PETITION TO LIST

The Western Ridged Mussel
Gonidea angulata (Lea, 1838)

AS AN ENDANGERED SPECIES
UNDER THE U.S. ENDANGERED SPECIES ACT

Photo credit: Xerces Society/Emilie Blevins

Submitted by

The Xerces Society for Invertebrate Conservation
Prepared by Emilie Blevins, Sarina Jepsen, and Sharon Selvaggio

August 18, 2020

The Honorable David Bernhardt
Secretary, U.S. Department of Interior
1849 C Street, NW Washington, DC 20240

Dear Mr. Bernhardt:

The Xerces Society for Invertebrate Conservation hereby formally petitions to list the western ridged mussel (*Gonidea angulata*) as an endangered species under the Endangered Species Act, 16 U.S.C. § 1531 *et seq.* This petition is filed under 5 U.S.C. 553(e) and 50 CFR 424.14(a), which grants interested parties the right to petition for issue of a rule from the Secretary of the Interior.

Freshwater mussels perform critical functions in U.S. freshwater ecosystems that contribute to clean water, healthy fisheries, aquatic food webs and biodiversity, and functioning ecosystems. The richness of aquatic life promoted and supported by freshwater mussel beds is analogous to coral reefs, with mussels serving as both structure and habitat for other species, providing and concentrating food, cleaning and clearing water, and enhancing riverbed habitat. The western ridged mussel, a native freshwater mussel species in western North America, once ranged from San Diego County in California to southern British Columbia and east to Idaho. In recent years the species has been lost from 43% of its historic range, and the southern terminus of the species' distribution has contracted northward approximately 475 miles. Live western ridged mussels were not detected at 46% of the 87 sites where it historically occurred and that have been recently revisited. Where this species still occurs, it is generally only found in small numbers or is known only from collections or observations of shells. Several populations in rivers where it has recently been known to occur across tens of river miles or in high density and abundance have experienced sudden, enigmatic die-offs that have reduced those populations considerably. The western ridged mussel is threatened by enigmatic die-offs, as well as direct habitat destruction and modification; impacts to water, including water management, water quality, and climate change; the potential for introduction of invasive species, overutilization from recreational harvest; disease; inadequate regulations; population demographic factors; and impacts to genetic diversity. These threats to the species' viability (resiliency, redundancy, and representation) exemplify the species' high risk of extinction. Further, existing regulations are inadequate to protect this species from factors that threaten its continued survival.

We recognize that this petition sets in motion a specific process placing definite response requirements on the U.S. Fish and Wildlife Service (the Service) and very specific time constraints upon those responses. 16 U.S.C. § 1533(b). We will therefore expect a finding by the Service within 90 days regarding whether our petition contains substantial information to warrant a full status review.

Sincerely,

Emilie Blevins   Sarina Jepsen   Sharon Selvaggio

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I. EXECUTIVE SUMMARY

The western ridged mussel (*Gonidea angulata*) is a species of freshwater mussel (Bivalvia: Unionidae) that historically occurred in river basins spanning portions of the western states of California, Idaho, Nevada, Oregon, and Washington, and the Canadian province of British Columbia. This species is the only extant member of its genus and evolutionarily unique with respect to the United States' freshwater mussel fauna (Lopes-Lima et al. 2017). Research indicates that the species has experienced a significant reduction in range from the historic distribution (43%; Blevins et al. 2017a), with the southern extent of the species' range in California having contracted northward approximately 475 miles as compared to the historic range. Live western ridged mussels were not detected at 46% of the 87 sites where it historically occurred and that have been recently revisited.

The western ridged mussels' viability, as measured by redundancy and representation of populations, has been significantly reduced. Further, the resiliency of the species is also greatly compromised; many recent records for the species are limited to observations of empty shells or only a small number of live animals from just a few locations within larger river basins (Xerces/CTUIR 2020). Extant populations in multiple rivers have also recently experienced rapid declines in abundance as a result of enigmatic die-offs, which may be caused by pathogens and other interrelated factors. These die-offs have occurred in spatially disjunct rivers and have resulted in devastating effects on mussel beds, often with thousands of mussels killed outright over the course of a single summer and spanning tens of river miles (Leis et al. 2018). For example, the Confederated Tribes of the Umatilla Indian Reservation monitored one site containing approximately 500 western ridged mussels per square meter in the Middle Fork John Day River between 2005 and 2010 and recorded a precipitous extirpation of the entire mussel bed (Maine et al. 2019).

In addition to the enigmatic die offs that have been recently recorded, the western ridged mussel faces multiple other threats, including direct habitat destruction and modification; impacts to water, including water management, water quality, and climate change; the potential for introduction of invasive species, overutilization from recreational harvest; disease; inadequate regulations; population demographic factors; and impacts to genetic diversity. Several characteristics also contribute to the species' high risk of extinction including its near-total immobility as an adult, reliance on perennial inundation and good water quality, the extended period of growth required prior to reaching sexual maturity (~7 years), and its strict reliance on a few species of host fish to successfully complete reproduction within a narrow temporal window (Blevins et al. 2017a,b). Combined with the level of decline in viability that the western ridged mussel has already undergone, the species faces a high risk of extinction, particularly given that existing regulations are inadequate to protect it from these threats.

As a species group, freshwater mussels are the most imperiled animals in the U.S., yet they are critical to healthy aquatic ecosystems and provide numerous invaluable services that contribute to clean drinking water, healthy fish populations, and biodiverse habitat (Haag and Williams 2014; Vaughn 2017). Freshwater mussels, including the western ridged mussel, are also significant to some tribes in the Pacific Northwest as a traditional cultural resource (CTUIR 2015; Norgaard et al. 2013). This petition presents the best scientific data available, including observations and distribution data from the Western Freshwater Mussel Database (Xerces/CTUIR 2020), which comprises data from more than 250 individuals, more than 100 institutions, and nearly 200 published and unpublished articles and reports. Based on this and other supporting information, this petition demonstrates that the western ridged mussel meets multiple criteria of an Endangered Species under the U.S. Endangered Species Act.

II. CANDIDATE BACKGROUND, STATUS, AND LISTING HISTORY

The western ridged mussel (*Gonidea angulata*) has no legal protection under the U.S. Endangered Species Act or any state endangered species statutes. To our knowledge, the western ridged mussel has never been petitioned for listing under the Endangered Species Act and it has no federal status. Canada lists *Gonidea angulata* as Special Concern, Schedule 1, under the Species At Risk Act, although it is currently proposed for reclassification to Endangered status (SARA 2019). Provincially, it is assessed as Endangered in British Columbia (COSEWIC 2010). NatureServe ranks the species as G3, Vulnerable throughout its range, N2, Imperiled in Canada, and N3, Vulnerable in the United States (NatureServe 2019). The International Union for Conservation of Nature (IUCN) ranks the species as Vulnerable (Blevins et al. 2016). The species is listed as a Species of Greatest Conservation Need in Washington (WDFW 2015), Oregon (ODFW 2016), Idaho (IDFG 2017), and California (CDFW 2015). The USFS lists the species as Sensitive in Oregon and Washington, and the BLM lists it as Sensitive in Oregon, Washington, and Nevada. The species is also categorized as "List 1: Threatened or Endangered" in Oregon (ORBIC 2019), "At-Risk" in Nevada (NNHP 2020), and a "Special Animal" in California (CNDDB 2019).

III. POPULATION STATUS AND DISTRIBUTION

A. Historic Distribution

The western ridged mussel historically occurred in the western U.S. states of Washington, Oregon, Nevada, Idaho, and California, as well as the Canadian province of British Columbia (Figure 1; Xerces/CTUIR 2020). The species was historically reported as far south as San Diego County in California and as far north as the Okanagan basin in the U.S. and into Canada. The species' historic range included coastal basins in California, Oregon, and Washington, east to the Salmon and upper Snake basins in Idaho, with records ranging from near sea level to at least 5,800 ft above sea level.

B. Recent Distribution and Population Status

The recent distribution of the western ridged mussel was assessed by Blevins et al. (2017a) using standardized methods and criteria developed by the IUCN Red List (2012). This analysis indicated a reduction in range of 43% from the historic distribution. Notably, the southern extent of the species' range appears to have contracted more than 475 miles northward from the Santa Margarita River in San Diego County to rivers north of San Francisco Bay, including the Russian River, which now represents the southernmost recent observation of live western ridged mussel in California. In the past few years, multiple surveys of historic western ridged mussel locations have been undertaken and die-offs of western ridged mussel have been observed in at least four river basins, and potentially as many as six rivers, across its range. Of the 318 western ridged mussel sites[1] documented in the Western Freshwater Mussel Database (Xerces/CTUIR/2020), 171 are historic (reported prior to 1990). Of these historic sites, approximately half (87) have been resurveyed for the western ridged mussel. Live western ridged mussels were not detected at 46% of the historic sites that were resurveyed, that is, at 40 out of 87 sites (Figure 2; Xerces/CTUIR 2020).

Since 1990, there has been increased interest in western freshwater mussels among biologists, leading to the formation of the Pacific Northwest Native Freshwater Mussel Workgroup in 2003, the development of a centralized database of mussel occurrence records by the Xerces Society in partnership with the Confederated Tribes of the Umatilla Indian Reservation (Figure 3; Xerces/CTUIR 2020), increased study and publication of original research, trainings and workshops related to freshwater mussel survey, identification, and management techniques, and development of restoration and management guidelines (Blevins et al. 2017b, 2019). This increased interest in freshwater mussels has translated to increased reporting of mussel records since 1990 (Figure 3). Though search effort has increased, only 13% of the more than 6,000 recent (1990-2020) freshwater mussel records in the Western Freshwater Mussel Database (Xerces/CTUIR 2020) are for observations of the western ridged mussel. Additionally, more than half of the recent western ridged mussel records come from just a few locations, and are the result of detailed surveys that have occurred in places like the Klamath River, the Owyhee River, Okanagan Lake and Skaha Lake. In contrast, historic records are more evenly distributed across as many as 86 different waterbodies. Further, when reported, recent observations of abundance at multiple sites indicate very low numbers of individuals (<50 live animals), or are based on observations of only empty shells, which may persist in the environment for years or even decades (depending upon environmental conditions) after the animal has died.[2]

Thus, despite an increase in recent search effort for freshwater mussels (Figure 3) and a targeted resurvey of historic sites, including numerous historic sites in California (Howard et al. 2015), a significant northward range contraction (~475 miles) has been observed. Additionally, the range of the western ridged mussel is the smallest among western North American species of freshwater mussels (which also includes *Margaritifera falcata* and several species of *Anodonta*, with which it frequently co-occurs), comprising just over one-third the average recent range size of those species (Blevins et al. 2017a).

