electrolysis (Figure 9). These technologies have different benefits and limitations, depending on the source port(s) and holding time for treated ballast water. In general, most ballast water treatment systems filter incoming ballast water multiple times prior to applying a killing agent like UV light or hypochlorite, and some mortality is expected to occur at the filtration stage. No information is currently available regarding the relative mortality rate of *L. fortunei* at the filtration stage versus after the killing agent is applied.

Figure 9. Ballast water treatment technologies utilized by regulated vessel arrivals to Washington from 2019-present.



Electrochlorination and electrolysis are equivalent technologies in which an electrical current is passed through saltwater to evolve sodium hypochlorite and hydrogen gas.

Systems that are electrochlorination- or electrolysis-based pass an electric current through saltwater in a contained cell to evolve sodium hypochlorite as a biocidal agent along with hydrogen gas. When used to treat freshwater ballast, as would be sourced from Stockton, vessels must either carry a supply of oceanic salinity water (often in a forepeak ballast tank) or must conduct an offshore ballast water exchange to ensure challenge water is of sufficient salinity to create hypochlorite. Oregon, which co-manages the Columbia River with Washington, requires that all vessels arriving to Portland, Oregon perform an open ocean exchange in addition to treating their ballast water. Some vessels calling on Washington ports do, therefore, conduct exchange and treatment together as a matter of course. For *L. fortunei*, this could increase mortality of any entrained larvae or small adults, though the species can survive pulse treatments of salinity up to 23 ppt (Sylvester and others. 2013). Introduction of oceanic water into ballast tanks already filled with fresh water should not, therefore, be generally utilized as a control method for *L. fortunei*.

Ballast water treatment systems that utilize UV light do not require the presence of saltwater but do require a minimum transmittance and are of higher concern for delayed mortality and regrowth of entrained organisms (Olsen and others. 2016, Romero-Martínez and others. 2021). Inspection of UV-based systems by WDFW inspectors indicates that vessel crews may not always replace the necessary UV bulbs on the recommended schedule, and that a combination of factors including challenge water quality may reduce UV transmittance below the value recommended by the system manufacturer and required by the US Coast Guard as listed in the system's USCG type approval letter.

Turbidity may be high at ports on the San Joaquin/Sacramento River delta and vessels do not always wait until conditions improve. When this occurs, any system that utilizes a filter may be overwhelmed. WDFW staff as well as the International Maritime Organization (IMO) are aware that vessel crews sometimes choose to bypass their ballast water treatment system on uptake in port, relying on exchange and treatment while underway to kill any entrained organisms. Ballast water exchange is not 100% efficient (Cordell and others. 2015) at turning over water in all portions of a ballast system, and while exchanging and treating water while underway may appear, *a priori*, to be a protective measure after treatment system bypass at port, we are unaware of any data to support this claim (although Bradie and others. (2023) presented a promising model simulation that supports use of exchange when ballast water treatment systems are inoperable). The IMO has adopted guidance measures for governments and vessel operators to address the problem of treatment system bypass due to challenging water conditions (MEPC 387(81)).

Ballast water from Stockton and adjacent ports was released to both salt and freshwater ports in Washington (Figure 10). While *L. fortunei* can survive saltwater shock, larvae and adults are not expected to survive longer term exposure to full salinity water at ports such as most of Seattle and Tacoma. It is not clear, however, what the impact of port adjacent rivers such as the Nisqually River at Tacoma and the Duwamish River at Seattle would have on occasional mussel survival, or how many unregulated vessels may berth at smaller ports along these rivers.

The ports of Longview, Kalama, and Vancouver are on the Columbia River and are fully freshwater ports that receive hundreds of arrivals every quarter. While 10 or fewer discharging arrivals from Stockton area ports occurred each year in Longview, Kalama, and Vancouver, some discharges were not fully treated
(Figure 11). It is not clear for all arrivals whether the discharged ballast was exchanged or managed in another manner.

Figure 10. Regulated arrivals from Stockton area, California to Washington ports.

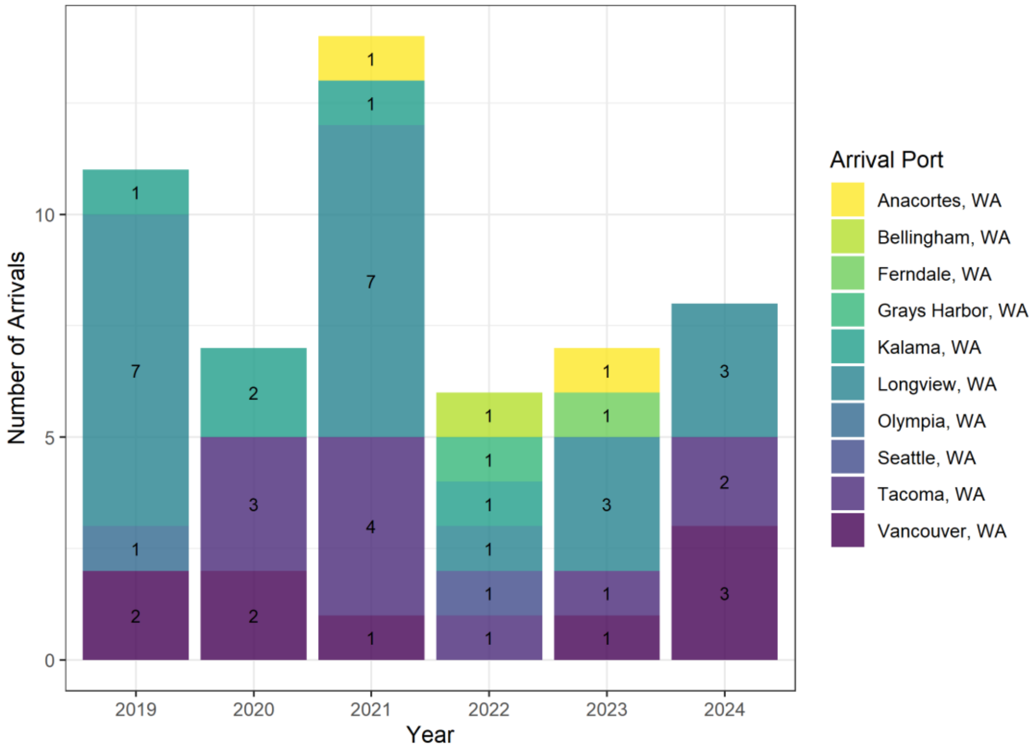
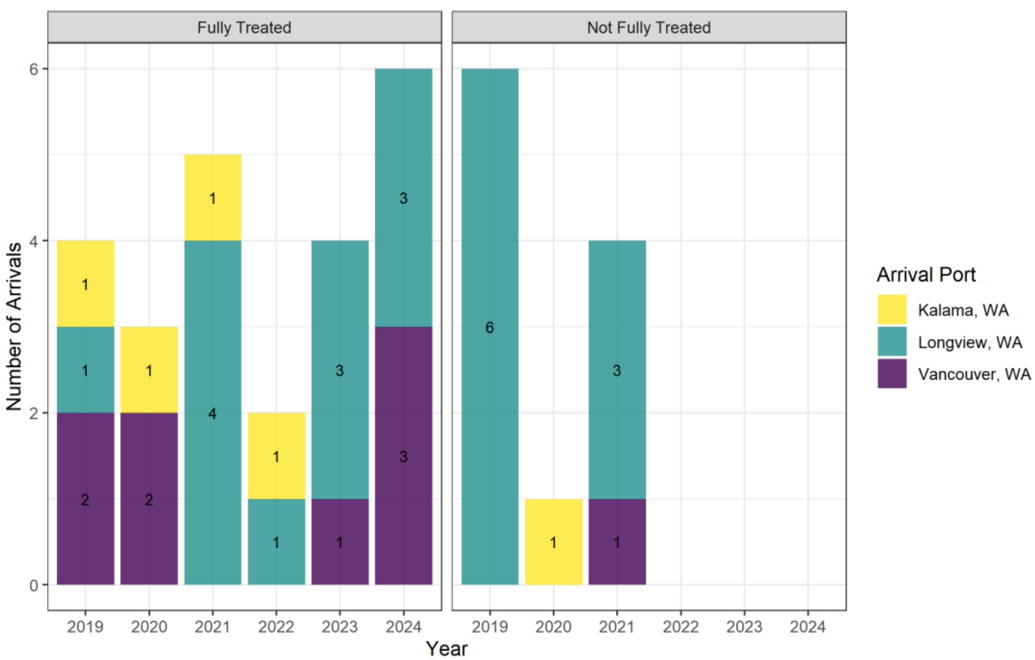


Figure 11. Regulated arrivals that discharged ballast taken at ports in the Stockton, CA area to Washington ports on the Columbia River.



Discharge events managed entirely with a ballast water treatment system are shown on the left, while discharging arrivals that did not fully treat ballast are on the right.

Additional Water Temperature Suitability Information

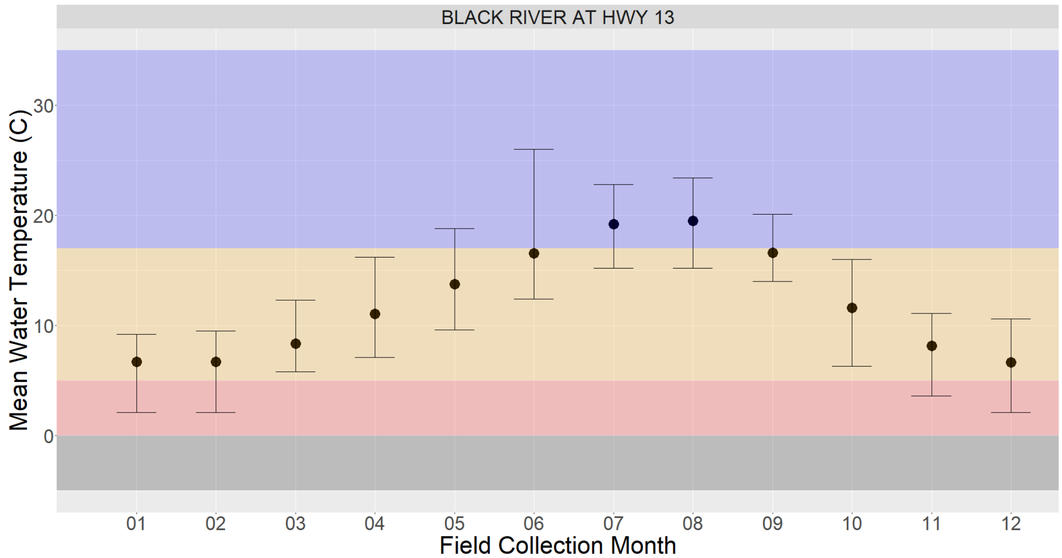
Table 4. Water temperature assessment location information.

Location Name	Years of Data	Latitude	Longitude	Suitability Criteria Met
Black River at Hwy 13	2019-2022	46.83034	-123.186	All
Chehalis River above Pe Ell	2019-2022	46.5464	-123.301	All
Chehalis River at Centralia	2019-2022	46.71179	-122.979	All
Chehalis River at Dryad	2001-2015, 2017-2018	46.6311	-123.251	All
Chehalis River at Porter	2001-2018	46.93918	-123.314	All
East Fork Lewis River near Dollar Corner	2001-2009, 2014-2018	45.8142	-122.592	All
Germany Creek at mouth	2019-2022	46.19611	-123.127	All
Humptulips River near Humptulips	2001-2009, 2011-2018	47.22981	-123.962	All
Naselle River near Naselle	2001-2004, 2012-2018	46.37288	-123.747	All
Newaukum River near Chehalis	2019-2022	46.6198	-122.945	All
Sammanish River at Bothell	2014-2015	47.75888	-122.203	All
Abernathy Creek near mouth	2019-2022	46.20581	-123.154	Survival
Cedar River near Landsburg	2002-2011, 2019-2022	47.39105	-121.921	Survival
Cowlitz River at Kelso	2001-2009, 2011-2018	46.14539	-122.914	Survival
Deep Creek near mouth	2019-2022	48.17253	-124.027	Survival
Deschutes River at East St Bridge	2001-2018	47.0117	-122.904	Survival
East Twin River near mouth	2019-2022	48.15049	-123.937	Survival
Hoh River at DNR Campground	2001-2003, 2005-2018	47.80675	-124.251	Survival
Kalama River near Kalama	2001-2003, 2004-2018	46.04732	-122.838	Survival
Little Spokane River near mouth	2002-2005, 2007, 2009-2010, 2012-2018	47.78323	-117.53	Survival
Mill Creek near mouth	2019-2022	46.19065	-123.178	Survival
Nisqually River at Nisqually	2001-2008, 2010-2018	47.06176	-122.696	Survival
West Twin River mouth	2019-2021	48.16289	-123.953	Survival
Crab Creek near Beverly	2001-2007, 2009, 2012, 2014-2018	46.82992	-119.831	Reproduction
Kettle River near Barstow	2002, 2005-2006, 2016-2017	48.78463	-118.125	Reproduction

