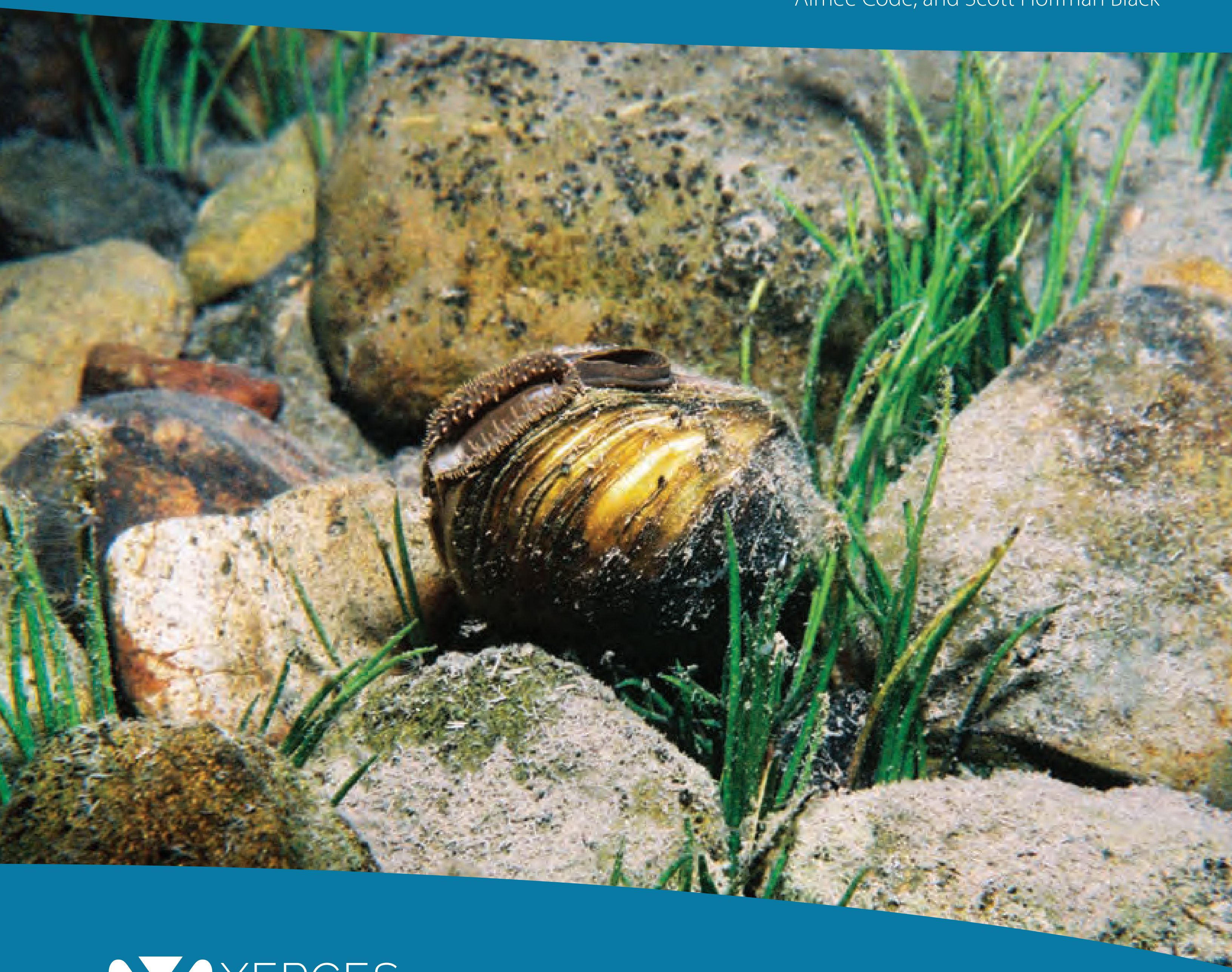
Conserving the Gems of Our Waters

Best Management Practices for Protecting Native Western Freshwater Mussels During 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

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The Xerces Society for Invertebrate Conservation

www.xerces.org

The Xerces® Society for Invertebrate Conservation is a nonprofit organization that protects wildlife through the conservation of invertebrates and their habitat. Established in 1971, the Society is at the forefront of invertebrate protection, harnessing the knowledge of scientists and the enthusiasm of citizens to implement conservation programs worldwide. The Society uses advocacy, education, and applied research to promote invertebrate conservation.

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Cover Photograph

A floater mussel by Roger Tabor, USFWS.

Contents

Acronyms and Abbreviations

ADI	Area of Direct Impact
AFS	American Fisheries Society
APE	Area of Potential Effect
BLM	Bureau of Land Management
BMP	Best Management Practice
BPA	Bonneville Power Administration
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
DOT	Department of Transportation
EPA	US Environmental Protection Agency
ESA	Endangered Species Act
IUCN	International Union for Conservation of Nature
MNR	Monitored Natural Recovery
NAS	Nonindigenous Aquatic Species
ODFW	Oregon Department of Fish and Wildlife
SCP	Scientific Collection Permit
UDWR	Utah Department of Water Resources
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
WDFW	Washington Department of Fish and Wildlife

Western freshwater mussels clockwise from top left: western pearlshell mussel (*Margaritifera falcata*), floater mussel (genus *Anodonta* or *Sinanodonta*), and western ridged mussel (*Gonidea angulata*) shell valves.

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Introduction

Freshwater mussels are native, benthic, filter-feeding animals that live in permanently inundated habitat, such as perennial rivers, streams, lakes, and ponds. Mussels improve conditions for salmon, lamprey, and other native fish by enhancing water quality and supporting rich aquatic communities (Box 1; Figure 1), making them integral to the protection and restoration of native fish populations. Even though restoration of aquatic habitat specifically for the benefit of salmon and other fish is a conservation priority in western North America, the contributions of freshwater mussels to healthy aquatic species and ecosystems has generally been overlooked and undervalued.

The Need for Freshwater Mussel Best Management Practices

Unfortunately, freshwater mussels are also among the most imperiled species in North America (Lydeard et al. 2004; Haag and Williams 2014), and some of our western species of freshwater mussels are declining across their ranges (Table 1; Blevins et al. 2017). These declines are likely a result of a number of interrelated factors, including habitat degradation and impacts to water quality and quantity, but also impacts from aquatic restoration work. Many restoration projects are focused on protection and enhancement of fish and their habitat, but freshwater mussels differ from fish in several important ways that make them vulnerable. Project designs and construction practices that do not consider these biological and ecological differences may not adequately protect freshwater mussels. Indeed, existing populations can be directly harmed if they are not included in project planning and design, and populations may take decades to recover, if they do at all.

MUSSELS ARE FOUND IN FISH-BEARING, PERENNIALLY WET HABITAT AND MAY BE PRESENT AT YOUR SITE

Mussels require permanently inundated habitat and burrowing substrate, making them vulnerable to changes in water levels and dewatering. They are relatively sedentary; sensitive to disturbance, low oxygen, and high water temperatures; and rely on relatively stable habitat that is protected from scouring flows, exposure, and shifting substrate. Because they are also somewhat cryptic, they can easily be trampled, crushed, or dislodged. They also have a complex life cycle that requires temporary attachment to fish for metamorphosis and dispersal (Box 1), so impacts to their hosts, including avoidance of habitat, can impact mussel reproduction.

Box 1. Benefits of Freshwater Mussels and Their Unique Life History

Freshwater mussels provide important benefits to native fish, aquatic ecosystems, and human communities. For example:

- Pacific lamprey larvae can grow faster when found near western pearlshell mussel beds, which capture, concentrate, and deposit food near their burrows (Limm and Power 2011).
- Western pearlshell mussels increase populations of other macroinvertebrates, which are an important food source for salmonids and other native fish (Howard and Cuffey 2006b).
- Floater mussels filter water and can remove pharmaceuticals and *E. coli* (Ismail et al. 2014, 2015).
- Other species, such as river otters, rely on freshwater mussels for sustenance, especially when other prey is scarce (Scordino et al. 2016).

Research has even shown that freshwater mussels can reduce bacterial populations, resulting in lower fish mortality and increased growth (Othman et al. 2015). These and other benefits are also discussed in detail by Vaughn (2017) and Strayer (2017).

Western Freshwater Mussel Life History

There are multiple species of freshwater mussels that inhabit fish-bearing streams, rivers, lakes, and ponds in western North America, from Alaska to Mexico and as far inland as Montana (see Table 1 for a list). Adult mussels burrow into sediment or sit between rocks, and are often not an obvious presence, though they can occur in mussel "beds" consisting of several to tens of thousands of animals. However, because they filter water through their gills to receive oxygen and food, they remove impurities and suspended solids from the water column, and their absence would be quickly felt.

Native freshwater mussels have a life cycle that relies on the presence of particular native fish to be successful. It starts when male mussels release sperm into the water. This is filtered out by females to fertilize their eggs. The eggs are deposited in gill chambers, where they are brooded and the larvae (glochidia) develop. When fully developed, the glochidia are released into the water. At this stage they must attach to host fish or perish. Glochidia live as external parasites on fish for a short period (usually between a week and a month) to complete their development to juveniles. They typically cause little to no harm to their host, and after they release, juvenile mussels bury into the sediment and grow to maturity.

Often, freshwater mussel species are discussed together, as if they are a uniform group, but our native species each have distinct differences in appearance, life history, and habitat needs. Appendix 2 includes detailed descriptions of western mussels, and a more complete description of their natural history and life cycle.

Table 1: The Category of Extinction Risk Assigned to Western Freshwater Mussels

Species/Species Group	Scientific Name(s)	Range Decline	IUCN Red List Status
western ridged mussel	*Gonidea angulata*	43%	Vulnerable
winged/California floater	*Anodonta nuttalliana, Anodonta californiensis*	33%	Vulnerable
western pearlshell	*Margaritifera falcata*	17%	Near Threatened
Oregon/western floater	*Anodonta oregonensis, Anodonta kennerlyi*	26%	Least Concern
Yukon floater	*Sinanodonta beringiana*	unknown	Least Concern

This status, based on Blevins et al. (2017) and Vinarski and Cordeiro (2011; *S. beringiana*), is not regulatory but does indicate the need to conserve declining freshwater mussel populations. Red List status was determined based on range decline thresholds as well as supplementary information regarding mussel die-offs, recent population extirpations, and non-reproducing populations.

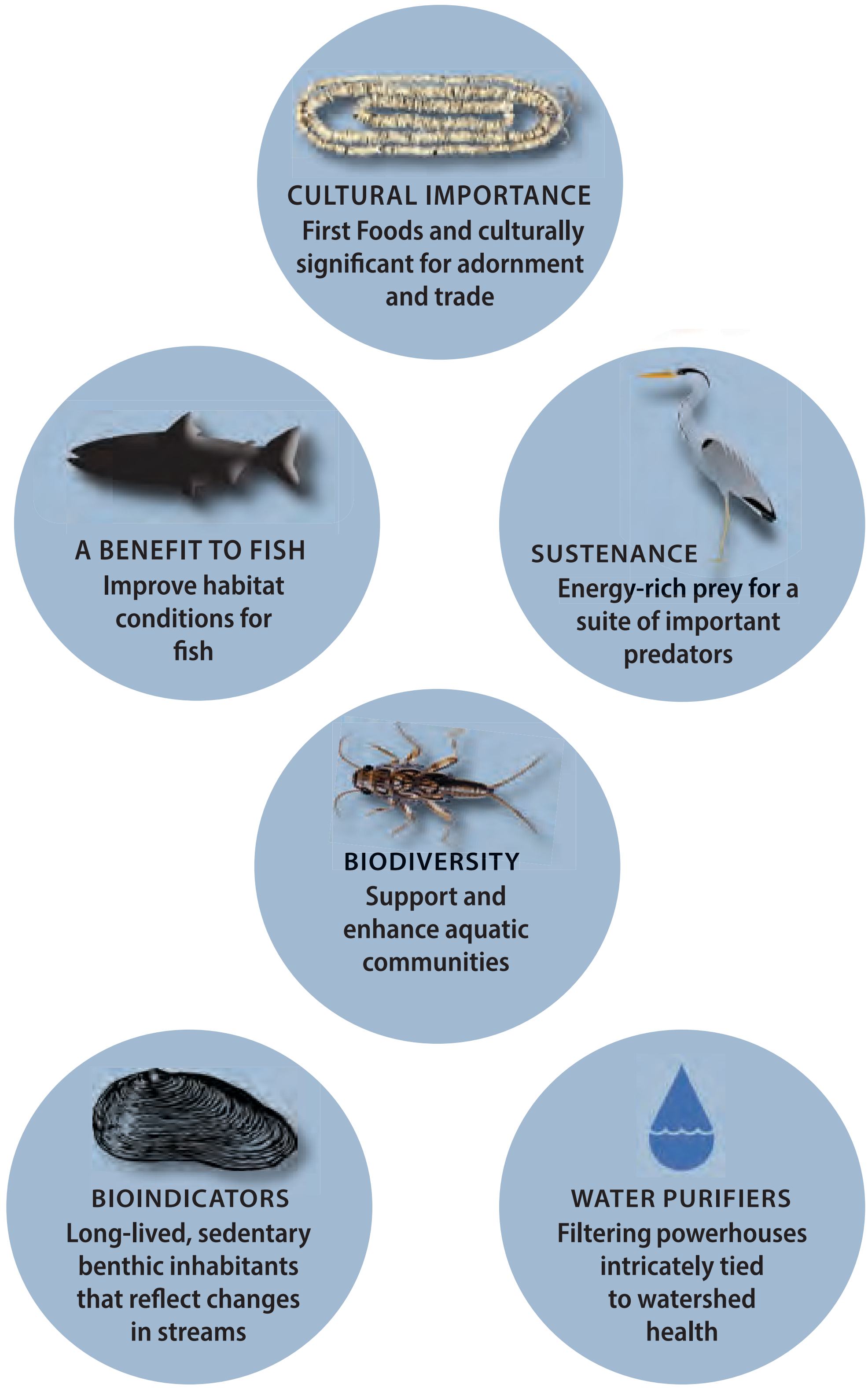
It is not uncommon to hear of projects where freshwater mussels were discovered too late to effectively rescue or protect them, especially when river reaches or ponds are dewatered, usually resulting in die-offs numbering thousands of animals. This situation is especially disheartening and frustrating to those who work in restoration, particularly when projects have otherwise been carefully planned. Loss of freshwater mussels, whether at a single site, throughout a watershed, or across the West, is cause for concern, and there is a great need to protect existing populations. In recognition of this, multiple state wildlife action plans have identified freshwater mussels as "species of greatest conservation need." State and provincial agencies often also require a permit to handle or "take" mussels. Should mussel populations continue to decline, more formal protection may become necessary. Because freshwater mussels provide so many benefits to aquatic ecosystems, protecting existing populations will also preserve existing ecosystem services at your site and ultimately maximize restoration outcomes. As a result, it is becoming ever more important to consider freshwater mussels during your work, including avoiding common pitfalls of projects (Box 2).

Who the Best Management Practices Are For

These guidelines provide practical, usable information to help incorporate freshwater mussels into a wide range of projects or activities throughout the ranges of western North American mussels: Arizona, California, Oregon, Washington, Alaska, Idaho, Montana, Wyoming, Utah, Nevada, British Columbia, and northern Mexico. Because of the wide range of job duties, project types, and work locations, not all best management practices (BMPs) will be applicable to your work. However, as projects are often a coordinated effort, the recommendations are relevant for staff working on aquatic or riparian restoration and construction projects at multiple levels, including

- project planners and managers,
- restoration practitioners and contractors,
- land and water managers,
- biologists and technicians, and
- volunteers and citizen scientists.

FIGURE 1: Benefits of Freshwater Mussels



By familiarizing yourself with the freshwater mussel BMPs in this document, and by determining whether mussels are present in watersheds and potential work sites as soon as possible, you can reduce the chance that your project will negatively impact mussels. Keep in mind that:

- If mussels are present at a project site, they will be present year-round, and seasonal in-water work restrictions that protect mobile species do not protect freshwater mussels. Mussels are relatively immobile, and an individual mussel may have been present onsite for decades or even a century.
- If mussels are extirpated or relocated from your site, it is unlikely that they will re-establish and return to pre-impact condition for years. Mussel populations can take decades to recover from impacts.
- As mussel beds are lost from more watersheds, the chances of recovery also dwindle. Therefore, it is best practice to protect existing mussel beds as much as possible.
- When impacts will be unavoidable, try to plan how you will incorporate BMPs more than a year in advance of project implementation. This is especially important if salvage and relocation is necessary, which ideally should also occur one year prior to implementation.
- It is best not to try and speed up re-establishment by placing mussels at newly created habitat either, which may lack important resources, especially food.

Box 2. Common Pitfalls of Projects

- Generally, people are unaware of western freshwater mussels.
- Protective measures for other species are believed to sufficiently protect freshwater mussels.
- Freshwater mussels are not included in early planning stages, even where permits are required.
- Freshwater mussels are not included in site evaluations, monitored, or used as an indicator of habitat condition or effectiveness of restoration.
- Data or field knowledge of freshwater mussel populations are not regularly included in standard field forms or otherwise reported, reducing the likelihood that observations are recorded and can be used by restoration planners, biological technicians, and monitoring biologists.
- Practitioners are not aware that freshwater mussel populations do not easily recover from many impacts, and recovery can take a decade or more.
- Practitioners are not aware that freshwater mussels require special salvage and relocation techniques that differ from other aquatic species.
- Methods for incorporating freshwater mussels and their habitat requirements into projects are not easily accessible to practitioners.

Project Timelines

Projects can vary considerably in lead time and extent of planning, and this variability makes it challenging to recommend a one-size-fits-all timeline or checklist. Figure 2 provides a model (ideal) timeline and recommended steps that can be adapted to your project needs. Depending on your project, you may simply not have two years—or even one—to plan your project or incorporate freshwater mussels. In other cases, you may be able to plan well in advance. Regardless of your particular situation or timeline, it is still possible and beneficial to incorporate freshwater mussels at some stage of your project. Incorporating mussels as early as possible into planning reduces the risk of encountering them in the middle of the project, when options are more limited, and enables to you to better protect the existing site values provided by freshwater mussels.

NO MATTER WHAT STAGE OF YOUR PROJECT, YOU CAN INCORPORATE FRESHWATER MUSSEL BMPS

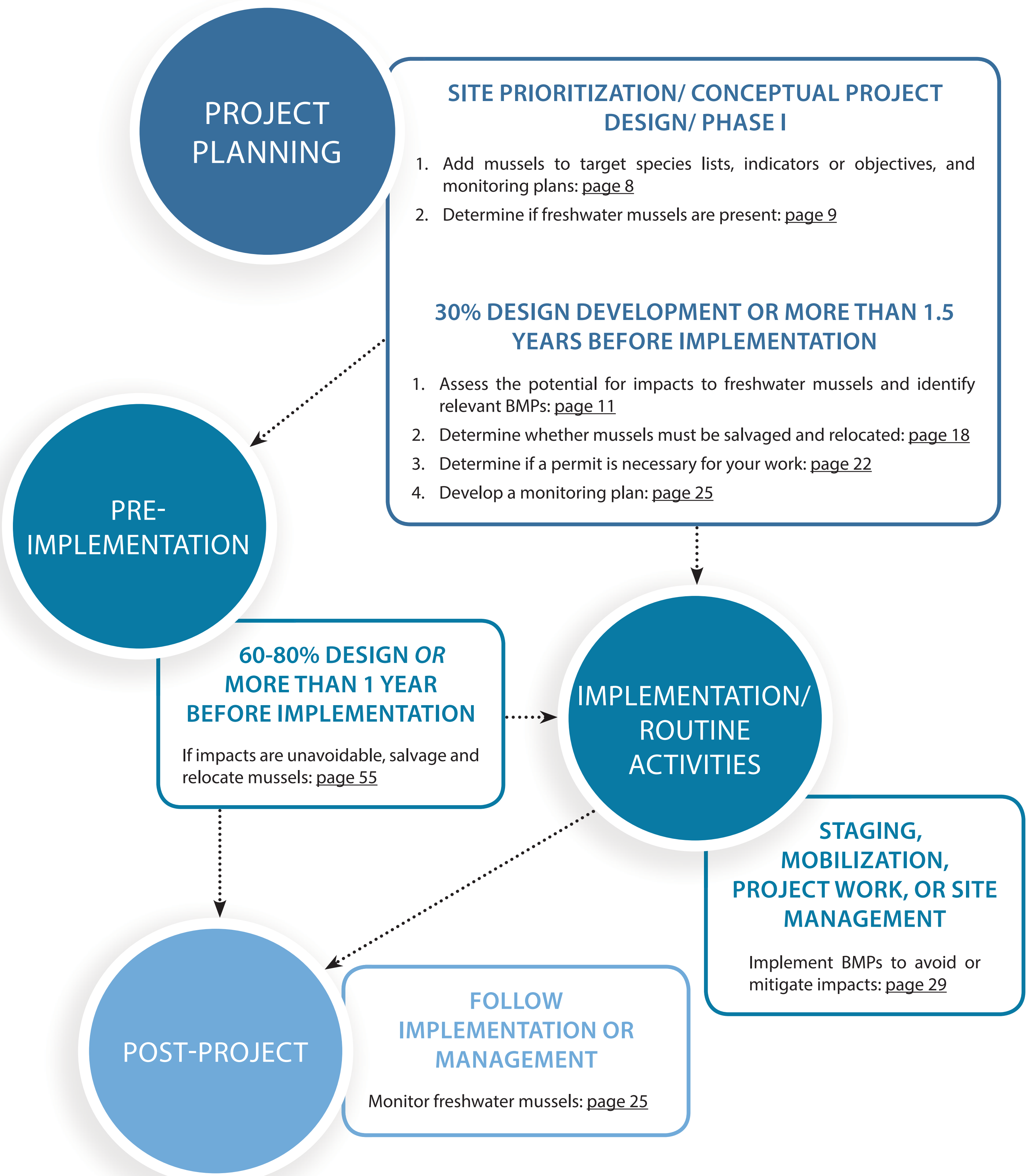
Further Resources

Appendices in this document include more detailed information on specific topics and additional resources:

- **Appendix 1** (page 80) offers a list of resources with links to field guides and presentations and contact information for regional experts,
- **Appendix 2** (page 82) presents detailed information on freshwater mussel life history and western species,
- **Appendix 3** (page 92) covers methods and resources for conducting surveys, and
- **Appendix 4** (page 102) presents case studies of relevant projects.

