Mussel-Friendly Restoration

A Guide to the Essential Steps for Protecting Freshwater Mussels in Aquatic and Riparian Restoration, Construction, and Land Management Projects and Activities

Emilie Blevins, Laura McMullen, Sarina Jepsen, Michele Blackburn,
Aimée Code, and Scott Hoffman Black

XERCES SOCIETY
for Invertebrate Conservation

THANK YOU

Many individuals contributed to the development and improvement of this document and the companion *Conserving the Gems of Our Waters* (available at http://xerces.org/conserving-the-gems-of-our-waters). For the full list of contributors, please refer to page 77 of that document. Special thanks to technical contributors and reviewers of this document: Beth Glidewell; Kevin Aitkin, USFWS; Emily Davis, Northwest Indian Fisheries Commission; Alexa Maine, Confederated Tribes of the Umatilla Indian Reservation; Bengt Miller, Skagit Fisheries Enhancement Group; Donna Nez, Confederated Tribes of the Umatilla Indian Reservation; Melissa Olson, The Nature Conservancy; Ted Parker, Snohomish County Public Works; Teal Waterstrat, USFWS.

Photograph courtesy Emilie Blevins/The Xerces Society.

Acknowledgments

Funding for this report was provided by the Confederated Tribes of the Umatilla Indian Reservation, Meyer Memorial Trust, The Nature Conservancy and Portland General Electric Salmon Habitat Fund, the Alice C. Tyler Perpetual Trust, and Spirit Mountain Community Fund.

Citation

Blevins, E., L. McMullen, S. Jepsen, M. Blackburn, A. Code, and S. H. Black. 2019. Mussel-Friendly Restoration: A Guide to the Essential Steps for Protecting Freshwater Mussels in Aquatic and Riparian Restoration, Construction, and Land Management Projects and Activities. 32 pp. Portland, OR: The Xerces Society for Invertebrate Conservation. (Available online at www.xerces.org).

Photographs

Our thanks go to the agencies, organizations, and individuals for allowing us to use their photos. Ownership of all photos remains with the photographers.

Front Cover

Western pearlshell mussels; photograph courtesy Emilie Blevins/The Xerces Society.

MUSSEL-FRIENDLY RESTORATION

A Guide to the Essential Steps for Protecting Freshwater Mussels in Aquatic and Riparian Restoration, Construction, and Land Management Projects and Activities

---

Contents

(Continued on next page)

MUSSEL-FRIENDLY RESTORATION

Although restoration will ultimately improve habitat for freshwater mussels, they must first survive the process. Mussels are sensitive to disturbance and limited in range. By incorporating the steps and recommendations in this guide into your work, you have the potential to protect and restore mussel populations, which, if conserved, will benefit the entire ecosystem. This document outlines the most pertinent information for restoration planners, site managers, fisheries biologists, contractors, and others as they work in the field. It is intended as a quick reference for protecting freshwater mussels, highlighting key best management practices presented in *Conserving the Gems of Our Waters* (available at http://xerces.org/conserving-the-gems-of-our-waters). Please refer to that document for the research and rationale behind the recommendations in this guide, and to find comprehensive information and best management practices.

Photograph courtesy Emilie Blevins/The Xerces Society.

WESTERN FRESHWATER MUSSELS AND RESTORATION

Freshwater mussels provide essential contributions to aquatic communities, salmon, other freshwater fish and macroinvertebrates, and humans, yet they are often overlooked. Mussels purify water by filtering, reducing turbidity, and removing contaminants. They provide and enhance habitat for other macroinvertebrates, support aquatic food webs, and cycle and store nutrients. In Western North America, mussels occur in many watersheds that support imperiled salmon, steelhead, and trout. If you work in freshwater ecosystems, there's a good chance your work will affect mussels.

Freshwater mussels, however, are among the most imperiled groups of species globally. In North America, more than 10% of species have already gone extinct. In western North America, mussel populations are declining in many watersheds across their ranges. This makes it ever more urgent that mussels are protected during projects in aquatic and riparian areas.

To live and reproduce, freshwater mussels require perennial rivers, streams, lakes, and ponds; the presence of fish; and an appropriate substrate into which they can burrow. They are present year-round, whether visible or burrowed below the surface of substrate, and are rather sedentary, often moving not at all or only a few meters over the course of their lives—which can be a long time. Mussels are unlike many other freshwater invertebrates in their longevity, reaching 10 to 100+ years of age. Given the right conditions, these animals will develop extensive "beds" of tens to tens of thousands of individuals, living in densities of up to 400 mussels/m^2. In places where mussel beds have not experienced adverse impacts, they may persist for many decades. This is evidenced by the presence of very old animals, as well as examples where mussel beds were first documented nearly 100 years ago and still occur today.

Restoration of freshwater habitats is critical to improving the condition of many western North American lakes, rivers, and streams that have been compromised by human practices. Mussels stand to benefit from restoration of freshwater habitats, but as species that are sensitive to disturbance and already limited in range, restoration—which often involves a component of disturbance—can also pose risks to mussels. Mussel populations can take decades to recover at sites where they have been extirpated. In addition, these impacts, when considered over the many watersheds and sites where restoration occurs, can result in multiple mussel beds in the same watershed being impacted over multiple years.