[1] A site is defined as all occurrence records occurring within a 2 km buffer, based on the shorter of two possible separation distances, as recommended in NatureServe (2004) mapping guidance for freshwater mussels.

[2] NatureServe (2004) mapping guidance for freshwater mussel occurrences categorize weathered shells as a "historic" occurrence, and only live or recently dead shells (as described therein) as evidence of current presence. Such information is not available in the Western Freshwater Mussel Database (Xerces/CTUIR 2020) for many reports of shells. However, it is likely that a subset of shell observations treated in this petition as "recent" (based on *observation* of the shell from 1990 to 2020) would be considered "historic" by NatureServe.

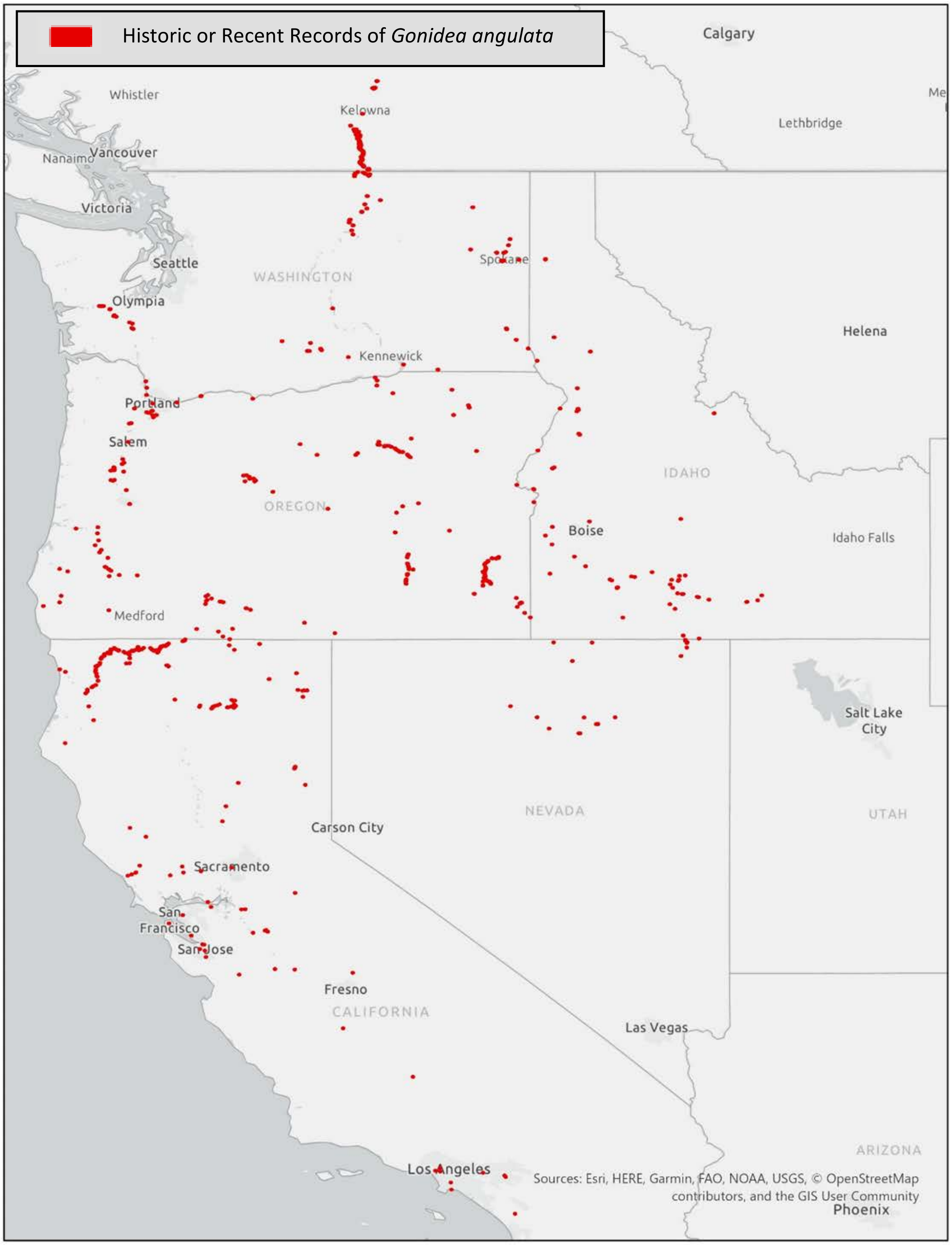

Figure 1. Observations (either shells or live animals) of *Gonidea angulata* from 1838-2020 (Xerces/CTUIR 2020).

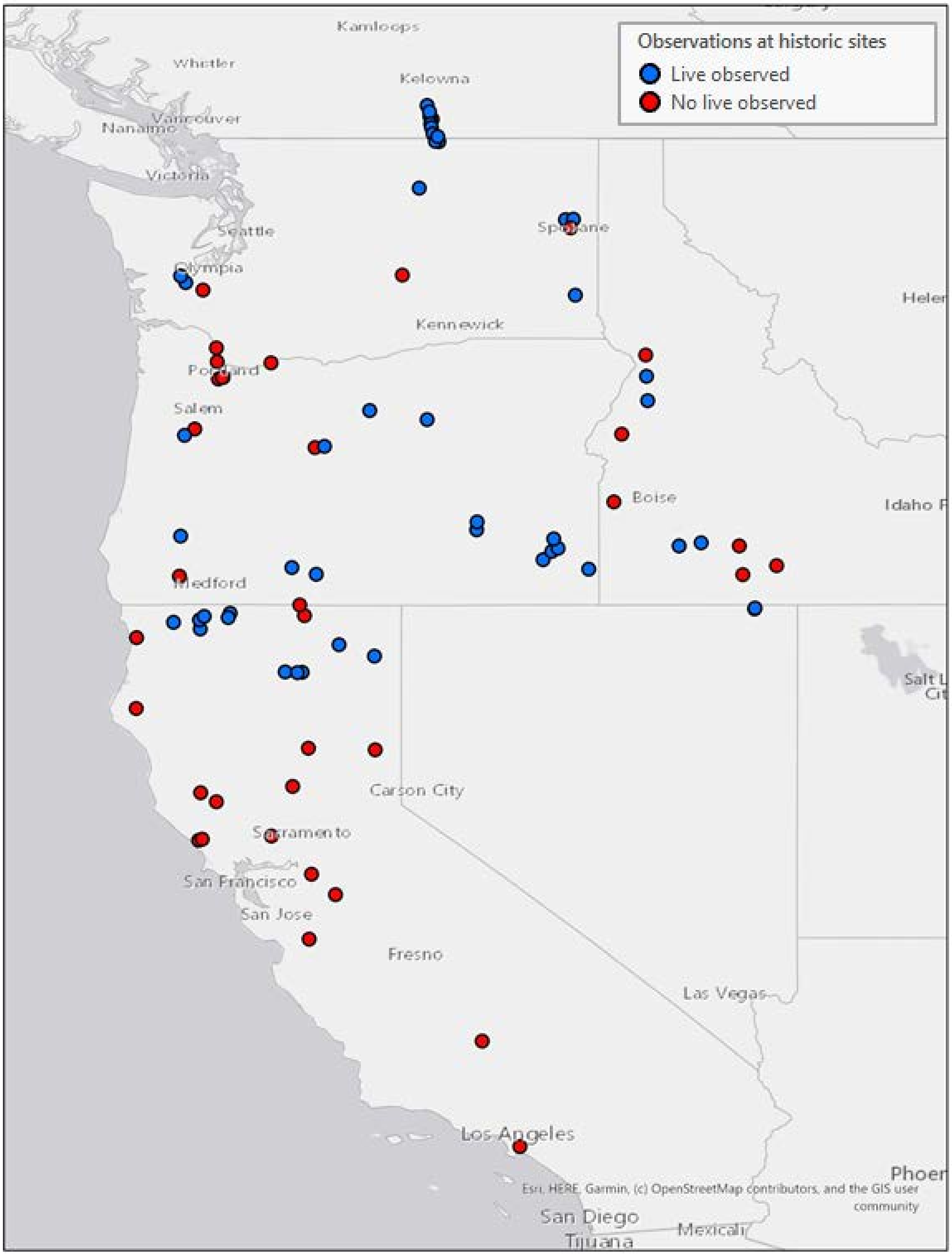

Figure 2. Of the 87 historic western ridged mussel sites that have been resurveyed in recent years (red and blue circles), live western ridged mussels were not detected at nearly half of those sites (40, red circles).

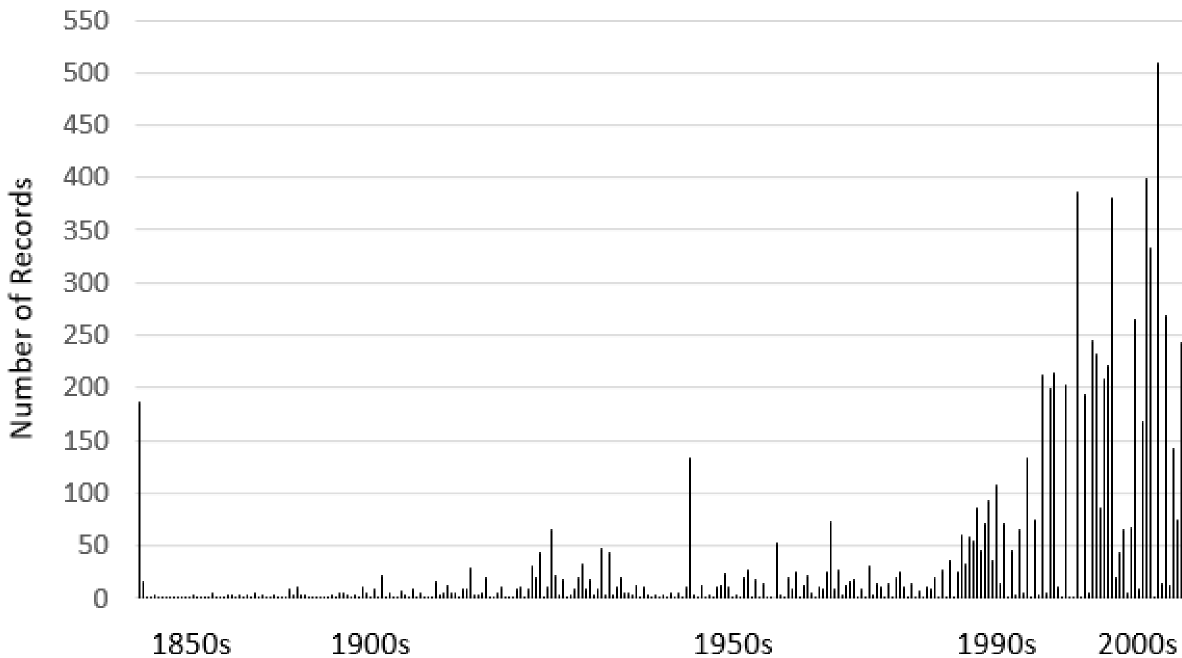

Figure 3. Specimen and observation records of western freshwater mussel species aggregated from museum collections, the published literature, and surveys indicate that search effort for freshwater mussels has greatly increased in recent years. Refer to Xerces/CTUIR (2020) for source data.