Figure 2: Idealized Project Timeline

This timeline includes recommended steps for including freshwater mussels in projects. See text for recommendations on adapting your timeline or project.



2

Site Prioritization and Conceptual Project Design

Mussels as Target and Indicator Species

Aquatic restoration projects often have specific biological goals (e.g., increased juvenile fish recruitment), habitat goals (e.g., increased spawning habitat), or ecosystem function goals (e.g., increased connectivity between floodplains and channels). As discussed above, there is good rationale to include mussels on target species lists or in restoration objectives (Figures 3 and 4), especially given that multiple states include one or more species as "species of greatest conservation need" in their state wildlife action plans or conservation strategies. Without explicit inclusion in project restoration goals and plans, mussels are easily overlooked, leading to the continued loss of populations. Also consider that mussels serve as good indicator species and are well-suited to monitoring plans, especially because like photo points or permanent plots, mussel beds are stationary and easily monitored over time. Refer to Appendix 2 (page 82) for more specific information on freshwater mussels and our native species.

Actually restoring areas *for* mussels remains a challenge because their habitat is not easily quantified and mussels may be responding to complex hydrologic and hydraulic variables (Strayer 2008). Without further data and research, it is far better to protect existing mussel populations rather than potentially lose the benefits they provide to habitat, water quality, and biodiversity. As you are developing your project concept, you should still consider how you can build mussel habitat or protect and enhance existing mussel habitat (Box 3). Information about sites where mussels currently exist near your project may also provide you with ideas or information for your project design, such as the type of substrate or channel features in which they are found (e.g., do they occur in sandy pools, behind large boulders, or wedged beside roots?).

PROTECT EXISTING MUSSEL POPULATIONS TO PRESERVE BENEFITS TO FISH, HABITAT, AND WATER QUALITY

Figure 3. Western pearlshell and salmonids benefit each other.

Figure 4: Western pearlshell mussels and brook lamprey (viewed together in the red circle) comprise part of a healthy stream ecosystem.

Determining if Freshwater Mussels are Present

If you have already begun work and discovered you have mussels onsite, jump ahead to the Salvage and Relocation BMPs (page 55).

The prioritization or conceptual design phase of your work is a good time to determine whether freshwater mussels are or could be present in your watershed, at your site, or within the boundaries of a proposed project (Figures 5 and 6), such as within the Area of Potential Effect (APE). Such information can help you conceive of a project that can incorporate freshwater mussels into the design. If you are unable to conduct surveys or otherwise determine whether freshwater mussels are present in advance of implementing your project, at a minimum, consider the potential for freshwater mussels to occur if

Box 3. Project Designs and Freshwater Mussels

Freshwater mussels use habitat that provides

- protection and stability from high flows and scour,
- burrowing sediment, and
- inundation and sufficient flows, especially near shores and banks.

Consider an overall project design that

- preserves some areas of stabilized habitat,
- incorporates a variety of substrate types,
- reduces the footprint of project elements at or near potential or existing mussel beds, and
- does not permanently alter flow or inundation over existing mussel beds.

your site occurs within the range of freshwater mussels, your site is perennially wet, and fish are present. Although you may later determine that mussels are not in fact present, treating a site as potentially having mussels can help you prepare a contingency plan, such as a salvage and relocation.

Contacting Experts

As a first step, consult with a mussel biologist or regional expert. The Xerces Society and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have developed and maintain a database of freshwater mussel observations and records for all western states. You can learn more at https://xerces.org/western-freshwater-mussels/ and request information on freshwater mussels in your area by contacting mussels@xerces.org. The Pacific Northwest Native Freshwater Mussel Workgroup also maintains an email list (pnwmussel@googlegroups.com) to which you can post and subscribe to receive messages. The Workgroup's website www.pnwmussels.org also provides information on freshwater mussels, including links to other resources. Local fish biologists may also have information on freshwater mussels, and reaching out to agencies or organizations who work in your watershed to ask about whether they've observed mussels may fill in any survey or knowledge gaps.

Figure 5. Could you have guessed that this little stretch of urban creek would be home to more than 3,000 floater mussels? Surveying prior to implementation enabled project managers to plan a salvage and relocation effort at this site in Crystal Springs Creek, which was later dewatered as part of a culvert replacement in Portland, Oregon.

Surveying for Mussels

After you've been in contact with experts, the next step is to survey for mussels at your site. Perhaps you have observed shells at or near your site or mussels have been reported from your river but your site has never been searched. Observations of shells (Figure 7) only provide preliminary information and should be followed-up with additional surveys that focus on documenting the presence of live mussels at the site. Preliminary mussel surveys can easily be combined with snorkel surveys for fish, although mussels can easily be missed if surveyors are not also specifically searching for mussels. Presence information will help with planning, but surveys should be designed to help you understand the following:

- which habitats and areas support mussels,
- the density and distribution of mussels throughout the site,
- which species or genera occur, and
- approximately how abundant they are onsite.

Ideally, you would also coordinate your efforts with others to have a better understanding of the distribution and abundance at your site relative to the rest of the watershed or region. When combined, this information will be important for assessing the potential impacts of your work and can help place your project in context.

By collecting this information as early as possible, the potential for complications later in your project is reduced, such as the need for an emergency salvage and relocation or a rush to find enough sites for relocations. For example, Washington Trout (2005) reported finding 74 times as many mussels as originally estimated for a salvage effort. Also refer to Appendix 3 (page 92) for much more detailed information and resources on conducting surveys for freshwater mussels at project sites.

Figure 6. From above, this stretch of river looks like any other (top) . But below the surface (bottom), a bed of western pearlshell mussels extends from the bank toward the middle of the channel and contains many thousands of mussels.

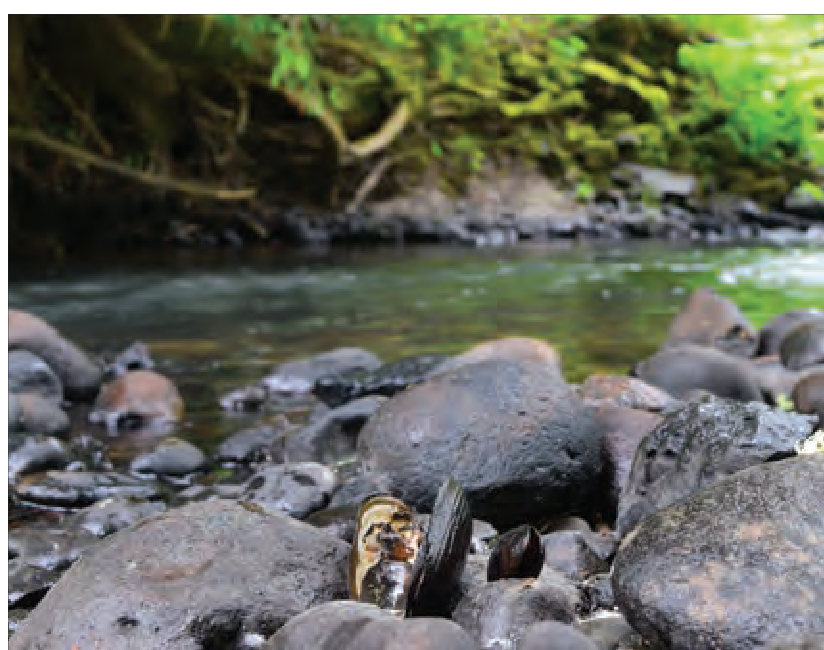


Figure 7. Mussel shells frequently wash up along shores and banks. Both articulated shells (both valves are still connected at the hinge line) and large shell fragments are signs that there is probably a mussel population at or near your site. The next step is to locate living mussels at your site and document the more detailed information described above. However, remember that mussels may be present even when no shells are observed along the shore.

3

Project Development and Review

During the project design phase, you should assess whether any elements or activities will affect mussels, identify BMPs that can be implemented, determine whether you will need to conduct a salvage and relocation, determine whether you need a permit, and develop a plan to monitor freshwater mussels. Because restoration work often targets reaches or basins, you may have multiple projects planned for your area. If so, consider how to avoid cumulative impacts to mussel populations throughout the larger project area rather than on a site-by-site basis (FMCS 2016).

Assessing Potential Impacts

By considering mussels early in the process, you may be able to evaluate other design alternatives or construction techniques, or even design around mussels (see Appendix 4 [page 102]). You should consider the full range of activities you plan to conduct and how overall site management may affect mussels. When assessing project impacts, it is important to evaluate the following:

- characteristics of the freshwater mussel population,
- the timing of your work, and
- the type of project, including areas of flexibility.

These are discussed in detail at right (Figure 8).

Timing Your Work

The earlier section on Project Timelines (page 6) discussed several considerations for when and how to incorporate freshwater mussels. Many project or activity timelines are dictated by a required in-water work window to protect listed species, whose needs may differ from freshwater mussels. In-water work windows will vary depending on the location of your work and the species or life stage present. If you are constrained by an in-water work window, it is especially important to implement mussel BMPs during construction and implementation. Adult and juvenile mussels will be present at a project site year-round, and warmer temperatures can stress mussels.

Additionally, in-water work windows have the potential to overlap with sensitive life stages of mussels, such as when females are brooding eggs, when glochidia are released and must attach to host fish, and when juvenile mussels first settle into the substrate (Figure 9; Appendix 2**)**. During these periods, low dissolved oxygen, activities that lead to host fish avoidance, or increased scour can all impact reproduction and recruitment in mussel populations. Additionally, during winter months, freshwater mussels adapt to winter conditions of higher flows and colder temperatures in part by burrowing farther

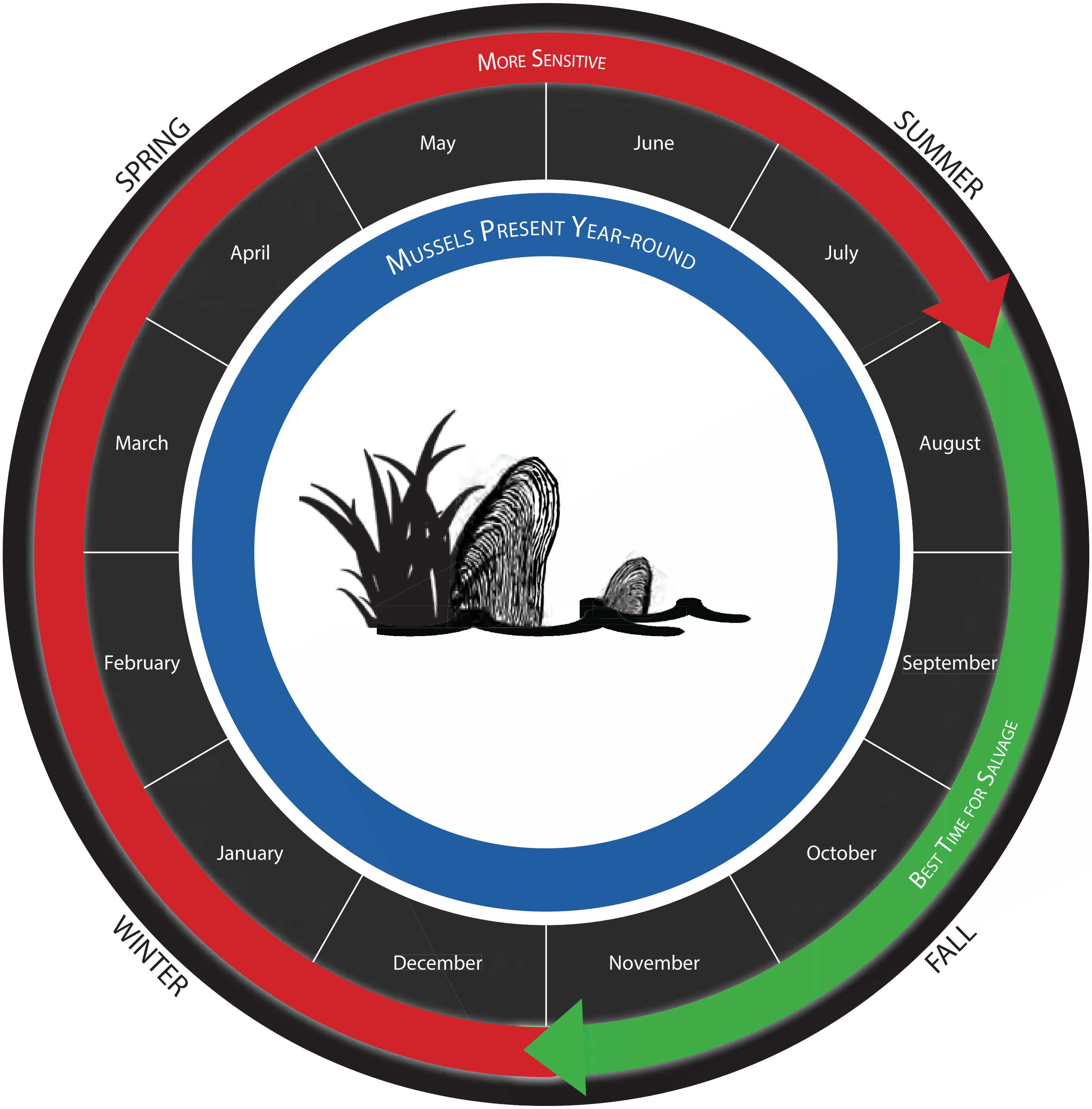
Mussels at Your Site

During surveys you should have determined the relative abundance, density, and distribution of mussels at your site. This information can help you identify areas of high mussel density to avoid in your project designs. It is also important to consider the mussel population at your site within the context of the larger waterbody or watershed. Three questions to address are:

- Do mussels occur in discrete beds or are they more continuously or randomly distributed?
  - Discrete beds of mussels are more easily avoided if projects are flexible. If mussels are more continuously or randomly distributed, avoiding direct impacts may be more difficult (Figure 8).
- Do you have a large or small population of mussels onsite?
  - Impacts to large populations are best avoided because these populations generally provide greater ecosystem services, take longer to recover, and are more difficult to effectively salvage and relocate. Larger populations are also more likely to be at or above self-sustaining thresholds and may serve as a source population to other sites.
  - Small populations tend to be easier to salvage and relocate effectively, although their significance should be considered within the context of populations in the watershed or region, especially if populations are few. Neither the size nor the density of mussels at your site can really indicate the importance of a population.
- How does your population compare to others in the waterbody, watershed, or region in terms of species, number of animals, location, levels of recruitment, or vulnerability to threats?
  - If your population differs from others with regards to the characteristics above, you may have special need to protect mussels at your site.
  - If your population is comparable to others in the watershed or waterbody, evaluate how restoration actions at your site and elsewhere in your watershed might impact mussel populations in the area as a whole.

Figure 8: The red circles in these images depict the distribution of freshwater mussels in two different bodies of water. In the river at left, freshwater mussels occur in discrete locations that provide protection from scouring winter flows. At right, mussels are distributed more continuously throughout the creek. In both waterbodies mussel beds can contain anywhere from 1 to 1,000+ animals. The differences in distribution, population size, and watershed context within and among these two waterbodies might lead to different approaches for protecting freshwater mussels at project sites.

FIGURE 9: Freshwater Mussels by Season



into the substrate (Balfour and Smock 1995; Haley et al. 2007). During summer months, mussels may also be more easily dislodged if they are shallowly burrowed and more active. If mussels are dislodged or disturbed when temperatures are especially cold or especially hot, they may be more susceptible to freezing or other damage.

If you determine that your work will require a salvage and relocation effort (see the next section, **Determining if Salvage and Relocation is Necessary** [page 18], for guidance), you should also time this effort to protect freshwater mussels to the extent possible (Box 4). Ideally this time period will overlap with your in-water work window to avoid any potential to impact listed species. Salvaging and relocating mussels one year in advance provides much more flexibility, but if it is not possible, consult with a mussel biologist in your region to identify an alternative time period that will work with your project schedule but still minimize adverse effects.

Project Type and Flexibility

Direct impacts from projects may include mortality of mussels and loss of habitat, while indirect impacts can include changes to the environment that affect flow, inundation, temperature, sediment transport, or substrate. Projects with greater impact on freshwater mussels generally have one or more of the following characteristics:

- include an area of direct impact (ADI) that overlaps with mussels,
- require temporary or permanent drawdown or dewatering where mussels occur,
- alter channels or waterbodies, including shores, beds, or banks,
- result in rapidly changing levels of flow and inundation, or
- incorporate use of chemicals.

Regardless of whether your project does or does not include one or more of these characteristics, you should still be able to avoid, mitigate, or minimize some impacts to mussels using BMPs for each of the project phases or types outlined below. Later sections of this document discuss these topics in more detail and present best management practices for avoiding or minimizing impacts.

Project Design and Engineering

Some impacts to freshwater mussels are best addressed during the design and engineering phase. The potential impacts will depend on the type of project or site, what activities will be necessary to achieve project or site goals, and how much flexibility you have in project design and implementation. If you have greater project flexibility, you may be able to shift project elements to alternative locations or leave areas of existing habitat undisturbed. In other cases, such as a fish passage project, the location of work may be inflexible. In either scenario, there are opportunities to reduce impacts to freshwater mussels.

Construction and Implementation

Existing protective requirements for in-water projects (e.g., RRMTWG 2008, NMFS 2013, USFWS 2013, and BPA 2016) include restrictions on the timing of in-water work; activities to reduce exposure to contaminants or spill potential; siting, staging, and accessing work areas; controlling erosion and dust; operation of equipment; and activities to minimize the spread of non-native, invasive species. These practices and requirements will offer some protection to freshwater mussels as well, but the BMPs provided in this document are intended specifically to safeguard mussels, particularly from activities that might lead to reduced feeding, reproduction, or dispersal, or might directly injure or kill them.

Box 4. Timing a Salvage and Relocation

If feasible, you should plan to conduct your salvage and relocation one year in advance, when you will have much greater flexibility. This will allow you to avoid:

- high levels of mortality associated with dewatering,
- conducting work during hottest or coldest temperatures, which can thermally stress mussels,
- impacting construction and implementation timelines,
- higher water, when mussels are not easily found, and faster flow, making conditions more dangerous for personnel,
- time periods when protected species are present, and
- impacts from other activities that increase disturbance or require in-water access.

If you are not able to salvage one year in advance, you should still aim for a time period that allows you to avoid the above issues. You will also be able to conduct a better salvage and relocation if you can dedicate more than one effort, giving mussels time to emerge if they are buried in the sediment. It is important to note that where mussels are dense, there may be many mussels not visible from the surface. Although you may not have the resources to do so, mussel salvages will likely be more successful if you

- include another sweep of the site 1–3 weeks later to collect any additional mussels that have moved to the surface,
- do not plan your only mussel salvage for the day of the fish salvage or dewatering, and
- continue to salvage and relocate mussels found during fish salvage and dewatering.

For example, temporary dewatering, increased movement of fine sediment, loss of habitat, and impacts from vibration (drilling or demolition) are all potential impacts from construction. Juvenile mussels may be especially affected by environmental impacts like sedimentation and scour.

Vegetation Management

Vegetation plays an important role in aquatic ecosystems, whether bankside or in-water. Macrophytes (aquatic plants that are rooted in water and may be emergent, submergent, or float) can provide important refugia and structural resources for both invertebrates and fish, while riparian vegetation along banks, shores, and floodplains, provides a source of important organic materials for aquatic food webs and also shades and cools water. In comparison to healthy, native vegetation, invasive species have the potential to alter ecosystems (City of Portland 2013; Gallardo et al. 2016), making management and control an important part of many restoration projects. However, management of invasive plants also has the potential to negatively impact freshwater mussels if activities result in erosion, disturbance of mussels and their habitat, impacts to water quality like increased turbidity or decreased dissolved oxygen, and exposure of mussels to chemicals. Freshwater mussels are often much more sensitive to certain chemicals than other species (Conners and Black 2004; Milam et al. 2005; Bringolf et al. 2007), and may be especially so during certain parts of the life cycle, such as breeding, the glochidial stage, or as juveniles. The vegetation management BMPs include recommendations to limit impacts of these management practices on freshwater mussels.

Nonindigenous Aquatic Animal Management

Invasive animals (here referred to as nonindigenous aquatic animal species, or NAS) can have serious and pervasive impacts on western North American aquatic communities, native species, and ecosystem function (Molloy et al. 2013; Sousa et al. 2014; Gallardo et al. 2016). The western United States is now home to more than 250 established nonindigenous freshwater animals, such as fish, mollusks, and mammals (USGS 2017). Control of introduced and established NAS is complex, and the impacts of these treatment methods have not been well-studied for western species of freshwater mussel, in large part because some NAS in the eastern United States are not yet established in western states (e.g., zebra and quagga mussels). The BMPs for NAS management cover approaches that have been used in the western United States, or may be used to combat potential future introductions, though as the status of NAS and management evolves, the effects of both introductions and treatments should be investigated for western mussels.