By incorporating the steps and recommendations in this guide into your work, you have the potential to protect and restore mussel populations to the benefit of the entire ecosystem.

> ALTHOUGH RESTORATION WILL IMPROVE HABITAT FOR MUSSELS, THEY MUST FIRST SURVIVE THE PROCESS.

Structure of this Guide

This guide is a companion to *Conserving the Gems of Our Waters*, not a replacement. It presents a summary of best management practices (BMPs) to protect mussels during restoration and construction activities, accompanied by a series of "Issues" and "Solutions" to help you address common challenges. These are based on questions and concerns shared with Xerces Society staff, and reflect the reality of managing habitats and projects. There is also a western mussel identification guide provided at the end of this document. For more information about freshwater mussel biology and conservation, refer to "Additional Resources" (page 32).

NOTE: It is recommended that you start with the first BMP, determining if mussels are present. If you are unable to begin with that step, however, best practice is to assume that mussels are present at your site and proceed to implement other BMPs at your site, especially #3 and #4.

BMP 1

DETERMINE IF MUSSELS ARE PRESENT

How do you begin to incorporate mussels into your project?

Determine what you have as soon as possible! Knowing whether and where mussels occur is the first step to successfully protecting populations. Mussels are commonly found in areas targeted for restoration, such as in deep sediment that may have accumulated behind undersized culverts, in riprap where sediment has filled in gaps between stable rocks, or other hydraulically stable areas.

It is most helpful if you can conduct surveys as much as a year or more before you begin your project, buying you more time to plan work around freshwater mussel beds. While you can still protect populations to some degree at multiple points during the development and implementation of your project, mussels have the best chance of survival if you are aware of them early in the process. In addition to reviewing the following issues and solutions, refer to more detailed information on conducting surveys, beginning on page 92, of *Conserving the Gems of Our Waters*. If you determine that mussels are present at your site, consult with an expert to plan the next steps. Before planning or executing a mussel survey, review the following issues and solutions.

ISSUE 1

You don't know whether mussels are even found in your watershed or general area.

SOLUTION

Access the following resources for more information about mussel occurrence and distribution in your area:

1. Request distributional data from the Western Freshwater Mussel Database (link in "Additional Resources," page 32).

2. Contact your local agency fish or wildlife biologists for more information about whether mussels have been observed in the area.

However, because western mussels are still highly under studied, keep in mind that mussel observations may not have been reported in your area. A lack of documented observations does not mean there are no mussels in the area.

ISSUE 2

You know mussels are present in your watershed, but you are unsure whether mussels occur at your project site.

SOLUTION

Conduct a preliminary survey (or contract with an experienced surveyor to conduct the survey), covering the entire site or project area to document whether and where mussels occur, in approximately what abundance, and which species (see page 29). Note locations with the highest density of mussels, information that can be later used in project design. Mussels often occur in a patchy distribution, so surveys are best conducted across multiple habitat types (Figure 1).

- Use gear that has been disinfected to avoid introduction of invasive species and diseases (see inset on page 7).
- Conduct the survey when conditions are clear and water levels or flows are low enough to survey safely and provide an unobstructed view of the bottom and bank. Avoid surveying under especially cold conditions, when mussels may be burrowed and out of sight.
- Survey any habitat that remains inundated each year (even pools within streams that are otherwise dry, ephemeral, or seasonal as well as man-made habitat like some ponds or ditches).
- Conduct a survey specifically for mussels, focusing your search on the substrate and along the bank. Surveys for fish or benthic macroinvertebrates, with opportunistic observations of mussels, are a good way of doing a coarse, large-scale assessment of presence–absence, but for a restoration project, where it is important to find as many of the mussel locations as possible, may miss mussels and in this case are insufficient for determining mussel presence.
- Document the location of live mussels, not just shells. Shells can accumulate downstream or in depositional areas away from the actual mussel bed. If you find unweathered shells or shell fragments, there could be a mussel population nearby.

Figure 1. Illustration of how a thorough site search can be planned, including surveys of upper project boundary (dashed line) and diagonal and bank to bank transect lines (arrows). White ovals show locations of dense mussel beds that were found. (Data Source: CTUIR. Map Source: Google, DigitalGlobe.)

ISSUE 3

Surveying the entire project site is impractical. For example, portions of the site have unsafe survey conditions, you don't have enough time to survey the entire site because it is too extensive, or you will be conducting your restoration work in only a portion of the site.

SOLUTION

Conduct a targeted survey effort based on your needs or limitations, while also looking for evidence of mussel occurrence in a less-intensive manner.

- If you are only conducting restoration work in a portion of the site, survey the Area of Direct Impact (ADI), which refers to the footprint of project elements (structures) or activities (excavation, dewatering, filling). Include areas up and downstream where effects such as changes in flow, inundation, scour, deposition, or other processes could occur. Aim to spend 4–8 person-hours minimum, depending on the area that needs to be covered. During surveys, document information on associated habitat (e.g., substrate type and size) and relevant habitat features (e.g., presence of stabilizing features like boulders or bedrock) for use in project design.
- If you are unable to conduct a survey in areas where project work will occur, consult with a mussel expert to determine whether mussels are likely to occur there.
- If your site is extensive and you have concerns about covering the full length or area of the project, recruit volunteers or colleagues to assist with the survey effort. With brief training, surveyors can dramatically increase the area that can be surveyed and also provides opportunities to engage with volunteers.
- During the course of other work, such as site visits and other data collection,

keep an eye out for shells along banks, shores, or in shallow water.