1. Recent Mussel Bed Die-Offs

In addition to the range contraction and absence of live mussels at nearly half of historic sites revisited, western ridged mussels have more recently been subject to large-scale die-offs in multiple rivers in the western U.S. The causes of freshwater mussel die-offs, where entire beds of mussels are nearly or totally extirpated, sometimes quite rapidly, are poorly understood and understudied. There has been a recent increase in interest and study of these phenomena, primarily by members of the Freshwater Mollusk Conservation Society, who, in 2018, convened a symposium to establish methods and collaborative partnerships to improve response to and study of die-offs.

Western ridged mussel die-offs have recently been reported from or observed in at least four western U.S. rivers (the Chehalis, Crooked, Middle Fork John Day, and Grande Ronde), with three potential other die-offs (also possibly the John Day, Weiser, and Owyhee) and have impacted populations spanning more than 50 miles in at least one of these rivers (Table 1; Figure 4). Because freshwater mussels are cryptic, and because western ridged mussel populations are not routinely monitored or studied across the species' range in the U.S., die-offs may go unnoticed. Additionally, it can be difficult to interpret field observations of empty mussel shells remaining in situ (as opposed to having washed ashore or downstream) in rivers or large numbers of mussels unburied and lying on the riverbed (as compared to their natural state being snugly burrowed into the sediment throughout their entire lives) (Figure 5). However, information on two better-studied die-off locations, the Chehalis River in southwestern Washington and the Crooked River in central Oregon, is provided below. In each case, thousands of freshwater mussels had already died by the time biologists observed and reported the impacts, as evidenced by numerous dead and empty mussel shells observed at each site. Samples of freshwater mussels from these two locations have also been included in a national study effort to examine the potential causal or associated factors of mussel die-offs (Leis et al. 2018).

Table 1. Summary of observations at four western ridged mussel die-off locations and three potential die-off locations. Freshwater mussel die-offs affecting other mussel species in the region only, such as *Margaritifera falcata*, are not reported here.

Location	Year First Reported	Observations of Mussel Die-Offs or Potential Die-Offs
Chehalis River, WA	2015	Observed Die-Off: Many tens of thousands of dead freshwater mussels (evidenced by empty shells within the substrate where live animals were observed two years prior), including western ridged mussels, are estimated over ~50 river miles. Recent observations by Xerces Society and WA state fish and wildlife biologists have revealed that impacts of the die-off have migrated upriver since it was first reported.
Crooked River, OR	2014	Observed Die-Off: First reported by PNW Mussel Workgroup member. Site snorkeled by Xerces Society biologist in 2018. Many thousands of shells still present and apparently unhealthy mussels observed unburied and atop the riverbed next to buried, live mussels. Additional unburied mussels were observed over the course of three visits during 2018.
Grande Ronde basin, OR	2017	Observed Die-Off: A biologist with the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Mussel Project observed and reported dead mussel beds at two sites in the Grand Ronde basin on private lands. Die-off appeared recent and spanned at least one mile at one site, with no live western ridged mussels. Thousands of dead western ridged mussels were observed at a second site with live floater mussels.
Middle Fork John Day, OR	2008	Observed Die-Off: The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Mussel Project documented a die-off at a western ridged mussel bed, underway in 2008 (Maine et al. 2019). The bed was completely gone by 2010. Follow-up surveys have not demonstrated bed recovery since the die-off.
John Day River, OR	2020	Potential Die-Off: A biologist with USFWS observed and reported hundreds of western ridged mussel shells and only one live adult mussel. The shells were scattered across the river bottom as well as observed in the substrate in place.
Owyhee River, OR	2017	Potential Die-Off: Public report of shells in 2017 spurred a 2019 survey by Xerces Society and OR state fish biologists. During the 2019 survey of ~49 RMs, many unburied mussels and numerous shells were observed throughout, although live western ridged mussels were also present throughout the survey area. Further monitoring is needed to determine if a die-off is occurring.
Weiser River, ID	2018	Potential Die-Off: A brief 30-minute survey by a Xerces Society biologist documented western ridged mussel shells in place and many other scattered. No live western ridged mussels were observed. Further monitoring is needed to determine if a die-off is occurring.

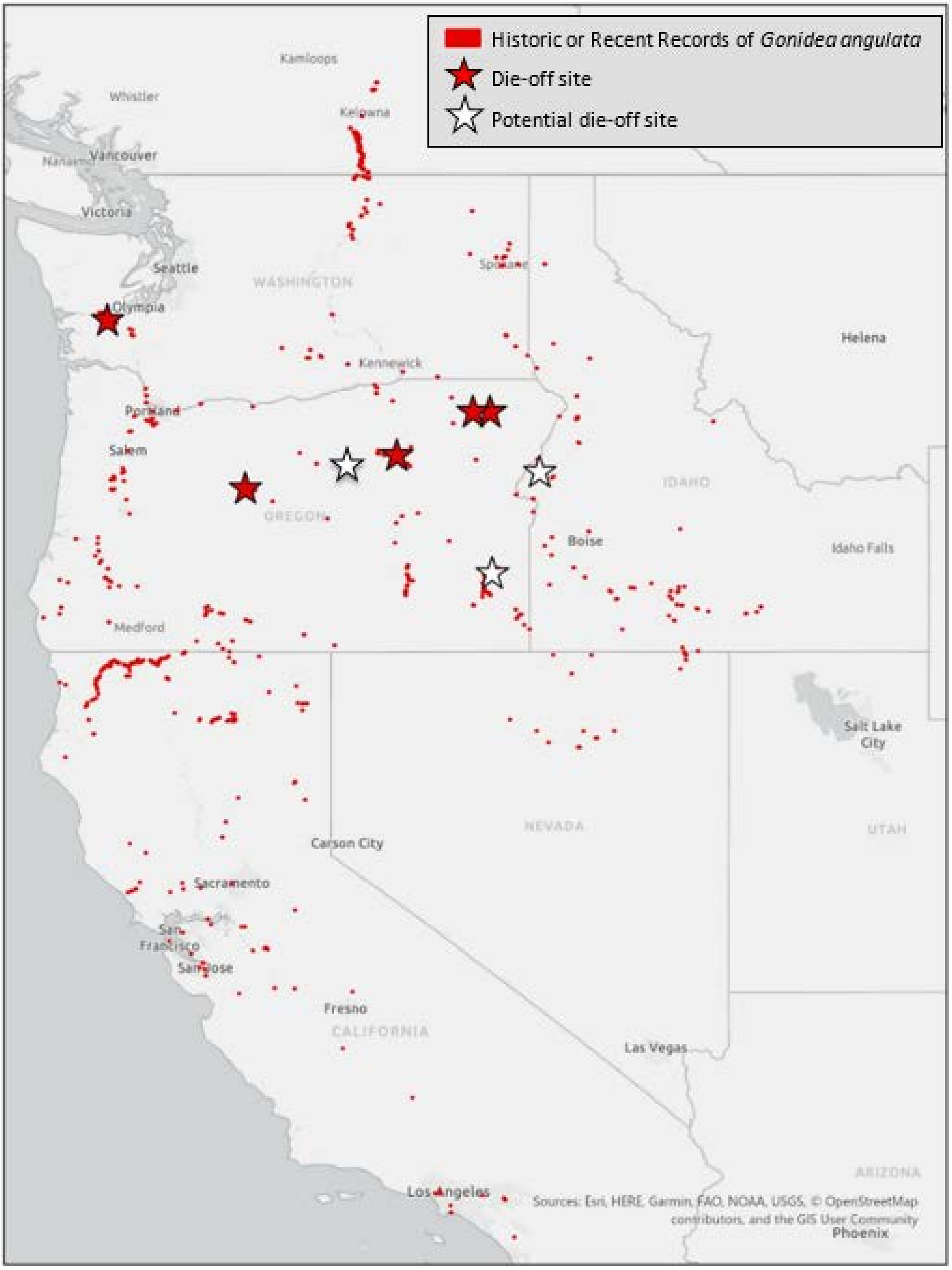

Figure 4. Enigmatic die-offs of western ridged mussel populations have been recently (since 2005) observed at locations in Oregon, Washington, and potentially Idaho.

Figure 5. Examples of observations at a potential die-off location in the Weiser River (top) and at a documented die-off location in the Crooked River (bottom) during mussel snorkel surveys. Top: Dead western ridged mussel shells were observed buried in the river bed as in life, as well as lying along the river bottom (not depicted). Bottom: During repeat visits in the summer of 2018, following the initial die-off report in 2014, mussels displayed abnormal behavior, becoming unburied, lying on the surface of the substrate, and apparently dying over the course of the season. Photo credits: Xerces Society/Emilie Blevins.

a) Chehalis River, WA

The Xerces Society was first alerted to a large-scale die-off of freshwater mussels, including the western ridged mussel, as well as *Margaritifera falcata* and *Anodonta oregonensis*, in the Chehalis River of southwest Washington in 2015 (Figures 6 and 7), following observations by a Washington state fish biologist. The original location of the observation was between Oakville and Porter, approximately river mile (RM) 43 to RM 33. Follow-up surveys in the summer of 2017 revealed that the die-off extended to a mussel bed comprised of western ridged mussels and *Margaritifera falcata* downstream near RM 24, where 46 western ridged mussel shells were found scattered among a small number of live western ridged mussels. Additional resurveys in 2019 at RM 24 and RM 33 did not successfully relocate any live western ridged mussels, despite having observed 21 live animals at RM 24 and 5 live animals at RM 33 in 2017.