Location Name	Years of Data	Latitude	Longitude	Suitability Criteria Met
Naches River at Yakima on US Hwy 98	2015-2018	46.63001	-120.515	Reproduction
Okanogan River at Malott	2005-2006, 2014-2018	48.28126	-119.705	Reproduction
Palouse River at Hooper	2009-2012, 2016-2018	46.75904	-118.148	Reproduction
Palouse River at Palouse (Bridge St)	2002-2012, 2014-2018	46.90911	-117.077	Reproduction
Similkameen River at Oroville	2001, 2003, 2006, 2014-2018	48.93479	-119.442	Reproduction
Stillaguamish River near Silvana	2002-2017	48.19678	-122.21	Reproduction
Tuannon River at Powers	2001-2008, 2010-2017	46.5382	-118.156	Reproduction
Walla Walla River near Touchet	2002-2007, 2014-2018	46.03763	-118.766	Reproduction
Wenatchee River at Wenatchee	2001, 2014-2015, 2017-2018	47.45874	-120.336	Reproduction
Wenatchee River near Leavenworth	2001, 2004-2006, 2014-2018	47.67637	-120.734	Reproduction
Yakima River at Kiona	2015-2018	46.25347	-119.478	Reproduction
Duckabush River near Brinnon	2001-2018	47.68398	-123.012	None
Green River at Kanaskat	2003-2017	47.31927	-121.894	None
Methow River at Twisp	2002-2008, 2010-2012, 2014-2019	48.35937	-120.115	None
Nooksack River at North Cedarville	2002-2010	48.84167	-122.293	None
North Fork Stillaguamish at Cicero	2001-2008, 2010-2014, 2016-2018	48.26788	-122.013	None
North Fork Stillaguamish near Darrington	2001-2008, 2010-2012, 2014-2018	48.28029	-121.703	None
Samish River near Burlington	2002-2008, 2016-2018	48.54582	-122.338	None
Skagit River near Mount Vernon	2004-2005, 2015-2017	48.44483	-122.335	None
Snoqualmie River at Snoqualmie	2002-2012, 2014-2019	47.5276	-121.812	None
South Palouse River at Pullman	2002-2006, 2009-2012, 2009-2012, 2016-2018	46.73248	-117.181	None

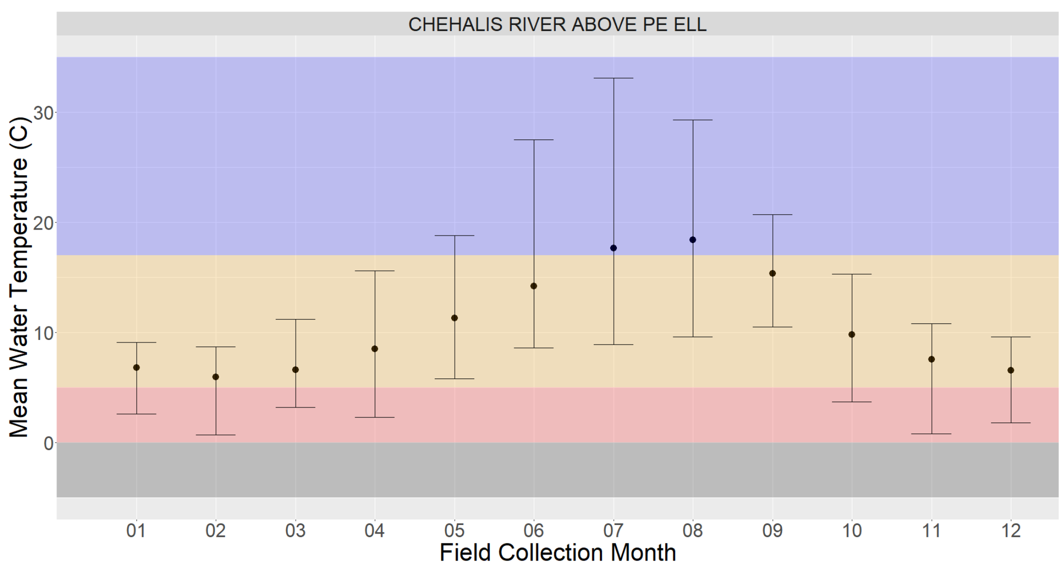
Location Name, Years of Data available for the analysis, Location Latitude and Longitude, what Suitability Criteria for Limnoperna fortunei were met at that location (All, Survival, Reproduction, or None) . A location was considered suitable if the mean water temperature was always >5 °C (survival) and was > 17 °C for at least 2 consecutive months (Reproduction).

Figure 12. Mean (+ maximum /- minimum) monthly water temperatures at Black River at Hwy 13.



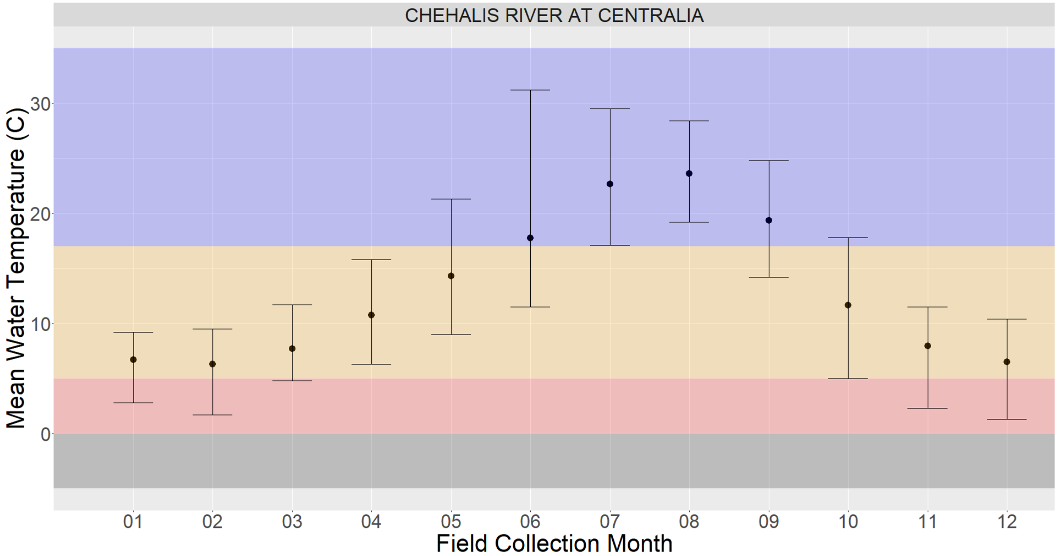
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 13. Mean (+ maximum /- minimum) monthly water temperatures at Chehalis River above Pe Ell.



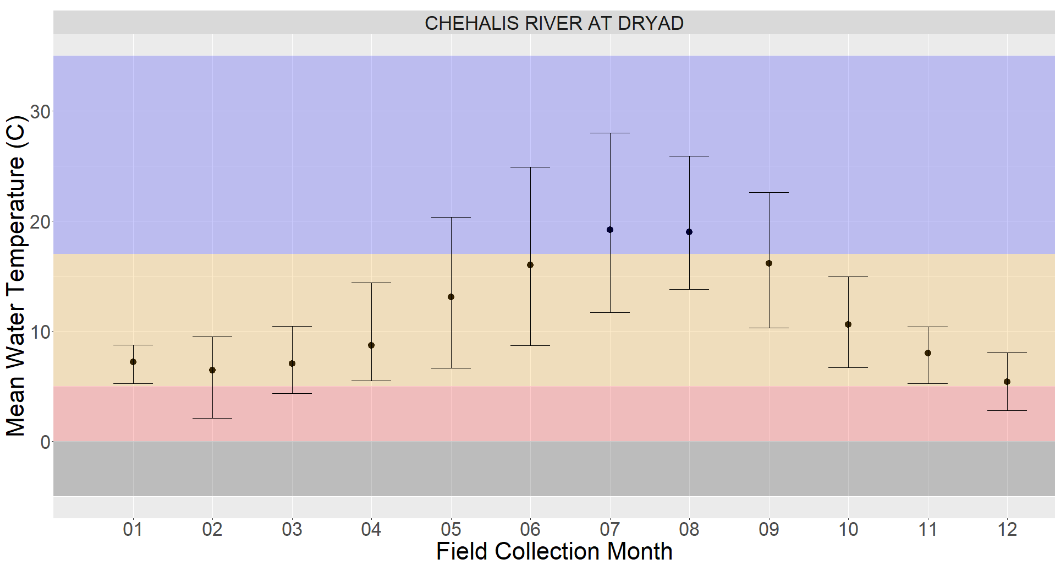
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 14. Mean (+ maximum /- minimum) monthly water temperatures at Chehalis River at Centralia.



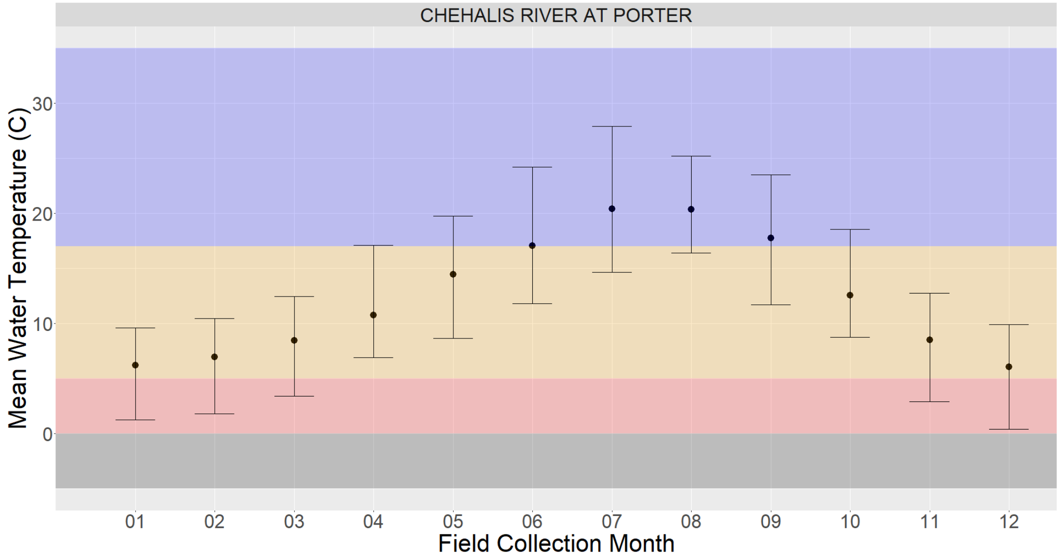
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 15. Mean (+ maximum /- minimum) monthly water temperatures at Chehalis River above Pe Ell.



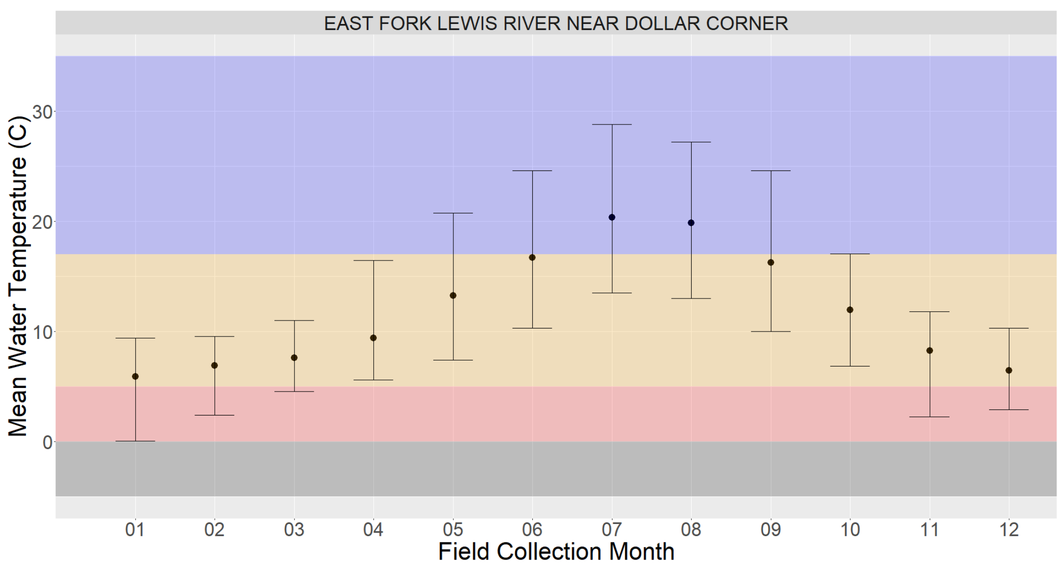
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 16. Mean (+ maximum /- minimum) monthly water temperatures at Chehalis River at Porter.



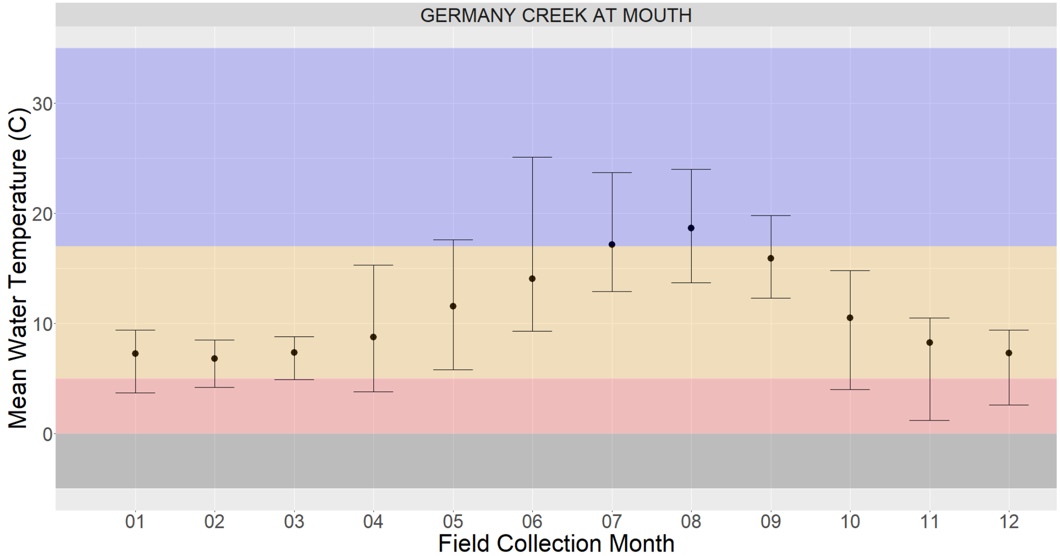
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 17. Mean (+ maximum /- minimum) monthly water temperatures East Fork Lewis River near Dollar Corner.