Flow Management and Restoration

Flow is the primary driving force of river ecosystem form and function, and characteristics such as the magnitude, frequency, duration, timing (including predictability), and rate of change of flow are ecologically important. The quantity and pattern of flow in a river not only directly influences organisms by providing aquatic habitat and exerting force, but also indirectly by physically altering and shaping habitat, temperature regimes, water quality characteristics (including dissolved oxygen), and transport of organic and inorganic substances (Poff et al. 1997). Flow is an important aspect of the environment for freshwater mussels, which respond to hydraulic parameters such as Froude and Reynold's numbers, shear stress, and velocity (Howard and Cuffey 2006a; May and Pryor 2015; Gates et al. 2015) and are sensitive to the timing and magnitude of flow (Howard and Cuffey 2006a; Black et al. 2015). Topics covered in this section include dam management, dam and diversion removal, and return flows.

Sediment Remediation

Sediments in freshwater can become contaminated with a variety of compounds accumulated over time, including nutrients (phosphorus, nitrogen, etc.), bulk organics (e.g., hydrocarbons like oil or grease), halogenated hydrocarbons or persistent organics (e.g., polychlorinated biphenyls (PCBs) and DDT and its degradates), polycyclic aromatic hydrocarbons (PAHs, which includes petroleum products or byproducts), and metals or metalloids (e.g., lead, copper, or arsenic) (EPA 1999). Our native freshwater mussels are at risk of contaminant exposure because they are commonly found in depositional or sheltered microhabitats, burrow into the sediment, and have relatively long lives. For example, Norgaard et al. (2013) documented bioaccumulation of copper, chromium, cobalt, tin, and cadmium in western ridged mussels downstream of a superfund site in the Klamath River. Claeys et al. (1975) also documented uptake of DDT and PCBs in floaters in the Columbia River. However, mussels can also be impacted by activities that treat, disturb, remove, or destroy sediments in which they are found. Contaminated sediment can either be remediated or isolated in-place or can be removed and treated or disposed of. The BMPs for sediment remediation cover potential approaches including monitored natural recovery, dredging, capping, and chemical remediation.

Determining if Salvage and Relocation is Necessary

Freshwater mussel salvage and relocation efforts are becoming more common, yet this practice is not without drawbacks and should be considered as one of multiple options rather than a perfect solution. For example, in one review, Cope and Waller (1995) found that overall survival of relocated and recovered mussels was less than 50%, and two studies examining survival in relocated western pearlshell reported between 25% and 95% survival (Fernandez 2013; Howard 2013). Moving mussels also has the potential to disrupt host fish relationships, spread disease or invasive species, interrupt reproductive activities, and cause stress. Relocation can also make mussels more vulnerable to displacement during subsequent high flows (Stodola et al. 2017). Additionally, most salvage and relocation efforts do not include juvenile mussels, which are typically buried and are too small to effectively find and move. For species that take multiple years to mature, loss of juveniles may set populations back as much as a decade.

SALVAGE AND RELOCATION SHOULD BE CONSIDERED AS JUST ONE OF MULTIPLE POSSIBLE BMPS

Once your designs are complete enough to have identified areas of direct impact (ADIs), you will need to determine if a mussel salvage and relocation is necessary. **This may be when you have approximately 60–80% designs, but should be early enough so that you can plan to salvage and relocate mussels a year before implementation. Relocation of mussels should be considered if:**

- your project site or location of project elements is inflexible and BMPs will not avoid direct mortality of mussels,
- you must temporarily or permanently dewater an area where mussels occur to complete the project, or
- indirect impacts are expected or found to result in mortality.

Even if a site will only be partially dewatered and will still provide some submerged habitat (that will also not reach high temperatures), you will need to plan to salvage and relocate mussels from areas that will dry (for more information, refer to the section on Dewatering (page 38). If you have determined that these situations apply to your project or activity, you need to plan for a salvage and relocation. Refer to the Salvage and Relocation BMPs (page 55) for guidance.

You may opt to leave mussels in place if:

- mussels occur outside of the area that will be directly impacted (ADI) and you do not anticipate impacts, or
- you are unsure whether to expect indirect impacts.

If you do opt to leave mussels, you should consider the full range of BMPs in this document and monitor mussels during the project, keeping an eye out for signs of distress (Box 5). You should still be prepared to salvage and relocate mussels. For example, if your project creates more dynamic habitat that may continue to evolve over time, consider whether mussels might be impacted later, such as when channels are reworked or areas scour out. Salvage and relocation may be necessary to avoid mussel die-offs under future conditions.

You may also encounter a situation where you must decide whether to conduct an Emergency Salvage and Relocation (page 63). For example, mussels may be encountered during or after dewatering, after chemicals have been applied to a body of water, or after channels have migrated or flow patterns have become altered (following initial restoration work).

If mussels have become completely exposed in such situations, you should conduct an emergency salvage and relocation. If mussels have "clammed up" or you assess that they may be able to withstand the disturbance, it may be better to just leave them in place. Moving only a subset of the mussels present has the potential to disturb an entire bed. If you do leave mussels in place, again, you should also monitor for signs of distress. Keep in mind that even with short notice, you may be able to implement other BMPs to minimize impacts in the course of your project or activity.

Figure 10. Top: A fresh dead shell (with mantle flesh still attached to the nacre) is not an uncommon site at a healthy mussel bed. However, large numbers of dead or dying mussels can suggest a problem, including water quality concerns, or disease. Bottom: Examples of shell middens with evidence of predation.

Box 5. Monitoring for Signs of Distress

Healthy mussel populations:

- Have a mix of live animals, a few dead individuals, and a smattering of weathered shells.
- Include mussels that may or may not be deeply burrowed.
- May occur near an obvious animal midden, evidenced by broken shells, shells with scratches or bite marks on the outside, and shells with little to no tissue inside (Figure 10).

You should be concerned if you observe:

- Many mussels that are dislodged, lying flat on the substrate, or buried under sediment and are unable to right themselves or dig out overnight.
- Mussels that are persistently "gaping," not closing quickly or tightly in response to disturbance (Figure 11).
- Many mussels attempting to move away in apparent avoidance of the project area.

Keep in mind that mussels may not attempt to move at all, and even if they appear to be trying, they are often too slow and their sense of direction too poor to effectively escape many impacts (Figure 12), especially project dewatering. Moving relatively small distances can take hours, especially when mussels take circuitous or meandering routes (Figure 13), or if they encounter impediments, such as coarser substrate.

Figure 11. A moribund mussel will not close when removed from water, and the soft body tissue may have a limp, shrunken, or swollen appearance.

Figure 12. Example of western pearlshell mussels in some distress. The mussel at the top left is flat on its side, lying on the substrate, while the mussel at the bottom right has been slowly moving away from an area, with the trail visible.

Figure 13. The circuitous path of this mussel is an example of the way in which mussels move. Moving relatively small distances can take hours, especially when mussels take circuitous or meandering routes, or if they encounter impediments, such as coarser substrate.

A Note on Mussel Die-Offs

Unexplained die-offs of mussel populations have been reported from multiple sites in the Pacific Northwest. These mussel die-offs are concerning and may be a result of unknown disease, spills of pollutants or toxics, warm temperatures or drying, or other human activities. As with some of the signs of mussel distress, you should also be concerned if you find

- 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 (Figure 14).

Please report your observations to the Xerces Society and the Pacific Northwest Native Freshwater Mussel Workgroup using a die-off reporting form (http://arcg.is/0K0SHG). Include any information you have, such as date; waterbody name and location (geographic coordinates if possible); observations of die-off (habitat conditions, approximate number and description of dead or dying mussels); mussel species (if known); and potential reason(s) for the die-off. Also, take photographs to document your observation.

Figure 14. These mussel shells are evidence that a die-off has occurred at this mussel bed.

Determining if You Need a Permit

Western species of freshwater mussels are not listed as threatened or endangered at either the state or federal level in the United States, nor at the provincial or national level in Canada. They are, however, widely recognized as species of conservation concern, and surveys and restoration projects may still require tribal, state, provincial, or national agency permits to handle, relocate, or otherwise collect or take freshwater mussels (Table 2, page 23). Securing a permit early in your planning process will allow you to conduct more complete surveys and familiarize yourself with agency requirements in advance of implementation. It is important to note that the information in Table 2 is not comprehensive and is subject to change. Be sure to consult with the appropriate agencies to determine any permits or requirements specific to your project prior to conducting any surveys or implementing a project.

Handling, collection, and take of native aquatic species, shellfish, and freshwater mussels in particular, usually requires, at minimum, a scientific collecting permit (SCP), though in some states and provinces the collection of freshwater mussels is generally still not granted under SCPs because mussel populations are too limited in number or distribution. SCPs are usually administered through state-level offices but may include a process that incorporates input on conditions or permit terms from local agency staff. Tribes may also have separate permits or requirements and should be contacted in the early stages of projects that may involve freshwater mussels. To demonstrate the range of permitting requirements, a summary of permitting in a subset of states and provinces follows.

In Oregon, a Scientific Take Permit is needed if you are taking freshwater mussels from the waters of the state. Oregon Department of Fish and Wildlife (ODFW) provides the following direction:

> A Scientific Take Permit is required for any person desiring to take marine fish, shellfish or invertebrates, freshwater fish, mussels, or crayfish from waters of this state for scientific or educational purposes (OAR 635-007-0900). If you are targeting any other aquatic organism, but may capture fish with the sampling methods used, you will also need a Scientific Taking Permit. Scientific or educational purposes include scientific research, monitoring and inventory, graduate student projects, rescue/salvage, and educational displays. "Take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, control, capture, or collect, or to attempt to engage in any such conduct. All species must be listed on the permit – including native, non-native, ESA-listed, and non-listed species.

ODFW recommends coordinating with staff early in the process to identify any additional considerations with permitting projects. The need for a permit is not limited to projects that involve federal or state threatened or endangered species; it is for all fish and wildlife under their management authority. The Oregon STP can take 4–6 weeks for processing. An application can be submitted at: https://apps.nmfs.noaa.gov/index.cfm. If you have questions about OR-STP permitting, please contact fish.research@state.or.us. Additional information can be found here: http://www.dfw.state.or.us/fish/license_permits_apps/index.asp. Note that ODFW permits are not necessary for snorkel surveys or visual observations that do not involve handling mussels.

In Washington, an SCP is required to collect shellfish for research, education, or display, though not for "transitory holding" for identification purposes. For hydraulic projects (projects that "use, divert, obstruct, or change the natural flow or bed of any of the salt or fresh waters of the state" [WAC 220-660-010]), a Hydraulic Project Approval (HPA) permit is required. An HPA permit includes provisions to protect "fish life," which includes all shellfish species, and the habitat that supports fish life. The

TABLE 2: State, Provincial, and National Wildlife Agency Designation and Protection Under Permit Requirements

Blanks indicate states where species do not occur.

Species	Common Name	OR	WA	CA	ID	AK	AZ	UT	WY	NV	MT	B.C.
Gonidea angulata	western ridged mussel	SGCN; SCP	SGCN; SCP; HPA	SGCN; SCP; other	SGCN; SCP					SCP		SARA; Red List; SCP
Margaritifera falcata	western pearlshell	SCP	SGCN; SCP; HPA	SGCN; SCP; other	SGCN; SCP	SGCN; SCP		SGCN; SCP; collection prohibited; SA	SCP	SCP	SGCN; collection prohibited	SCP
Sinanodonta beringiana	Yukon floater	*	*	*		SGCN; SCP						*
Anodonta nuttalliana	winged floater	SGCN; SCP	SGCN; SCP; HPA	SGCN; SCP; other	SCP		fishing license	SCP; collection prohibited; SA	SCP	SCP		SCP
Anodonta californiensis	California floater	SGCN; SCP	SGCN; SCP; HPA	SGCN; SCP; other	SGCN; SCP		SGCN; SCP; collection prohibited	SGCN; SCP; collection prohibited; SA	SGCN; SCP	SGCN; SCP		SCP
Anodonta oregonensis	Oregon floater	SCP	SCP; HPA	SGCN; SCP; other	*	SCP		*		*		SCP
Anodonta kennerlyi	western floater	SCP	SCP; HPA	SGCN; SCP; other	*	SGCN; SCP		*		*		SCP

HPA: Protected under Hydraulic Project Approval permit requirements by state agency. If covered by HPA, no SCP required.
Other: Additional permits or other requirements may be applicable depending on the nature of the project.
Red List: B.C. provincial designation recognizing imperiled species.
SA: Protected under Stream Alteration permit requirements by state agency.
SARA: Species At Risk Act designation of Schedule 1, Special Concern. This status is applied to species that are not endangered or threatened but at risk.
SCP: Protected under scientific collecting permit or scientific take permit requirements by state wildlife agency.
SGCN: Species recognized as being a conservation priority within the state ("Species of Greatest Conservation Need").

*The Xerces Society does not consider the species to occur in this state/province. However, some records exist but have not been verified. If the species occurs, it would similarly be covered by state/province permit requirements like other species of freshwater mussel in the state/province.

Washington Department of Fish and Wildlife also recommends coordinating with staff early in project development to determine what permits may be needed for surveys or project implementation.

In California, an SCP is required to "take, collect, capture, mark, or salvage, for scientific, educational, and non-commercial propagation purposes." Permits are administered through the Wildlife and Fisheries Division of the California Department of Fish and Wildlife (CDFW). The Fisheries Branch within that division reviews SCP applications and will consult with biologists at the CDFW regional or local level to review and approve permits. Additionally, during California Environmental Quality Act review of projects, significant impacts to freshwater mussels must be disclosed and alternatives or mitigation measures must be implemented to the extent feasible. Other permits or authorizations may also be necessary depending on the project and associated activities. For example, a Lake and Streambed Alteration permit is necessary for activities that result in substantial change to rivers, streams, or lakes, or the associated bed, channel, or bank.

In Montana, possession or harvest of freshwater mussels is prohibited in fishing districts inhabited by the western pearlshell; this species is known to occur in the Western and Central Fishing Districts. Freshwater mussels are otherwise protected in the state by Administrative Rule Section 12.2.501, which prohibits the take or possession of "freshwater mussels or their shells for sale or commercial distribution."

In Utah, collection of native freshwater mussel species is prohibited. Additionally, the Stream Alteration program of Utah's Division of Water Rights evaluates projects such as "new or replacement bridges or culverts, utility line installation, bank stabilization, and other activities adjacent to natural streams" to determine, in addition to other considerations, whether "the project unreasonably or unnecessarily endangers aquatic wildlife" (UDWR 2008). If not, the application is approved but will include limitations or conditions following review by Utah Division of Water Rights and Utah Division of Wildlife Resources.

In British Columbia, mussels fall under two national laws, the Fisheries Act and the Species at Risk Act. Under the federal Fisheries Act, mussels are considered a fish and thus are regulated by its Fishery (General) Regulations, which requires licenses for "Fishing for Experimental, Scientific, Educational, Aquatic Invasive Species Control or Public Display Purposes" (Section 52) and for the "Release of Live Fish into Fish Habitat and Transfer of Live Fish to a Fish Rearing Facility" (Section 56). The Fisheries Act also requires that projects avoid causing serious harm to fish, unless authorized (Section 35). The federal Species At Risk Act (SARA) prohibits the killing, harming, harassing, possession, capturing, or taking of a species listed as extirpated, endangered or threatened; it also prohibits the damage or destruction of a residence or the destruction of any part of the critical habitat of such a listed species, unless authorized (Sections 73 and 74). The Canadian government is considering changing the SARA status of the western ridged mussel (*Gonidea angulata*) from Special Concern to Endangered. If the species' designation does change, SARA permitting requirements will apply to the species.

In addition to state, provincial, or national agencies, in some places additional permits may be necessary. For example, for a project involving relocation of freshwater mussels to a stretch of creek located in a city park in Portland, Portland Parks and Recreation requires a Research Permit. The permit includes no fees but places limits on activities to protect park resources. Other permits may include fees, which can be subject to change. In general, permitting requirements are subject to change, and during your permitting process for fish or other covered activities, take steps to ensure that you have secured the necessary permits for mussels, whether you have already identified a mussel population or there is potential for you to encounter them during project implementation. Contact information for state, provincial, and national agencies that grant permits are included in Appendix 1 (page 80).

Developing a Monitoring Plan

When to Monitor

Mussels are long-lived, making it important to track the effects of construction, restoration, and management activities over time (Figure 15). Because they are relatively sedentary, it is feasible to set up plots and track populations for both a short period of time and long-term. Currently there is limited information on the following:

Population Status and Trend—As discussed above, it is important to understand freshwater mussel populations in context, as it can be difficult to evaluate the impacts of a single project or basinwide plan when the distribution and abundance of freshwater mussels is unknown. There are multiple examples of how biologists have already incorporated freshwater mussels into existing monitoring efforts like fish surveys or macroinvertebrate sampling. You may also wish to develop a mussel-specific survey plan for your river, lake, or basin. Keep in mind that regardless of whether you add mussels to your existing effort or not, it is important to train surveyors on how to look for and identify freshwater mussels (Appendices 2 and 3 [pages 82 and 92, respectively]).

BMP Implementation and Effectiveness—A key component of BMP implementation is monitoring freshwater mussels for signs of distress or evidence of mortality (Box 5 [page 20]). Monitoring mussels both during and after implementation can help refine and improve BMPs, especially if you were unsure whether mussels would be impacted by certain practices or activities. Because restoration sites will continue to evolve over time, monitoring can provide valuable information on both short- and long-term effects.

Salvage and Relocation Success—There is currently little information on how commonly western freshwater mussels are relocated during projects and even less information on the success of these efforts, although some efforts have been documented (*see* Determining if Salvage and Relocation is Necessary [page 18] and Appendix 4 [page 102]). If possible, monitoring one to two months after the project implementation is complete can provide important post-relocation mortality information before the shells of mussels that have suffered mortality are washed downstream. This short-term monitoring can help you refine methods and improve survival rates, though you should limit further handling at this point (WDNR 2014; Tiemann et al. 2016). Monitoring should also be conducted at least one, two, and five years post-relocation to determine whether relocation was ultimately successful. Where monitoring will be completed over multiple years, aim for methods that do not require handling to reduce disturbance.

MONITOR

1. AFTER 1-2 MONTHS: DID THE SALVAGE WORK?
2. AFTER 1 YEAR: DID MUSSELS ESTABLISH AT THE NEW SITE?
3. BETWEEN 2-5 YEARS: WAS RELOCATION A VIABLE STRATEGY?

Ideally, monitoring efforts will span years and will also expand to evaluate the effects of relocation on growth, reproduction, and recruitment (Hart et al. 2016).

Figure 15. Monitoring provides valuable information and can inform relocation, restoration, and habitat management.

How to Monitor

When developing your monitoring plan, you should aim to collect the same information outlined in Surveying for Mussels (page 11), including recording evidence of healthy mussel populations (Box 5) with mussels of multiple size or age classes. To help you evaluate the effectiveness of BMPs or salvage and relocation efforts, you can estimate abundance (before and after), mark mussels, and/or use grids or transects.

Marking Mussels

Marking a subset of the mussels you are monitoring will enable you to track specific mussels (especially if the unique number of each tag is noted) or generally track mussels that have been surveyed or relocated. Tagging also provides an opportunity to measure the length and height of each mussel. Mussels can be marked using small vinyl shellfish tags (Figure 16; Floy Tag and Manufacturing, Inc., Seattle, Washington) or PIT tags applied to mussel shells (Lemarié et al. 2000; Hartmann et al. 2016; Ashton et al. 2017). Tags can also provide useful information on movement of animals if animals are placed in transects or plots. PIT tags are particularly useful if mussels are dislodged or difficult to observe and can reduce the need to handle mussels.

Figure 16. Vinyl shellfish tags are easily attached to the outer shell.

Marking of mussels should be done in a shaded area out of direct sun. Monitor the mussels continuously for signs of distress. To mark mussels with a shellfish tag, briefly wipe the shell dry and clean, then gently scrub a small patch of the left shell valve along the posterior ridge extending from the beak (umbo) with a green scrubbing pad. Placing the tag toward the posterior end makes it more likely to be visible if mussels are not completely buried. While holding the tag in tweezers, apply cyanoacrylate adhesive (e.g., Loctite or Krazy Glue) to the back of the tag and then gently depress it onto the shell. You can also affix PIT tags with RFID antenna. The cyanoacrylate adhesive should cure in water as you gently depress the tag against the shell. Other types of glue are not recommended because they have not been tested to ensure they cure quickly and properly in water. However, dental cement is also effective, particularly in rocky habitat, and can dry quickly, but is more expensive.

Plots, Transects, and Grids

When mussels are relocated, they can also be placed directly into permanent plots or belt transects to improve the chances of encountering relocated animals during later surveys (Figure 17). Note the transect number and tag number, if tagged, of each mussel. Monitoring searches should take place both within and outside of the exact site of relocation to capture any mussels that may have moved short distances before settling.

Placement of a grid system over the relocation site can also pinpoint mussel locations. A grid system can be surveyed with the use of a hand-held grid constructed of PVC pipe. The grid should consist of a single row of 0.25 m^2 squares. The number of squares will depend on the size of your stream and the area in which mussels are relocated, as well as the number of surveyors. The grid can be placed at the downstream end of the relocation site and flipped end over end, progressing upstream. Within each transect and plot, count the number of relocated mussels (live animals and shells) and note the transect number and plot number for each count. Make sure that you adequately mark locations of plots, transects, or start locations for grid systems (using rebar, GPS, flagging, or other appropriate methods).

Figure 17. A marked grid with tagged freshwater mussels.

4

Best Management Practices for Project Design and Implementation

The following lists cover a wide range of best management practices (BMPs) you can use to help guide your project and avoid impacts to freshwater mussels. Refer to the section of known Knowledge Gaps (page 65) to read more about topics of research that would improve understanding of projects and activities.