ISSUE 4

You are unsure if handling freshwater mussels requires a permit, or if you are unsure of how to obtain a permit.

SOLUTION

Determine if you will need a permit for your survey by contacting your state fish and wildlife agency. A summary table by state or province is also available on page 23 of *Conserving the Gems of Our Waters* (see Additional Resources for details).

NOTES

A Note on Gear Disinfection

- **Clean**: Remove debris before leaving a site. Use a high pressure spray or scrubbing brush to remove materials stuck on or in cracks or seams. Disinfect with Virkon® Aquatic (soaking gear in a 1% solution for 10 minutes) or a bleach solution (soaking in a 10% solution for 10 minutes).
- **Drain**: Drain water from containers before leaving a site.
- **Dry**: Allow equipment to dry before use in new waterbodies.

BMP 2

DESIGN PROJECTS TO AVOID IMPACTS TO MUSSELS

How can you design your project to be mussel friendly?

Mussel beds are an underwater ecosystem, so it may be more helpful to view them like infrastructure that must be protected (such as a bridge) or like a sensitive habitat (such as a wetland) to be preserved. If an abundant mussel population and the benefits that it provides is lost, the ecological condition of a restored site may, in fact, be poorer than prior to restoration, so when projects and mussels overlap, often the best option is simply to protect the mussel population where it occurs, if possible. With that in mind, as you design your restoration project, it is worth considering the following questions:

- Is it possible to conduct your restoration work at a site or another area within your site where dense mussel beds do not occur?
- Is it possible to design the location of or reduce the footprints of project elements or activities to reduce the magnitude of impact?
- Is it possible to preserve existing areas of stabilized habitat and maintain existing flow and inundation over mussel beds?

> WHEN PROJECTS AND MUSSELS OVERLAP, THE BEST OPTION MAY BE SIMPLY TO PROTECT THE MUSSEL POPULATION WHERE IT OCCURS

As you consider opportunities to design your restoration project to protect freshwater mussels and enhance habitat, review the following issues and solutions.

ISSUE 5

You are looking to design your project to avoid impacts to mussel beds.

SOLUTION

In order to include mussels when designing your project, you will need to:

1. Map information from the mussel survey(s), including locations where mussels are present and their relative density.
2. Determine if or where the activities listed below, which could impact mussels, could occur, as well as the overall footprint of such activities; include outputs from flow or hydraulic modeling if applicable. Keep in mind that the following list is not comprehensive and that you should consult with a mussel expert to assess whether other activities also have the potential to impact mussels.
    - Changes in flow (magnitude) or inundation (drawdown or dewatering)
    - Fill of existing inundated habitat, alteration of the thalweg, or removal or movement of sediment, including along banks, shores, and in bottom substrate
    - Removal of stabilizing structures or placement of new structures or habitat features
3. Design your project to avoid these activities (or their subsequent effects on flow or scour) where mussels occur, including a buffer of 5 meters or larger from mussel beds.

ISSUE 6

You are not able to fully design your project to avoid mussels, but would like to design your project to be as mussel friendly as possible.

SOLUTION

You can design your project to be more mussel friendly by:

- Avoiding the densest concentrations of mussels, protecting beds of multiple species, and leaving as much existing mussel habitat as possible, as well as salvaging mussels from areas where impacts cannot be avoided (page 11).
- Considering an overall project design that adds or preserves some areas of stabilized habitat. When considering removal of structures such as historic revetments, rip rap, or pilings, determine whether such structures have created habitat for mussels and could be retained.

- Using "soft" approaches for bank stabilization (such as native vegetation, rootwads, or soil end wraps with plantings). Avoid using loose materials like riprap or rock on steeper slopes and in waterbodies where sediment is insufficient to fill large gaps between materials.
- Minimizing bank disturbance generally, as well as considering options for reshaping, lowering, or reducing the angles of banks and shores in preference over more built approaches. Return any native or natural materials (e.g., rocks or logs) removed or disturbed to their original location or an appropriate alternative, and fill holes remaining after structures are removed or demolished.

NOTES

BMP 3

SALVAGE AND RELOCATE MUSSELS WHEN IMPACTS ARE UNAVOIDABLE

When and how should you salvage and relocate mussels?

If you must undertake activities where mussels occur, such as replacing an undersized culvert or dredging contaminated sediment, plan to salvage and relocate mussels in advance (ideally, more than a year in advance) of implementation. As a conservation tool, salvage and relocation has had, in some cases, very poor success, making it an option that should be used only when disturbance to mussels during the course of your project cannot be avoided.

YOU WILL NEED TO RELOCATE MUSSELS IF:

- Your project site or the location of project elements is inflexible and following other BMPs described in this document will not avoid direct mortality of mussels.
- To complete the project, you must temporarily or permanently dewater or drawdown an area where mussels occur.
- Indirect impacts are expected or found to result in mussel mortality, such as sediment deposition resulting from an upstream dam removal.