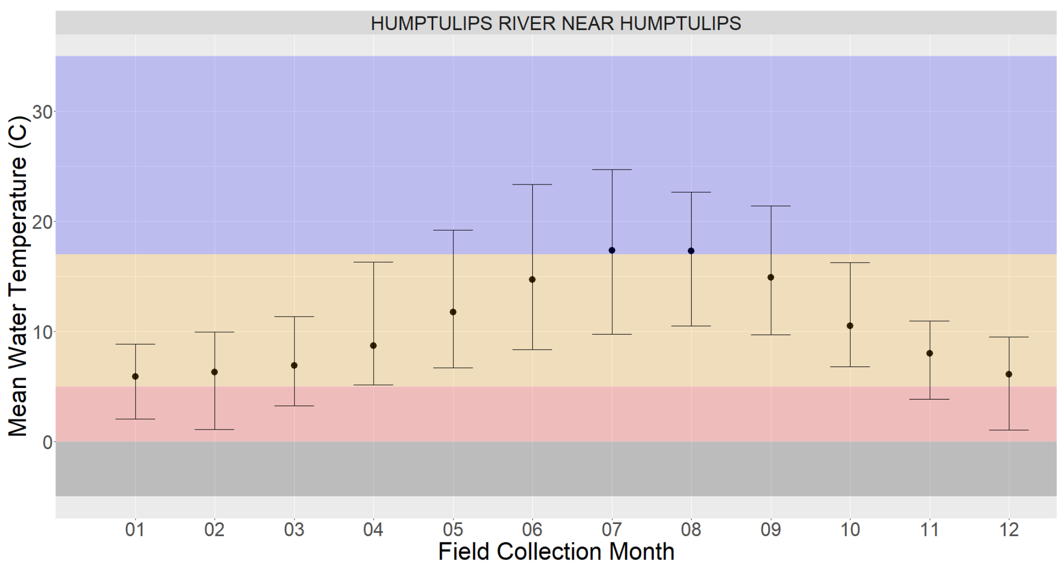
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 18. Mean (+ maximum /- minimum) monthly water temperatures at Germany Creek at mouth.



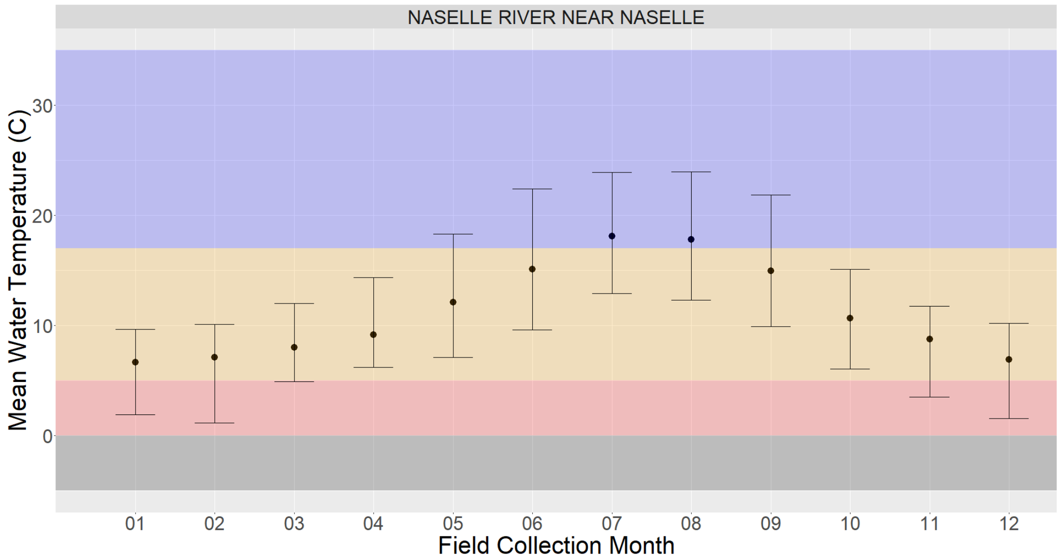
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 19. Mean (+ maximum /- minimum) monthly water temperatures at Humptulips River near Humptulips.



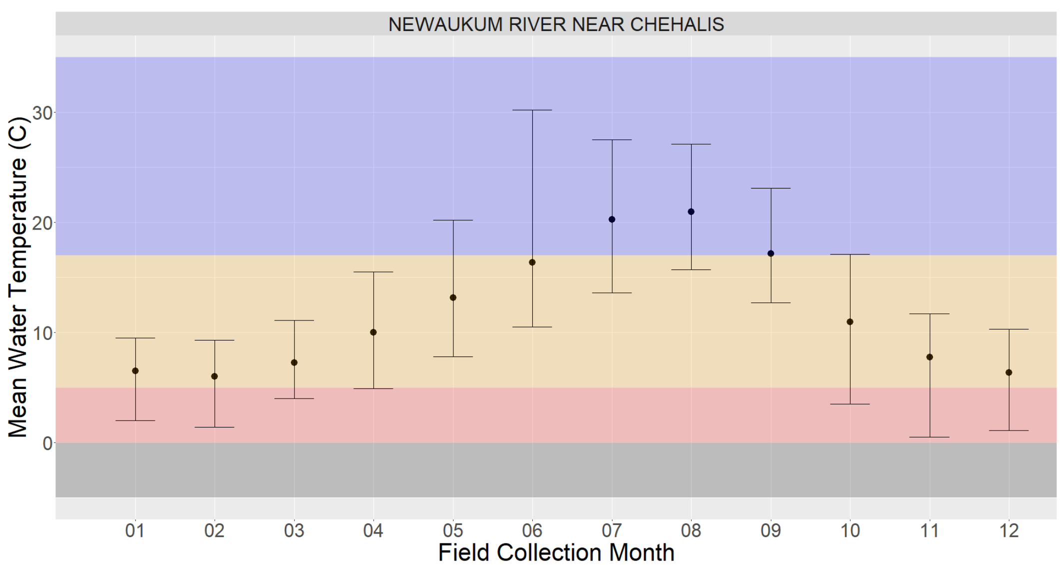
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 20. Mean (+ maximum /- minimum) monthly water temperatures at Naselle River near Naselle.



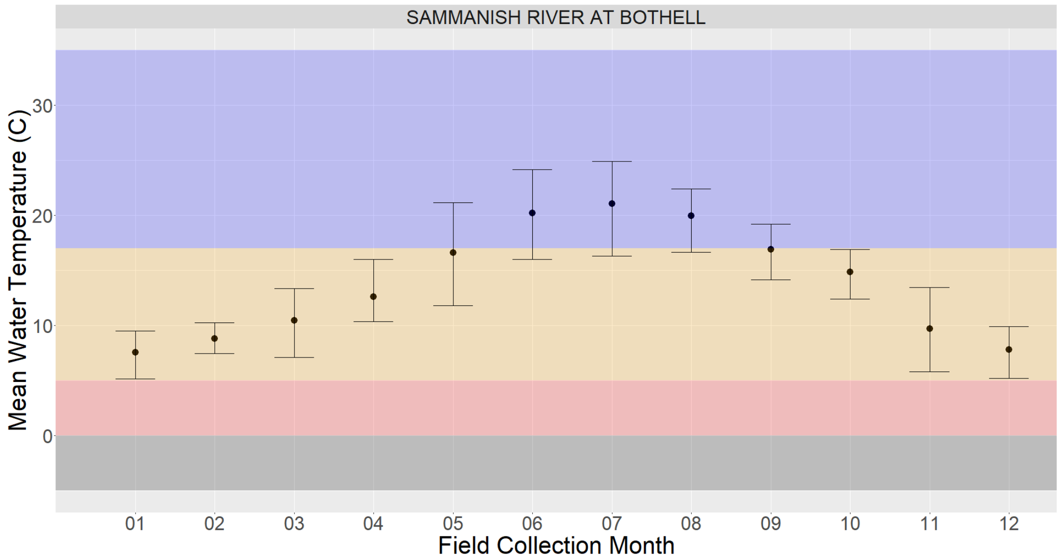
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 21. Mean (+ maximum /- minimum) monthly water temperatures at Newaukum River near Chehalis.



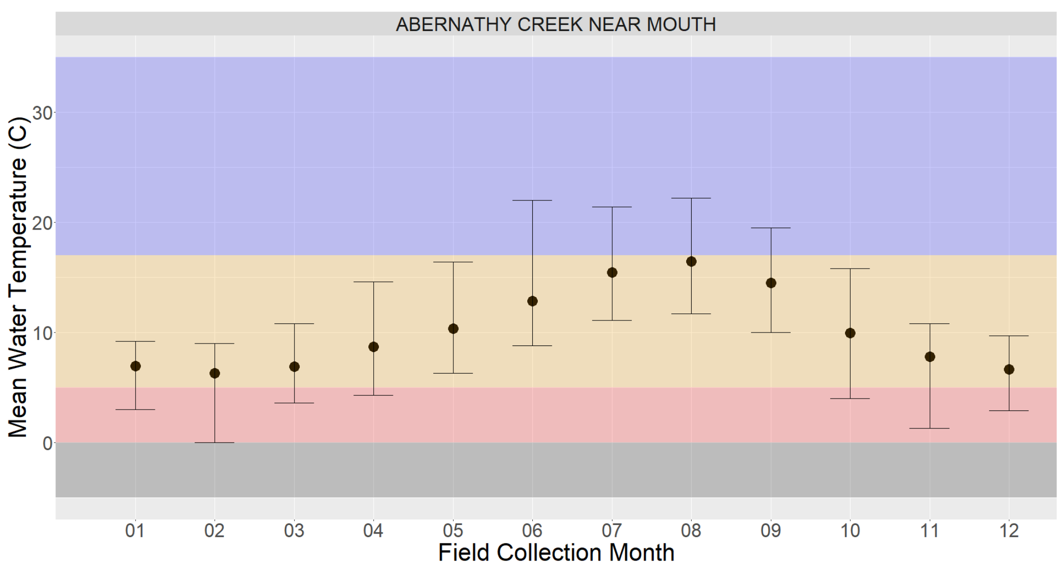
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 22. Mean (+ maximum /- minimum) monthly water temperatures at Sammanish River at Bothell.



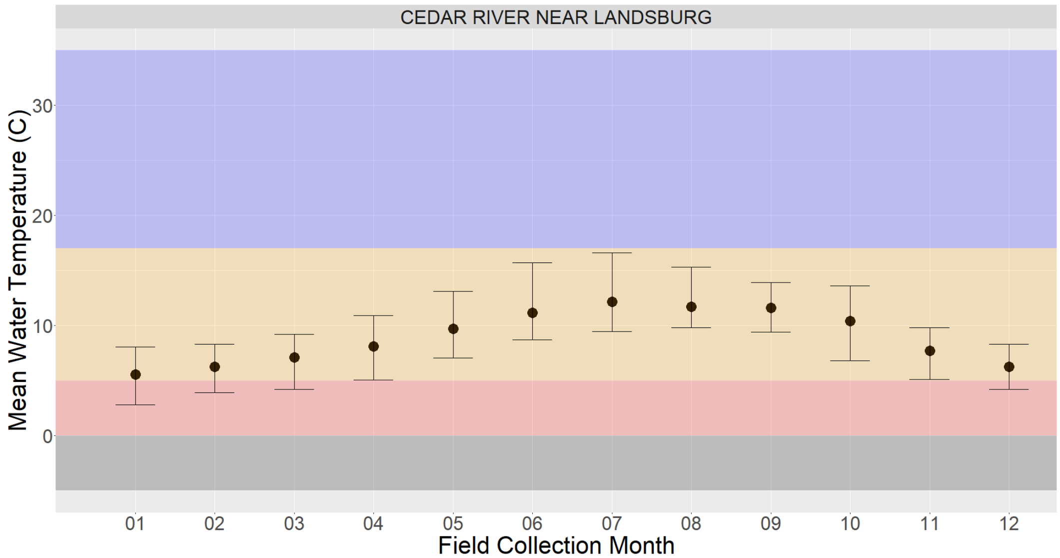
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. Mean monthly water temperatures also > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 23. Mean (+ maximum /- minimum) monthly water temperatures at Abernathy Creek near mouth.