GENERAL PRACTICES

- Time work to avoid sensitive life stages (Figure 9).
- Leave as much existing habitat as possible and favor projects and designs that allow you to protect mussels onsite rather than having to salvage and relocate them.
- Salvage and relocate mussels that will be directly impacted by the project following the BMPs for Salvage and Relocation (page 55).
- Avoid drawing down water or dewatering a habitat before conducting a survey and planning for a potential salvage and relocation.
- Avoid complete elimination of host fish from isolated habitat (e.g., following dewatering or rotenone treatment), as surviving freshwater mussels will be unable to reproduce.
- Avoid recurring activities in favor of methods that reduce overall disturbance at the site. When possible, phase construction or demolition activities to minimize the time period over which discrete in-water disturbances occur.
- If feasible, establish an exclusion area (including a buffer distance of at least 5 m) around areas with freshwater mussels. The area should protect mussels from direct and indirect effects. Clearly define and (if necessary) mark the full boundary of the exclusion area using obvious equipment or structures such as flagging, poles, construction fencing, or similar. Monitor equipment or structures to ensure debris does not block or divert flow near mussels, and keep the boundary markers in place and in good condition throughout the project.
- Conduct outreach and education about freshwater mussels and BMPS, including internal staff training, to encourage adoption.

PROJECT DESIGN AND ENGINEERING

- Avoid placing in-water structures near freshwater mussels. Instead, place supports for infrastructure, like bridges or roadways, on land. Generally, consider alternative designs or locations of project elements to avoid mussel beds or large aggregations.
- Avoid constricting flow and increasing velocity or scour in the vicinity of a freshwater mussel bed or large aggregation, and generally maintain natural flow to the greatest extent possible.
- To the extent feasible, avoid use of "hard" materials or methods (such as riprap, gabions, or retaining walls), instead using "soft" approaches for bank stabilization (such as native vegetation, rootwads, or soil end wraps with plantings).
- Avoid the use of loose materials like riprap or rock on steeper slopes and in waterbodies where sediment is unlikely to fill large gaps between materials.
- 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.
- If you are using hydraulic modeling to design or evaluate an in-water project, use model outputs to evaluate the project or project element footprint (including scour diameters) or impacts from changes in shear stress and water velocity and depth. Use this information in combination with freshwater mussel location data to help you assess impacts.
- Ensure that infrastructure is designed so that it is unlikely to trap debris. Periodically monitor and remove any debris.
- Design culverts following fish passage guidelines and avoid elimination of burrowing habitat.
- Minimize bank disturbance generally, but consider options for reshaping, lowering, or reducing the angles of banks and shores in preference over more built approaches.

Figure 18. This broad culvert replaced an older, narrower culvert, and was one of several similar projects intended to improve fish passage in a single creek. Floater mussels were found upstream of the old culvert, and a salvage and relocation effort was conducted by Xerces Society and agency staff, as well as volunteers, before construction began. Mussels were also salvaged during the fish salvage and dewatering phases. The group effort ensured that more than 3,000 mussels were saved.

- When building a retaining wall, maintain as much natural bank or shoreline as possible and, if feasible, set the wall back from the water.
- When building a revetment or using gabion boxes (wire or mesh baskets housing loose materials like rock), place materials above ordinary high water to the extent feasible. When materials must be placed at the shoreline, notch or leave gaps of natural shoreline and vegetation.

Further Information on Project Design and Engineering

Fish Passage Restoration

Removal of barriers to fish passage is one of the more common types of restoration project. These projects often have multiple benefits, including improving infrastructure like road crossings, increasing access to historic fish spawning habitat, and improving local conditions at degraded streams (Figure 18). Freshwater mussels also benefit from these projects, especially when host fish can transport mussel glochidia to new habitat. It is important to explicitly consider freshwater mussels in fish passage projects, as mussels are commonly found in the vicinity of existing culverts or pipes, especially if sediment, which forms burrowing habitat for mussels, has accumulated. These projects also commonly involve temporary dewatering during construction, and unfortunately freshwater mussels have often been discovered after dewatering has already begun.

Culvert replacement projects often have very little lead time, meaning that recommended timelines for incorporating mussels (more than a year in advance) can be unrealistic. The best way to address the issue of timing is to incorporate mussel surveys into preliminary barrier surveys and prioritization. For example, when surveying for and recording fish passage barriers, it would be beneficial to conduct a brief survey for freshwater mussels and record if they are present. When prioritizing barriers to work on, any additional site visits could also include a brief survey for freshwater mussels. However, if this is not possible, follow the other guidelines in Box 4 and work with a mussel biologist to identify a time window that works within your project's constraints.

Because the footprint of these projects is generally not extensive, salvage and relocation of mussels may be straightforward and easily prepared for. Culvert designs that follow fish passage guidelines should also benefit mussels, but it is important to avoid elimination of burrowing sediment. Designs that minimize bank and bed disturbance, do not constrict flows, and retain natural features will benefit mussels.

Channels and Off-Channel Habitat Connections

When designing in-channel and off-channel habitat, consider how your designs will affect flow of water over freshwater mussels. For example, braided channels and floodplain connections increase the diversity and complexity of habitat, but these designs may also spread flow or reduce wetted area in channels below the minimum depths needed by mussels. Freshwater mussels can be impacted if flow becomes stagnant or habitat dries.

When existing side channels, sloughs, and floodplain features like ponds are re-connected to the main channel of a river and become permanently inundated, these habitats can support freshwater mussel populations and provide refuge from high flows and unstable substrate. Floater mussels are commonly found in these habitats, and western ridged mussels and western pearlshell mussels have also been observed using these features, although the latter two species can be negatively impacted by changes in flows from lotic to more lentic habitats. In addition, native fish like juvenile salmonids, which serve as host fish for the western pearlshell, also often utilize these sheltered habitats.

Depending on the mussel species present, it is important to evaluate how your work might increase

Figure 19. Bridge footings that span streams reduce the need for riprap, as seen along the right bank, that makes for poor mussel habitat unless sediment readily accumulates.

or decrease flow in the vicinity of the mussel bed. If new channels or ponds are created, keep in mind that mussels may not immediately colonize these areas. Such habitat can initially lack food and other necessary resources, although mussels may establish populations after these areas have had time to develop.

In-Water Structures

In-water structures, either temporary or permanent, have the potential to directly cover or otherwise impact mussel habitat if they alter substrate depth, substrate materials, water velocity, water levels, or result in greater shear stress (the force of water moving against the substrate or mussel). Mussels are generally sensitive to changes in flowing water and wave energy. For example, Snook (2015) found that western ridged mussels did not occur at sites with excessive fetch (exposure to wind, which can be used as a proxy for wave action and turbulence), as high fetch can increase shear stress. Any debris that becomes trapped along in-water structures also has the potential to lead to local scour. Removal of racked debris quickly by lifting (not dragging) can minimize impacts, but avoiding placement of infrastructure in-water is preferable.

Permanent Structures

Examples of in-water structures whose primary purpose is not to improve aquatic habitat include infrastructure like piles, piers, wing walls, foundations, culverts (although they may improve fish passage), and pipes (Figure 19). When in-water structures are placed, an area of habitat will be directly lost under the actual footprint of the structure. There will also be an area of permanently altered habitat extending some distance from the structure (e.g., resulting from placement of protective materials like riprap or areas where scour may be expected). When culverts or pipes are not buried or do not maintain normal depths of substrate or materials in stream bottoms, mussels can be excluded. When habitat is not permanently altered, mussel populations may be able to recover or recolonize an area, but short-term impacts should be avoided as much as possible.

In-water structures specifically intended to improve aquatic habitat include rootwads, logs, boulders, or other natural materials. These structures provide long-term benefits to aquatic

Figure 20. Among the rocks in this photo, the mussel can be spotted by its fleshy foot, visible just outside the shell margin at the arrow. What's wrong with this picture? This mussel is upside-down! In sandier habitat, a mussel could more easily re-anchor itself so that it is upright and filtering, but in coarser substrate, dislodged mussels may not be able to right themselves. In this position, the animal is also more vulnerable to desiccation and predation.

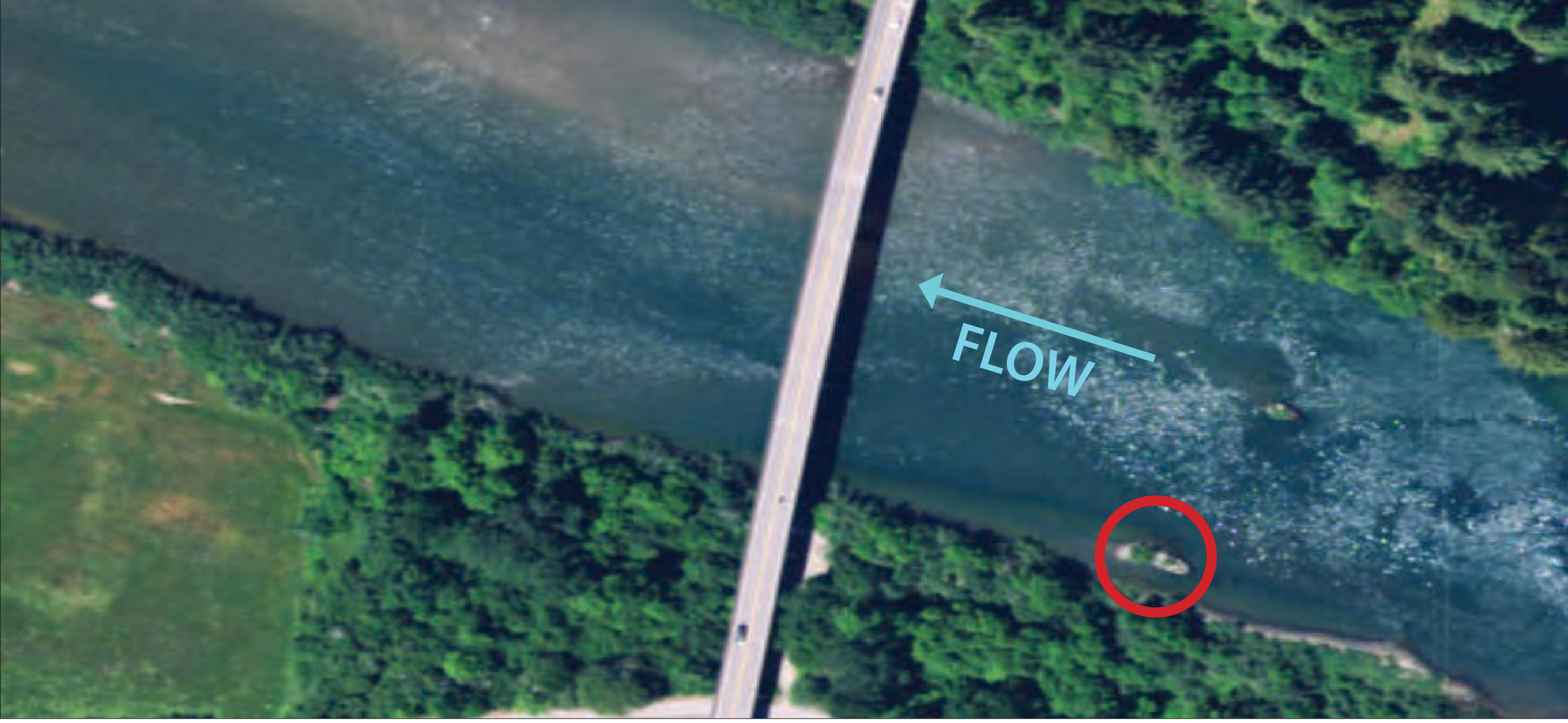


Figure 21. A bridge once crossed this river to the right of the existing bridge. The old concrete piling circled in red was left in place and created a sheltered area along the bank (note the relative smoothness of the river downstream of the piling) where thousands of western pearlshell are now found. This feature mimics other hydraulic controls upriver, like bedrock outcrops, where the species is also found.

ecosystems and freshwater mussels, but their placement at or near existing mussel populations could also impact mussels in many of the same ways as other in-water structures. If your project is flexible, site these objects away from and downstream of existing mussel beds or large aggregations.

Temporary Structures

It is important to avoid or minimize placement of temporary structures, such as those used during bridge construction or other infrastructure projects, below ordinary high water (OHW). Mussels naturally experience a range of water conditions, including periods of increased velocity or shear stress, but during construction activities, populations will simultaneously experience multiple stressors. Maintaining normal flows, levels, exposure, and temperatures will ensure that the combined effect of stressors is limited. Freshwater mussels can also be more easily dislodged if they are not well-anchored or have burrowed into shallower or finer sediments (Figure 20). The depth of burrowing may vary seasonally, with mussels often burrowing deeper into the substrate during winter months and burrowing more shallowly during warmer months (Balfour and Smock 1995). During warmer months when mussels are actively reproducing, feeding, and growing, they may also be more susceptible to activities that disturb substrate or increase flows (Haley et al. 2007). Avoid placing in-water structures that constrict flow or large clusters of structures, which can especially increase water velocity or water depth.

Removal of Structures

Some projects may include removal of existing in-water structures. When freshwater mussels are present, it is important to evaluate the existing benefits afforded by these features before removing them. For example, a piling, bridge, or undersized culvert that does not impede fish passage may be providing hydraulic benefits by slowing down the flow of water and allowing the formation of more complex channel habitat or sheltering habitat from high flows (Figure 21). Structures may also catch large wood and sediment as they flow downriver, possibly reducing maintenance tasks elsewhere, such as removal of racked debris. If historic construction materials do not result in other environmental concerns, such as the release of toxic chemicals, it may be more beneficial to leave them in place. Refer to the section on

Figure 22. Eroding banks, like those visible in the background, are part of a natural recovery process in this restored stream. However, where eroding banks threaten site values, like the trail across the foreground, bank stabilization may be necessary.

Figure 23. Freshwater mussels are often found wedged in rootwads, along banks, and behind boulders. Restoring complex shorelines with microhabitats and native vegetation provides multiple benefits. Many of the elements that benefit salmon also benefit freshwater mussels.

Impacts from Vibration, Drilling, or Demolition (page 39) for more discussion of structure removal.

Bank and Shore Stabilization

Erosive forces such as high flows, wind, precipitation, waves, and recreation can cause destabilization of land adjacent to or forming the boundary between terrestrial and aquatic habitat. These erosive forces can cause soil and bank material to slough into the water. Destabilization of shores and banks is part of a naturally occurring disturbance regime that can enhance natural habitat. However, erosion can result from or be accelerated by human activities both onshore and in-water and may be inconsistent with site values (Figure 22). Freshwater mussels can be sensitive to the effects of erosion (including increased suspended solids and sediment deposition), which can affect feeding, respiration, and reproduction (Gascho Landis and Stoeckel 2016; Tuttle-Raycraft et al. 2017). Sedimentation can also bury individuals; for example, relic western pearlshell beds have been observed buried under sediment (Vannote and Minshall 1982). Krueger et al. (2007) also found that some western pearlshell and western ridged mussels were unable to dig out of sediment, in this case suction dredge mine tailings, and subsequently died. However, freshwater mussels can also be impacted by bank and shore stabilization activities or structures. When bank and shore stabilization is necessary because erosion threatens site values, certain materials and methods may be more beneficial to or protective of freshwater mussels, especially if a mussel bed occurs at or near the impacted area. For example, Libois and Hallet-Libois (1987) found that mussels occurred in greater number and denser aggregations where banks were more natural as compared to riprapped or rocked areas or walls. Similarly, McDowell (2001, in Brim Box et al. 2004) found higher abundance of western pearlshell in river channels that were not straightened, riprapped, or barbed.

While many factors determine the suitability of particular stabilization approaches and the choice of materials, some options maintain more natural habitat features than others or may be more protective of freshwater mussels. The effects of "hard" approaches (bank armoring) should be compared and contrasted to more "soft" approaches that incorporate natural materials, although regulations may restrict the types of material that can be used in stabilization projects or may stipulate other design and construction requirements (e.g., Washington Administrative Codes requirements for Hydraulic Project Approval; see discussion in WDFW 2006; guidelines in BPA 2016). The appropriateness of different structures or methods also depends on the site, and may be influenced by the nature of the site (lakeshore or riverbank), location of erosion (at the toe of a slope or along a margin or shoreline), the general cause of erosion (terrestrial or current/wave), aquatic values (location of the freshwater mussel bed), available space (narrow riparian margins or floodplain), and the presence of infrastructure (buildings, bridges, or roads). Shorelines and banks may also be protected by state or federal laws, so options for bank and shoreline protection may be limited. A combination of materials and approaches may also be necessary or preferred to maximize project goals.

Vegetation is often protective against erosion by reducing water velocity, stabilizing land, retaining sediment, and providing habitat and microrefugia (Figure 23). The first protection against erosion is to retain vegetation at the shore or bank (Schiereck 2004). Certain types of vegetation, like willow, cottonwood, or other floodplain tree species, can better withstand the greater force at the outer edge of a bank or may be more resilient. Similarly, sedge mats have dense root systems and can resprout from existing root masses and trap sediment. These types of plants also provide habitat for western freshwater mussels (Howard and Cuffey 2003; Haley et al. 2007). Low-growing vegetation does not have the benefit of reducing water temperatures as compared to canopy-forming plants, and plants with stiffer stalks and roots will more effectively reduce velocity (Schiereck 2004).

Retaining walls or other vertical structures are commonly used where banks are steep, available space is limited, or infrastructure must be protected or supported. Walls that do not cover banks and are set back from the water are preferable (Figure 24). Revetments are also commonly used on sloping banks and consist of loose, hard materials, such as riprap, rock, or stone. Riprap is composed of large blocks of angular rock, generally placed on top of a layer of fabric or other material to stabilize smaller sediment grains. Gabions, which consist of wire or mesh baskets housing loose materials like rock, may be used instead of placing loose material (Figure 25). These structures do not generally provide benefits to freshwater mussels because they are often composed of angular rock with large gaps, where freshwater mussels are unable to easily settle or anchor. However, in waterbodies that transport and deposit enough sediment to fill gaps, riprap may provide stability and protected areas that support mussel populations once there has been sufficient time for sediment to accumulate. If gabion baskets are placed above the shoreline rather than at or below ordinary high water, much like the retaining wall that is set back in Figure 24 they will not cover potential mussel habitat. However, because rock and riprap (and gabion baskets, if broken) consist of loose material, over time individual rocks may move downslope and into mussel habitat. Avoiding use of loose materials on steeper slopes and including a setback distance from the water can minimize movement or shifting of materials into mussel habitat.

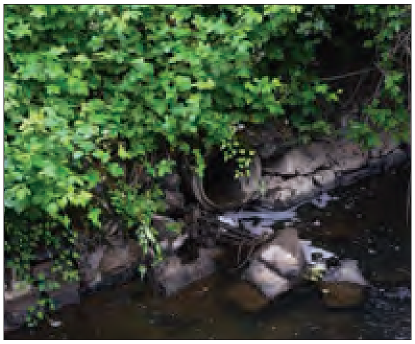


Figure 24. Left: Retaining walls that cover banks and are built up from the streambed limit mussel habitat. Right: When walls are set back from the water's edge, a larger area of natural shoreline is retained, which can provide better mussel habitat.

Additionally, where revetments are necessary, including notches or pockets with more natural banks or shorelines could provide some benefits to freshwater mussels, as well as other benefits, such as floodplain or off-channel habitat connectivity. Reshaping, lowering, or reducing the angles of banks and shores can also create benched habitat, improve vegetation establishment, and increase habitat complexity, although decreasing slope angle could also reduce the stability afforded by loose rock or riprap. Generally, reshaping and contouring shorelines, including benches of varying elevations, can increase habitat for aquatic and riparian vegetation, as well as freshwater mussels.

Figure 25. Gabion baskets are commonly used to protect infrastructure on slopes and banks but can limit habitat and vegetation.

Figure 26. When working in an area where mussels are present, clearly marking areas to avoid can reduce the risk of trampling or otherwise inadvertently disturbing habitat.

CONSTRUCTION AND IMPLEMENTATION

Dewatering

- Dewater an area slowly to allow mussels time to emerge 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 freshwater mussels upstream of the diversion.
- Site any bypass systems for water used in construction away from freshwater mussels, outside of your buffer. Return high-quality water at normal temperatures downstream of mussels.
- If feasible, maintain or add habitat features that provide depressions or microrefugia during drawdown or natural drying.

Construction

- Use containment systems for construction or demolition to prevent pollutants, mobilized soil, or debris from entering the water.
- Monitor the containment system and promptly remove any debris that does enter the water by lifting, rather than dragging. Similarly remove any racked debris from structures.
- Minimize any area that will be dredged and, if feasible, avoid completely dewatering the area that will be dredged.
- Return any native or natural materials (e.g., rocks or logs) that are removed or disturbed to their original location or an appropriate alternative, and fill any holes remaining after structures have been removed or demolished.

- Implement standard BMPs to avoid hazardous material spills or leaks that could impact mussels.
- Convey stormwater or runoff from construction activities or structures away from mussel habitat and route through a filtering and settling treatment before returning to the waterbody.
- Minimize erosion resulting from activities like clearing and grubbing on floodplains or banks, including minimizing the amount of vegetation that is cleared, leaving root systems intact, and/or installing erosion control measures until vegetation can reestablish. Clearly mark areas for clearing and grubbing with construction fencing or similar. Replant with native plants similar to those removed.

Further Information on Construction and Implementation

If you are regularly working in an area where mussels are present, you should take steps to minimize disturbance during routine or planned activities. Mussels can "clam up" to avoid poor conditions over short durations, but repeated disturbance may cause undue stress. Mussels are also easily trampled and dislodged by feet and equipment. With so much to learn about western mussels, including their tolerance for different kinds of disturbance, it is best to take a precautionary approach when working in an area where you may routinely encounter mussels.