BMPs related to dewatering or drawdown are also discussed in BMP 5 (page 20), but it is worth noting here that mussels can die quickly when they become exposed to the air, particularly when conditions are warm. Although mussels are able to crawl slowly, their ability to move is limited, especially under stressful conditions, and mussel kills are likely during these events (see pages 16 and 17). To avoid mussel kills, you should coordinate early with a freshwater mussel expert to evaluate your project. You will

need to avoid extremely hot temperatures and stressful conditions during salvages and be prepared to carefully handle mussels. To conduct your salvage and relocation you will need to:

- Identify potential relocation sites.
- Develop a salvage and relocation plan.
- Procure permits, if necessary (see BMP 1).
- Budget for and acquire all necessary equipment in advance.
- Conduct sweeps to salvage mussels at least twice before implementation.

For step-by-step instructions on salvaging and relocating mussels, read the full BMP recommendations on page 55 of *Conserving the Gems of Our Waters*. Refer also to Issues 7, 8 and 9, and the recommended solutions.

ISSUE 7

You need to identify potential relocation sites.

SOLUTION

The following principles can be used to identify candidate relocation sites (see Figure 2). It is best practice to identify more than one in the event that you encounter many more mussels than anticipated (which commonly occurs!) or conditions change at your primary site.

Figure 2. Candidate mussel relocation sites should occur in the same watershed upstream of the project area and have an existing mussel population with similar habitat features as the salvage site. (Photograph courtesy Michele Blackburn/The Xerces Society.)

1. Candidate relocation sites should
    - occur in the same watershed,
    - have similar gradient and substrate,
    - have an existing population of mussels of the same species, and
    - be located in habitat upstream of the project area to avoid impacts that will extend downstream beyond the project site.
2. You should avoid relocating mussels to
    - newly created habitat,
    - habitat without burrowing substrate,
    - sites without an existing population of mussels,
    - habitat without host fish,
    - sites that may be dredged,
    - areas that may become dry or have stagnant flow,
    - areas that dry or scour,
    - sites that may be restored or disturbed in the future, or
    - sites with other concerns, such as point source discharge.

If there are no other existing mussel populations nearby, refer to other recommendations on page 56 of *Conserving the Gems of Our Waters*.

ISSUE 8

You do not know the exact footprint of the project or the plan will likely be altered during implementation.

SOLUTION

Salvage as many mussels as you can in the vicinity of the potential areas of direct impact (ADI). Flag areas of larger mussel aggregations that occur outside the potential ADI and buffer to signal to the crew the areas they need to specifically avoid. Work with the crew lead to be onsite during implementation so that you can direct them to avoid areas where mussels occur but from which they could not be salvaged in advance.

ISSUE 9

You must salvage and relocate mussels from your project site without advance planning.

SOLUTION

In the case of an emergency salvage, take the following actions:

- Have equipment on hand during all projects that will enable you to conduct an emergency salvage, such as mesh bags and a bubbler bucket or cooler with towels and ice packs.
- If you have begun dewatering, delay total dewatering in order to gain more time to salvage and relocate mussels. Construct temporary holding pens or place mussels in mesh bags in an area that is not being dewatered to gain more time, but do not pile them on one-another.
- If there are more mussels to salvage than you are able to before they are killed, prioritize salvaging individuals of each mussel species present and mussels from the largest aggregations or from areas that will be most impacted, such as within the ADI.
- If you must quickly place mussels in a new site without having evaluated sites for candidacy as described above (Issue 7), return to that site the next day to determine if mussels are in distress (see pages 16 and 17) or will need to be relocated to another site.
- Place mussels individually and gently on their sides, allowing them to re-anchor themselves. **Mussels should not be dumped from buckets, even if you are in a rush to relocate them, as they are likely to perish if relocated in this manner.**

For more information, see *Conserving the Gems of Our Waters*.

NOTES

BMP 4

PROTECT MUSSELS FROM IMPACTS DURING CONSTRUCTION AND DEWATERING

How can you protect mussels onsite during project implementation?

If you have found mussels at your project site but determined that mussels do not fall within the immediate footprint of project structures or elements, you may still need to take steps to avoid impacts to mussels. Some basic considerations include:

- Establish and mark an exclusion area around mussels. This should include the bed, plus a buffer distance of at least 5 meters.
- Avoid constricting flow and increasing velocity or scour near mussels.
- Avoid activities that will result in recurring disturbance when possible. For projects that require phasing, such as some construction or demolition activities, minimize the time period over which discrete in-water disturbances occur.
- When possible, phase construction or demolition activities to minimize in-water disturbances, including reducing the amount of time temporary in-water structures (e.g., piles or diversions) are in place and using the minimum number of these structures possible.
- Monitor mussels for signs of distress (pages 16 and 17) and be prepared to salvage and relocate them (page 11). Have equipment on hand to conduct an emergency salvage, such as mesh bags and a bubbler bucket or cooler with towels and ice packs.