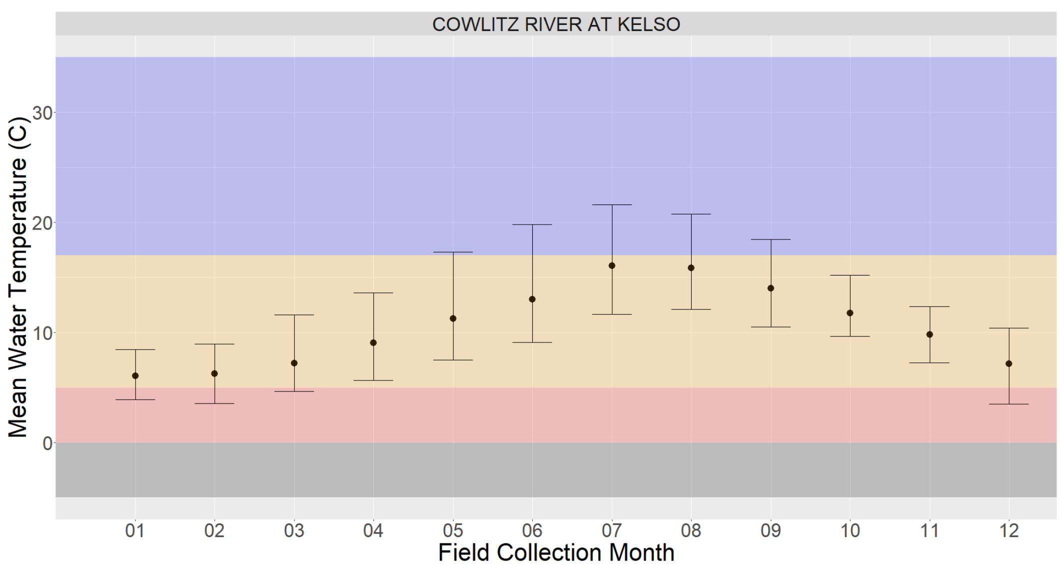
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 24. Mean (+ maximum /- minimum) monthly water temperatures at Cedar River near Landsburg.



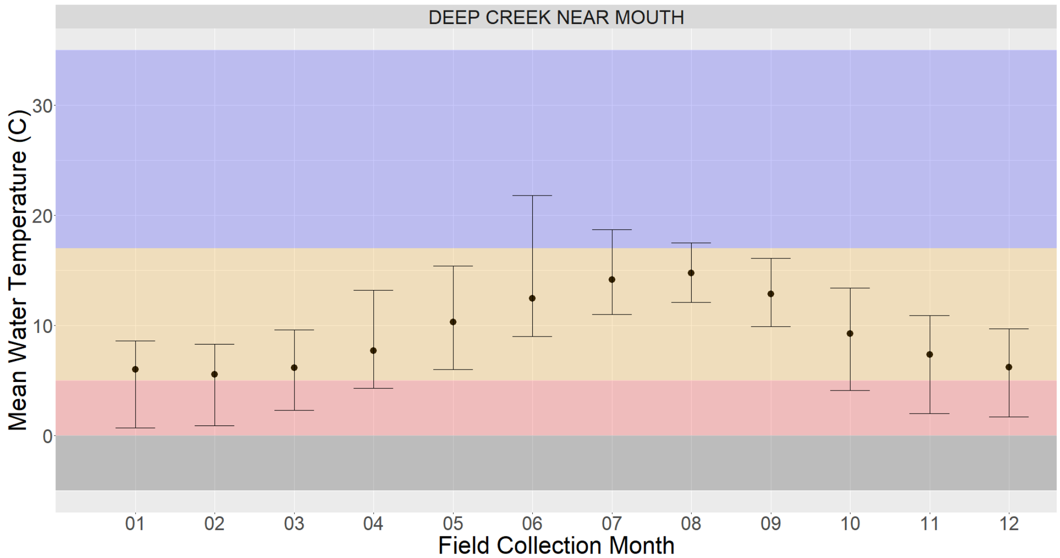
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival, though conditions would remain unsuitable for reproduction.

Figure 25. Mean (+ maximum /- minimum) monthly water temperatures at Cowlitz River at Kelso.



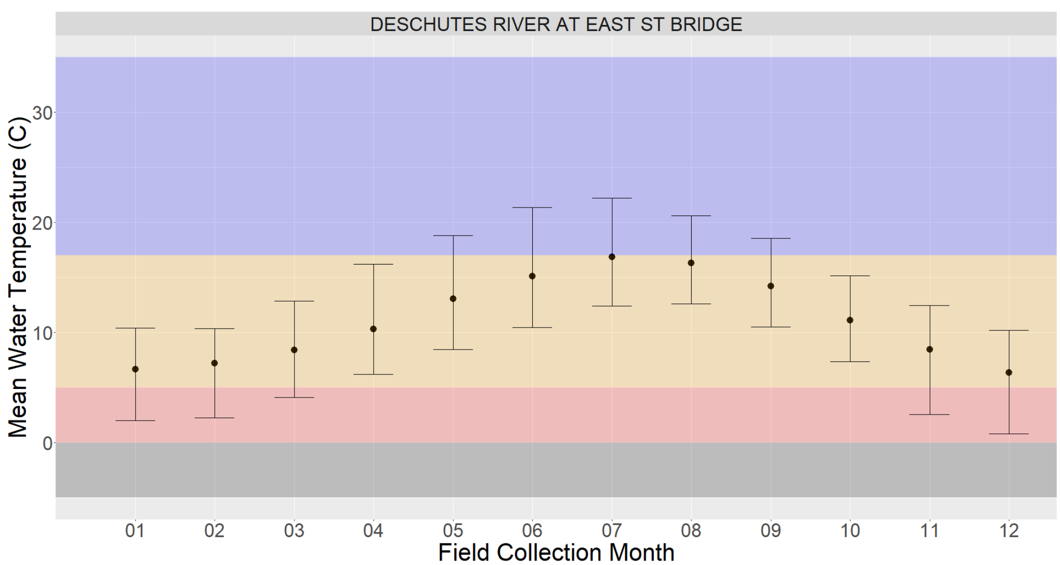
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 26. Mean (+ maximum /- minimum) monthly water temperatures at Deep Creek near mouth.



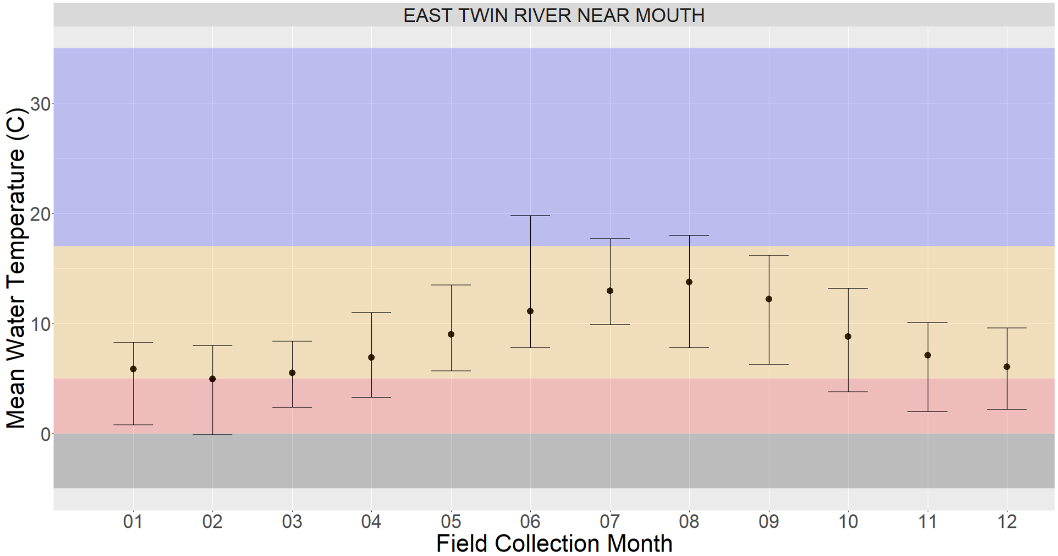
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 27. Mean (+ maximum /- minimum) monthly water temperatures at Deschutes River at East St Bridge.



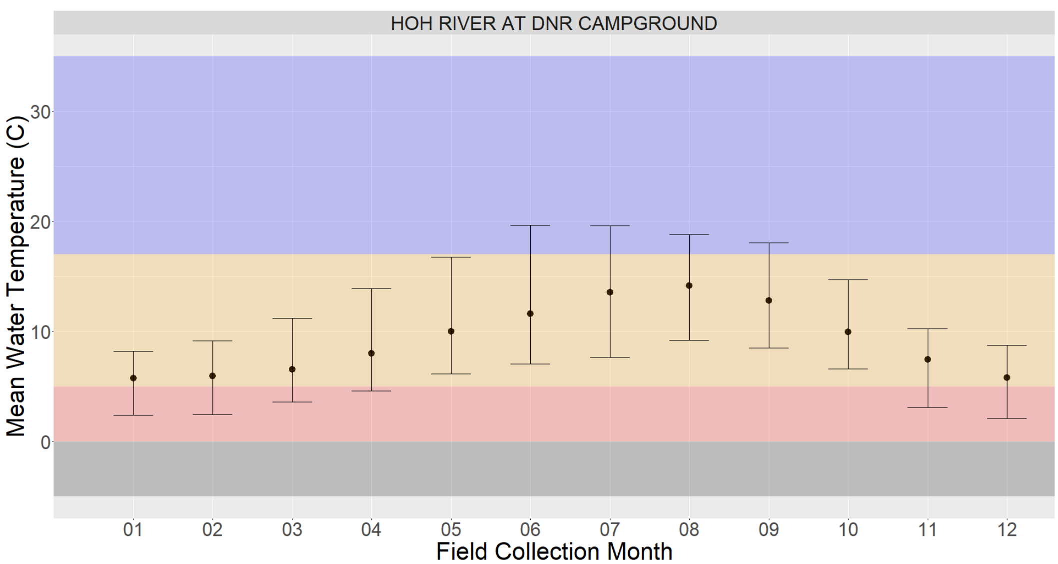
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 28. Mean (+ maximum /- minimum) monthly water temperatures at East Twin River near mouth.



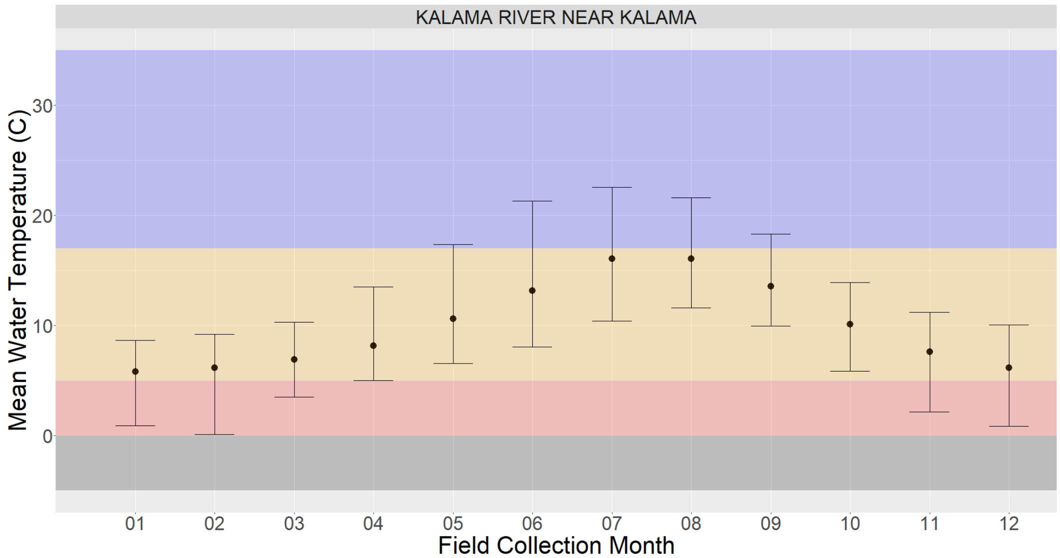
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 29. Mean (+ maximum /- minimum) monthly water temperatures at Hoh River at DNR Campground.



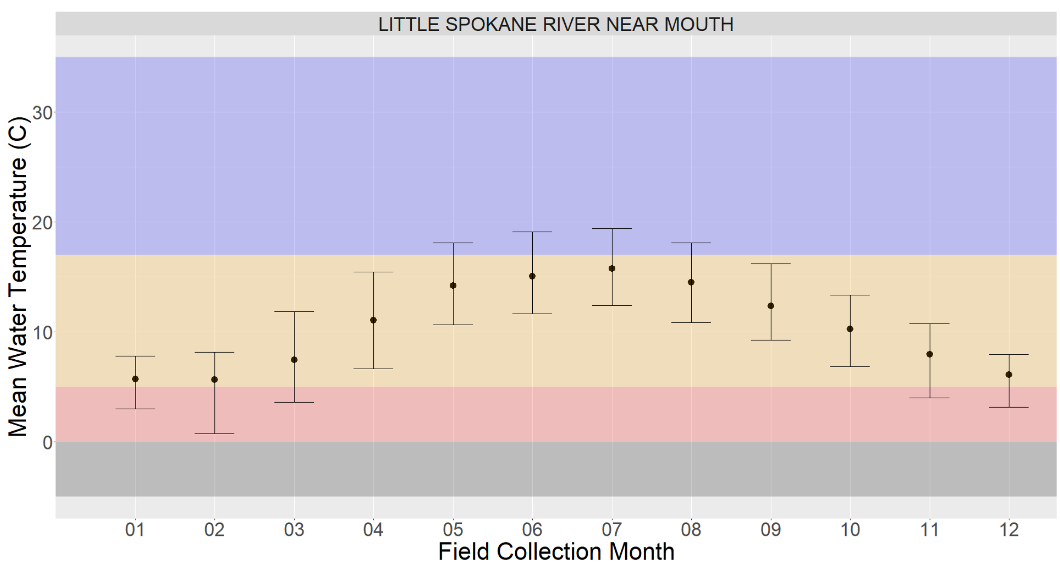
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 30. Mean (+ maximum /- minimum) monthly water temperatures at Kalama River near Kalama.