For example, it is good practice to establish an area of avoidance around large aggregations of mussels and their habitat. Restrict activities and access in this area. Fences, silt fences, flagging, or the placement of natural barriers on land such as brush or downed logs can serve as a visual sign to the project manager as well as be a natural deterrent to activity in the area (Figure 26). If restoration sites or other projects will result in increased public access, include signage or more permanent barriers to reduce activity near mussel beds (Figure 27). Ensure that the areas upstream, adjacent to, and at the mussel site are all included. Depending on the type and frequency of an activity, a larger or smaller buffer may be necessary, but 5 m around the outer area of mussel habitat should provide some protection from direct disturbance. Activities within the riparian corridor on land may not require as large of a buffer, but where possible, intact riparian or shoreline habitat should be maintained. The best management practices discussed elsewhere in this document can also improve protections during specific routine activities.

Figure 27. Like other sensitive areas, public access should be avoided at the site of a mussel bed. While freshwater mussels are well-suited for environmental education or community restoration projects, it is best to leave mussel beds alone much of the time. Signage and barriers like this to deter frequent access to sensitive areas and can benefit mussels and their habitat.

Figure 28. This channel was dewatered to replace a downstream culvert. Water was pumped around the project area to allow for access. Mussels were salvaged and relocated before the area was dewatered, during the fish salvage, and during the final drawdown.

Dewatering

Dewatering is often necessary to access stream or lake beds and banks to perform maintenance, install, remove, or replace structures, bury materials, and re-contour shorelines. Reservoirs may also be drained to promote sediment flushing (see the section Flow Management and Restoration [page 46]). When new channels are constructed, flow may also be permanently diverted from old channels. Dewatering activities can range from permanent to temporary and complete (draining) to incomplete (lowering), and water may also be temporarily diverted for use in construction. Some projects may require periodic dewatering, particularly if related to maintenance activities, while restoration projects may result in a single dewatering event. The extent of dewatering is also an important aspect; total dewatering may be necessary for in-channel work, while lowering of water levels may be sufficient for other restoration activities. For example, when culverts are replaced or installed, streams generally need to be dewatered before this process occurs. Sometimes, water is pumped around the construction area, sometimes it is moved below the area by a gravity system, or water might be diverted into a temporary side channel (Figure 28).

Dewatering is likely the restoration activity that has had the most direct and significant negative impact on western freshwater mussels. In many cases, mussels have only been discovered after draining and dewatering has begun and a large population of mussels is suddenly visible and in distress. As a group, freshwater mussels are poorly adapted for surviving rapid dewatering (Figure 29). Species like the western pearlshell and western ridged mussel are less commonly found in habitats that dry up entirely. In comparison, floater mussels may inhabit floodplain ponds that occasionally dry completely, usually resulting in large die-offs. Mortality of mussels after stranding (also called emersion) can sometimes be quite high depending on the temperature, length of emersion, and mussel species. Mussels often occur near shores and along the edge of banks, and dead mussels have been observed along pool margins and near shorelines, where they apparently died from exposure following sudden stranding (Haley et al. 2007; Nedeau et al. 2009; Clarke 2010).

The timing of dewatering, like other activities, is an important consideration, even if dewatering is performed gradually. Many dewatering projects are timed during allowable in-water work periods intended to be protective of salmon or other listed species, but if possible you should avoid dewatering during sensitive life stages of mussels, such as reproduction, or when temperatures are warmer or colder. Even if dewatering is performed at slower rates or is incomplete, many mussels could become stranded. Freshwater mussels can also naturally experience drying at shorelines and along whole reaches during seasons or years of low precipitation, and the effect of this natural drying can be equally devastating

Figure 29. If mussels are encountered during dewatering, rescuing as many as possible as quickly as possible can ensure that at least some of the population survives.

to mussel populations (Golladay et al. 2004; Haag and Warren 2008). Best management practices for protecting mussels during dewatering include not fully dewatering an area and/or minimizing the extent, salvaging mussels before dewatering occurs, continuing to salvage mussels as they emerge during dewatering, and siting the intake and return sites away from freshwater mussels.

Impacts from Ground-disturbing Activities
Construction projects often require staging areas or cleared space on land to access and build structures. These areas can require clearing and grubbing to remove vegetation that limits access, but ground-disturbing activities can also increase erosion and sedimentation adjacent to mussel habitat, especially if stabilizing root systems are removed or damaged. Because mussels can be sensitive to turbid water and burial, ground disturbing activities have the potential to at least temporarily reduce habitat quality. Where feasible, minimize any erosion impacts resulting from activities like clearing and grubbing on floodplains or banks, including minimizing the amount of vegetation that is cleared. Also, leave root systems intact and/or install erosion control measures until vegetation can reestablish and replant with native plants similar to those removed (Figure 30).

Dredging is a specific form of ground disturbance in which an area may first be dewatered or cleared followed by removal of material such as sediment and rock. Dredging is often conducted for navigation, flood control, or drainage, as well as sediment remediation (also see the section on BMPs for Sediment Remediation [page 51]). Mussels can be impacted by the dewatering activities associated with dredging or displaced and killed directly by the dredging itself. Machinery and equipment can crush and kill mussels, and dredging may remove habitat or decrease habitat suitability. Dredging activities are thought to have caused local extirpations of freshwater mussel populations in the southeastern United States (Bogan 1993), and dead mussels have been found in dredge spoils (Neves et al. 1997). Dredging should be avoided or minimized where freshwater mussels are present. Dredging a smaller area, not dewatering when dredging, and salvaging and relocating any mussels in the area of direct impact (from either dewatering or dredging) should be incorporated into dredging plans and activities. Return any materials (rocks, logs, etc.) that are removed or disturbed to their original location or an appropriate alternative.

Figure 30. Reducing ground disturbance (such as clearing and grubbing) during projects limits impacts to mussel populations, which can often be found near the shoreline, as at this site.

Impacts from Vibration, Drilling, or Demolition
Pile drivers and vibratory hammers can be used to install temporary and permanent support structures. Very little is known about the noise and vibration effects from these methods on invertebrates, including mussels. Other burrowing bivalves have displayed avoidance behaviors in response to underwater vibrations at levels below the thresholds considered protective of fish (Peng et al. 2016; Solan et al. 2016).

Vibrations from installation and demolition activities could vibrate ambient water and bed substrate, and the type of habitat in which these activities occur is also important. In flowing water, sediment can be suspended and transported downstream, which could remove burrowing habitat or bury mussels. Lakes or slow-moving waters could experience a temporary increase in turbidity. In addition to habitat alteration, mussel behavior or health could be impacted, or mussels could be dislodged. Mussels can "clam up" when conditions are poor, but this occurs at the expense of activities that require mussels to be open and filtering, such as reproducing and feeding. If mussels are dislodged and unable to crawl or reposition themselves, they may be more vulnerable to predation or stranding. Activities that also disturb host fish may impact reproduction if activities occur during sensitive life stages. If vibrations dissipate quickly, occur further away or over a shorter duration, or are few or spaced out over time, negative effects may be lessened, although research is needed to confirm this. Use of bubble curtains or other standard BMPs could also reduce impacts.

Demolition also has the potential to impact freshwater mussels if debris falls into habitat or onto individuals. Containment systems should be used to catch any falling debris, and any debris that enters the water should be lifted, not dragged, when removed. After structures are removed, fill in any holes with similar-sized substrate and materials.

VEGETATION MANAGEMENT

- Before engaging in vegetation management activities, research and write an integrated management plan for vegetation.
- If feasible, establish an exclusion area as described in the BMPs for Construction and Implementation (page 36).
- Avoid use of herbicides in water and limit use of herbicides along banks near mussels, especially herbicides that have been shown to have negative effects on mussels.
- Among physical methods, avoid mechanical methods and mowing buckets in favor of hand-pulling and cutting.
- Avoid clear-cutting or removing vegetation within an area entirely, especially if vegetation stabilizes banks or provides shade. Conduct work in stages and replant bare areas with native vegetation

Figure 31. Invasive plants like purple loosestrife, the large dark patch extending into this floodplain lake, can reduce aquatic habitat along banks and shores and exclude native plants and animals, including freshwater mussels.

to reduce erosion and sedimentation, especially those with complex bank and shore-supporting root systems.

- 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 any state licensing requirements. For example, generally only a state-licensed applicator with an aquatic endorsement can legally apply herbicides over water. Additionally, herbicide labels are legal documents, and directions for use must be followed.
- As feasible, minimize the area to which herbicidal compounds are applied, use the lowest effective concentration, and plan for the fewest number of applications.
- For all methods, as feasible, limit the number of times and the total extent disturbed.

Box 6. Taking an Integrated Approach

The "Guide for Developing Integrated Aquatic Vegetation Management Plans in Oregon" by Gibbons et al. (1999) provides valuable information on how to:

- develop an integrated plan for vegetation management,
- determine when and how to manage infestations,
- define management goals,
- implement strategies, and
- monitor to detect introductions and evaluate the efficacy of treatment actions.

Further Information on Vegetation Management

Vegetation management is an important tool for restoration of habitat at sites in and along waterways, especially where invasive species degrade habitat or alter ecosystem processes (Figures 31 and 32). However, freshwater mussels are often found near banks and shores, and management activities that disturb these areas (e.g., increase erosion or disturb the substrate) can impact them. Freshwater mussels can also be particularly sensitive to certain chemicals, often much more so than other tested species (Conners and Black 2004; Milam et al. 2005; Bringolf et al. 2007). It can be difficult to balance the management and treatment of invasive plants with protection of habitat and native species. Taking an integrated approach to vegetation management can assist with planning to help reduce the chance that practices will impact freshwater mussels and other native species (Box 6). Be sure also to coordinate with neighbors, agencies, and other restoration practitioners in the project area to address vegetation management issues and identify priorities. Coordinated vegetation management can help reduce the potential for greater exposure and risk from herbicides to the aquatic environment and increase the effectiveness of vegetation management practices.

Aquatic Vegetation

Management of aquatic invasive plants has a greater potential to affect freshwater mussels than management of terrestrial plants because of the potential for direct disturbance to mussels or their habitat. For example, if macrophytes are pulled by hand, mussels can inadvertently be dislodged. Rotovating in lakes can dislodge, bury, and crush mussels, resulting in mortality. Freshwater mussels may also be excluded from areas of lakes that have been rotovated, except in areas inaccessible to equipment (Mageroy et al. 2017). Mechanical cutting and mowing buckets (Bradshaw buckets) can also displace


Figure 32. This planting project is helping to restore riparian habitat near a bed of western pearlshell mussels.

mussels (Aldridge 2000). Because excessive growth of macrophytes can also lead to sediment accumulation (Bunn et al. 1998), macrophyte removal can increase turbidity in rivers (Garner et al. 1996; Bunn et al. 1998; Aldridge 2000). Dewatering, dredging, suction dredging, or installation of impermeable bottom barriers to exclude vegetation can also impact freshwater mussels (refer to discussions under the BMPs for Construction and Implementation [page 36] and Sediment Remediation [page 51). The impacts of vegetation management will be minimized by adapting the BMPs outlined above and developed by others (e.g., WDFW 2015).

Use of herbicide can have the benefit of killing plants while leaving root systems and plant material relatively intact (and thus reducing the impacts of erosion and sedimentation). Pulling and cutting plants also, unfortunately, can enhance invasive plant growth or spread, as fragments can settle out and form new plants in some species. However, herbicides are not always effective for managing aquatic invasive plants, especially if plants become resistant (Koschnick et al. 2006), and freshwater mussels appear to be especially sensitive to certain herbicides or additives (Conners and Black 2004; Milam et al. 2005; Bringolf et al. 2007). Because mussels are sessile, have relatively long lifespans, must filter water for food and oxygen, and contact sediment (especially as juveniles), they are at high risk of exposure to chemicals applied in waterbodies. Glochidia and juveniles can be even more susceptible than adult mussels (Bringolf et al. 2007).

With the widespread use of chemicals to control plants, the detection of multiple chemicals in surface waters has also become concerning. For example, Carpenter et al. (2008) detected as many as 34 pesticides in water samples from a single creek in the Clackamas Basin of Oregon. Glyphosate, triclopyr, and 2,4-D were commonly detected together and often comprised the greatest proportion of a pesticide load in a given sample (Carpenter et al. 2008). Unfortunately, many chemicals approved for aquatic use have not been tested for their effects on freshwater mussels. Exceptions include chemicals like 2,4-D, which has been shown to have negative effects on important freshwater mussel physiological processes (Milam et al. 2005; Alves and Oliveira 2014). Among species groups tested, freshwater mussels are also among the most sensitive to endothall and fluridone (Archambault et al. 2015). Because there is reasonable potential that many aquatic herbicides not yet tested for effects on freshwater mussels may also be toxic, it is recommended that where freshwater mussels are present, physical methods be used instead of herbicides. If herbicides are used, apply them outside sensitive life–stage periods to decrease potential risk of exposure.

Riparian Vegetation

As with aquatic vegetation management, management of invasive riparian plants can impact freshwater mussels if activities alter aquatic habitat (e.g., increase erosion, disturb substrate, or contaminate water or bottom sediments). For this reason, activities like controlled burning should avoid removing vegetation that stabilizes stream banks or provides stream shade. Water withdrawals for use in controlled burns should also be sited away from mussel beds. Use of grazing animals can result in denuded banks or reduced water quality from nutrient inputs, such as livestock defecation. If grazing is used, it should consist of short periods of light livestock access to areas near, but not at, the bank and should occur during dry periods when erosion is less likely (Figure 33).

As with aquatic herbicides, some herbicides and additives used to control terrestrial invasive plants have been shown to have negative impacts on freshwater mussels. For example, lab tests have shown that MON 0818, a surfactant used in conjunction with glyphosate, is acutely toxic to freshwater mussel glochidia at concentrations lower than expected environmental concentrations (Bringolf et al. 2007). Mussel glochidia were also among the most sensitive aquatic organisms tested for toxicity of IPA salt, which is also used in conjunction with glyphosate (Bringolf et al. 2007). The herbicide sethoxydim has been shown to cause altered mantle growth and reduced epithelium thickness in freshwater mussels acutely exposed to a sub-lethal dosage (Lopes-Lima et al. 2006). Nonylphenol ethoxylate, a surfactant used in conjunction with imazapyr, has been found to be toxic to freshwater snails, suggesting that other aquatic mollusks like freshwater mussels might also be sensitive (Grisolia et al. 2004).

Herbicides and additives used to manage invasive riparian vegetation have the potential to contact mussels. Water-soluble herbicides may disperse via runoff during rain events or with irrigation. Application errors might also result in overspray. Herbicides prone to evaporate or drift can settle on waterbodies, and eroding sediment can also convey chemicals downstream. Chemicals that are the least likely to disperse into or throughout aquatic environments should have decreased potential for exposure to freshwater organisms. The University of California Agricultural and Natural Resources Statewide Integrated Pest Management Program (http://ipm.ucanr.edu/PMG/menu.pesticides.php) evaluates this potential and assigns a "Runoff Risk Rating" for some pesticides.

While many gaps exist, initial research into glyphosate (technical-grade; Bringolf et al. 2007), imazapyr (Grisolia et al. 2004), and florpyrauxifen-benzyl (Buczek et al. 2017), have not indicated high toxicity. For more information on general best management practices relating to herbicide use, including measures to evaluate and reduce environmental risk, refer to the document *Best Management Practices for Wildland Stewardship: Protecting Wildlife When Using Herbicides for Invasive Plant Management (Cal-IPC 2015).* For summaries of research articles assessing toxicity of herbicides and additives to freshwater mussels refer to the Xerces Society's Impacts of Pesticides on Invertebrates (IPI) Database (https://pesticideimpacts.org/) and use the search term "mussel".

NONINDIGENOUS AQUATIC ANIMAL SPECIES (NAS) MANAGEMENT

- Avoid use of methods that isolate or damage freshwater mussels and their habitat, such as installation of impermeable benthic barriers or suction dredging.
- Aim for rotenone exposure to mussels that is no greater than 4 ppm, limited in duration (less than ~12 hours), and not subject to additional drift. If rotenone concentration will exceed recommendations, limit treatment duration.
- Should treatment of invasive mollusk species become necessary, field test use of molluscicides like Zequanox® on western freshwater mussels before use. Explore methods to minimize secondary impacts such as reduced dissolved oxygen or other changes in water chemistry.
- As with eastern species of freshwater mussels, evaluate the impacts of other emerging methods of NAS management on western freshwater mussels prior to implementation.

Figure 33. Grazing animals can denude banks and directly impact freshwater mussels if not excluded.

Rotenone

Rotenone has been used by numerous agencies across states and provinces to eradicate nonindigenous and undesirable fish species, with western states like Utah, Washington, and California applying nearly 50% of all rotenone use reported between 1988 and 2002 (AFS 2005). The effects of rotenone on western species of freshwater mussels has not been studied. However, research and observations of unionid and margaritiferid mussels have provided some information regarding how rotenone use may affect western mussel species. For example, a 10-year post-treatment survey in a river treated with rotenone found similar abundance and composition of mussels in the treated river as compared to reference rivers. Both adult mussels more than 10 years old and juvenile mussels were found (Hart et al. 2001). Still, this study did not directly measure mortality following rotenone treatment.

Larsen et al. (2011) found that the European freshwater pearl mussel (*Margaritifera margaritifera)* "clammed up" for 8.5 to 10 hours with no mortality. Adult mussels also did not exhibit avoidance behavior during riverine rotenone treatments, although glochidia attached to fish were killed with their fish host. However, Larsen (2015) observed avoidance behavior, such as clamming up, falling over, and increasing movement in response to a riverine rotenone treatment. Mussels also expelled sperm and unfertilized eggs. An anecdotal observation of juvenile *M. margaritifera* exposed to a short-term low dose (2 ppm of 3% rotenone for 2 hours) found that mortality was not significantly different than unexposed mussels (Mageroy, pers. comm.).

Anecdotal observations suggest that western freshwater mussels such as floaters were not killed during rotenone applications in Oregon (Smith, unpub. obs.). However, loss of mussel populations was reported anecdotally following rotenone applications in the Umatilla River in Oregon (Howard 2005). Treatment of lakes with large doses of rotenone over extended periods of time (two days of active treatment, with lethal levels present for more than a month and detectable levels for nearly a year) have resulted in complete mortality of *M. margaritifera* within 6 months of treatment (Larsen 2015). These

Figure 34. Zebra mussels can occur in great density and affix themselves to submerged infrastructure or habitat. These invasive mussels do not require a host fish for reproduction. They are less than 50 mm in size, making them much smaller than our native species.

mussels were located in the river just below and ~4 miles downstream from a treated lake. Dolmen et al. (1995) found that *M. margaritifera* were not killed by treatments of rotenone at <5 ppm for <8 hours, although higher concentrations (>30 ppm for 12 hours) resulted in mortality.

In addition to limiting exposure of rotenone (both concentration and duration) avoid rotenone applications during mussel breeding periods. Ensure that accumulation or drift of rotenone does not extend beyond the treatment window. If rotenone concentration is expected to exceed recommendations, limit the treatment duration. Complete loss of host fish from rotenone treatments, such as eradication of fish from lakes or ponds, should also be avoided when mussels are present. Monitoring of the effects of rotenone treatments on western species would also provide valuable information.

Molluscicides

Multiple chemicals and treatments have been developed for control of invasive mollusk species, such as zebra mussels (*Dreissena polymorpha)* and quagga mussels *(Dreissena rostriformis bugensis),* which are collectively known as dreissenids (Figure 34). Several pilot projects in surface waters have included use of copper products, dewatering, and potassium chloride (subject to approval by USEPA), with varying success (MNDNR 2015). These treatments may be recommended for more widespread use in the future, pending full study, but currently only two are advised for application to surface waters (as opposed to closed systems) by the U.S. Army Corps of Engineers: Natrix™ (copper-based) and Zequanox® (a biopesticide) (Glomski 2015).

Natrix™ was originally developed as an algaecide but now has an EPA special use label in certain states for invasive mollusk control. Mortality of dreissenid mussels after exposure to Natrix™ in flow-through laboratory tests ranged between ~60 and 100% after 156 hours (Claudi et al. 2014). Additional studies of the effects of Natrix™ on native mussels are needed to assess the potential impacts of use.

Zequanox® is composed of a killed strain of bacteria, *Pseudomonas fluorescens. M*ortality of dreissenid mussels (Figure 34) after exposure to Zequanox® in laboratory tests reaches levels of 70 to 100% (Molloy et al. 2013; Whitledge et al. 2015). Zequanox® is nontoxic to humans, biodegradable, and poses minimal risk to multiple non-target species including many unionid mussels (including some species of *Anodonta*), other aquatic invertebrates, and fish (Molloy et al. 2013; Meehan et al. 2014; Whitledge et al. 2015). However, application of Zequanox® can result in temporary increases in turbidity and decreases in dissolved oxygen (Meehan et al. 2014; Whitledge et al. 2015). Large die-offs of invasive mussels can also increase ammonia levels and decrease dissolved oxygen (Sousa et al. 2014), which may harm native mussels.

Because dreissenid mussels have the potential to greatly impact western aquatic habitats and communities, preventing the introduction and establishment, and eradication of any existing individuals at new sites is a priority. Further research into the effects of chemical control methods on western species is needed and should be evaluated in advance of dreissenid introduction.

Carbon Dioxide

Carbon dioxide is currently being explored as a deterrent for NAS such as silver carp in the eastern United States (Cupp et al. 2017). Research is as-yet limited regarding the effects of this treatment on freshwater mussels, but some studies have suggested that it has the potential to impact native species. For example, eastern freshwater mussel species including *Lampsilis siliquoidea, Pyganodon grandis,* and *Amblema plicata* have all displayed physiological indicators of stress in response to intermittent and chronic exposure to carbon dioxide, despite their ability to buffer acidosis (Hannan et al. 2016). Other research has shown that *L. siliquoidea* may experience mortality as result of exposure to carbon dioxide, where either longer exposure or higher concentrations of carbon dioxide elicit higher mortality (Waller et al. 2017). Juvenile mortality, impacts to shell growth, and behavioral effects were also observed in experimental treatments, and Waller et al. (2017) recommend concentrations of carbon dioxide be <76 mg/L under continuous infusion, although they suggest that higher concentrations may be less harmful with only brief exposure. These species-specific responses to exposure, and differences in response to chronic and intermittent exposure, and potential for recovery under certain conditions (Hannan et al. 2016; Waller et al. 2017) suggest that research specific to western species of freshwater mussels is needed before carbon dioxide is used for NAS management in western North America.