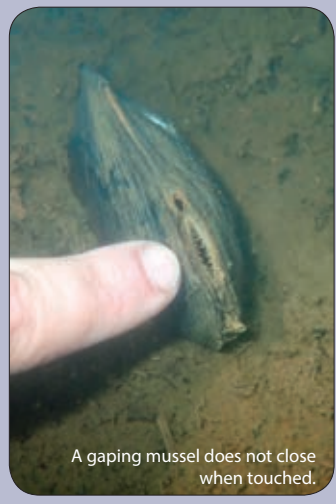
Refer also to the issues and solutions discussed on pages 18 and 19.

SPECIAL ISSUE

A note on recognizing when mussels are in distress

Often, you can recognize that mussels are in distress based on site conditions. If water levels are dropping, leaving mussels exposed, or water temperatures are high enough to stress fish, mussels are likely suffering. You should take notice if you observe any of the following:

- many mussels that are dislodged, lying flat on the substrate, or buried under sediment and unable to right themselves or dig out overnight,
- mussels that are persistently "gaping," not closing quickly or tightly in response to touch, or
- many mussels attempting to move away in apparent avoidance of the project area.



A gaping mussel does not close when touched.

These are all signs that mussels are in distress. If you observe any of these during your project, you should consider relocating mussels away from the impacted area to avoid a mussel kill.

A mussel die off.

A sick mussel from an ongoing die-off lies next to a burrowed, apparently healthy mussel.

In recent years, biologists have also observed a number of unexplained mussel die-offs. Although healthy populations of mussels often have a number of empty shells present, there are typically many healthy individuals nearby. In contrast, you may be witnessing a mussel die-off if you observe:

A mussel attempting to escape adverse conditions by crawling away. (Photograph courtesy Matthew Baerwalde/Snoqualmie Indian Tribe.)

- large numbers of mussels wasting away (e.g., gaping, bloated) or dead (with an accompanying foul smell),
- many floating shells, or
- many empty shells sitting upright in the substrate.

These observations are unlike those of animal predation, which often consist of piles of broken shells with bite or scratch marks.

If you observe what you think may be a mussel die-off, contact the Xerces Society (mussels@xerces.org) and your state fish and wildlife agency (see "Additional Resources").

A predated mussel.

All photographs courtesy Emilie Blevins/The Xerces Society, unless otherwise noted.

ISSUE 10

You may need to dewater or drawdown an area as part of your project, but your preliminary surveys did not detect mussels in the drawdown footprint or you were unable to effectively survey the area that will be drawn down.

SOLUTION

Mussels are commonly encountered during dewatering, particularly if they were buried under the substrate and not easily seen during surveys. Ideally you will have already salvaged mussels before dewatering occurs. However, in the event that mussels may still be present in the footprint, you should:

- Dewater an area slowly to allow mussels time to become visible and be salvaged.
- Minimize the area that will be dewatered, and if feasible, do not completely dry out habitat. Instead, divert a portion of the flow, leaving six or more inches of water.
- When re-watering habitat, minimize turbidity and erosion and monitor for any stranding of mussels upstream of the diversion.
- If feasible, maintain/add habitat features that provide depressions or microrefugia for protection during drawdown or natural drying.

ISSUE 11

Mussels occur downstream or just upstream of the area you will be working in and not directly within the project footprint. However, construction activities could impact mussels.

SOLUTION

Take the following steps to avoid downstream impacts:

- Site any bypass systems for water used in construction away from mussels and return high-quality water at natural temperatures downstream of mussels.
- Place infrastructure above ordinary high water if possible. If these must be in-water, design structures so they are unlikely to trap debris and monitor them so that debris is quickly removed.

- Use containment systems to prevent pollutants, mobilized soil, or debris from contaminating water, and convey stormwater or runoff from construction activities or structures away from mussel habitat and route through a filtering and settling treatment before returning. Remove any debris by lifting; do not drag it through the water or substrate.
- Minimize erosion resulting from activities like clearing and grubbing or when contouring or shaping banks or shores. Keep soils or other materials intact when excavating or filling and minimize the amount of vegetation cleared, leave root systems intact, and replant with native plants appropriate for the site.

NOTES

BMP 5

PROTECT MUSSELS FROM IMPACTS DUE TO WATER MANAGEMENT ACTIVITIES

How can you adapt water management to protect mussels?

Although adaptable, mussels are sensitive to sudden changes in depth of water, extent of inundation, rate of flow, and water quality, including turbidity and sedimentation that can result from water management activities such as dam operations. Review the following issues and solutions to reduce impacts to mussels.

ISSUE 12

You are developing or implementing environmental flows prescriptions or other conservation-based practices as part of dam operations or diversion management.

SOLUTION

You can incorporate the following recommendations (based on research cited on page 48 of *Conserving the Gems of Our Waters*), including those in Table 1.

- Avoid large, rapid reservoir drawdowns. Also avoid large, extended sediment flushes and ensure that sediment is uncontaminated.
- Time sediment flushes to occur around the natural time a sediment flush would occur.
- Generally, limit the duration of sediment release projects near mussel beds and monitor for burial of mussel beds and other impacts.

Table 1 Summary of Recommendations for Management of Diversions, Dams, or Environmental Flow Programs for Western Freshwater Mussels.