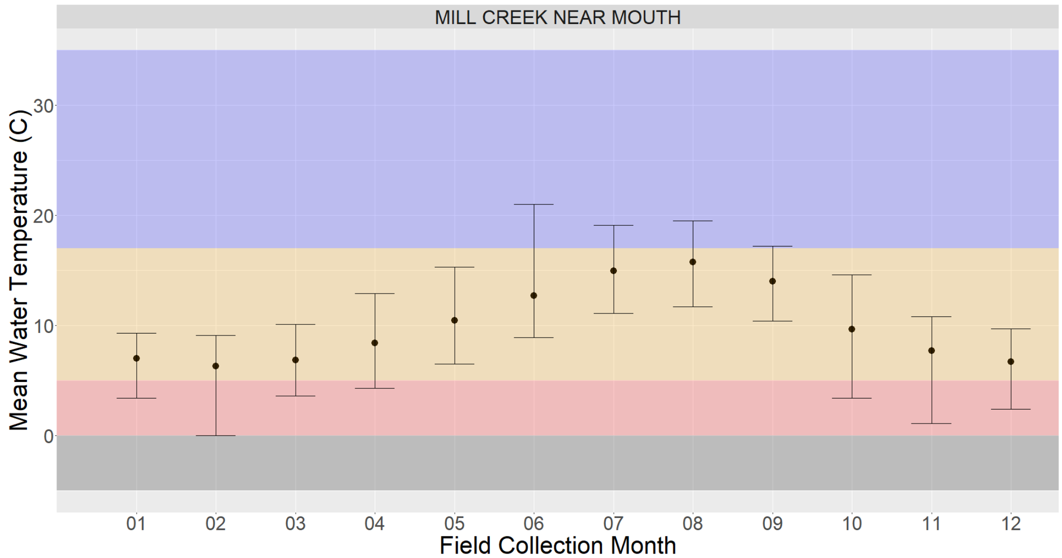
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 31. Mean (+ maximum /- minimum) monthly water temperatures at Little Spokane River near mouth.



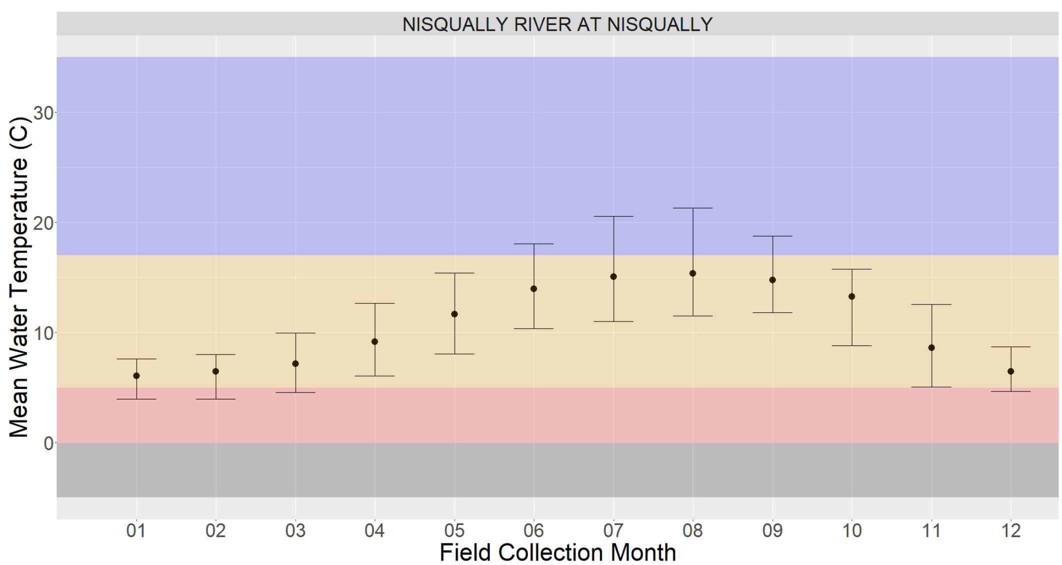
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 32. Mean (+ maximum /- minimum) monthly water temperatures at Mill Creek near mouth.



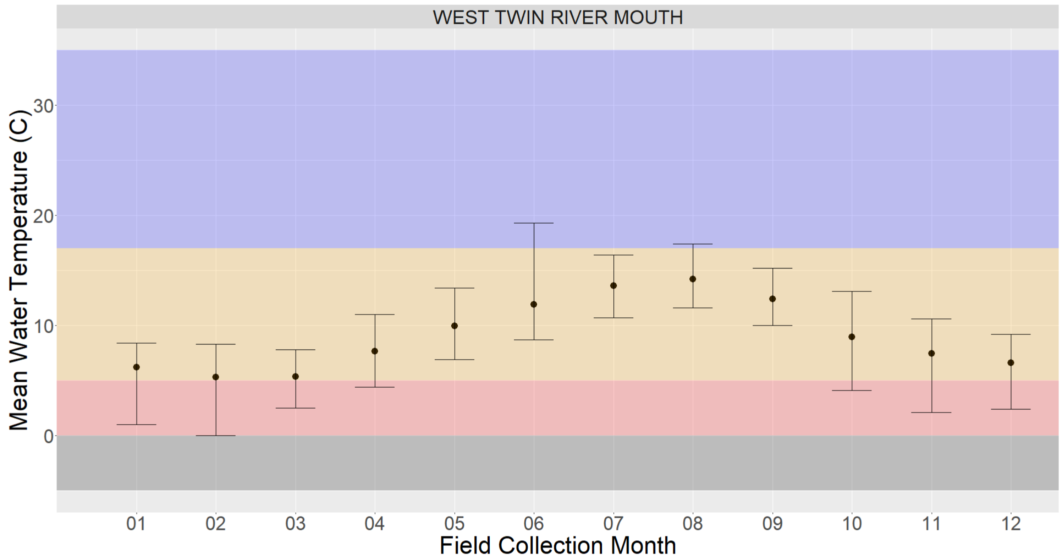
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 33. Mean (+ maximum /- minimum) monthly water temperatures at Nisqually River at Nisqually.



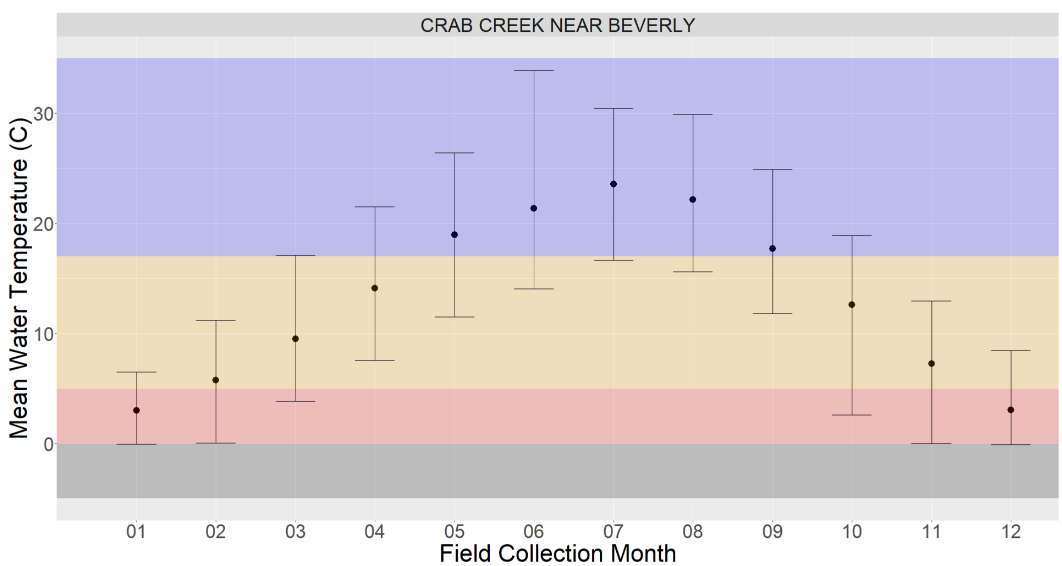
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 34. Mean (+ maximum /- minimum) monthly water temperatures at West Twin River mouth.



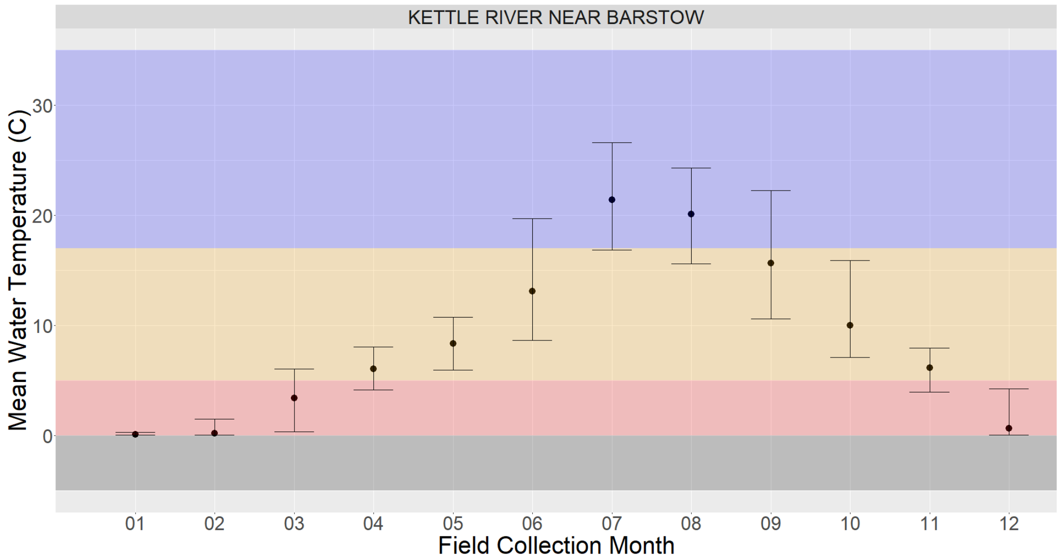
Mean monthly water temperatures at this location are > 5°C; thus, mortality from low temperatures may be minimal for *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* reproduction. Minimum and maximum monthly water temperatures imply that water temperatures may vary between favorable or unfavorable conditions for *L. fortunei.*

Figure 35. Mean (+ maximum /- minimum) monthly water temperatures at Crab Creek near Beverly.



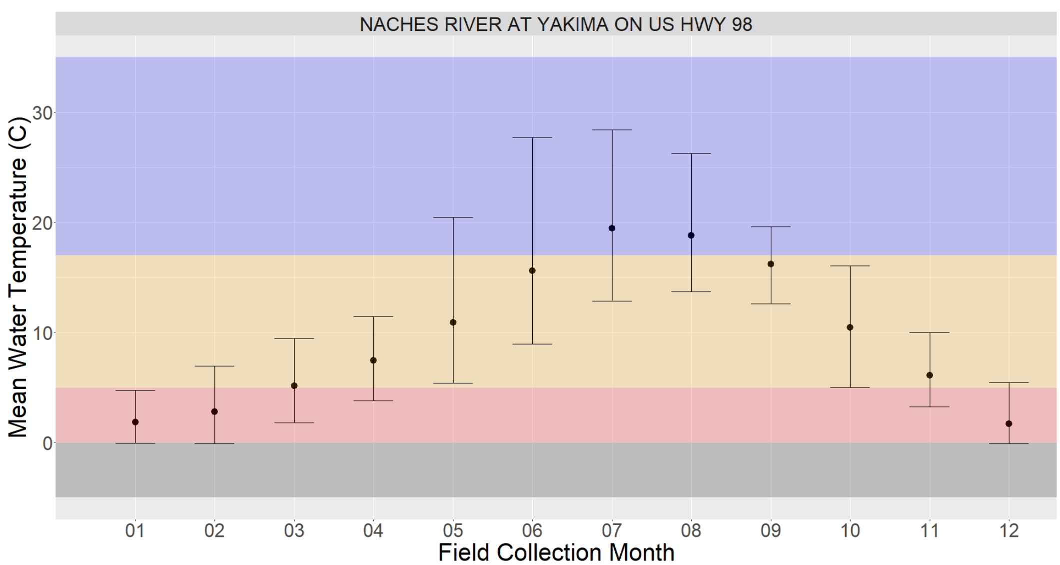
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 36. Mean (+ maximum /- minimum) monthly water temperatures at Kettle River near Barstow.



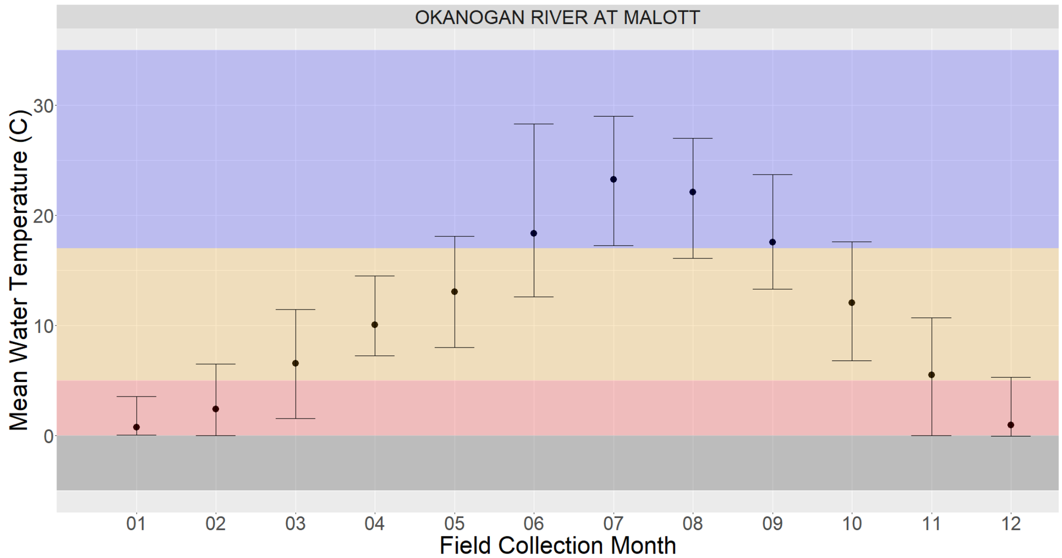
Mean monthly water temperatures at this location are frequently below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 37. Mean (+ maximum /- minimum) monthly water temperatures at Naches River at Yakima US Hwy 98.