Surveys were also conducted at RM 76 in 2017, documenting a large bed of *Margaritifera falcata* numbering in excess of 100,000 mussels. Upon resurveying the site in 2019, evidence of substantial die-off was obvious, with an estimated 42% mortality of *Margaritifera falcata* in sample quadrats, although a small number of live and dead western ridged mussel was also observed. Follow-up surveys should be conducted at the site and upstream to determine if the die-off has further impacted mussel populations, particularly given the pattern observed at downstream locations. Additionally, preliminary results have identified a novel virus with epidemiological effects suggesting a connection with the die-offs (T. Goldberg, unpublished data), and research regarding the virus and die-off continues through a collaboration with the USFWS, WDFW, USGS, UW - Madison, and the Xerces Society.

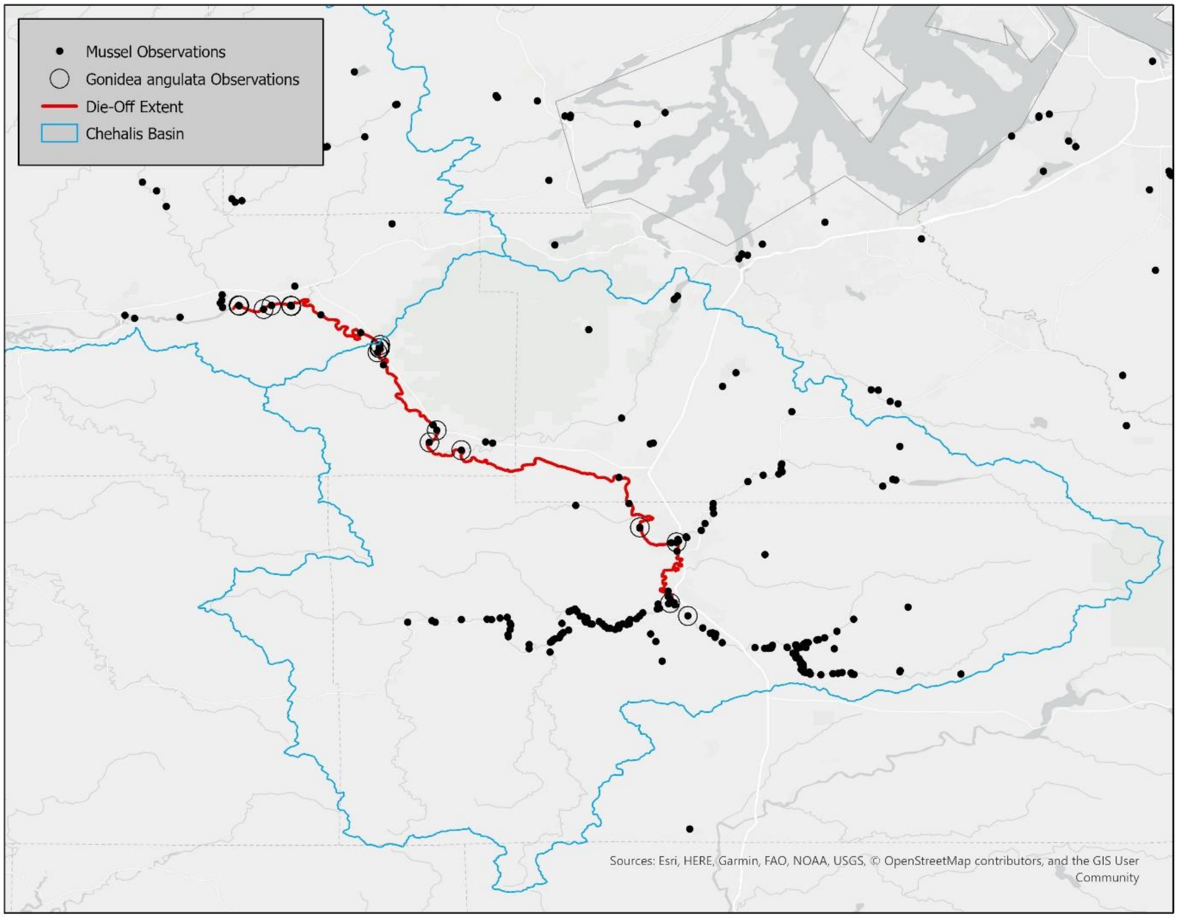

Figure 6. Extent of the die-off observed in the Chehalis River, Washington state (topmost left star in Figure 4), as of fall 2019. Measuring approximately 50 miles, the die-off is inclusive of nearly all known western ridged mussel beds in the basin. This population also represents a genetically-distinct population of the western ridged mussel relative to other populations (Mageroy et al. 2017).

Figure 7. Images from the Chehalis River mussel die-off. Clockwise from top left: 1. Shells scatter the bottom of the river where a large number of freshwater mussels have recently died. 2. Western pearlshell shells have accumulated near RM 24. 3. A recently-dead western ridged mussel, as well as 46 empty western ridged mussel shells and 21 live western ridged mussels, were observed at RM 24 in 2017. 4. A western ridged mussel shell can remain lodged in the sediment where it died for some time after death. Photo credits: Xerces Society/Emilie Blevins.

b) Crooked River, OR

A die-off observation in the Crooked River at Smith Rock State Park was first reported to the Pacific Northwest Native Freshwater Mussel Workgroup in 2014 by one of the workgroup's members. The site was known to have an abundance of western ridged mussels, likely numbering in the thousands or tens of thousands, based on the number of shells observed. A Xerces Society biologist visited the site of the reported die-off in the summer of 2018 and was able to both confirm the presence of live western ridged mussels at the site, as well as an apparently continuing die-off, with multiple adult western ridged mussels uncharacteristically unburied and lying atop the substrate (Figure 5, bottom). A subsequent site visit later in the summer also documented additional fresh shells and apparently sick mussels, several of which were collected for pathogen testing. The remaining number of live western ridged mussels at the site is unknown, as is the annual mortality rate. It is also unknown whether the population is reproducing at this time. As with the Chehalis, preliminary results have identified the same novel virus in mussels sampled from the Crooked River (T. Goldberg, unpublished data), and research regarding the virus and die-off continues through a collaboration with the USFWS, USGS, UW - Madison, and the Xerces Society.

2. Recent Distribution by State and Province

a) Washington

Washington state is the northernmost extent of the species' range in the United States, where either shells or live animals have been reported recently (since 1990) from the Similkameen and Okanogan River watersheds, the Chehalis River watershed, the lower Snake River watershed, the Spokane River watershed, the lower Yakima River watershed, the Colville River watershed, and the Columbia River near Bridgeport (Xerces/CTUIR 2020). Frest and Johannes (1992) report finding the species represented only by shells at two of five surveyed locations and only in low abundance at two other locations on the Snake River. In a study by Krueger et al. (2007), the authors report that the species has been extirpated from some locations in Washington in the Columbia and Snake basins. Decline of two populations of the western ridged mussel in the Little Spokane River (extirpation of one and near-extirpation of the other) were reported by Brian Lang in 2000 (Jepsen and LaBar 2012). A 2018 search in the Lewis River, the type locality for the species, by Xerces Society staff also did not recover any evidence of the species' recent presence. Additional observations of distribution, abundance and declines are reported for two watersheds below.

(1) Similkameen Basin—

The western ridged mussel was documented at 24 surveyed reaches in the Similkameen River watershed by Krueger et al. (2007), but abundance was reported as "often low (10's of individuals observed in a mesohabitat unit)," despite having the potential to occur in greater abundance (10's to 1,000s), as observed at a subset of sites. Notably, this study documented the negative impacts of suction dredge mining on the species, an activity which the authors also observed in the river during the study.

(2) Chehalis Basin—

The western ridged mussel populations in the Chehalis River, where more intensive mussel surveys have occurred since 2017, have experienced widespread and sudden decline from at least river mile 21 to river mile 76, discussed in greater detail above. Surveys in tributaries to the mainstem Chehalis have also resulted in only a single western ridged mussel observed in the Newaukum River and none in the Skookumchuck River, a river from which the species was historically documented, despite documentation of another species of mussel, *Margaritifera falcata*, spanning approximately 7 river miles in the Newaukum and 21 river miles in the Skookumchuck.

b) Oregon

Historic or recent observations of the species in Oregon (shells or live animals) have been reported from river basins spanning Oregon's three major freshwater ecoregions. However recent occupancy (since 1990) in most rivers is represented by observations of only a handful of shells or live mussels, or they occur in rivers that have also experienced sudden declines. The species can occur in abundance, as has been observed in the Donner und Blitzen and Owyhee Rivers. The following examples detail declines in several of the major river basins of Oregon.

(1) Willamette Basin—

In the mainstem Willamette River, recent observations of the western ridged mussel by Pacific Northwest Native Freshwater Mussel Workgroup members have been limited to five sites (Xerces/CTUIR 2020). Among these, at one site (Willamette River, near RM55), only seven animals were originally observed, but during a return visit three years later, only two shells were observed, while just upstream in 2003, only a single live western ridged mussel was observed within a bed of *Margaritifera falcata*. At another site (Willamette River, near RM135), one live animal was reported in 2000 by a Pacific Northwest Native Freshwater Mussel Workgroup member, but when revisited in 2018, only shells were observed. Other recent observations from the Willamette River include a single live mussel (RM177.5), a single shell (one each near RM30, RM 131, and RM 113) or multiple shells (between RM 131.5 and 122) (Xerces/CTUIR 2020).

Recent observations in tributaries to the Willamette have similarly resulted in documentation of few populations and low abundance. For example, only shell fragments have been observed by a Pacific Northwest Native Freshwater Mussel Workgroup member in the Tualatin River at two sites (Fields Bridge and near Fanno Creek), despite recent surveys and observations of other species of freshwater mussels there and elsewhere in the river (Xerces/CTUIR 2020). In the Calapooia River, a single shell was observed in 2018 by a Xerces Society biologist near the site of a 1994 USGS record, approximately 3 miles from the mouth. Additional surveys for the species at six sites in the lower river in 2019 resulted in observation of just 6 live western ridged mussels by USFWS biologists. Single western ridged mussel beds have each been observed by Pacific Northwest Native Freshwater Mussel Workgroup members in the Long Tom River (near the mouth), the Coast Fork Willamette River (near the mouth), and Muddy Creek (east of the Willamette near Junction City). Environmental DNA samples (eDNA) from a historic site at Lake Oswego collected by Utah State University staff did not pick up evidence that the species still occurs there, while eDNA samples from Muddy Creek (west of the Willamette River between Monroe and Corvallis) collected by a biologist at the BLM have indicated the species is present, although actual abundance is unknown.