Flow Characteristic	Recommendation
Magnitude	• Avoid extensive drying or complete dewatering for any length of time without relocating mussels first. • Avoid flows that significantly increase siltation of substrate. • Avoid very high flows for long periods of time and during sensitive life stages. High flows can also impact feeding and growth or scour out sediments needed for burrowing.
Frequency	• Implement flow events at frequencies that would be similar to natural flows in that river basin. • Avoid too-frequent high flows that could impact recruitment over multiple years.
Duration	• Implement both the lowest and highest flows for short durations to reduce any impacts from turbidity.
Timing	• Consider impacts of timing of flow events on the thermal profile of a river, especially in relation to freshwater mussel and host fish life history. • Avoid very high, very low, or pulse flows during sensitive life stages, particularly when mussels may interact with host fish. Also avoid high flows when mussels may be more susceptible to dislodgement, particularly during months when they are actively feeding and reproducing. • Implement flow events when they would naturally occur in the river basin, and avoid times when air or water temperatures may be more stressful to exposed or active mussels.
Rate of Change	• Ramp-up higher flows gradually, rather than pulsing, to reduce potential for dislodgement. • Decrease flows with a gradual draw-down, rather than rapidly, to avoid stranding.

- Avoid discharging return flows in the immediate area of mussels. Discharge only high-quality water of normal temperatures that mimic natural flows into waterbodies containing mussels.
- Manage flows from dams to maintain natural low flows and avoid drying and dewatering mussels and their habitat. Use guidelines from Table 1 to develop environmental flow prescriptions or augment dam operations.

ISSUE 13

You are planning to remove a dam and mussels occur in the waterbody or watershed.

SOLUTION

Incorporate mussels into dam removal planning, including surveys, salvage, and relocation efforts in advance of implementation. Additionally, when removing dams, choose mussel relocation sites that will not be further impacted by increased sedimentation and channel migration. If you expect a large release of sediment, minimize the transport of fine sediments by creating a pilot channel and stabilizing exposed habitat.

NOTES

BMP 6

PROTECT MUSSELS FROM OTHER COMMON LAND OR RESOURCE MANAGEMENT ACTIVITIES

What steps can you take to protect mussels during other common restoration or management activities?

You may plan to undertake many other management activities either at or within aquatic habitat. This may include managing and treating invasive vegetation, dealing with other aquatic invasive species, or addressing issues with contaminants, including contaminated sediment. Mussels can be sensitive to chemicals and contaminants, many of which have not been tested for their effects on western species. Review the following issues and solutions to protect mussels during these activities.

ISSUE 14

You must deal with invasive plants at your site but want to limit exposure of mussels to chemicals or other impacts such as loss of shade or increased sediment inputs.

SOLUTION

Before engaging in vegetation management activities in riparian and aquatic habitats near mussel populations, develop an integrated vegetation management plan that addresses weed issues in the area, methods to prevent re-establishment, diverse management techniques, and approaches to reduce risk of herbicides to non-target organisms. Additionally, incorporate the following practices into your work:

- During site preparation, eliminate weeds and weed seeds to keep habitat intact and reduce potential for re-infestation.
- Avoid use of herbicides in water and limit use along banks near mussels, especially those shown to have negative effects on mussels (see discussion on page 41 of *Conserving the Gems of Our Waters*).
- As feasible, apply herbicide applications directly to unwanted plants to minimize the treated area, and use the lowest effective concentration and fewest number of applications to achieve management. Monitor to identify whether applications impact mussels.
- Utilize methods such as hand pulling and cutting in preference to mechanical methods of treatment.
- Conduct work in stages and replant bare areas with native vegetation, especially species with complex root systems that support banks and shores. Avoid total removal of vegetation.
- Locate water withdrawals for restoration projects (such as for use in controlled burns or temporary irrigation) away from mussel beds.
- If grazing is used to control vegetation, restrict animal access to banks and shores to reduce erosion and trampling of mussel beds.
- Be aware of and follow all regulations associated with herbicide use and application, including licensing requirements.

ISSUE 15

You are preparing plans to deal with infestations of invasive aquatic species, such as zebra mussels, New Zealand mud snails, nonnative fish, or other animal species.

SOLUTION

Implement the following practices to limit impacts to native mussels:

- Avoid use of methods such as impermeable benthic barriers, which can isolate or damage mussels and their habitat.
- Rotenone applications: Limit rotenone exposure near mussels to no greater than 4 ppm for less than ~12 hours.
- Molluscicide applications: Field test use of molluscicides like Zequanox® on western freshwater mussels before use.
- Evaluate the impacts of other emerging methods of management on western mussels prior to implementation, including use of carbon dioxide or salt to treat or prevent aquatic invasions.
- Follow the recommendations for disinfection of equipment (page 7) to avoid introducing invasives.

ISSUE 16

You must conduct environmental remediation activities at or near a site where mussels occur.