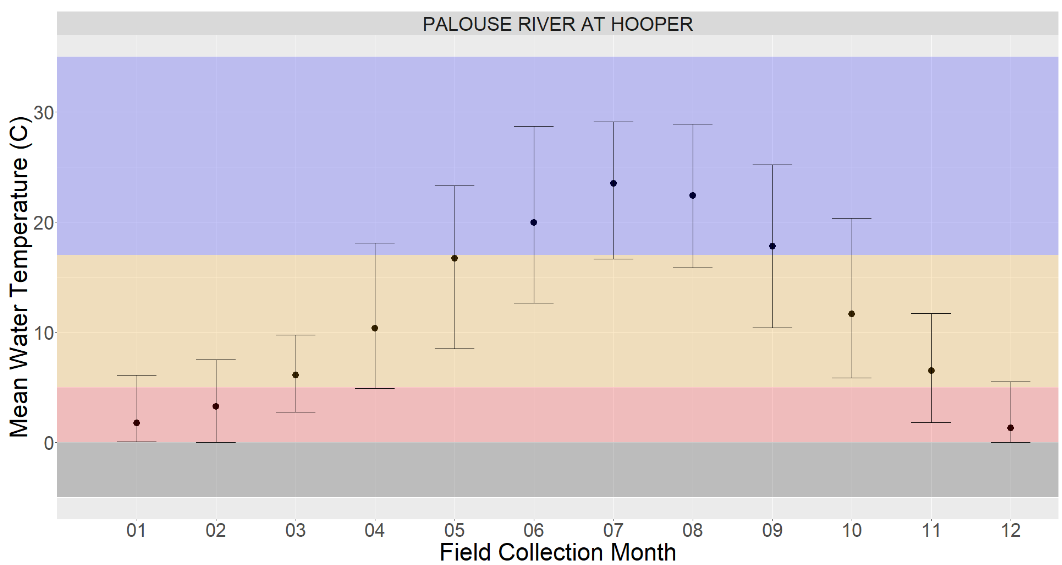
Mean monthly water temperatures at this location are frequently below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 38. Mean (+ maximum /- minimum) monthly water temperatures at Okanogan River at Malott.



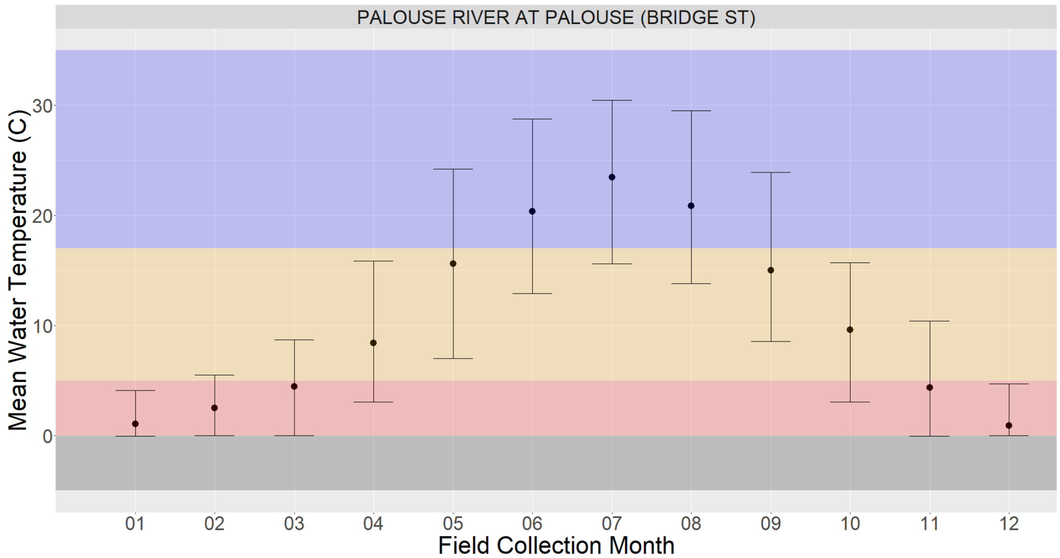
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 39. Mean (+ maximum /- minimum) monthly water temperatures at Palouse River at Hooper.



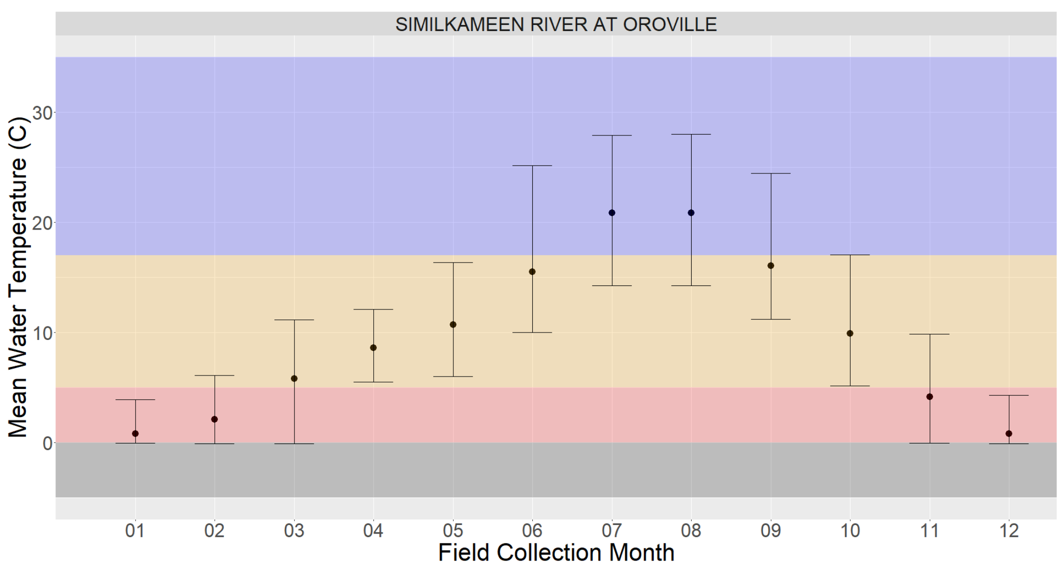
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 40. Mean (+ maximum /- minimum) monthly water temperatures at Palouse River at Palouse (Bridge St.).



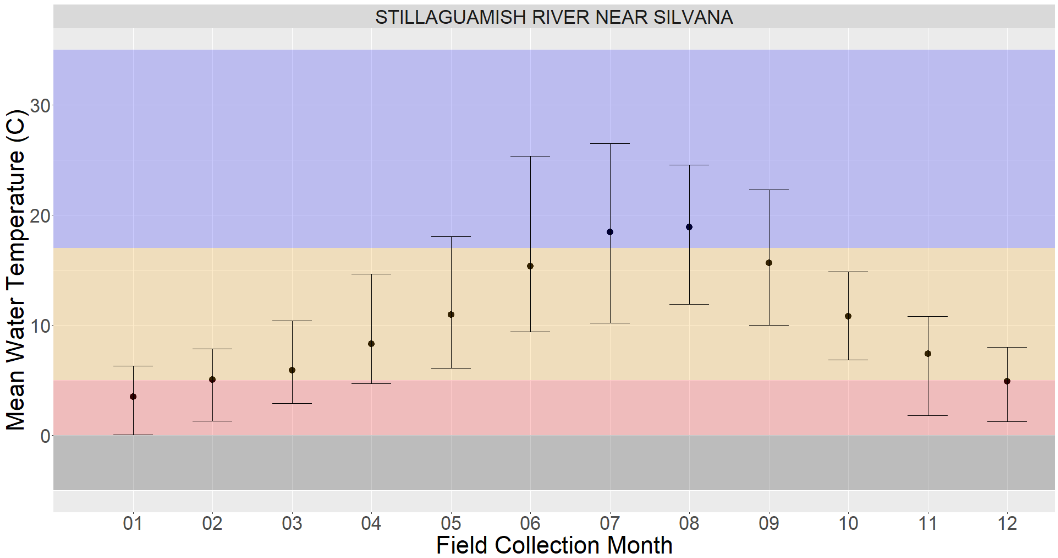
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 41. Mean (+ maximum /- minimum) monthly water temperatures at Similkameen River at Oroville.



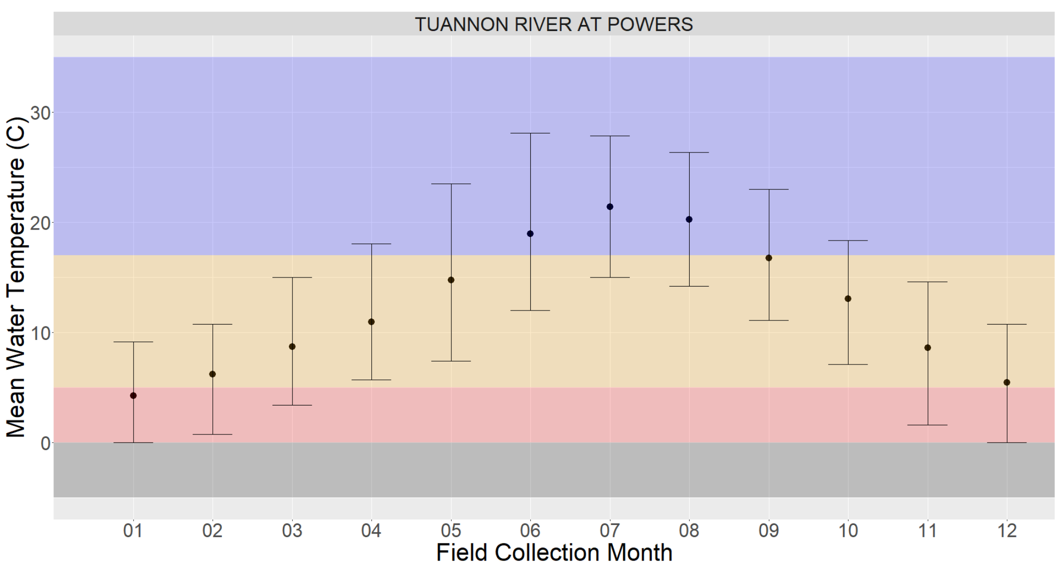
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 42. Mean (+ maximum /- minimum) monthly water temperatures at Stillaguamish River near Silvana.



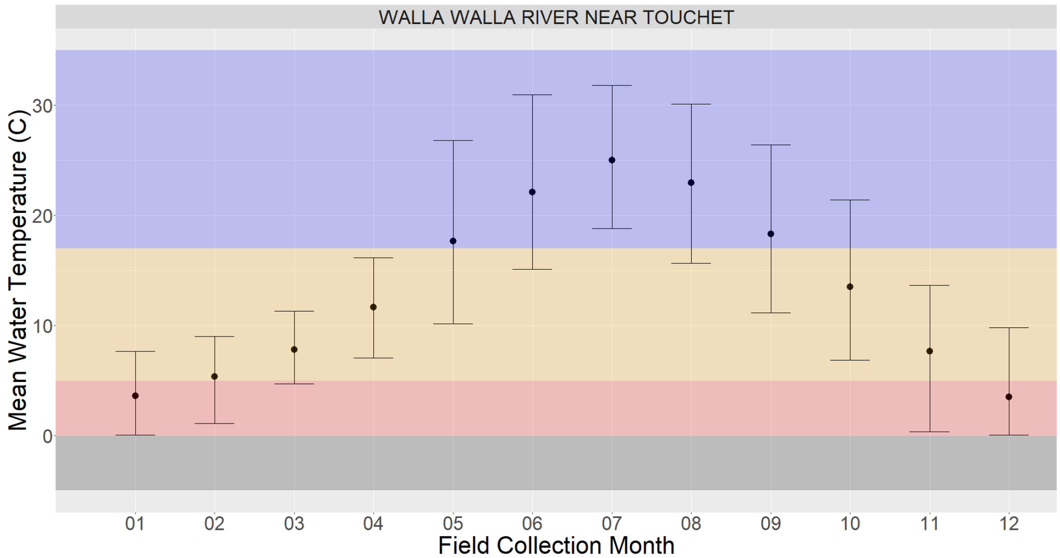
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 43. Mean (+ maximum /- minimum) monthly water temperatures at Tuannon River at Powers.