(2) Crooked Basin—

In the mainstem Crooked River in the lower river and in the upper river near the Crooked River Canyon, recent observations of the western ridged mussel include multiple locations where only shells or shell fragments have been observed, as well as one live animal (Vinson 2005; Vinson 2008; Xerces/CTUIR 2020). Beyond the mainstem, only a single live mussel and several shells have been observed at a single site in the South Fork Crooked River by Xerces Society staff and an Oregon state fish biologist in 2019. Live mussels were observed in abundance in the lower river prior to 2014 at Smith Rock State Park. However, the main documented bed, occurring within Smith Rock State Park, has since undergone a sudden die-off, with continuing attrition of remaining live mussels annually as a result of a yet-unknown cause (discussed above in more detail).

(3) Upper John Day Basin—

The western ridged mussel is recently known in the upper John Day Basin from locations in the Middle Fork and North Fork, and John Day mainstem (Xerces/CTUIR 2020). Surveys by CTUIR (Brim Box et al. 2006) reported the western ridged mussel as comprising just 8% of the mussel fauna by total numbers of animals, the lowest of the three genera present in the John Day basin. Hegeman (2012) also conducted surveys in multiple reaches in the Middle Fork John Day River, and found the western ridged mussel to be the least abundant mussel species where it comprised <1% of mussel abundance by species. In 2003, just 21 animals were observed across all surveyed reaches in the North Fork John Day River (Brim Box et al. 2006). Maine et al. (2017) also found that in repeat surveys of western ridged mussel beds in the Middle Fork John Day between 2003 and 2015, mussel abundance had declined. One monitoring site ("*Gonidea* Bed") that had density estimates of 500 western ridged mussels per square meter had evidence of a die-off beginning in 2008, with western ridged mussels absent by 2010 (Maine et al. 2019). Another potential die-off consisting of hundreds of shells and one live western ridged mussel was reported at the Priest Hole recreation site on the mainstem John Day River in 2020 (Figure 8). These locations are denoted in Figure 4 as "observed" and "potential" die-off locations.

Figure 8. Western ridged mussel shells at the John Day River potential die-off site scattered (left) and in place (right). Photo credits: Teal Waterstrat.

(4) Owyhee Basin—

The western ridged mussel is known historically and recently from the Owyhee River, including from surveys conducted by O'Brien et al. (2004) and in 2018 and 2019 by Xerces Society biologists and OR state fish biologists. O'Brien et al. (2004) documented the species in dense beds of >100 individuals in just 4 of 15 surveyed locations. Surveys were conducted in 2018 and 2019 in response to a citizen report of a potential die-off between 22 and 25 river miles below the bridge at Rome, OR. During the 2018 surveys near Three Forks, the western ridged mussel was observed in beds from the mouth of Warm Springs Canyon downstream to Three Forks. However, multiple mussels were observed unburied and lying atop the substrate, which is uncharacteristic of the western ridged mussel and has been frequently observed at locations where die-offs have occurred. Surveys were again conducted in the summer of 2019 via kayak from the bridge at Rome downstream to the Birch Creek takeout, a distance of ~50 river miles.

The western ridged mussel was apparently present throughout much of this stretch of river, including both younger and older age classes, but observations also included an abundance of shells throughout all surveyed reaches, as well as numerous mussels uncharacteristically lying atop the substrate, unburied. The abundance of shells and unburied mussels warrants further investigation into the health and long-term resilience of this population. This location is denoted in Figure 4 as a "potential" die-off location.

c) Nevada

The western ridged mussel is recently reported from three basins in northern Nevada: the Humboldt River basin, the South Fork Owyhee River basin, and the Salmon Falls basin. Records in the Western Freshwater Mussel Database (Xerces/CTUIR 2020) provide little information on the status of these populations, although live mussels have been recently reported at several sites. The species is reported from a single shell in at least one waterbody (Maggie Creek, Humboldt basin). Hovingh (2004) observed a population near Carlin in 1993, but the current status of this population is also unknown.

d) Idaho

The western ridged mussel is recently reported from nine rivers in Idaho (the Jarbridge River, Bruneau River, Clearwater River, Malad River, Salmon Falls Creek, Little Salmon River, Salmon River, Snake River, and Weiser River), although more than half of all observations are from the Snake River, and only shells at a potential die-off site were observed in the Weiser River. Records in the Western Freshwater Mussel Database (Xerces/CTUIR 2020) provide little information on the status of these populations, although Frest and Johannes (1995) reported that the species was "known to be extirpated from many of the old sites, including much of Snake system, but still common in some areas…Formerly in Little Granite Reservoir (Frest & Johannes 1992b); but this population is believed to have been extirpated by the 1993 drawdown." Vannote and Minshall (1982) observed that the western ridged mussel was more abundant in a reach of the Salmon River, ID ("upper 40-km canyon reach of the 'River of No Return' of the Salmon River") as compared to *Margaritifera falcata*, but the current status of the population is unknown. A survey at a site in the Little Salmon River near New Meadows, ID by Xerces Society staff in 2018 resulted in observation of just 12 western ridged mussels. The only recent observation from the Weiser River resulted in documentation of many scattered shells and no living individuals by Xerces Society staff in 2018. Shell arrangement at this site in the Weiser River (empty but in situ, "burrowed" as in life; Figure 5, top) suggested mussels may have died in-place, a common observation at other locations where sudden die-offs of the species has been observed. This location is denoted in Figure 4 as a "potential" die-off location.

e) California

The western ridged mussel has likely experienced its greatest range decline in California. In 1981, malacologist Dwight Taylor reported the species' status as "Probably eradicated in much or most of original range in California." The species is recently known from just 17 waterbodies in 13 river basins in California (Table 2), or approximately one-third of the species' historic distribution in the state. Further, nearly 80% of all recent records come from just two rivers (the Klamath River and Pit River), and the species is found in abundance in the Klamath River. Taylor (1981) and Coney (1993) previously reported that the species was likely extirpated from southern California and most of the Central Valley. Extensive surveys by Howard (2008, 2010) at historic locations where mussels occurred, summarized in Howard et al. (2015), as well as recent survey data submitted to the Western Freshwater Mussel Database, have found no evidence that the species still occurs in southern California. Howard et al. (2015) also report the total loss of several California historical sites, which are either now dry or have been permanently altered. In northern California, Howard (2010) reported that when found, western ridged mussels were often “sparsely dispersed and not found in dense beds,” with exceptions at sites in the Klamath and Pit Rivers. As part of surveys of 52 sites in California, O’Brien (2019) located just 3 western ridged mussels. These individuals occurred in only 2 of the 9 historic sites surveyed for the species, and all were older individuals with no evidence of recruitment at the sites.

At the recent southern extent of the species’ range, approximately 475 miles north of the historic southern extent, records from the Napa River and Lake Berryessa are based on collections of shells only, while records from the Russian River are based on observations of just three live animals (O’Brien 2019; Xerces/CTUIR 2020). Statewide, Howard et al. (2015) documented that the species is extant at only 55% of resurveyed historical locations.

Table 2. Waterbodies and watersheds with recent (since 1990) observations of live western ridged mussels in California, with the exception of the Lake Berryessa and Napa River, which are based on observations or collections of shells (Xerces/CTUIR 2020).

Waterbody	Watershed
Last Chance Creek	East Branch North Fork Feather
Lost River (Clear Lake Reservoir)	Lost
Klamath River	Lower Klamath
Fall River	Lower Pit
Hat Creek	Lower Pit
Pit River	Lower Pit
Tule River	Lower Pit
Russian River	Russian
Salmon River	Salmon
Napa River (shells only)	San Pablo Bay
Scott River	Scott
Shasta River	Shasta
South Fork Trinity River	South Fork Trinity
Klamath River	Upper Klamath
Pit River	Upper Pit
South Fork Pit River	Upper Pit
Lake Berryessa (shells only)	Upper Putah

f) British Columbia

The western ridged mussel is classified as “Endangered” in British Columbia, as a result of its limited distribution, continued decline at a number of sites, and a high risk of continued decline (COSEWIC 2010). The species is recently known from just six waterbodies in a single basin (Okanagan).

IV. CURRENT AND POTENTIAL THREATS – SUMMARY OF FACTORS FOR CONSIDERATION

The following factors pose substantial threats to the survival of the western ridged mussel: *A. The present or threatened destruction, modification, or curtailment of its habitat or range; B. Overutilization for commercial, recreational, scientific, or educational purposes; C. Disease or Predation; D. The inadequacy of existing regulatory mechanisms; and E. Other natural or manmade factors affecting its continued existence*. Below we summarize the rationale and available evidence for each factor.

A. The Present or Threatened Destruction, Modification, or Curtailment of its Habitat or Range

Freshwater mussels require adequate conditions for multiple life stages consisting of abundant, connected aquatic habitats with stable substrates, perennial inundation, and protection from scour and deposition (Haag 2012). Indeed, habitat for the western ridged mussel includes rivers with wide floodplains, low slope, large components of sand and gravel substrate, and large boulders (reviewed in Blevins et al. 2016). The western ridged mussel, like other freshwater mussels, faces a wide range of threats occurring in aquatic ecosystems. These include direct habitat destruction and modification, including activities that disturb shoreline, channel, and bank habitats, such as dredging and mining, straightening and armoring of channels, and construction activities that alter existing habitat directly or indirectly. Even aquatic habitat restoration activities that change aquatic conditions without considering freshwater mussels that occur can pose a significant threat to western ridged mussels. Threats also include indirect impacts to mussel habitat. These may occur through reductions in water availability (quantity) and dewatering or drawdown of water levels, changes to the natural flow and level regimes (timing, volume, rate, and temperature) and connectivity, impacts to water quality, as well as the impacts of climate change. Introduction of invasive species also threatens the habitat and range of the western ridged mussel.

1. Habitat Destruction and Modification

Findings in the recent national assessment of fish habitat in the United States by Crawford et al. (2016) demonstrate that key basins where the western ridged mussel occurs or historically occurred are at a high risk of aquatic habitat degradation, including California's Central Valley, Oregon's Willamette Valley, southeast Washington (Walla Walla to Spokane), parts of western Washington (Portland, OR to Seattle), and the Snake River Plain in Idaho. In one portion of the species' range, the Okanagan Basin of British Columbia, there have been marked changes to hydrology and declines in water quality, increased development and alteration of shoreline habitat, and channelization and stabilization of riverine habitat (COSEWIC 2010). Such alterations are well-documented in many other river basins within the species' historic range, including the Willamette (Hulse et al. 2002), the Chehalis (ASRP Steering Committee 2019), the Snake (USEPA 2002; NWPCC 2004; SRSRB 2011), and the Klamath (CRS 2012). Indeed, Howard et al. (2015) reported the total loss of several river sites historically occupied by the western ridged mussel, which are either now dry or have been permanently altered. In the species' range in Canada, it is believed that historically the greatest impacts to the species were through the creation of dams and concrete weirs at sites in the Okanagan River, as well as channelization of river habitat, resulting in the destruction or degradation of habitat (COSEWIC 2010).