Other Control Methods

Other control methods for NAS could include benthic barriers, hand harvesting, suction dredging, or use of biological control methods (Sousa et al. 2014), although some activities may be restricted or require a permit. If invasions of NAS are not yet at high levels in a water body, hand harvesting or collection, traps, or nets may be effective removal methods that are less harmful to native freshwater mussels. Methods that impact beds, banks, and shores, like impermeable benthic barriers and suction dredging, can have many negative impacts on freshwater mussels (also discussed in the sections Impacts from Ground-disturbing Activities [page 39] and BMPs for Sediment Remediation [page 51]), and should be the last choice among methods. Recent use of sodium chloride to eradicate African clawed frog in ponded habitat in Washington (e.g., WDFW 2017) should also be assessed for the potential to impact freshwater mussels. Guidelines on how to avoid introducing or spreading NAS through contaminated gear are also provided in Appendix 3.

FLOW MANAGEMENT AND RESTORATION

- Avoid large, rapid reservoir drawdowns. Also avoid large, extended sediment flushes and ensure that sediment is uncontaminated.
- Generally, limit the duration of sediment release projects near freshwater mussel beds.
- Avoid discharging return flows in the immediate area of freshwater mussels. Discharge only high-quality water of normal temperatures that mimic natural flows into waterbodies containing freshwater mussels.
- Manage flows from dams to maintain normal low flows and avoid drying and dewatering mussels and their habitat. Use guidelines from Table 6 (page 49) to develop environmental flow prescriptions or augment dam operations.
- Incorporate freshwater mussels into dam removal planning, including surveys, salvage, and relocation efforts in advance of implementation.
- When removing dams, choose relocation sites that will not be further impacted by increased sedimentation and channel migration.
- Minimize the transport of fine sediments by creating a pilot channel and stabilizing exposed habitat.

Further Information on Flow Management and Restoration

Dams

As of 2006, more than 75,000 medium- to large-sized dams impounded rivers in the United States (Graf 2006; Figure 35). Impoundments formed by dams can differ from natural lakes in many ways, including having greater depth towards their downstream end (closer to the dam), and can alter the

Figure 35. Across western North America, rivers of all sizes have been impounded and dammed, altering flow and habitat upstream and downstream.

original channel by increasing average depth and reducing flow velocity. Fine sediment often accumulates, which can suffocate mussels, and intolerable near-anoxic conditions are found in some areas of impoundments (Watters 1999). The hypolimnion (lower layers of water) of impoundments can also become exceedingly cold and have low dissolved oxygen, which can reduce mussel growth and reproduction (Watters 1999; Haag 2012). All western species of mussels have been reported from reservoirs, though uncommonly, apart from floaters, which prefer finer sediments and are more tolerant of ponded habitats (Frest and Johannes 1993; COSEWIC 2003; Helmstetler and Cowles 2008; Tiller and Timko 2014; Xerces/CTUIR 2017). The western pearlshell appears particularly intolerant of slower or still-water habitats, and Starkey (2015) noted that abundance declined with increasing proximity and influence of a reservoir.

Freshwater mussels can also be sensitive to discharge from dams, which may draw water from the hypolimnion. Even small dams that release water from the surface can alter hydrology and water temperature (Lessard and Hayes 2003). Dams also strongly influence downstream flow, including duration and frequency of inundation of habitat (Graf 2006), which can alter physical habitat directly below the dam or further downstream (Watters 1999; Bunn and Arthington 2002). Regulated flow regimes associated with dams can also result in decreased connectivity of rivers to lateral habitat such as floodplains and off-channel pools (Bunn and Arthington 2002), and low flows can reduce submerged habitat and result in increased water temperature (Gates et al. 2015). These characteristics can influence the distribution of western freshwater mussels. For example, during surveys of the lower Klamath Basin, Davis et al. (2013) observed that floaters were found in highest abundance directly downstream of Irongate Dam, while western ridged mussels and western pearlshell were most abundant in lower reaches and absent from the immediate area below the dam. Davis et al. speculate that thin-shelled floaters benefit from the year-round stable flows and substrate associated with Irongate Dam releases.

In general, impacts from dams (reduction or elimination of host fish passage, upstream impoundment effects, and downstream flow and habitat changes) have also resulted in changes to freshwater mussel populations and communities elsewhere in the United States (Watters 1996, 1999; Galbraith and Vaughn 2011; Haag 2012; Gates et al. 2015; Tiemann et al. 2016), but are not well-studied in the western United States. Many observations have confirmed that dam drawdowns can result in western freshwater mussel mortality (Frest and Johannes 1992; Tiller and Timko 2014), while another study has documented a shift in western species abundance and occupancy under a changing sediment regime, with western pearlshell inhabiting areas of coarser substrate and western ridged mussel in areas of finer sediments (Vannote and Minshall 1982). Other impacts from dams, such as loss or reduction of host fish, are implicated in western mussel declines, but more research is needed (Blevins et al. 2017).

Flow Management

Creating a flow prescription and releasing environmental flows (e.g., flow releases from dams that mimic more natural or ecologically targeted flows) is one method to lessen effects of altered flow regimes and restore ecosystem benefits and societal function (Richter and Thomas 2007). Environmental flow programs can be developed based on different methodologies, including those that have a focus on hydrology, hydraulics, habitat, or target organisms, like freshwater mussels. Examples of environmental flow programs in the United States include the Willamette River (Oregon), the Bill Williams River (Arizona), and the Green River (Kentucky), among others (TNC 2012). Implementing environmental flows in dammed rivers has the potential to improve aquatic habitat conditions for freshwater mussels, as well as host fish populations (Gates et al. 2015). Release of more natural flow regimes from dams has been shown to improve mussel density, decrease incidence of hermaphroditism, improve overall mussel body condition and decrease parasitism, and decrease stress in freshwater mussels (Galbraith and Vaughn 2011).

However, environmental flow programs often focus on hydrology and hydraulic conditions or are developed with a specific focus on fish habitat and biological requirements. While these may overlap well with freshwater mussel life history and needs in some ways, environmental flows could be further modified to protect or improve benefits to freshwater mussels. For example, permanently wetted habitat is a key requirement for freshwater mussels, and time periods or life stages critical to freshwater mussel establishment and recruitment may differ from other considerations used to set target flows (Gates et al. 2015). Environmental flow modelling specifically for freshwater mussels has been little studied, but ideally would consider mussel life histories and important traits like reproductive phenology, brooding length, host species' life history and method of host infection, and physiological tolerances. For example, lower flows during a mussel species' breeding season might ensure that juveniles establish in permanently inundated areas. Examples of recent efforts to develop environmental flow methodologies for freshwater mussels are described by Hansen et al. (2016) and Parasiewicz et al. (2017). Recommendations for dam management and environmental flow prescriptions are outlined in Table 6. Also refer to Gates et al. (2015), which further details approaches for developing environmental flow recommendations that are more protective of freshwater mussel populations.

Sediment Release

Impoundments can build up sediment over time, starving downstream reaches of natural amounts of sediments. One method used to remediate this problem is controlled flushing of sediment into the downstream reaches of the river. Although there are several methods for sediment flushing, the most common method is draining of the reservoir, followed by flushing of previously deposited sediments over a prolonged period (Crosa et al. 2010; Gallerano and Cannata 2011). Sediment flushing can be beneficial for creating freshwater mussel habitat and restoring downstream geomorphology, if sediment is uncontaminated and of appropriate size, especially in sediment-starved reaches. However, intense or prolonged sediment flushes or pulses can also reduce the quality of existing habitat and impact aquatic species. High levels of suspended solids and siltation can impact organisms during and after sediment flushing events, resulting in fish and benthic invertebrate mortality (Crosa et al. 2010). Mussels are also sensitive to turbidity, sedimentation, scour, and disturbance events. Buried relic mussel beds have been found under 30–100 cm of sand and gravel in depositional areas (Vannote and Minshall 1982), suggesting that mussels are vulnerable to large sediment fluxes. If sediment pulses are planned in rivers with freshwater mussel populations, pulses should be timed to avoid sensitive mussel life stages and monitoring should be conducted to assess impacts to mussel beds, including burial.

Dam Removal

As infrastructure in the United States has begun to age, many dams have become unsafe or expensive to update, or have outlived their purpose. Removal has become a widespread practice, with nearly 1,400 dams removed since 1912 and 72 in 2016 alone (American Rivers 2017). Many older dams lack fish passage and are barriers to mussels and their host fish. Dams are not typically removed to restore freshwater mussel populations (but see Haag 2012), though dam removal can increase connectivity, restore habitat, and restore more natural flows for the benefit of freshwater mussels and other aquatic species. However, dam removals can also greatly impact freshwater mussel populations by draining

Table 6: Summary of Recommendations for Dam Management and Environmental Flow Programs that Incorporate Freshwater Mussels

Flow Characteristic	Recommendation
Magnitude	- Avoid extensive drying or complete dewatering for any length of time without temporarily or permanently relocating mussels first. - Avoid flows that significantly increase siltation of substrate. - Seasonally high flows can be beneficial to mussels, but 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, 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.

occupied habitat in impoundments, and downstream sedimentation can bury mussels, resulting in high rates of mortality or population extirpation (Sethi et al. 2004; Cooper 2011; also refer to BMPs for Construction and Implementation [page 36]). Because western species of freshwater mussels can inhabit both the impoundments and the reaches upstream and downstream of dams, it is important to survey for mussels prior to dam removal projects. Design projects to protect freshwater mussels, including planning for salvage and relocation of populations prior to dam removal. For example, Cowles et al. (2012) report moving western pearlshell from areas below dams on the Elwha River, Washington, into a tributary in advance of dam removal beginning in 2011.

Some examples of dam removals that have incorporated freshwater mussels are described by McCombs (2014) and Peyton and Fleece (2015) including considerations of bed stability, burrowing substrate, shear stress, and host fish. BPA (2016) establishes practices for dam or water control structure removal in small impoundments depending on sediment composition. When 65% of the sediment by weight is >2 mm in diameter (d35 >2 mm), excavation is not necessary. When d35 is <2 mm, partial removal of fine sediments to create a pilot channel and stabilization of exposed banks using native vegetation is necessary. Because river channels are often reworked following dam removal, it is also important to carefully choose relocation sites that will not be further impacted by increased sedimentation and channel migration.

Return Flows

Return flows are a type of water-trading that occurs when water that has been taken from its natural channel, is used for another purpose, and later returned to the same channel, usually at a different point than the point from which it was taken. Often return flows are used in conjunction with irrigation practices. Return flows can help lessen the low-flow effects of removing water from streams for irrigation, which is important for freshwater mussels as they require permanently inundated habitat. For example, return flows can provide some consistency of water input and depth during warm summer months, and may be able to convert fragmented mussel habitat to connected habitat (Clarke 2010). Return flows, however, can have their own set of complications. Returning water can be warmer than water in the channel and may be carrying inorganic and organic pollutants that were found in upland areas and agricultural fields. For example, return flows have been shown to sometimes carry significant amounts of salts and nitrates into freshwater systems (Causapé et al. 2004). An investigation by the Bureau of Reclamation and U.S. Geological Survey revealed that surface-water irrigation return flows to the Columbia River basin frequently contain pesticides, with the most commonly detected being atrazine, bentazon, diuron, 2,4-D, chlorpyrifos, and azinphos-methyl (Wagner et al. 2006). As a result, the use of return flows in flow restoration should be carefully assessed, particularly when freshwater mussel populations are present. Return flows should consist of high-quality water at seasonal temperatures that result in more natural flows.

Diversion Removal

Removal of instream water diversions, such as gravity-fed channels and canals or pumps, and subsequent flow restoration (increasing water quantity) can also help restore and improve habitat for freshwater mussel populations. Often diversion structures consist of a diversion dam, headgate or pump, and these structures can vary in materials used, size, and design. Flow restoration may not necessarily include removal of physical structures, but if so, topics relevant to diversion removal are discussed above and in multiple other sections, including under BMPs for Project Design and Engineering (page 30).

SEDIMENT REMEDIATION

- Avoid using sediment remediation approaches if sources and means of contaminant transport have not been addressed. Identify root causes and reduce inputs prior to disturbing aquatic habitat.
- Avoid methods that require complete site dewatering and/or dredging. Replace dredged and/or cover capped sediments with natural habitat features. Ensure that sediment is of a size and depth that permits burrowing of mussels.
- If the site includes a subset of area(s) that are uncontaminated or can otherwise be left alone, maintain as much natural vegetation and substrate material as possible. Natural areas within remediation sites may provide appropriate places to relocate mussels.
- Ensure that freshwater mussels are directly considered in approaches based on Monitored Natural Recovery.
- Minimize drift of contaminated sediment when dredging or capping. Cofferdams and/or silt curtains should be used to isolate contaminated sediments as they are being removed or treated.
- If using conventional capping methods, avoid using large quantities of structures or materials with flat surfaces or large pores.
- If using carbonaceous geosorbent techniques (materials that bind with contaminants and consist of organic matter such as charcoal), minimize the dosage and mix products into the sediment to decrease uptake by organisms rather than using a thin layer artificial capping approach (Abel et al. 2017). Also minimize turbidity associated with mixing and take care not to disturb or damage existing mussels.
- If using carbonaceous geosorbents, avoid direct applications to mussels and use of smaller particle sizes that can clog gills. Avoid use of petrogenic (derived from petroleum) activated carbon products when biogenic (derived from living plants or animals) products are available.
- Evaluate the risks and benefits of adding nutrients to sediments capped or being treated with activated carbon to make up for those lost due to binding (Han et al. 2017).
- Consider using biochar instead of activated carbon as the sorbent material (Han et al. 2017). Overall, biochar may be less toxic to organisms and thus a good alternative to activated carbon, though activated carbon is a more effective sorbent (Han et al. 2017).

Further Information on Sediment Remediation

Contaminated sediment can either be remediated or isolated in-place or can be removed and treated or disposed of. Examples of potential approaches include:

- waiting and monitoring natural recovery (dissipation or breakdown of contaminants or transport of sediment),
- dredging (sediment excavation and removal),
- capping (covering sediment with clean material), and
- in situ remediation of sediments with a chemical product.

The method(s) selected for sediment remediation will largely depend on current or potential adverse effects from contaminated sediments. A baseline risk assessment can provide important information to help identify risks associated with any actions. Although freshwater mussels will ultimately benefit from reduced exposure to contaminants, they can be impacted by activities that treat, disturb, remove, or destroy sediments in which they are found.

Monitored Natural Recovery

Monitored natural recovery (MNR) is based on the principles of "biodegradation, biotransformation, bioturbation, diffusion, dilution, adsorption, volatilization, chemical reaction or destruction, resuspension, and burial by clean sediment" (Magar et al. 2009) to reduce contaminants or contaminated sediments to acceptable levels within an acceptable period of time. The effectiveness of MNR depends on a number of site- and situation-specific considerations, including the likelihood of recovery and the timeframe over which chemical transformation happens, contaminant mobility and bioavailability is reduced, and physical isolation and/or dispersion occurs. Importantly, MNR differs from a "No Action" approach by incorporating "extensive risk assessment, site characterization, predictive modeling, and targeted monitoring to verify source control, identify natural processes, set expectations for recovery, and confirm that natural processes continue to reduce risk over time as predicted" (Magar et al. 2009).

Monitored Natural Recovery does not involve direct intervention so the potential for harm beyond existing exposure risks is low. The choice to rely on MNR, however, should be based on an informed model that evaluates the benefits or feasibility of MNR. The model for any remediation project should specifically include an evaluation of "Contaminant Bio-Uptake and Accumulation" for freshwater mussels, which assesses the "degree of exposure, partitioning, and accumulation of contaminants in biota" (Magar et al. 2009). Additionally, potential effects on freshwater mussels should be identified if they occur in the waterbody or are otherwise influenced by actions at the site (i.e., they occur downstream).

Mussels should also be incorporated into effectiveness monitoring, particularly because they are sensitive to contaminants, long-lived, and relatively sessile. Information collected from effectiveness monitoring should also be made available to inform use of MNR elsewhere. More direct sediment remediation actions, such as dredging, capping, or in situ chemical treatment have the benefit of reducing contaminant exposure more quickly than MNR. However, these methods may also have negative impacts on mussel populations, whether they occur at the site or elsewhere in the waterbody.

Figure 36. Topsoil and sand were mixed to form a thin-layer cap over contaminated lake sediments. This cap does not support freshwater mussels, although they do occur in adjacent natural substrate.

Dredging

Remediation by dredging results in active removal of contaminated sediment from a site over a short time period and has the potential to provide long-term benefits by directly reducing the existing pollutant load. However, it can also result in the destruction of habitat or resuspension of contaminants. If a dredged area must first be dewatered, freshwater mussels will be further impacted (see the subsection on Dewatering in the BMPs for Construction and Implementation [page 36]). For additional discussion of this practice, refer to Impacts from Ground-disturbing Activities also in the BMPs for Construction and Implementation (page 39).

Capping

Artificial caps cover the sediment to isolate contaminants and limit resuspension and other routes of exposure. Caps can be used to physically isolate and stabilize contaminated sediment to reduce exposure to water and biota. Materials such as sand, gravel, or other clean sediment can be used, as can other permeable and impermeable liners (Figure 36). In areas with greater potential for scour, stone or riprap may be used to further stabilize the sediment. These materials are placed singly or in layers on top of the contaminated sediment and should be thick enough to isolate contaminants from burrowing benthic animals. Geomembranes, which consist of synthetic materials, may also be used in areas of groundwater upwelling to reduce upward migration of contaminants (EPA 2004). Capping may be combined with in situ remediation methods to treat contaminants while isolating them.

Capping generally has a lower cost in comparison to dredging, which requires offsite disposal of material and possibly treatment. Other methods like MNR and dredging may also run a greater risk of resuspension of contaminants compared to capping. However, capping will likely directly kill mussels and may also impact mussel host fish. Mussels will need to be salvaged and relocated in advance if they occur in an area that will be capped. Native freshwater mussels require substrate of specific size and depth for burrowing and are commonly found in protected areas of sand and gravel substrate. The material used for capping has the potential to either provide habitat for mussels or to exclude them from formerly occupied areas. Riprap and geomembranes alone are unlikely to provide habitat for mussels. Capping material also alters nutrient composition and availability in the substrate and may eliminate aquatic vegetation that supports food webs. As with newly-created habitat, freshwater mussels may not have enough resources, and these impacts may be particularly important for juvenile mussels, which collect food from the substrate via pedal feeding.

Minimize the area to be capped use smaller sized, loose capping material like sand and gravel. Also maintain as much natural vegetation and substrate material as possible. Retain an area left uncapped or untreated to support freshwater mussels, selecting for areas with quality habitat and/or reduced impacts from contaminant exposure. Ensure that mussels are salvaged and relocated to this area in advance of work.

In Situ Chemical Remediation

In situ remediation of sediments with chemical products rely on the interaction between contaminants and reagents that are applied to or mixed with the contaminated sediments. This BMP does not cover the full range of in situ chemical treatment options, which depend in large part on the nature of the contaminant(s) (e.g., organic or inorganic, volatile or nonvolatile), and would require a much more extensive review of research beyond the scope of this document. Rather, this section illustrates how a specific class of chemical product applied at a contaminated site has the potential to remediate sediment and considers the effects of the product on mussels.

Carbonaceous Geosorbents

Carbonaceous geosorbents (CGs) chemically isolate contaminants by bonding either surficially (adsorption) or within (absorption) the geosorbent, with both processes generally referred to as sorption. Examples of CGs include biochar, activated carbon, and kerogen (Gagné et al. 2011; Han et al. 2017). Products like magnetic biochar and magnetic activated carbon, which can later be recovered from sediments, are also available. Recovery is not 100% efficient, though magnetic biochar has a higher recovery rate from sediment than magnetic activated carbon (Han et al. 2017). CGs are commonly used to immobilize one of the most significant classes of pollutants: hydrophobic organic contaminants (HOCs), which includes multiple types of contaminants, such as PCBs, DDT, chlordane, and PAHs. HOCs bioaccumulate in affected organisms, and toxic effects can increase as HOCs move up the food web, making these chemicals important targets for remediation. Benthic organisms that absorb HOCs into their fatty tissues can later cause toxicity in birds, fish, or even humans (Janssen and Beckingham 2013).

In a variety of invertebrates, sediment remediation using activated carbon has been shown to reduce bioaccumulation of HOCs. The optimal dose of activated carbon for reducing bioaccumulation varies by invertebrate species, but in most tested invertebrates, doses of activated carbon at 3% or more result in significant remediation and doses of activated carbon above 5% have not been shown to provide much additional improvement of bioaccumulation (Janssen and Beckingham 2013). In some organisms, such as the oligochaete *Lumbriculus variegatus*, activated carbon has been shown to significantly reduce HOC uptake at doses as low as 0.1%, though more significant effects are seen at higher doses (Abel et al. 2017).