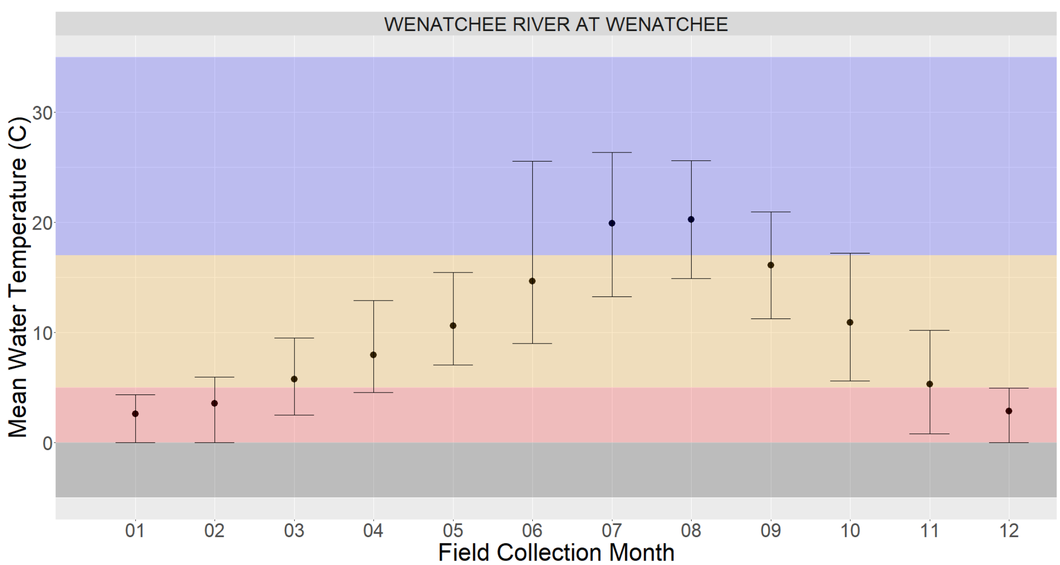
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 44. Mean (+ maximum /- minimum) monthly water temperatures at Walla Walla River near Touchet.



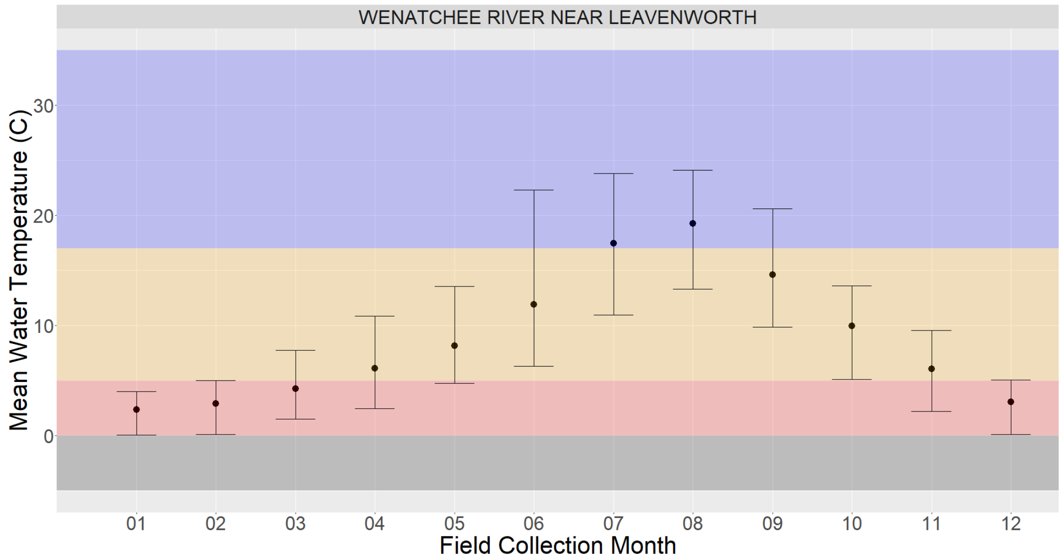
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 45. Mean (+ maximum /- minimum) monthly water temperatures at Wenatchee River at Wenatchee.



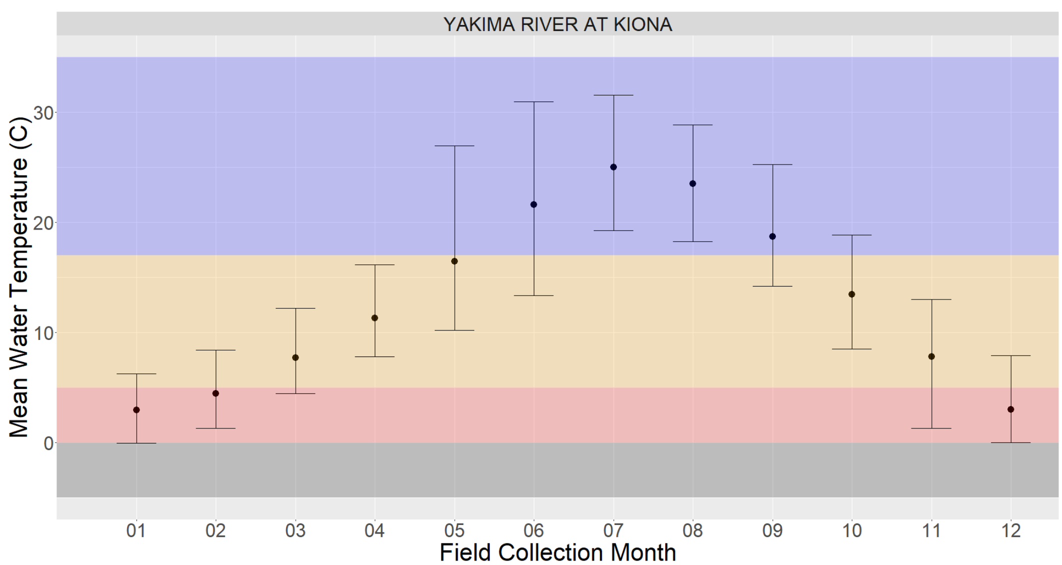
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 46. Mean (+ maximum /- minimum) monthly water temperatures at Wenatchee River near Leavenworth.



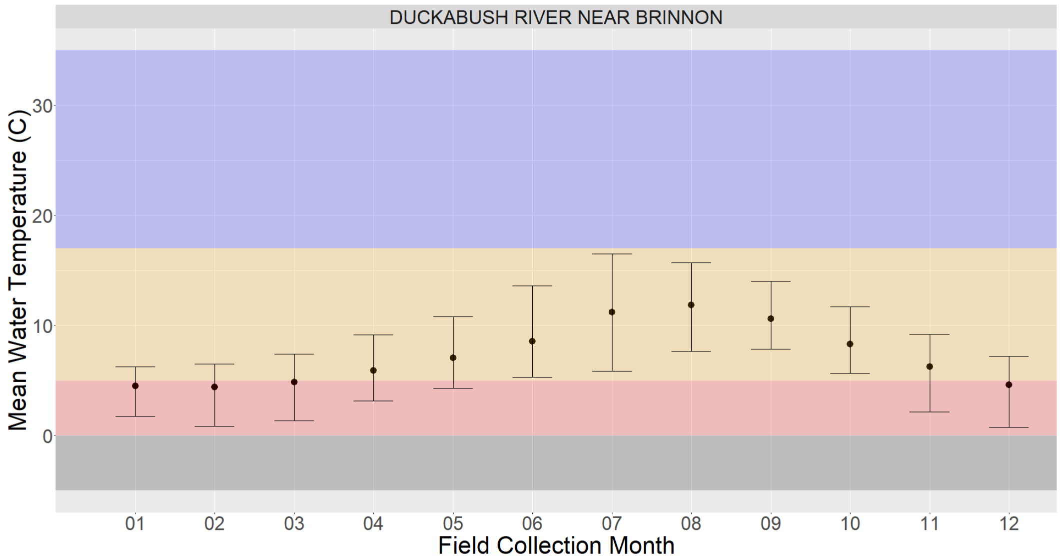
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 47. Mean (+ maximum /- minimum) monthly water temperatures at Yakima River at Kiona.



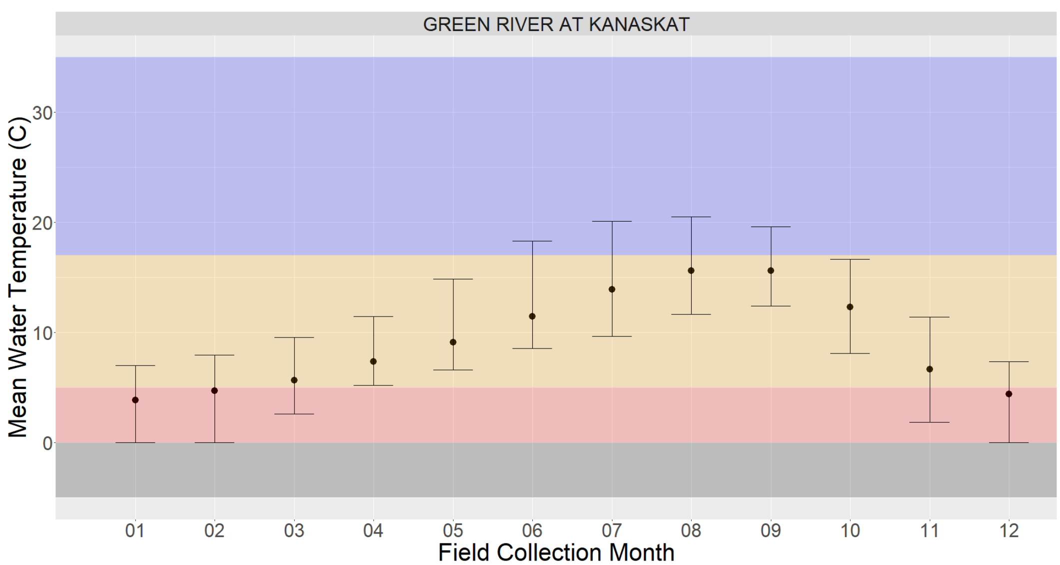
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 48. Mean (+ maximum /- minimum) monthly water temperatures at Duckabush River near Brinnon.



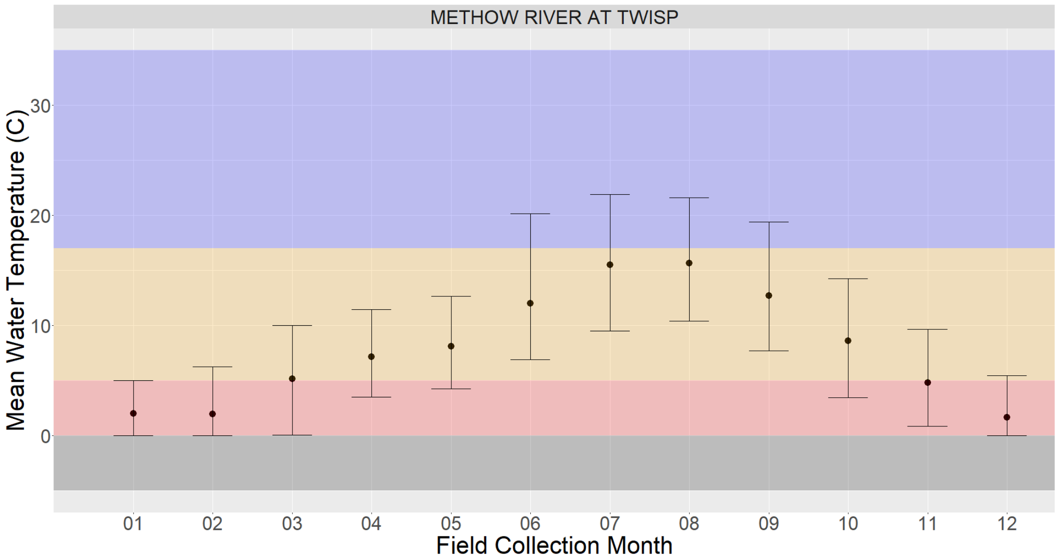
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. In addition, monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival, though conditions would remain unsuitable for reproduction.

Figure 49. Mean (+ maximum /- minimum) monthly water temperatures at Green River at Kanaskat.



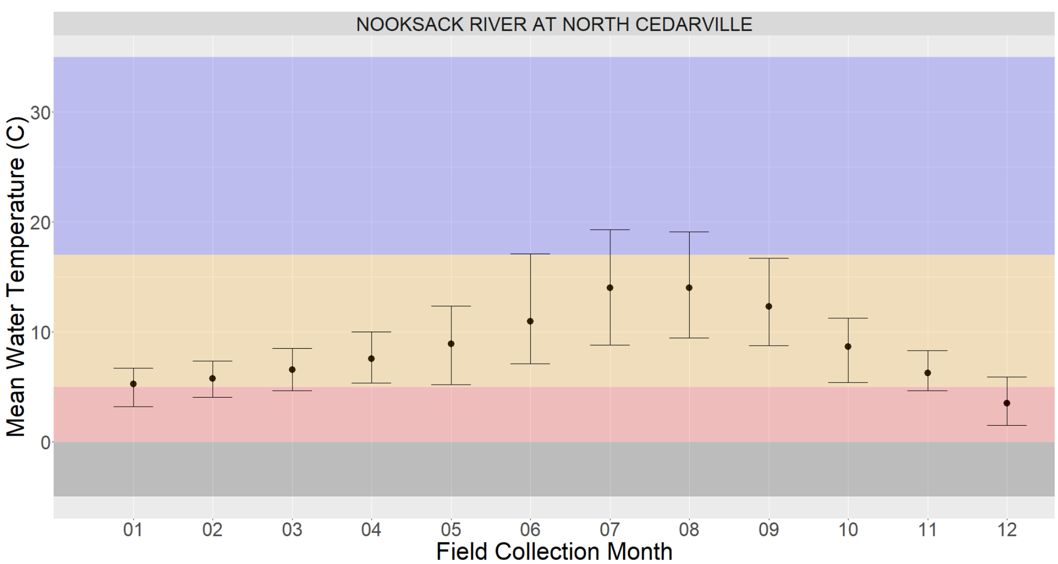
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. However, minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 50. Mean (+ maximum /- minimum) monthly water temperatures at Methow River at Twisp.