Habitat destruction and modification continues to impact the species. For example, suction dredge mining has historically occurred in freshwater mussel habitat across the species' range. Although California, Oregon, and Washington all have restrictions or requirements placed on suction dredge mining, Oregon, Washington, Idaho, and Nevada still allow the practice in areas where western ridged mussels have potential to occur. Suction dredge mining (Figure 9) and other activities that disturb stream beds can kill mussels that become buried and destroy habitat (Krueger et al. 2007). Disturbance can also result in abortion of eggs by brooding females (Haley et al. 2007).

Figure 9. Example of an active mining claim (in 2017) adjacent to a western pearlshell mussel bed, in the North Fork John Day River, OR, where the western ridged mussel also occurs. The newly-constructed sluice was established within an existing long-term mussel monitoring plot. Photo credit: Xerces Society/Sarina Jepsen.

Restoration and Other In-Stream Construction Activities

In-stream construction activities, including restoration projects and transportation or other anthropogenic activities that do not purposefully protect freshwater mussels, pose a threat to western ridged mussel populations.

Hundreds of millions of dollars are spent annually to restore aquatic habitat for salmonids in the Pacific Northwest (Barnas et al. 2015) and numerous projects, such as more than 1,000 culvert replacement projects in Washington state alone, are anticipated in the future.[3] Yet, restoration projects often proceed without knowledge of whether or not freshwater mussels occur within the project area, since freshwater mussel surveys are not required by permitting agencies (Blevins et al. 2017b). In many cases, dense freshwater mussel beds are discovered only once rivers are dewatered, for example in channel re-meandering or floodplain connection projects or during culvert replacement projects (EB and SJ personal observation; Blevins et al. 2017b). At this point, hasty attempts may be made to save the animals, but these unplanned efforts are rarely successful (summarized in Blevins et al. 2019). Given the importance of freshwater mussels to salmonids and other aquatic life, restoration projects may be doing more harm than good when they overlook this ecologically important, yet cryptic, group of animals. Restoration projects that occur in western ridged mussel habitat and fail to consider them in project planning and implementation pose a significant threat to the continued survival of this species.

Restoration and other in-stream construction activities can directly or indirectly impact mussels in a number of ways. Since mussels are cryptic, they are often overlooked and go unnoticed in the planning phase of projects, particularly a species like the western ridged mussel, which burrows deeply. They have multiple characteristics that make them vulnerable during in-stream construction work, including the fact that they: are extremely sedentary, require perennial inundation of fresh water, must interact with a host fish during the release of larval mussels to complete the life cycle, and rely on habitat that remains relatively stable year-round and for a time span of decades (Blevins et al. 2016). Restoration and other in-stream construction activities can impact the species' ability to burrow into suitable habitat; result in crushing, smothering, drying out, and other causes of direct mortality; reduce the availability of suitable habitat; alter patterns of scour, which can result in later dislodgement and mortality of burrowed juvenile and adult mussels; reduce breeding success by causing stress, which may lead to abortion of developing eggs, or alter host-fish/mussel interactions during the limited breeding period (Haley et al. 2007; Levine et al. 2007; Peck et al. 2007; reviewed in Blevins et al. 2017b). Repeated disturbances or disturbances that last for an extended period may cumulatively impact mussel beds, given the relatively sedentary nature of freshwater mussels.

2. Impacts to Water Quantity, Natural Flow and Temperature Regimes, and Quality

Water Quantity

Water quantity has been described as one of the most important emerging issues in freshwater mussel conservation (Haag and Williams 2014). Freshwater mussels rely on perennial flows that support native fish and aquatic ecosystems, yet Grantham and Viers (2014) found that water rights allocations in California total approximately five times the state's annual runoff, while in

[3] https://www.wsdot.wa.gov/Projects/FishPassage/default.htm

some major river basins allocations exceed available natural surface water by as much as 1,000%. Reduction in water flows and levels directly destroy and modify habitat for freshwater mussels, which require wetted habitat to persist, grow, and reproduce. Indeed, impacts to water availability were recognized early on for their negative effects on freshwater mussels like the western ridged mussel and species with which it co-occurs. For example, malacologists noted that "the draining of ponds and lagoons and the use of river waters for irrigation so threaten to exterminate [the floater mussel] that in a few years it will be almost impossible to obtain an adequate idea of its former distribution" (Hannibal 1912). Dewatered habitat can result in direct mortality of freshwater mussels (Haley et al. 2007; Nedeau et al. 2009; Clarke 2010). Dwight Taylor wrote in 1981 that threats to the western ridged mussel included "pollution; lowering of water-table through agricultural development; changes in stream flow through damming or increased flooding due to overgrazing or logging; elimination of natural fish hosts on which life cycle depends (Taylor 1981). Continued and future impacts to western water availability are anticipated as a result of ever-increasing demand and changes to historic patterns of rainfall and snowmelt under climate change (Dettinger et al. 2015), and are likely to negatively impact the persistence of the western ridged mussel.

Natural Flow and Level Regimes and Connectivity

The natural flow and level regimes of freshwater ecosystems (including magnitude, frequency, duration, timing, and rate of change; Poff et al. 1997) are similarly vital to the western ridged mussel and other species of freshwater mussels. However, impacts to these regimes in freshwater habitats have resulted from construction and operation of dams and water diversions throughout the species' range (Kondolf and Batalla 2005; Poff et al. 2007; Richter et al. 2016; Zimmerman et al. 2017). Freshwater mussels depend on flows to support respiration, feeding, and reproduction, and habitats that dry as a result of water level fluctuation can exclude mussels. Negative effects of altered regimes, for example from pulsed flows, could disrupt reproduction in the species, due to a relatively short gravid period and the potential for high flows to disrupt spawning, the release of glochidia, or excystment and establishment of juveniles (Haley et al. 2007). For example, spates occurring shortly after juvenile settlement could reduce recruitment (Layzer and Madison 1995). Discharge is also known to influence the species' growth (Black et al. 2015). In other U.S. rivers, dams have disrupted connections between mussels and their host fish (Watters 1996; Galbraith et al. 2018), and western ridged mussels may similarly be at risk.

Water Quality (Contaminants)

Contaminants (pesticides, nutrients, metals, ions, and/or industrial or pharmaceutical compounds) may affect mussels directly via mortality or via sublethal effects. In addition, contaminants may affect mussels indirectly, through impacts to their food sources or reproductive host species (USEPA 2007). Pollutants can impact mussels through multiple mechanisms, including by altering growth, respiration, metabolism, reproduction (including feminization), recruitment, and direct mortality (Cope et al. 2008; Strayer 2008; Haag 2012). Because of their complex life history, freshwater mussels have multiple routes of exposure to contaminants, including: water (glochidia, encysted, juveniles and adults); sediments (juveniles and adults); pore water (juveniles and adults); fish hosts (glochidia, encysted); and diet (juveniles and adults) [Buczek and Cope 2017].

Decline in water quality as a result of waste discharges and nonpoint source pollution has had a large impact on freshwater mussel populations (Strayer 2008; Haag 2012). As a result of exposure, which may be intensified in mussels given their relatively sessile nature, mussels can develop a pollutant "burden" (Hartmut and Gerstmann 2007), which can impact mussels at all life stages, though pollutants can also have disproportionate effect on younger life stages (Bringolf et al. 2007; Wang et al. 2007; Moore and Bringolf 2018).

Negative effects are reported to freshwater mussels for salts (Wang et al. 2018); nitrates (Moore and Bringolf 2018); ammonia, sulfate, copper, nickel, and zinc (Wang et al. 2017); and a wide range of other chemicals present in the environment (Bryan 2016; Archambault et al. 2017). While toxicity effects data is quite limited for most Unionidae, freshwater mussels are known to be especially sensitive to particular pesticides, nutrients, metals and ions (Raimondo et al. 2016; Conners and Black 2004; Milam et al. 2005; Bringolf et al. 2007; Wang et al. 2010). For example, multiple freshwater mussel species were found to be more sensitive than other aquatic species (including cladocerans whose toxicity responses are typically used in setting aquatic life benchmarks and water quality standards) to alachlor, metolachlor, ammonia, potassium, chloride, sulfate, copper, and nickel (Wang et al. 2015). Several of these contaminants (and others) have been detected, sometimes at concerning levels, in recent monitoring results within the basins that have exhibited die-offs.

A wide variety of pesticides are frequently detected in the waters and sediments of rivers and streams of Oregon and Washington (ODEQ 2015; ODEQ 2020; Noland et al. 2019; Nickelson 2018). Certain widespread active ingredients, including pyrethroids, and organochlorines (e.g. DDT), are lethal to mussels at low concentrations below 10 parts per billion. Numerous other pesticides may kill or result in abnormal development to fifty percent (EC50, LC50) of mussel test subjects, especially larval and juvenile life stages, at slightly higher levels (USEPA 2017).

Contaminants at concerning levels are documented within or near many of the river segments where die-offs are known to have happened. These include contaminant impairments under 303(d) of the Clean Water Act. For example, the Chehalis River mainstem and lower tributaries near the die-off site contain Category 5 303(d) listings for PCBs and mercury. Numerous metals, nutrients and pesticides, some above state water quality criteria, have also been detected in Oregon watersheds where die-offs have occurred, even though monitoring efforts in those watersheds have been sparse. In addition, a tributary of the Chehalis is designated by the state as a "moderate" level nitrate priority area; this tributary empties into the mainstem where mussels have recently died off. Recent USGS monitoring on a lower portion of a tributary near the Chehalis die-off site also documented concerning levels of total nitrogen, total phosphorous and contaminants in sediment.

In the western U.S., freshwater mussels encounter pollutants as they filter water, such as DDT residues and PCBs (Claeys et al. 1975); chromium, cobalt, copper, cadmium, tin, and lead (Norgaard et al. 2013); and microcystins (Kann et al. 2010), although research has been limited, and thus the full magnitude of risk of pollutants to western ridged mussel population viability is largely undocumented.