Although activated carbon can reduce bioaccumulation of HOCs in invertebrate species, some invertebrate species experience negative impacts from activated carbon exposure. Reports are mixed concerning the severity of effects of activated carbon on benthic and stream-dwelling biota. At the community level, activated carbon has been shown to significantly reduce macrobenthic biomass and species diversity. Some observed negative effects of activated carbon on invertebrate species include reduced growth, reduced lipid content, lowered survival, and behavioral changes such as decreased burrowing or predator response. Activated carbon can cause lethal effects in some invertebrates at low doses. It can also indirectly affect organisms through changes to sediment characteristics, decreasing nutrient availability, or altering the chemical composition and pH of water in the area (Janssen and Beckingham 2013; Lillicrap et al. 2015; Han et al. 2017).

Unfortunately, studies have not been published directly examining effects of CGs on freshwater mussels, although there have been some studies regarding effects of CGs on other freshwater and marine bivalves. For example, the freshwater clam *Corbicula fluminea* has demonstrated reduced growth at dosages of activated carbon above 1.3% (Jannsen and Beckingham 2013). Of those saltwater clams and mussels that have been studied, no studies have documented detrimental effects of activated carbon on their growth, survival, or reproduction (Lillicrap et al. 2015).

If activated carbon particles are too small, such as powdered forms, they are more likely to bioaccumulate and cause distress in some organisms (Janssen and Beckingham 2013; Lillicrap et al. 2015). Mussels actively filter water and feed on particles of ~20 μm in size (Strayer et al. 2004) at or near the surface of the sediment, and fine sediments can clog gills (Ellis 1936). Activated carbon may also reduce nutrient availability in sediments, and the negative effects of activated carbon on organism health in some invertebrates appear to be stronger in sediments with lower nutrient availability (Han et al. 2017). Because freshwater mussels are relatively sessile they may be unable to avoid or escape from areas treated with activated carbon to increase access to nutrients. Additionally, activated carbon caps can reduce oxygen levels even in deeper sediments (Abel et al. 2017), which may have further impacts on mussels. Applying CGs of a larger particle size and at lower dosages may reduce impacts to both adult and juvenile freshwater mussels, but further research is needed. Adding nutrients back to a site may also be beneficial, but again, further research is needed. Other techniques or products, such as magnetic biochar, should be studied for their potential benefits and risks.

SALVAGE AND RELOCATION

Planning

- Coordinate early with a freshwater mussel expert to evaluate your project, and to determine whether a salvage and relocation is necessary. Identify potential relocation sites, and develop a mussel salvage and relocation plan in advance of project implementation (Figure 37).
- Ideally, plan for your salvage to occur at least a year in advance of your project during the optimal seasonal conditions. If this timeline is not possible, work with a mussel biologist to identify an alternative time period that will enable you to salvage before implementation and avoid extreme temperature and flow conditions. Aim for a time period when daily temperatures are trending cooler and temperature extremes from day to night are less.
- If feasible, after the initial salvage effort, give buried mussels time to emerge (at least a day or up to several weeks later) and plan to conduct another sweep of the site. Where mussels are abundant or sediment is fine, multiple sweeps (two to three) may be necessary.
- Have someone familiar with mussels onsite during dewatering and implementation, and plan to salvage any remaining mussels immediately prior to construction and/or during dewatering or fish salvage.
- Prepare to salvage and relocate many more mussels than originally estimated. High density mussel beds may have individuals buried beneath one another that were not included in initial abundance estimates. Salvage sites may commonly have many times more than the number of mussels originally estimated.
- Although you should salvage mussels during dewatering, do not plan your sole mussel salvage for the day of dewatering, when water will be turbid and you will have limited time to collect mussels before they become stressed.

Figure 37. In this excerpt from a mussel salvage plan, courtesy Emily Davis of the Confederated Tribes of the Warm Springs Indian Reservation, the locations from which mussels will be salvaged are outlined in detail for personnel. Other information to include in a salvage plan is discussed on page 58.

Section 1 (Stations 0-15)

This section starts just below the bridge at Vincent Creek at station 00 and extends downstream to about station 15, coinciding with a large, fenced water gap where Section 2 starts. Areas for planned structures that need to be searched for mussels are as follows. Upstream and downstream limits of each area are marked with pin flags. Unless otherwise specified, search across the channel to approx. mid-channel. RR= River Right. RL= River Left. Wooden stakes usually have station numbers and planned structure type written on them so you can keep track of where you are.

Standalone riprap and rock barbs are marked with spray paint but not listed here. Be sure to search each one.

- Log structure at Station 5, RR--Pay extra attention to the downstream 20' of this area, because a pool will be excavated here.
- Alcove 1, Station 8, RR.
- Large area of riprap at Station 13, RL--Unlike most areas of riprap where you would just search along the base, this riprap needs also to be searched extending into mid-channel and about 10' upstream and downstream from each end (this is marked).

Selecting Relocation Sites

- Avoid relocating mussels to:
  - sites without an existing population of mussels,
  - newly created habitat,
  - habitat without host fish,
  - areas that have been dredged,
  - areas that may become dry or have stagnant flow,
  - areas that may have future impacts, including planned restoration, or
  - areas that experience scour.
- Relocate mussels to:
  - sites with an existing population of mussels of the same species,
  - habitat upstream of the project area, and
  - sites near your project in the same watershed.
- If there are no other existing populations nearby, or you think the sites lack habitat for placing additional mussels, identify sites with apparent similar habitat. Consider placing mussels in tributaries, especially if other nearby reaches or waterbodies will later be restored. If feasible, conduct a pilot relocation study in advance of the full relocation. Conduct the study as early as possible to determine if mussels can survive there (1–3+ years in advance if you can).
- Identify and rank multiple potential relocation sites in the event that conditions change at your primary site or many more mussels are discovered than anticipated.
- Aim for similar density (or an increase of no more than 25–50%) of mussels at the relocation site.

Preparing to Salvage

- Ensure that you and other personnel are familiar with the relocation site and how to collect and handle mussels before the day of the salvage.
- Budget for and procure all the necessary equipment in advance. Have extra mesh bags, coolers, and other equipment on hand to keep the salvage running smoothly in case you must salvage many more mussels than anticipated.
- Adequately mark the boundaries of your salvage area (the area of direct impact and an appropriate buffer distance).

Salvaging

- Do not salvage if temperatures are especially hot or cold or if flows are predicted to increase or decrease much in the days following. Check weather forecasts and USGS gaging stations to help you predict conditions in advance (see Appendix 1 [page 80]).
- Orient personnel the day of the salvage to ensure that they are familiar with the salvage plan, will be able to find mussels, and know how to properly collect, hold, transport, and place mussels (Figure 38).
- Use the salvage effort as an opportunity to reach out and train other restoration planners,

practitioners, biologists, landowners, and volunteers.

- During initial and subsequent salvages, conduct at least two passes with a systematic search method.
- Minimize handling, exposure, or other stressors associated with mussel salvage and relocation, especially time out of water. Maintain ambient conditions (e.g., local water temperature on the day of the salvage) as long as possible and limit time out of water to less than 5 minutes using mussel rafts or mesh bags.
- Keep mussels damp, cool, and out of direct sun when marking or holding and during transport (following detailed guidelines on page 61).

Figure 38. Familiarize yourself and others with sites in advance of salvage and relocation.

Relocating

- Place mussels gently on top of the substrate at the relocation site to allow them to reanchor themselves and avoid damaging them. If you are experienced in handling and relocating mussels, you may instead place mussels directly into the substrate, but this is not generally recommended.
- If you find that mussels tumble or are shifted by higher flows at your replacement site, move them to another area of the site that is more shielded from high flows, such as behind boulders or woody structures.

Monitoring and Documenting the Effort

- Monitor relocated mussels following recommendations discussed in the section Developing a Monitoring Plan (page 25).
- Document your mussel salvage and relocation at (http://xerces.org/freshwater-mussel-relocation-form/).

Further Information on Salvage and Relocation

The following sections discuss important points to keep in mind as you plan your salvage and relocation. Not all BMPs for salvage and relocation may apply to your situation or be implementable at your site, and working with a mussel biologist can help you plan and prioritize conservation actions. Even with careful surveys prior to project implementation, you may only discover that mussels are present at your site after the onset of restoration or construction activities. Mussels can be cryptic and may occur in small numbers or low density at a site. If you must conduct a last-minute or emergency salvage and relocation, you should still briefly review the information on Conducting a Planned Salvage and Relocation (below), but you can then refer to the section Conducting an Emergency Salvage and Relocation (page 63), which outlines how to approach a salvage and relocation when you have limited time. Once you have completed the salvage and relocation, make sure that mussels are surveyed for and incorporated into your next project so that you will be able to conduct a planned salvage and relocation.

Freshwater mussel salvage and relocation guidelines for western mussels were developed in 2009 by the Pacific Northwest Native Freshwater Mussel Workgroup (Luzier and Miller 2009). The BMPs and discussion in this section include many of the valuable recommendations provided by Luzier and Miller, but have been updated and expanded based on recent literature, and experience gained and lessons learned since 2009.

Conducting a Planned Salvage and Relocation

Developing a Salvage Plan

As with a fish salvage, developing a salvage plan for freshwater mussels can ensure that logistical information is agreed upon and available to your team and collaborators. Your mussel salvage plan, as with a fish salvage plan, should cover the steps that will be taken to find, handle, and remove mussels, and hold, transport, and relocate them. It should also include specific information about where mussels will be removed from and where they will be relocated to, as well as backup options. Make sure that you will have access rights up and downstream of salvage and relocation sites if you conduct work on private property. Set aside several potential days for the salvage and relocation, especially if there is potential for temperatures to be too hot or cold, flows to be too high, or you plan the salvage outside of an in-water work window. You may also need to work around salmon or other listed species.

Personnel

Many relocation efforts in the Pacific Northwest have been accomplished by teams of mussel experts, project managers, and volunteers (Figure 39). Engaging volunteers in such efforts has many benefits, including opportunities for community outreach and environmental education (Mazzacano and Blackburn 2015). As mussel expertise expands in the Pacific Northwest, mussel relocation efforts will ideally be conducted similar to fish salvages, with adequate planning and budgeting and clear conservation goals incorporated into project planning stages. Working with experts can help ensure that BMPs are appropriately implemented at your site, and is especially important when projects occur in remote areas or under conditions not generally safe for volunteers.

Much of the same equipment needed for mussel surveys (see Appendix 3 [page 92]) should be used for mussel salvages and relocations. If volunteers will be assisting you, you may also need to supply refreshments, extra clothing or equipment like waders, wetsuits, masks and snorkels, site maps, printed instructions, and example mussel shells and identification guides. Other specialized equipment includes

- flagging, marking paint, or pin flags to mark search areas or transects for later monitoring
- walkie talkies or cell phones to communicate with others if you are split into several groups or must cover a large area
- buckets to temporarily hold mussels during measurement or marking and before transfer to coolers
- coolers to hold mussels for transport
- ammonia alert device or card (as used in aquariums) to monitor ammonia levels in water
- frozen water bottles or ice packs
- clean towels or quilts to absorb water and protect mussels from frozen water bottles or ice packs (make sure materials are free from soap or other residue)
- green scrubbing pad
- adhesive (cyanoacrylate or dental cement)
- shellfish tags and tweezers for affixing them
- PIT tags and waterproof scanners

- many small rags to dry shells before attaching tags
- hard hats and safety vests
- vehicle for transport, such as a car, off-road vehicle, wheelbarrow, or hand truck

Plan to procure this equipment well in advance of your salvage and relocation, particularly if you must have approved vendors, need to construct your own equipment (i.e., dredge net or viewing bucket), or require specialty items. Disinfection of all equipment that has been used previously is also necessary. A recommended protocol is provided in Appendix 3 (page 92).

If your salvage and relocation will occur over several days, be sure to organize gear at the end of each day to keep things running smoothly. If you have purchased equipment, be sure to retain it for future salvages. You may be able to lend it to others to support additional salvage efforts.

Figure 39. These snorkelers are salvaging freshwater mussels before a restoration project. Training was provided by a biologist familiar with freshwater mussels and the site.

Salvage Area

After you have conducted your pre-implementation survey to identify where mussels occur, which species are present, and the approximate size of the population, the next step is to determine the area over which the salvage will occur. This area should include the footprint of any activity or construction element and adjacent areas that may be affected. In the case of dewatering, this would include all areas that will be exposed, regardless of where any other activity may take place (e.g., removal of a flow constrictor downstream that may result in dewatered banks upstream should consider both the site of removal and the dewatered areas).

Mussels should also be relocated from within a set buffer distance around project or structure footprints. In cases where scour analyses provide more detailed, site-specific information, buffers should include areas where hydraulics may change and scour may occur. Minimum buffers should be 5 m upstream and lateral to areas of direct impact and 10 m downstream. However, refer back to the section Assessing Potential Impacts (page 12), for guidance on whether minimum buffer distances are adequate given the extent of the project's activities or footprint, as well as whether project-specific buffers provided by Clayton et al. (2016) are more protective.

If you are not able to salvage mussels across your entire project area (see the subsection on Mussels at Your Site in Project Development and Review [page 13]), you can also identify priority areas based on zones of density (see Estimating Density [page 98] in Appendix 3). For example, you may prioritize moving scattered or sparsely distributed mussels to areas of higher density or develop thresholds of density to prioritize salvage areas.

Ensure also that the salvage area is delineated by flagging or other markers prior to beginning work. Natural features can also be used to delineate the salvage area but should clearly be identified.

Relocation Site

It is important to select a relocation site in advance of project implementation and the mussel salvage (Box 7). You should also identify backup or overflow relocation sites.

Box 7. Selecting a Relocation Site

An optimal site has all of the following characteristics:

- An existing population of the species, with available habitat.
- Is upstream of the work site.
- Is near the project area in the same watershed.
- Will not be restored or disturbed in the future.
- Will not dry or scour (Figure 40).
- Does not have other concerns, such as a point source discharge, stormwater outflow, irrigation return flow, or is the site of water withdrawal.

If you cannot identify a site with the above characteristics, you may need to choose a site that is:

- Downstream of the project (but only for projects that do not have activities that will result in downstream impacts at the relocation site).
- In the same watershed and within similar habitat (e.g., do not place animals from flowing water into ponds or lakes, or vice versa), that supports other mussel species.
- In a nearby tributary and within similar habitat.

Do not relocate mussels to newly created habitat because food and other resources will be lacking at new sites. These sites may also be too dynamic for freshwater mussels until conditions have stabilized. Additionally, relocated mussels may be at greater risk of displacement for some time following relocation (Stodola et al. 2017).

Sometimes you may not know of other mussel populations, or they will not occur upstream of your site. In these cases, you should work with a mussel biologist to identify the best alternative option, such as a location with similar habitat and gradient. Note that a site may not be able to support freshwater mussels, perhaps because it periodically dries, host fish are not present, or a toxic substance or disease is found there. It can help to know whether a diverse native fish community is also present at the potential site. If there are barriers to fish movement, mussel reproduction may be impacted.

If feasible, conduct a pilot relocation study in advance of the full relocation. Conduct the study as early as possible to determine if mussels can survive there (1 to 3+ years in advance if you can). If many mussels will be moved, relocating mussels to several sites may also be necessary, so reconnaissance surveys may be needed at multiple locations. Outplanting has been done in California (case study in Appendix 4 [page 102]) and in eastern United States rivers, constituting a form of facilitated re-colonization. Such efforts have the potential to increase species' resilience and restore populations extirpated by historic activities. Tributaries may also serve as refugia within dammed systems or in rivers whose mainstem may be more naturally active.

Given concerns over the spread of disease or outbreeding depression, standard mussel salvages (i.e., those for which little is known about the population's genetics or are not part of a larger study) should limit movement of mussels to new sites within the same river network or subbasin. If mussel recolonization is a goal, it may be more appropriate to propagate mussels, since both pathogen infection and genetic diversity can be better controlled in a laboratory setting.

Regardless of where mussels are relocated, be sure to adequately record site information for both the salvage area and the relocation site, as well as information included in the relocation reporting form (http://xerces.org/freshwater-mussel-relocation-form/), including the species and number of mussels, the date, purpose, etc.

Collecting Mussels for Relocation

Personnel should split into groups to perform each task during mussel collection. One group should be responsible for manually collecting mussels from the site and placing them in containers for temporary holding, and a second group should plan to assist with collecting those containers as they fill, walking along the bank or shore and ensuring proper holding conditions of collected mussels. Depending on where mussels will be relocated to, you may need a designated driver to transport mussels to the relocation site. You may also need to have personnel that initially assist with collection, then move to the relocation site to begin replanting mussels. Another group can focus on measuring and marking mussels.

Mussel collection should be done gently by hand so that shells do not crack and the edges of shells, where shell growth occurs, are not damaged. Dredging should generally be avoided. It should only be used to collect floater mussels in deeper water or habitat with mucky sediment and lower visibility. Dredging should not be used in other habitats or with species like western ridged mussel and western pearlshell. These species should be collected by hand because they are typically more firmly rooted or occur in habitat where dredging will be damaging and ineffective. If rakes are used, take care to not puncture shells with rake tines.

Some protocols recommend that relocations include at least two passes, comparing the numbers collected during each. During the second pass, if you collect at least 10% as many mussels as in the first pass, do a third sweep. Complete as many sweeps as possible, allowing fines to settle or clear between passes to improve visibility, and continue until the number of mussels you collect is below the 10% threshold (Figure 41).

To avoid salvaging more mussels than you can relocate in the same day, conduct an incremental salvage and relocation. Identify discrete, reasonably-sized or small blocks from which to salvage mussels and sequentially tackle the blocks, both collecting and relocating mussels from a block on the same day. Stop when you have reached capacity for a single day and later return to complete the remaining blocks. Prioritize areas from which to salvage based on the project footprint or zones of density.

Holding and Transport

Handling and transport time should be minimized to the greatest extent possible, as transport stress limits the success of your salvage and relocation effort. Once mussels have been removed from the waterbody, you will need to protect them by keeping them damp, cool, and out of direct sun.

Figure 40. Mussels placed along the shoreline at this relocation site were stranded just a few weeks later when the creek's flow rapidly declined.

Figure 41. Hundreds of western pearlshell mussels inhabit this reach a quarter mile from the stream's headwaters. Salvaging mussels, even from a small stream like this, can require multiple passes.

If you are able to keep the mussels sufficiently cool, it may be feasible to transport them out of water and covered with damp, cool towels. A benefit of this method is that the mussels remain "clammed up," which prevents excessive fouling of transport water. Mussels will build up waste over time if they are open and filtering. This method is preferable only if you are able to keep them damp and cool enough, and if they will remain out of water for no more than the time it takes you to salvage and transport them. You may need to maintain cooler than ambient temperatures by placing wetted towels under and over the mussels. Layers of icepacks or frozen water bottles can be used to keep mussels cool, but they must be placed below mussels to avoid crushing. Do not use loose ice or place ice directly against mussels.

If your salvage and relocation will take longer than a few hours (and, therefore mussels will need to be allowed to filter and release wastes) *or* you will not be able to keep mussels cool, you should leave mussels in mesh bags securely anchored at the site and submerged in flowing water until they are ready for transport. Be sure to not over-pack mussels in bags to avoid crushing them or damaging shell margins. In lakes and ponds or sluggish waters, you might be able to construct a "holding pen" by placing fencing or yard-edging material into the substrate, allowing mussels to move around within the blocked off area.

If you place mussels in coolers or fish transport containers, they should be covered at least by two inches of water. The water in the cooler should be maintained at temperatures similar to or several degrees cooler than ambient conditions. This can be done by adding or exchanging the water and layering with icepacks or frozen water bottles as described above. Limit how long mussels are held by this method, and watch for signs of thermal stress like persistent gaping. Overly warm or cold water can thermally stress mussels, and on warmer days, water is likely to become warmer than the ambient water temperature. You will need to aerate the water (with an aquarium bubbler, for example) and insert an ammonia card, which will alert you to the buildup of ammonia, to which mussels are highly sensitive. Mussels may build up ammonia especially quickly if they are found in more eutrophic waters, where they may be more adapted to quick metabolization. Change out water and replace it with native water if the ammonia card indicates there is a buildup of wastes.

If mussels must be held overnight in coolers (not recommended!), consider placing coolers in a facility with ambient temperatures several degrees cooler than river temperatures and collect extra water from the home river or lake so you can change out water.

Keep track of the number of mussels that you collect and relocate. Either when transferring mussels from mesh bags to coolers or before replacing mussels at the relocation site, it is also a good idea to mark at least a subset of the mussels you have salvaged (see the section How to Monitor [page 27]).

Placement

Improper placement is likely a major contributor to relocation failure. Mussels should be placed gently *onto* the substrate at the relocation site to avoid damage to the shell or animal. A mussel biologist with relocation experience, however, may recommend placing mussels directly *into* the substrate. If this is done, it is very important to orient mussels properly, with the anterior end in the substrate—and gently. If you place mussels improperly, they may die because they are unable to reorient themselves (Figure 20). In faster flow and coarser sediment, you can still place mussels gently on the substrate in pockets near larger rocks, boulders, or plant roots to help brace them against flow. Avoid stagnant water or deep pools, which generally do not provide adequate flow.

Mussels should not be dumped from containers into the relocation site. Mussels may not be able to reorient themselves from piles, leaving them at greater risk of being washed downstream or damaged. They may also be highly visible and vulnerable to predators. Document weather and other conditions during relocation (e.g., air and water temperature, time out of water, etc.) as well as methods used to collect and place mussels and share this information with the Xerces Society to help improve BMPs (Figure 42).

Conducting an Emergency Salvage and Relocation

You may have encountered mussels:

- during fish surveys or other activities immediately before implementing your project,
- in the middle of an activity like dewatering, or
- exhibiting signs of distress.

If you have encountered mussels immediately prior to or during project implementation, it is important to get in touch with agency staff and mussel biologists to determine the next steps. If mussels are already exposed or at risk of harm, then an emergency salvage should be conducted to move mussels from areas that will be completely dewatered or where activities will otherwise directly impact mussels (Figure 43) to a safe location quickly. It will be important to monitor mussels that are relocated following an emergency salvage to determine whether the location you chose is sufficient or you will need to move mussels to another site.