SOLUTION

Implement the following practices to limit impacts to native mussels:

- Identify root causes of contaminant transport and reduce inputs prior to disturbing aquatic habitat.
- Avoid methods that require complete site dewatering and/or dredging, and replace dredged and/or cover capped sediments with natural habitat features. To permit mussels to burrow, ensure that sediment includes fines and is at least 1 foot deep.
- Maintain as much uncontaminated natural vegetation and substrate material as possible. Natural areas within remediation sites may provide appropriate places to relocate mussels.
- Ensure that mussels are directly considered in approaches based on Monitored Natural Recovery.
- Minimize drift of contaminated sediment when dredging or capping. If using conventional capping methods, avoid using large quantities of structures or materials with flat surfaces or large pores.
- Minimize the dosage of sorbent materials and mix products into the sediment to decrease uptake by organisms and avoid direct applications to mussels. Use larger particle sizes that are less likely to clog gills.

NOTES

BMP 7

MONITOR MUSSELS BEFORE, DURING, AND AFTER RESTORATION

How can you incorporate monitoring into your work?

Biological monitoring is important for tracking restoration effectiveness, and mussels are well-suited to monitoring—individuals can persist for multiple years in the same location under good conditions. Because mussels also contribute to healthy aquatic ecosystems and can be sensitive to degraded water quality, mussels can serve as important sentinels for overall watershed health. Additionally, mussel populations have rarely been monitored in western North America, so the information you collect can contribute to a greater understanding of freshwater mussel populations. Fortunately, data collection can also be easily incorporated into existing snorkel survey efforts. Below are some issues and solutions for incorporating mussel monitoring into your work.

ISSUE 17

You would like to incorporate mussel monitoring into your work but are unsure where to begin.

SOLUTION

Monitoring approaches depend in part on the questions you are looking to answer, so identify your questions and goals first. Consider which of the following approaches might pertain to your specific site condition, questions, or goals. Refer to page 25 of *Conserving the Gems of Our Waters* for details on mussel monitoring methods.

- **BMP implementation effectiveness**: During restoration implementation, you can monitor for real-time impacts and evidence of mussel distress (pages

16 and 17). Documenting how mussels respond to restoration can provide information to improve mussel BMPs and is easily accomplished by observing freshwater mussels at your site during and after restoration activities.

- **Salvage and relocation success**: Salvage and relocation efforts often vary in their effectiveness at conserving mussel populations. To evaluate the effectiveness of a mussel salvage, you can monitor mussels at several intervals following the salvage. For example, monitor 1–2 months after a salvage to determine if the salvage was successful in the short term, after 1 year to determine if the mussel population was able to re-establish at the new site, and between 2–5 years to assess whether the relocation was ultimately a viable strategy.
- **Benefits of mussels to restoration, or of restoration to mussels:** Mussels contribute to uplift of restoration sites. Restoration projects also have the potential to create mussel habitat. Very little monitoring has been conducted to evaluate the contributions of mussels to restoration work. Additionally, few projects examine whether mussels have been able to recolonize restoration sites. Monitoring restoration sites for the presence and contributions of mussels can provide valuable insights, including data regarding the restoration designs or habitat features that best support mussels. Note that mussels can remain quite small and difficult to detect for 5 or more years (depending on the species).

NOTES

What other information is available to you?

GLOSSARY

ADI: the area of direct impact, referring to the footprint of project elements or activities

Aperture: either of two fleshy openings visible when a mussel is open and filtering

Hinge: the connection point between two valves of the shell

Host Fish: species of fish to which mussel larvae temporarily attach to complete metamorphosis

Lateral tooth: a thickening of the shell internally along the hinge line

Mussel bed: an aggregation of individual mussels within an area

Papillae: extensions of tissue along the incurrent aperture

Pseudocardinal tooth: a protrusion of the shell internally, appearing knob-like

Umbo: oldest part of the shell near the hinge line and often worn, also called the "beak"

Western pearlshell mussel. (Photograph courtesy Emilie Blevins/The Xerces Society.)

WESTERN MUSSEL IDENTIFICATION GUIDE

Floaters (Genus *Anodonta* or *Sinanodonta*)

- Very difficult to identify to species due to wide variety of shapes, sizes, and shell coloration
- Shells thin and smooth, with no hinge teeth
- Inhabit wide range of habitats: low to mid gradient streams, stable backwater areas, lakes and ponds
- Occur mainly at low to mid elevations
- Host fish include dace, redside shiner, sculpin, stickleback, and some salmonids

- Incurrent aperture: papillae singular and "finger-like," ~2–4 cm long
- Excurrent aperture: no papillae, short, ~1 cm long
- Shell size: up to ~180 mm, but highly variable in size depending on species, location, and age of mussel; adults of some species may be half the maximum length in some habitats

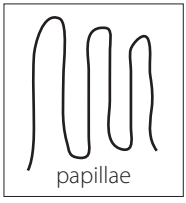
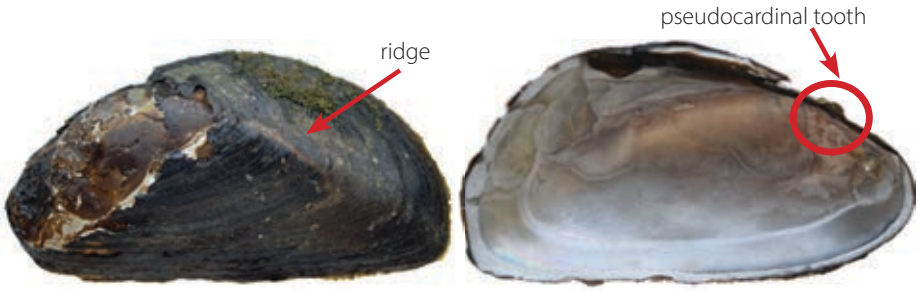


Image credits: Emilie Blevins/The Xerces Society (top 3 photos), Roger Tabor/USFWS (bottom photo).