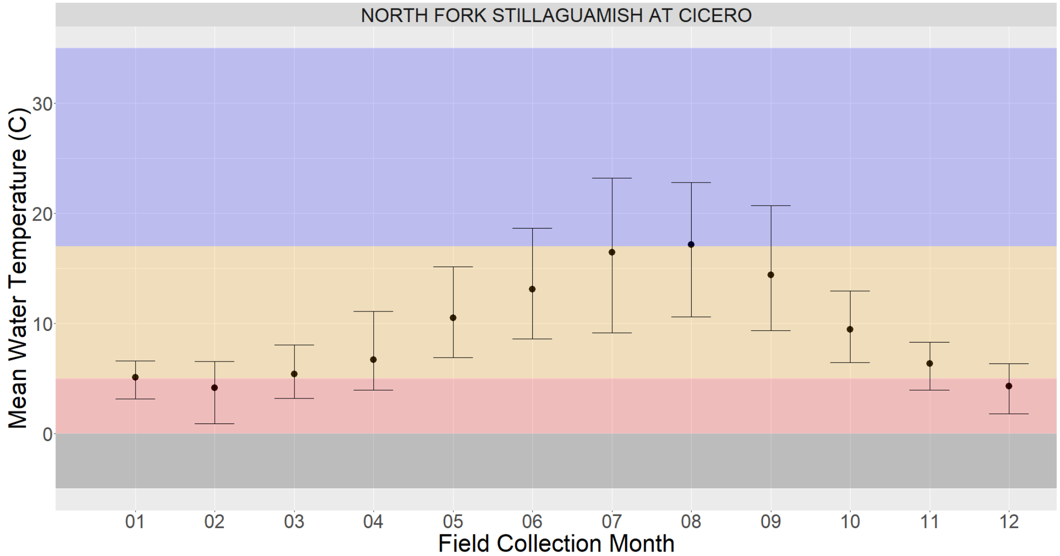
Mean monthly water temperatures at this location are frequently below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 51. Mean (+ maximum /- minimum) monthly water temperatures at Nooksack River at North Cedarville.



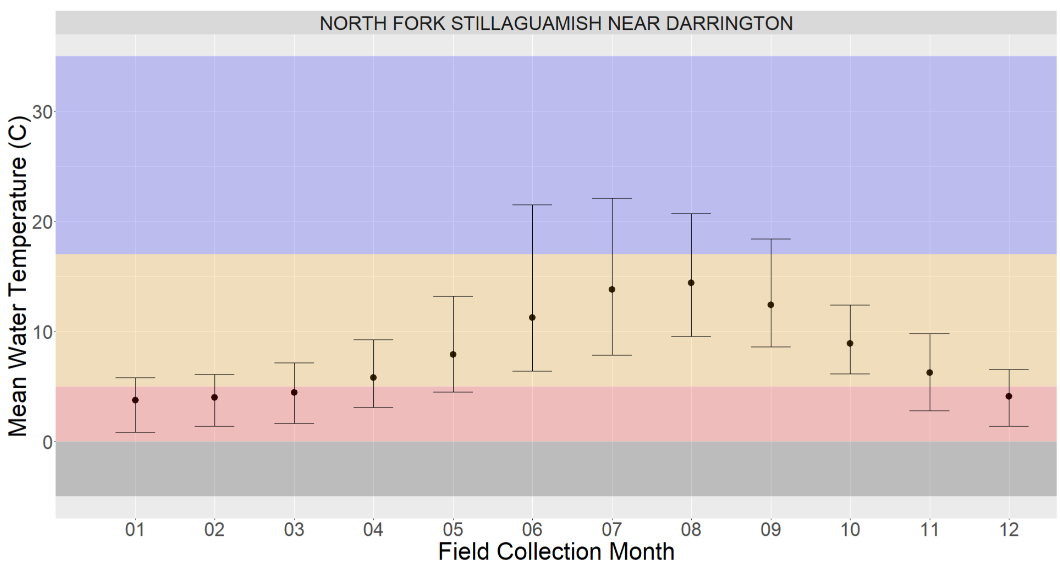
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 52. Mean (+ maximum /- minimum) monthly water temperatures at North Fork Stillaguamish at Cicero.



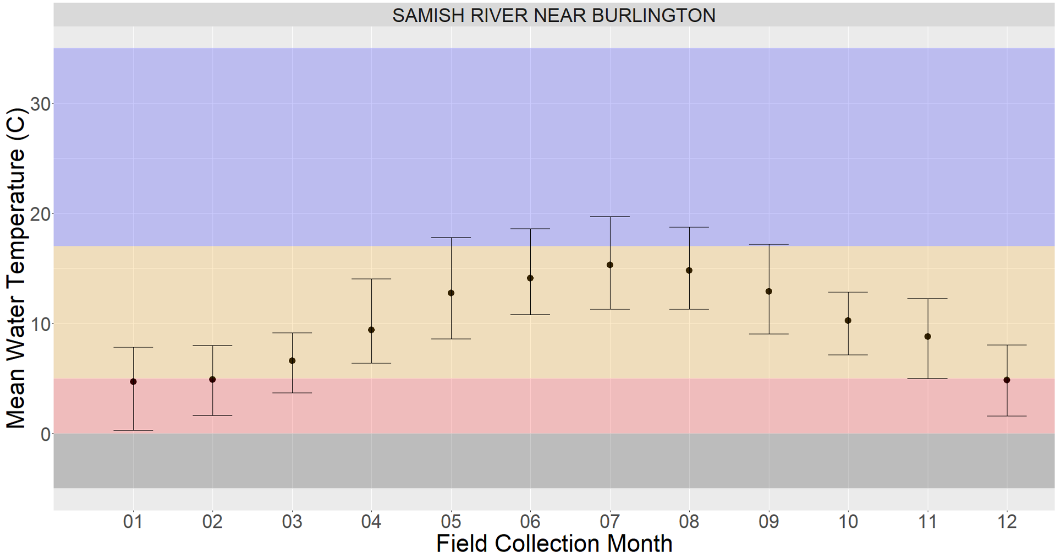
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.

Figure 53. Mean (+ maximum /- minimum) monthly water temperatures at North Fork Stillaguamish near Darrington.



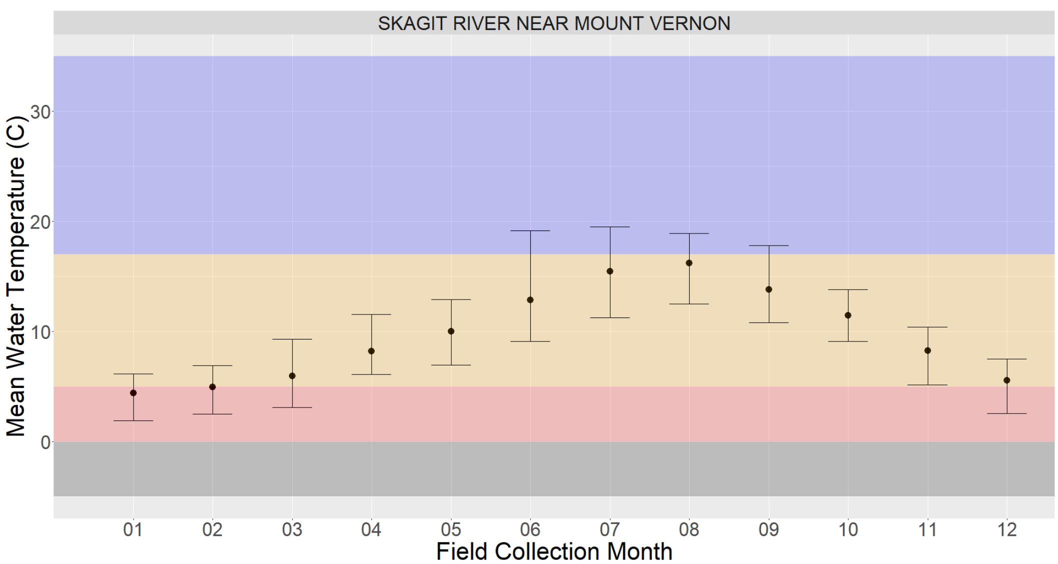
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *L. fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* reproduction. Minimum and maximum monthly water temperatures imply that water temperatures may vary between favorable or unfavorable conditions for *L. fortunei.*

Figure 54. Mean (+ maximum /- minimum) monthly water temperatures at Samish River near Burlington.



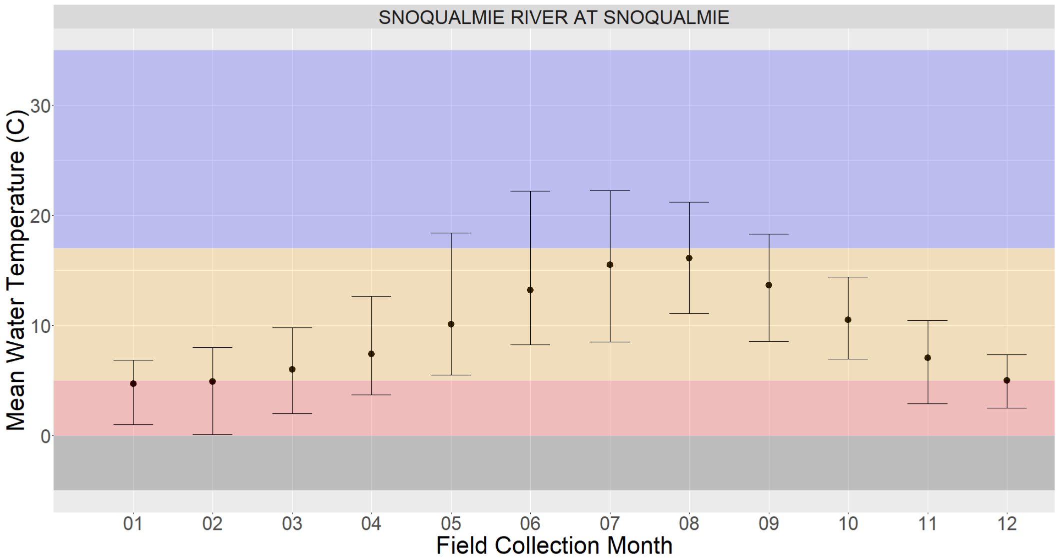
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *L. fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* reproduction. Minimum and maximum monthly water temperatures imply that water temperatures may vary between favorable or unfavorable conditions for *L. fortunei.*

Figure 55. Mean (+ maximum /- minimum) monthly water temperatures at Skagit River near Mount Vernon.



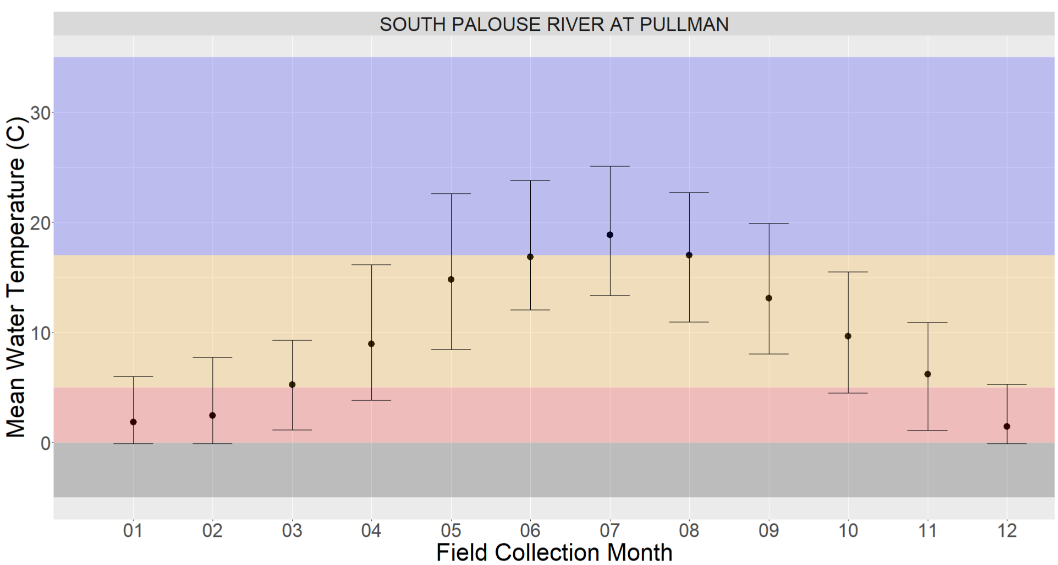
Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *L. fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* reproduction. Minimum and maximum monthly water temperatures imply that water temperatures may vary between favorable or unfavorable conditions for *L. fortunei.*

Figure 56. Mean (+ maximum /- minimum) monthly water temperatures at Snoqualmie River at Snoqualmie.



Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *L. fortunei*. In addition, mean monthly water temperatures are not > 17°C for two months; therefore, conditions appear unsuitable for *L. fortunei* reproduction. Minimum and maximum monthly water temperatures imply that water temperatures may vary between favorable or unfavorable conditions for *L. fortunei.*

Figure 57. Mean (+ maximum /- minimum) monthly water temperatures at South Palouse River at Pullman.



Mean monthly water temperatures at this location drop below 5°C; thus, mortality from low temperatures may impact *Limnoperna fortunei*. However, mean monthly water temperatures > 17°C for two months; therefore, conditions appear suitable for *L. fortunei* to reproduce. Minimum and maximum monthly water temperatures imply that water temperatures may fluctuate between favorable or unfavorable conditions for *L. fortunei* survival and reproduction.