Water Temperatures and the Impacts of Climate Change

Other impacts to water quality include alterations to the natural thermal regime of rivers (Caissie 2006) as a result of dams and other river modifications. For example, chronically low water temperatures have been shown to eliminate mussel populations (Miller et al. 1984), while high water temperatures can also have dramatic effects on mussel populations and their habitats (see next section on Climate Change).

The western ridged mussel is at particular risk of habitat destruction, modification, and curtailment as a result of climate change impacts. The species has already declined significantly throughout much of its range in lower latitudes, where water availability and quality has been impacted (Hannibal 1912; Taylor 1981). Temperature impairments and dissolved oxygen impairments (dissolved oxygen drops as temperature increases) for aquatic life are currently widespread in rivers and streams across the historic and current range of the western ridged mussel, including within the areas for which die-offs have been recently documented (ODEQ 2020; WDOE 2020). Climate change is altering precipitation patterns and is predicted to increase the severity and variability of floods or droughts, as well as increase air and water temperatures (Bates et al. 2008). In the western U.S., this will result in further alterations to flow regimes (Tohver et al. 2014; DeBano et al. 2016). Reduced snowpack results in diminished late season flows, while decreased summer precipitation will exacerbate low flows. Increased precipitation in other months can result in greater flood risk (Tohver et al. 2014).

These impacts to warming temperatures and changing patterns of precipitation are modified by management of aquatic ecosystems, water resources, and infrastructure at the local level. For example, water quality is affected both by ambient temperatures and volume of water, and where dams alter the storage and release of flows or water diversions reduce instream flow, mussels may locally experience exacerbated conditions. Fish passage barriers can also limit access of both host fish and mussels to upstream habitats, which may provide cold water refugia. Research suggests that freshwater mussels may already be experiencing their thermal limit as waters have warmed (Pandolfo et al. 2010). This is concerning as high water temperatures and low flows have been demonstrated to have multiple impacts to freshwater mussels, including leading to direct mortality of individuals and population extirpation (Golladay et al. 2004; Haag and Warren 2008), affecting the burrowing ability of mussels, which enables mussels to avoid emersion and escape predation (Archambault et al. 2013), and influencing host-fish/mussel interactions and species distributions (Terui et al. 2014; Archambault et al. 2018).

3. Invasive Species

Aquatic invasive species have the potential to dramatically alter ecosystems by modifying habitat, altering nutrient cycles, competing for resources, and directly harming native species. A major freshwater invader, the zebra mussel (*Dreissena polymorpha*) has caused large declines in native freshwater mussel populations in eastern North America. First introduced to the Great Lakes in the 1980s, the species rapidly spread through eastern waterways, resulting in major impacts to native freshwater mussel abundance and distribution, with regional extinction rates of North American freshwater mussels accelerating by 10-fold (Ricciardi et al. 1998). Zebra mussels have the potential to form dense populations rapidly, resulting in biofouling, which can smother native mussels and affect movement and feeding (reviewed in Haag 2012).

Although zebra mussels have not yet established in western waterways, the threat remains that populations could be introduced and become widespread as occurred in eastern North America. In 2019 alone, 18 boats stopped in Washington state were found to be contaminated with zebra mussels.[4] In 2018, zebra mussel larvae were detected in Tiber Reservoir in Montana, resulting in a declared natural resource emergency for the state's waterbodies.[5] Zebra mussel introduction

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[4] https://wdfw.wa.gov/news/record-year-washington-prevention-aquatic-invasive-species

[5] http://dnrc.mt.gov/divisions/cardd/docs/misac-docs/113016-eo-on-aquadic-invasive-task-force.pdf

and establishment is considered the most serious, plausible threat to the western ridged mussel in Canada (COSEWIC 2010). The introduced Asian clam (*Corbicula fluminea*) also has the potential to impact western ridged mussel. This species has become established throughout many rivers in western North America. It has the potential to reach very high densities and to succumb to periodic mass die-offs, which could affect food availability and water quality (Strayer 1999; Haag 2019). Indeed, an abundance of Asian clam shells have been documented at a site in the Tualatin River (Fields Bridge) where western ridged mussel shells have been historically reported, but where no live western ridged mussels have been observed recently despite observations of other species of western freshwater mussels in 2019 by staff at the Xerces Society.

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

To the best of the petitioners' knowledge, the western ridged mussel is not produced or sold commercially. However, recreational harvest of freshwater mussels by the general public, including the western ridged mussel, does occur.[6] Unregulated recreational harvest of long-lived species, like the western ridged mussel, can have especially damaging impacts, particularly when mussel beds consist of few individuals as discussed in Section II.B.2. The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is working to restore freshwater mussels, including the western ridged mussel, to restore ecological function and sustainable tribal harvest opportunities in the future. Tribal harvest is a reserved treaty right, but CTUIR's mussel project work has found that few populations of mussels are currently robust enough to withstand harvest at any level. Critical uncertainties regarding tissue contaminant or pollutant loads are also a factor affecting tribal harvest. The inadequacy of regulations pertaining specifically to recreational harvest is discussed further in Section D.

C. Disease or Predation

Enigmatic die-offs are a highly significant emerging concern for the western ridged mussel and pose a substantial threat to the continued persistence of the species. Large, unexplained kills of western ridged mussel beds have been observed in at least four rivers in Oregon and Washington, and possibly three other rivers in Oregon and Idaho, respectively, beginning as early as 2005 (Figure 4). Die-offs of freshwater mussels have also been recently reported in other North American Rivers affecting large numbers of a variety of freshwater mussel species, including Wisconsin, Ohio, and Virginia (Leis et al. 2018). These die-offs differ from other spill-related causes of mussel mortality, such as that observed in the Clinch River in 1998. However, many of the attributes of enigmatic die-offs observed elsewhere have been observed in western ridged mussel die-offs, including an apparent seasonal nature of intensity, continuing die-offs across mussel beds and species, and advancement of die-off impacts upriver.

To investigate potential causes of the die-offs, samples of live western ridged mussels and *Margaritifera falcata* were collected from two die-off locations (the Crooked River, OR and Chehalis River, WA respectively) and analyzed for bacteria and virus associations. Preliminary results have identified a novel virus with epidemiological effects suggesting a connection with the die-offs (T. Goldberg, unpublished data). It is hypothesized that any disease found to cause die-offs in *Margaritifera falcata* in the Chehalis River would also be responsible for the

[6] https://www.idahopress.com/boiseweekly/food_and_drink/year_of_idaho_food/demystifying-gem-state-seafood/article_53e1ec7e-5f82-5092-b64d-4f982681b5d7.html

simultaneous die-off effects observed in the western ridged mussel and in *Anodonta oregonensis*. In the case of the Chehalis River, western ridged mussel specimens were not targeted for collection because there were few animals and there was concern that collection of specimens would further impact the apparently small population. Further work is necessary to understand the characteristics of a potential disease and the role of other potentially-contributing factors. Should a virus be responsible for the observed die-offs, this pathogen could be spread to other waterbodies, and threaten western ridged mussel populations anywhere that it spreads.

Although predation of the western ridged mussel has been documented through observations of animal shell middens along riverbanks, presumably those of otters or other mammalian predators, it is not understood to be a substantial threat to the survival of the species.

D. The Inadequacy of Existing Regulatory Mechanisms

Existing regulations fail to protect the western ridged mussel from threats it faces from habitat loss or modification (see also discussion in the section: *Restoration and Other In-Stream Construction Activities*), including impacts to instream flows; recreational harvest, handling, or collection; pollution; and disease. For example, suction dredge mining, which has the potential to kill freshwater mussels and damage their habitat (Krueger et al. 2007), is variably regulated and insufficient to protect the species or its habitat. California, Oregon, and Washington all have restrictions or requirements placed on suction dredge mining that specifically address impacts to freshwater mussels. However, although suction dredge miners are directed to avoid areas with freshwater mussels in Oregon and Washington, many members of the public are unfamiliar with freshwater mussels and may not notice or recognize a mussel bed in an area selected for mining. Idaho's EPA General Permit for suction dredge mining actually allows the activity in the Bruneau River below Hot Creek, in a portion of the Spokane River, in parts of Jordan Creek, and in Shoshone Creek, all of which are areas where the western ridged mussel has historically or recently been documented. Nevada's dredging permit does not address any protections to freshwater mussels, just restrictions intended to protect species of fish.

There are no federal or state-level requirements that mussel surveys be conducted or that harm be minimized or mitigated prior to implementation of in-stream construction activities, including aquatic habitat restoration work. In-stream construction activities that do not survey for freshwater mussels prior to in-stream work have already resulted in the destruction of Pacific Northwest freshwater mussel beds (Blevins et al. 2017b) and pose a significant threat to the future survival of the western ridged mussel.

Other regulations may have potential to protect the species, but their existence and application is limited. For example, Washington state does require a Hydraulic Project Approval (HPA) permit for projects that "use, divert, obstruct, or change the natural flow or bed of any of the salt or fresh waters of the state,"[7] and includes provisions for protecting "fish life," which is also inclusive of shellfish species and the habitat that supports fish life.[8] However, freshwater mussels remain relatively unknown among many biologists involved in work requiring an HPA, and its actual application to reduce impacts to freshwater mussels is limited, given that the western ridged mussel is not included in the state's Priority Habitat and Species list. Without more direct

[7] https://apps.leg.wa.gov/wac/default.aspx?cite=220-660-010&pdf=true

[8] https://apps.leg.wa.gov/wac/default.aspx?cite=220-660-030&pdf=true

protections for freshwater mussels, existing regulations are inadequate to protect the western ridged mussel and its habitat.

A patchwork of regulations regarding recreational harvest by the general public is also insufficient to protect the species. For example, although recreational harvest of western freshwater mussels by the general public is prohibited in Washington and Oregon's fishing regulations, Nevada, Idaho, and California do not prohibit recreational harvest. Indeed, recreational harvest of freshwater mussels in Idaho by the general public, including recreational harvest of western ridged mussel, is allowed.[9] Even in states that restrict recreational harvest, it may still occur.[10] In comparison, scientific collection or take permits are required for freshwater mussels in Washington, Oregon, Nevada, Idaho, and California. However, these permits are generally restricted to activities related to scientific, educational, or display purposes. These permits do not protect freshwater mussels from take activities not involving science or education, such as take resulting from dewatering or habitat alteration.