Western Ridged Mussel (*Gonidea angulata*)



- Shell can be thick, usually with distinctive ridge from umbo to posterior edge, with small or absent pseudocardinal teeth
- Has a strong foot that anchors; animal harder to pull up for examination
- Prefers runs and riffles in low to mid-gradient streams
- Occurs at low to mid elevations
- Host fish understudied but include sculpin

- Incurrent aperture: papillae bifid, branched and non-uniform along "trunk," ~2–4 cm long
- Excurrent aperture: no papillae, short, 1–2 cm long
- Shell size: up to 180 mm

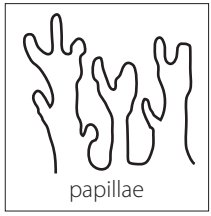
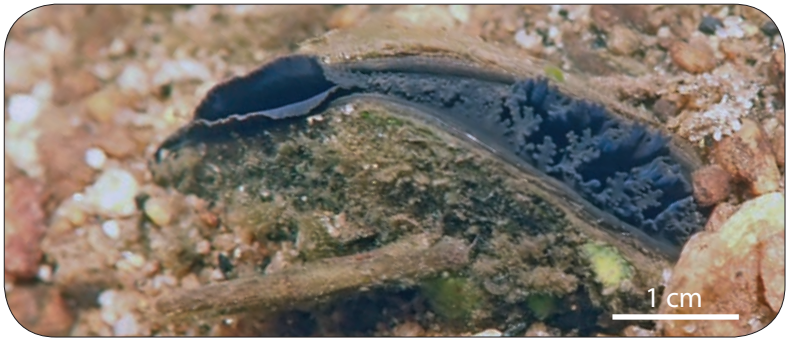


Image credits: Michele Blackburn/The Xerces Society (top 2 photos), Katie Hietala-Henschell/The Xerces Society (bottom photo).

Western Pearlshell (*Margaritifera falcata*)

- Shells can be thick, with lateral and pseudocardinal teeth
- Inhabits flowing rivers and streams
- Occurs at high, mid, and low elevations
- Host fish include multiple species of salmon, cutthrout trout, rainbow trout, and steelhead



- Incurrent aperture: papillae fleshy and "tree-like," ~2–5 cm long
- Excurrent aperture: no papillae, ~2–4 cm long
- Shell size: up to 185 mm

Image credits: Michele Blackburn/The Xerces Society (top 2 photos), Emilie Blevins/The Xerces Society (bottom photo).

ADDITIONAL RESOURCES

For a full list of additional resources, including information on permitting agencies, consult *Conserving the Gems of Our Waters*, available at http://xerces.org/conserving-the-gems-of-our-waters.

- Detailed guidance on conducting mussel surveys, including guidance on handling and data to collect: page 92 in *Conserving the Gems of Our Waters*.
- Information on incorporating mussel monitoring into your work: page 25 in *Conserving the Gems of Our Waters*.
- A review of western mussel life history and habits: page 82 in *Conserving the Gems of Our Waters*.
- A discussion of observations that should be reported: pages 16 and 17 in this document and page 20 in *Conserving the Gems of Our Waters*.
- More information on where to report your observations and access more information:
  - Xerces Society Western Freshwater Mussel Information:
    - Website: http://xerces.org/western-freshwater-mussels
    - Contact: mussels@xerces.org for the Western Freshwater Mussel Database
  - PNW Native Freshwater Mussel Workgroup:
    - Workgroup Email: pnwmussel@googlegroups.com
    - Website: www.pnwmussels.org
  - PNW Mussel Field Guide:
    - Website: http://xerces.org/identification-guides/freshwater-mussel-guide
  - Form for reporting a relocation:
    - Website: http://xerces.org/freshwater-mussel-relocation-form
  - Form for reporting a die-off:
    - Web form: http://arcg.is/0K0SHG
  - iNaturalist project: Freshwater Mussels of the Western U.S.:
    - Website: http://tinyurl.com/jhdbfow

The Xerces Society is a nonprofit organization that protects the natural world by conserving invertebrates and their habitat. Established in 1971, the Society is a trusted source for science-based information and advice and plays a leading role in promoting the conservation of pollinators and many other invertebrates. We collaborate with people and institutions at all levels and our work encompasses all landscapes. Our team draws together experts from the fields of habitat restoration, entomology, education, and conservation biology with a single passion: Protecting the life that sustains us.

The Xerces Society for Invertebrate Conservation
628 NE Broadway Ste. 200 , Portland, OR 97232
tel 503.232.6639 • fax 503.233.6794 • www.xerces.org

Regional offices from coast to coast.

19-013_01