Freshwater mussels are sensitive to pollutants present in and discharged to waterbodies (see discussion of water quality above) and may not be sufficiently protected by existing water quality standards, as was demonstrated for many species of mussels with respect to ammonia standards (USEPA 2013a,b). Existing regulations are also insufficient to protect the western ridged mussel from disease. Recent enigmatic die-offs have been observed in multiple river basins, with resultant devastating declines in abundance, and possibly resulting in extirpation of some populations. These die-offs are currently the subject of epidemiological investigations (Leis et al. 2018), with preliminary results suggesting a newly-discovered virus contributing to die-offs in at least one river. Very little is known about disease in freshwater mollusks, and the potential impacts of disease spread among western ridged mussel populations is unknown but likely devastating to the species' future viability. No regulations are in place to protect mussels from disease spread among rivers, particularly the transfer of a virus between rivers via clothing, footwear, and aquatic gear.

The bulk of the western ridged mussel's range is located in the U.S., but the northernmost portion of its range extends into southern British Columbia in Canada, where it is listed as Endangered by the province (COSEWIC 2010) and is being considered for uplisting from Special Concern, Schedule 1 to Endangered at the national level (SARA 2019). These designations protect the species only in the Canadian portion of its range, which constitutes approximately only 3% of its historic range, making these designations insufficient to provide meaningful protection to the species as a whole.

E. Other Natural or Manmade Factors Affecting its Continued Existence

1. Reproduction and Population Demographic Factors

Dispersal within populations and colonization of new habitat is dependent on successful attachment of larval mussels to host fish (see Section VII.), but barriers to fish passage, including undersized culverts and dams, and impacts to host fish habitat probably limit the western ridged mussel's capacity to disperse and reproduce. The mussel-host fish interaction is highly important

[9] https://www.idahopress.com/boiseweekly/food_and_drink/year_of_idaho_food/demystifying-gem-state-seafood/article_53e1ec7e-5f82-5092-b64d-4f982681b5d7.html

[10] http://www.dailyventure.com/travel/Camping-on-the-Willamette-River

for mussel reproduction. If mussel densities and host fish densities are reduced to the point where they no longer connect, mussel reproduction will decline or completely fail (Downing et al. 1993). The current rate of reproduction, survival, or mortality is unknown for nearly all populations of western ridged mussel. However, in other species of freshwater mussels, including *Margaritifera falcata*, with which this species can co-occur, limited or nonexistent recruitment has been documented and is a concerning issue limiting the future viability of populations (Howard and Cuffey 2006). Low levels of recruitment have been documented in some western ridged mussel beds by Mageroy (2015) in the Okanagan Basin, B.C., where recruitment levels are below the minimum threshold estimated for maintenance of populations. COSEWIC (2010) notes that, in one Canadian population, only about 5 to 10% of mussels of a dense bed were observed releasing conglutinates in synchrony. O'Brien (2019) documented no evidence of recruitment at sites at the current southern extent of the species range. Further, reproductive success may be dependent on a minimum bed density, as observed in other mussel species (Downing et al. 1993).

Equilibrium mussel species, like the western ridged mussel, characterized by long lifespans, slow growth, long time to maturity, and low annual reproduction, tend also to have low adult mortality and accumulate in high abundance where habitat remains undisturbed (Haag 2012). However, a number of remaining sites have low abundance and may lack recruitment entirely. The cause(s) of apparently higher adult mortality and low recruitment in the species remain unstudied with the exception of recent mussel bed die-offs, but may have great impact on the continued existence of the species.

2. Genetic Diversity

Recent genetic analyses of western ridged mussel populations at sites in the Okanagan basin in Canada, and the Chehalis, Klamath, Pit, and Columbia basins in the U.S. by Mageroy et al. (2017) did not reveal large differences in the population genetics between Canadian and U.S. western ridged mussels. However, the Chehalis, WA sample did contain a haplotype not found in other sampled basins. Since the Chehalis River population appears to be genetically unique among other western ridged mussel populations, the potential extirpation of that population as a result of the present die-off will reduce the species' viability and representation across the landscape. The limited connectivity of populations such as those inhabiting coastal basins, as compared to those located in larger basins like the Columbia, may further impact the species' viability.

V. TAXONOMIC STATUS

The western ridged mussel was first described by Lea (1838), and originally assigned to the genus *Anodonta*. The genus *Gonidea* was established by Conrad (1857), to which the western ridged mussel was reassigned by Simpson (1900). The western ridged mussel is the only extant species belonging to that genus, and is genetically differentiated from other North American freshwater mussel species, with its closest genetic relationships to mussel species in Turkey, Italy, and China (Lopes-Lima et al. 2017). The western ridged mussel is a valid species; its status was upheld by Williams et al. (2017).

VI. SPECIES DESCRIPTION

The western ridged mussel is a bivalve mollusk in the family Unionidae. It is characterized by an outer shell consisting of two valves reaching up to five inches in length. The outer color is yellowish-brown to black, and the shell is generally thick and obovate to trapezoidal in shape (Burch 1972; Clarke 1981; Nedeau et al. 2009). The interior of the shell, consisting of the nacre (mother-of-pearl) may vary in color from “livid bluish white or with a salmon-colored flush in the concavity of the valve, all salmon-colored, or elegant purple partially or throughout” (Dall 1908). An angular ridge runs from the beak of the shell to the posterior margin, which varies in prominence; some specimens may almost entirely lack the ridge (var. *subangulata*, Hemphill 1891; var. *haroldiana*, Dall 1908) or there may be two prominent ridges (*biangulata*; Sowerby 1869). Mantle papillae are present at the incurrent aperture and are “bifid, branched and non-uniform” and often a pinkish or purplish color (Blevins et al. 2019).

VII. SPECIES LIFE HISTORY

The western ridged mussel is reported to live 20 to 60 years, though published observations appear to underestimate maximum age (e.g., Black 2012). In many mussel beds, western ridged mussels burrow deeply into sediment, where often only their incurrent and excurrent apertures are visibly flush with the bottom substrate, although they may also be only partially buried where sediment is coarser (Hemphill 1891; Vannote and Minshall 1982; Haley et al. 2007; Mageroy 2015). They, like other freshwater mussels, are filter feeders, filtering bacteria, phytoplankton and zooplankton, fungal spores, and algae from the water (Haag 2012).

The species may reach sexual maturity around the age of seven years, although estimates are based on growth rate observations, which may vary significantly among populations (Mageroy 2015). Regardless of sexual maturity, some mussel populations have maximum growth/length in certain habitats (Haag 2012). O’Brien et al. (2013) reported that western ridged mussel releases glochidia in the spring when daily average water temperatures warmed above 11°C. CTUIR field observations have recorded gravid western ridged mussel in the Middle Fork John Day River between late June and late July at water temperatures from 17-23°C (Maine et al. 2019). Host fish usage by western ridged mussel includes hardhead (*Mylopharodon conocephalus*), Pit sculpin (*Cottus pitensis*), tule perch (*Hysterocarpus traski*) (Haley et al. 2007), and margined and shorthead sculpin (O’Brien et al. 2013). O’Brien et al. (2013) speculated that conglutinates were released at night based on host fish feeding ecology, and any glochidia that had not attached by midday did not survive. Encystment on host fish lasts between 10 and 13 days (O’Brien et al. 2013; Mageroy 2015).

VIII. IMPORTANCE OF MUSSELS TO AQUATIC ECOSYSTEMS

Freshwater mussels, including the western ridged mussel, improve water quality by acting as biofilters. They are powerful filter feeders that can remove a significant amount of particles suspended in the water column and from the interstitial spaces of the benthos (Vaughn et al. 2008; Welker and Walz 1998). In high densities, collectively they can filter a substantial quantity of water, increasing water clarity for salmonids and other fishes. Research on floater mussels that co-occur with the western ridged mussel has shown that mussels can remove pharmaceuticals, personal care products, herbicides, flame retardants, and *E. coli* as they filter, storing them in their tissues or excreting them as biodeposits (Ismail et al. 2014). Other research has shown that freshwater mussels can reduce bacterial populations in the water, resulting in lower fish mortality and increased fish growth (Othman et al. 2015).

Freshwater mussels also directly provide habitat and modify habitat -- the physical structure created by mussel shells in a river bed provides habitat for other organisms. Algae grows on mussel shells, which is consumed by macroinvertebrate grazers. Hard mussel shells provide habitat in areas with softer substrates; crevices in and between shells provide invertebrates with protection from predators and strong flows. Empty shells of dead mussels also provide habitat (reviewed in Vaughn 2017). In western Oregon, for example, crayfish are often observed residing in dead mussel shells. Indeed, freshwater mussel beds have been shown to host a higher abundance and diversity of macroinvertebrates--an important source of food for juvenile salmonids and other organisms--than similar habitat without mussels.

Dense mussel beds can serve as biodiversity hotspots in a river system. When mussels consume, excrete, and deposit nutrients, this can lead to an increase in benthic algae, which then leads to an increase in macroinvertebrates (Vaughn and Spooner 2006; Spooner et al. 2012). Research in northern California demonstrated that benthic macroinvertebrate abundance was greater in the presence of western pearlshell mussel beds, a species that co-occurs with the western ridged mussel, as mussels remove food particles from the water column and excrete these nutrients as biodeposits, making them more available for consumption by the benthic macroinvertebrate community (Howard and Cuffey 2006). Pacific lamprey larvae are also known to grow faster when found near western pearlshell mussel beds, which capture, concentrate, and deposit food near their burrows (Limm and Power 2011). Vertebrate species, such as river otters, rely on freshwater mussels for sustenance, especially when other prey is scarce (Scordino et al. 2016).

As mussels feed, they recycle nutrients by consuming and storing them in their tissues, or converting them to feces or pseudofeces, or to dissolved nutrients (Strayer 2014). En masse, mussels can significantly improve water quality through this process, abating excess nutrients. When mussels excrete soluble nutrients, they are consumed by algae and heterotrophic bacteria, and those nutrients cascade up aquatic food webs.

IX. CONCLUSION

Freshwater mussels are important components of aquatic ecosystems, yet as a group, face widespread declines in the U.S. Although the western ridged mussel was historically distributed from southern California north to southern British Columbia and east to Idaho and Nevada, the species inhabits closer to half of its historic range. Yet, in many of the rivers where it has recently been documented, it is often known from only a few live individuals or shells. In other rivers where it has recently occurred in abundance or across multiple reaches, enigmatic die-offs pose an incredible threat to the species' viability. These observations, combined with numerous threats to the species' aquatic habitats, indicate that the species should be listed as an Endangered Species under the U.S. Endangered Species Act in order to prevent extinction.

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