If you discover mussels after you have begun dewatering, conduct a salvage and relocation. If you discover mussels during implementation but are unsure whether a salvage and relocation is required, pause your work if possible and refer to the sections Determining if Salvage and Relocation is Necessary (page 18) and Monitoring for Signs of Distress (page 20) to help you evaluate the situation. Keep in mind that if you do not have appropriate equipment for moving mussels and no knowledge of how or where to move mussels, it may also be best to leave them where they are, as long as habitat is not totally dewatered and mussels will not be crushed or otherwise directly killed.

If you have determined that you should move mussels at this point, much of the information provided in Conducting a Planned Salvage and Relocation (page 58) should be reviewed to help you implement an emergency salvage and relocation. Regardless of circumstances, you should contact the permitting agency as soon as possible to identify the next steps, including determining whether there is additional potential to impact mussels at the site and whether a permit for the "take" that has already occurred is required and can be secured. Some additional issues and solutions are provided in Box 8 to help you succeed.

Figure 42. Michele Blackburn of the Xerces Society gathers data on tagged mussels to help refine salvage and relocation techniques.

Box 8. Solutions to Common Issues in Emergency Mussel Salvages

Issue: You have begun dewatering and discover mussels at your site.

- Solution: Delay total dewatering if you can. An emergency salvage can and should be conducted to avoid a mussel kill.

Issue: You are only able to salvage a subset of the mussels at your site.

- Solution: Prioritize salvaging mussels from the largest aggregations or from areas that will be most impacted, such as within the ADI.

Issue: You must quickly identify a relocation site.

- Solution: If feasible, construct temporary holding pens or place mussels in mesh bags at the site to gain more time to identify an appropriate relocation site. If that is not possible, quickly scout out areas upstream of your project with similar gradient and substrate and move mussels to this location. Do not move them to newly constructed habitat. Consult with a mussel biologist to determine if the relocation site is adequate and develop a plan to move mussels to a more appropriate site, if necessary. Monitor relocated mussels as you would with a planned salvage to learn whether your relocation was successful.

Issue: 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 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 project manager 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: You must compromise between rescuing more mussels or taking more care with relocating mussels.

- Solution: Collecting many more mussels than you can properly place will likely still result in high rates of mortality. Again, consider constructing a temporary holding pen or placing mussels in mesh bags to hold them until they can be relocated. If that is not possible, collect as many mussels as you can quickly place at the relocation site, placing them 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. They will be vulnerable to predators or being washed downstream, their shells may become damaged, or they may ultimately be unable to right themselves and will perish.

Figure 43. Dewatering can quickly kill freshwater mussels, especially when conditions are warm or cold and mussels are exposed. This live mussel is rapidly becoming exposed following a drawdown.

5

Knowledge Gaps

Research in the following areas would improve management recommendations to conserve western freshwater mussels.

DESIGN AND ENGINEERING

- Key microhabitat and flow preferences of western freshwater mussels (FMCS 2016).

CONSTRUCTION AND IMPLEMENTATION

- How western mussel species respond to stranding, including their ability and proclivity to vertically burrow or move horizontally in a variety of habitats, rates of dewatering, and duration of dewatering.
- The proximate cues for horizontal movement in mussels due to dewatering (dissolved oxygen concentration, temperature change, water change itself, seasonality, etc.).
- The effects of vibration and drilling on western mussel species, including testing and monitoring the effects of different methods on a variety of substrates, such as 1) spacing vibrations over time, 2) vibrating for shorter periods of time, 3) minimizing the number of structures vibrated, 4) increasing the distance of vibrations, and 5) using methods that result in more rapid dissipation of vibrations.

VEGETATION MANAGEMENT

- The toxicity of herbicides and additives on native western freshwater mussels, including laboratory studies examining herbicide toxicity exposure through sediment, studies examining effects of a wider range of herbicides, adjuvants, and their combinations, chronic exposure effects, and impacts of whole life cycle exposures (Archambault et al. 2015; Wang et al. 2017). Additional research should examine short and long term sub-lethal effects of herbicides and adjuvants (Archambault et al. 2015) on:
    - juvenile mussel growth,
    - glochidial metamorphosis success,
    - hemolymph and tissue analysis,
    - mussel movement or burrowing, and
    - mussel metabolism.

- Impacts from multiple simultaneous stressors, including herbicide exposure, and indirect effects of herbicide exposure on mussel diets (Archambault et al. 2015).
- The toxicity of commonly used herbicides and additives, including imazapyr, nonylphenol ethoxylate, aminopyralid, and herbicides containing triclopyr.

NAS MANAGEMENT

- The effects of piscicides and molluscicides on western species of freshwater mussels, including novel delivery methods that limit exposure of native species. Studies testing any potential for toxicity of Natrix™ and Zequanox® to additional aquatic organisms and freshwater mussels can be used to establish limits for application (Molloy et al. 2013).
- The effects of emerging NAS treatments in western waterbodies, such as use of sodium chloride to eradicate invasive frogs.

FLOW MANAGEMENT AND RESTORATION

- Development of environmental flow frameworks that include western freshwater mussel species.
- Development of technical recommendations for sediment flushing practices to minimize impacts to western freshwater mussels.
- The effects of return flows on western mussels.

SEDIMENT REMEDIATION

- The potential for caps or clean fill material to provide suitable mussel habitat, both short-term or long-term. Research evaluating how characteristics such as grain size, TOC, DOC, DO, pH, etc. affect capping suitability.
- The effects of activated carbon, biochar, and magnetic sorbents on western freshwater mussel species, examining both lethal and sub-lethal effects.
- The effects of MNR, dredging, capping, and chemical remediation on mussel host fish populations.

SALVAGE AND RELOCATION

- Optimal densities of mussels at sites with existing populations in a variety of conditions, as well as how to define "success" for a relocation effort (FMCS 2016).
- Methods to more easily and accurately estimate densities to improve mussel estimates and assessment.
- The optimal temperatures and flow conditions for relocating mussels, especially to develop guidelines such as maximums and minimums or differences between air and water temperature.

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Appendix 1. Additional Resources and Links

Field guides and State and Provincial Agency Resources:

- Xerces Society Western Freshwater Mussel Page: http://xerces.org/western-freshwater-mussels/. Email records to mussels@xerces.org for inclusion in the Western Freshwater Mussel Database.
- Contact the PNW Native Freshwater Mussel Workgroup: pnwmussel@googlegroups.com; www.pnwmussels.org.
- Pacific Northwest Freshwater Mussel Field Guide: http://xerces.org/identification-guides/freshwater-mussel-guide/
- Collection of links to other guides: http://pnwmussels.org/field-guides/
- State protocols for mussel surveys: http://molluskconservation.org/Mussel_Protocols.html
- Relocation Form: http://xerces.org/freshwater-mussel-relocation-form/
- Die-off Observation Form: http://arcg.is/0K0SHG
- Data sheet: http://www.wvdnr.gov/Mussels/Main.shtm
- USGS Water Data: https://waterdata.usgs.gov/nwis
- iNaturalist project: Freshwater Mussels of the Western U.S.: http://tinyurl.com/jhdbfow
- Wyoming Citizen Science Project: https://www.wyomingbiodiversity.org/Initiatives-Programs/CitSci/know-your-mussels-native-mussels-wyoming

Invasive Aquatic Species Resources

- https://tpwd.texas.gov/publications/pwdpubs/media/pwd_lf_t3200_1958_arrp_guidelines_packet.pdf
- https://nas.er.usgs.gov/default.aspx
- http://www.syndel.com/products/biosecurity-supplies-disinfectants/virkon-auqatic/virkon-aquatic-10-lb-tub-virkdlb0010.html
- www.wdfw.wa.gov/ais/reporting

States and Provinces Where Permits May be Needed (may vary by activity):

- NOAA permits: https://apps.nmfs.noaa.gov/index.cfm
- Wyoming: https://wgfd.wyo.gov/Permits/
- Idaho: https://idfg.idaho.gov/license/applications
- Oregon: http://www.dfw.state.or.us/fish/license_permits_apps/index.asp; fish.research@state.or.us
- California: https://www.wildlife.ca.gov/Licensing/Scientific-Collecting

- Washington: http://wdfw.wa.gov/licensing/scp/ and http://wdfw.wa.gov/licensing/hpa/
- Alaska: http://www.adfg.alaska.gov/index.cfm?adfg=license.main
- Arizona: https://www.azgfd.com/license/speciallicense/scientificcollection/
- Utah: https://wildlife.utah.gov/utah-licenses/certificate-of-registration.html and http://nrwrt1.nr.state.ut.us/strmalt/
- Nevada: http://www.ndow.org/Forms_and_Resources/Special_Permits/
- B.C.:
    - National: http://www.pac.dfo-mpo.gc.ca/fm-gp/licence-permis/sci/index-eng.html; http://www.dfo-mpo.gc.ca/aquaculture/management-gestion/intro-eng.htm; http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html; http://www.dfo-mpo.gc.ca/species-especes/sara-lep/permits-permis/index-eng.html
    - Provincial: http://www.frontcounterbc.gov.bc.ca/Start/fish-wildlife/

Herbicide or Other BMP Information

- http://ipm.ucanr.edu/PMG/menu.pesticides.php
- https://pesticideimpacts.org/
- https://wdfw.wa.gov/publications/01490/wdfw01490.pdf
- http://www.wsdot.wa.gov/maintenance/roadside/esa.htm

Appendix 2. Western Freshwater Mussels

Mussel Biology and Life History

Freshwater mussels are native, benthos-dwelling bivalves. They inhabit fish-bearing streams, rivers, lakes, and ponds that have year-round flow or inundation. Adult mussels burrow into sediment using a muscular foot and are oriented upright with two halves (valves) of the mussel shell slightly open (Figure A2.1 and A2.2). Mussels filter water through their gills via openings known as the inhalant and exhalent apertures, receiving oxygen and food while also filtering impurities and suspended solids from the water column, some of which are re-deposited as pseudofeces and available as food for other species. Mussels may occur singly, sparsely (<1 mussel/m^2), or may be densely packed (up to 400 mussels/m^2) in aggregations known as mussel beds. Often, freshwater mussel species are discussed together, but our native fauna includes multiple species with differences in appearance and life history (next section), although multiple species may also occur together where habitat preferences and ranges overlap. You may also observe Asian clams at your site (Figure A2.3), but these animals are smaller and nonnative. Native fingernail and pea clams (Figure A2.3) may also be present.

Figure A2.1 Left: Arrows clockwise from left indicate: (1) the anterior end, where the foot extends; (2) the beak (umbo) of the shell, closest to the anterior end; (3) the hinge of the shell, connecting the two valves; (4) the exhalent aperture; (5) the inhalant aperture siphon with papillae. Right: A floater mussel as seen underwater.

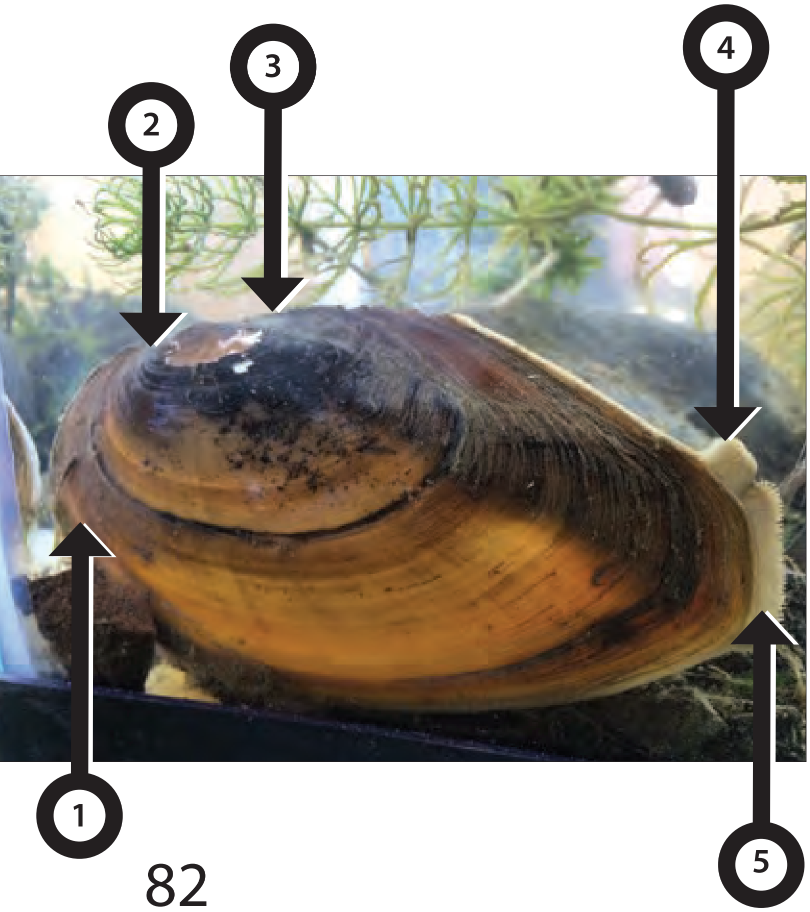


Figure A2.2: Freshwater Mussel Life Cycle

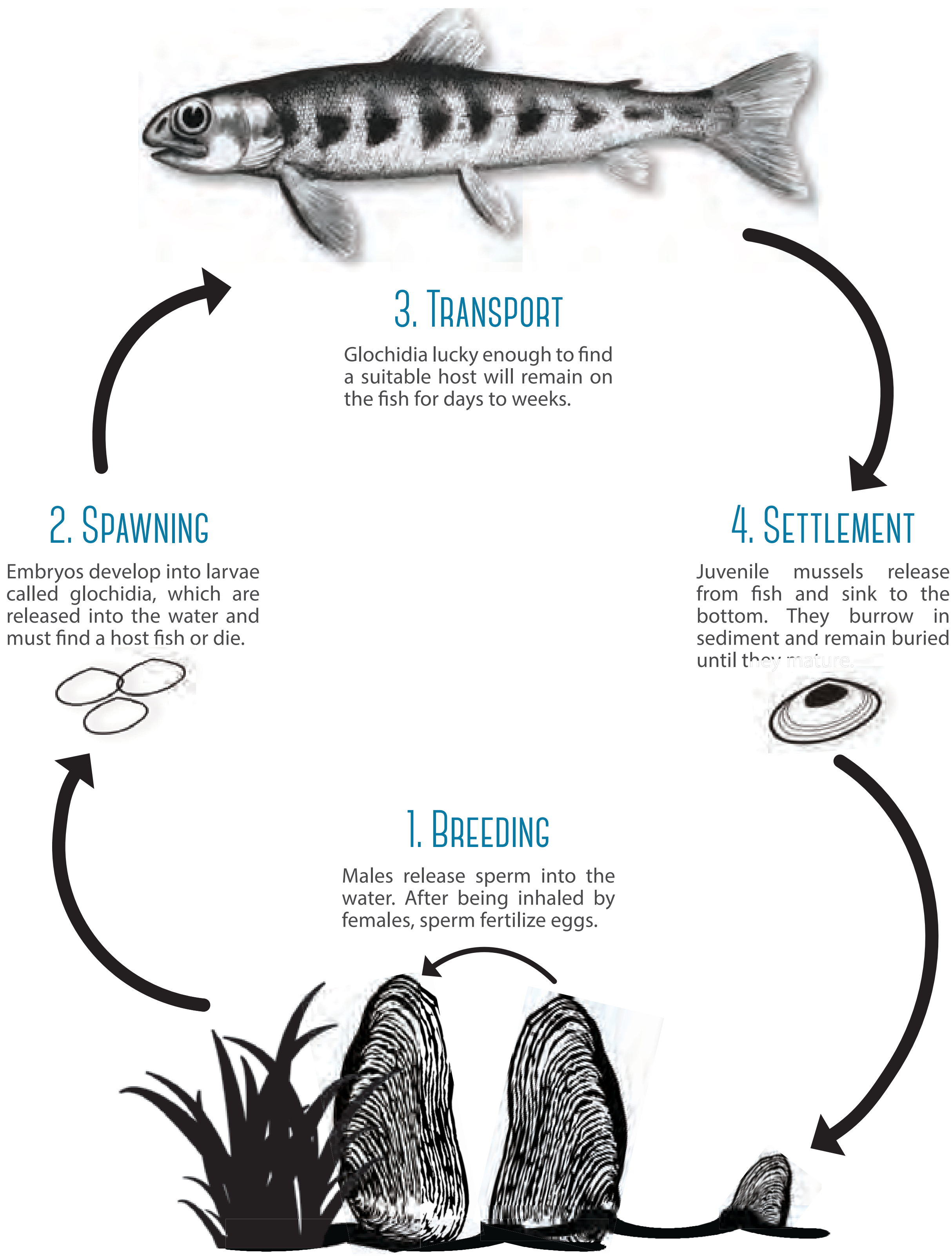


Figure A2.3. Above and bottom left: invasive freshwater clams (genus *Corbicula* [at right of arrow]) are smaller and rounder in appearance than freshwater mussels (at left of arrow). Bottom right: native fingernail and pea clams are also much smaller and rounder in appearance than freshwater mussels.

Native freshwater mussels share a similar complex life cycle. Mussel reproduction is influenced by water temperatures, although species can vary widely across their ranges. For reproduction, male mussels release sperm into the water column where it is filtered by a female mussel, whose eggs are fertilized, then deposited into special gill chambers and brooded. Glochidia, the name for mussel larvae, develop from the eggs in these marsupia, where they are kept safe and well oxygenated. Fully developed glochidia are released into the water column, where they must attach to host fish as temporary external parasites. Glochidia may be released from mussels as a mass called a conglutinate that looks like food and attracts fish (Figure A2.4), or they may drift in the water column until encountering a fish host.

Glochidia attach to fish gills, fins, and the body, traveling with fish as they swim throughout a watershed. After a short period (generally between one week and one month), mussels release from their host fish, becoming juveniles and bury into the sediment, where they grow to maturity (A2.4, bottom right; Nedeau et al. 2009). Some mussel species are host generalists when it comes to host fish while others specialize on one of a few species (see Table A2.1). During certain life stages (e.g., during spawning and brooding, glochidial encystment, and as juveniles) mussels can be especially sensitive.

Figure A2.4. Images of freshwater mussel glochidia in conglutinates (top left and bottom left) or glochidial-web mass (top right). Top left and right: western ridged mussel and floater. Bottom left: western pearlshell. Bottom right: juvenile mussels, like this floater, are much smaller than adults, and can be even smaller than pictured here.

Table A2.1: Confirmed Host Fish of Western Freshwater Mussels

Confirmed native and nonnative host fish of western freshwater mussels (based on observation of natural glochidial infections and glochidial metamorphosis [O'Brien and Brim Box 1999; O'Brien and Williams 2002]). Knowledge of host fish may be limited to just one or several states or regions. Host fish in other states may differ.

Mussel Species	Fish Species	Reference
Anodonta	Pit sculpin (*Cottus pitensis*)	Haley et al. 2007
Anodonta	Sacramento pikeminnow (*Ptychocheilus grandis*)	Haley et al. 2007
Anodonta	tule perch (*Hysterocarpus traski*)	Haley et al. 2007
Anodonta	torrent sculpin (*Cottus rhotheus*)	Maine et al. 2016
Anodonta	threespine stickleback (*Gasterosteus aculeatus*)	Martel and Lauzon-Guay 2005; Maine et al. 2016; Barnhart, unpublished data, 2016
Anodonta	redside shiner (*Richardsonius balteatus*)	O'Brien et al. 2013; Maine et al. 2016
Anodonta	speckled dace (*Rhinichthys osculus*)	O'Brien et al. 2013; Maine et al. 2016
Anodonta	prickly sculpin (*Cottus asper*)	Martel and Lauzon-Guay 2005
Anodonta	green sunfish (*Lepomis cyanellus*)	Haley et al. 2007
Anodonta	hardhead (*Mylopharodon conocephalus*)	Haley et al. 2007
Gonidea angulata	hardhead (*Mylopharodon conocephalus*)	Haley et al. 2007
Gonidea angulata	Pit sculpin (*Cottus pitensis*)	Haley et al. 2007
Gonidea angulata	tule perch (*Hysterocarpus traski*)	Haley et al. 2007
Margaritifera falcata	Chinook salmon (*Oncorhynchus tshawytscha*)	Karna and Millemann 1978
Margaritifera falcata	coho salmon (*Oncorhynchus kisutch*)	Karna and Millemann 1978
Margaritifera falcata	cutthroat trout (*Oncorhynchus clarkii*)	Karna and Millemann 1978
Margaritifera falcata	rainbow trout/steelhead trout (*Oncorhynchus mykiss*)	Murphy 1942; Karna and Millemann 1978
Margaritifera falcata	brown trout (*Salmo trutta*)[1]	Murphy 1942

[1] Nonnative to the western United States

Other suspected host fish have been reported, but further experimentation is needed to validate observations.

For *Margaritifera falcata*, these include: bull trout (*Salvelinus confluentus*), kokanee salmon (*Oncorhynchus nerka*), Lahontan redside (*Richardsonius egregius*), prickly sculpin (*Cottus asper*), speckled dace (*Rhinichthys osculus*), Tahoe sucker (*Catostomus tahoensis*), threespine stickleback (*Gasterosteus aculeatus*), and brook trout (*Salvelinus fontinalis*) (Murphy 1942; Meyers and Millemann 1977; Karna and Millemann 1978; Steg, in Jepsen, et al. 2012).

For *Gonidea angulata*, these include: leopard dace (*Rhinichthys falcatus*), longnose dace (*Rhinichthys cataractae*), margined sculpin (*Cottus marginatus*), northern pikeminnow (*Ptychocheilus oregonensis*), Pit roach (*Lavinia symmetricus mitrulus*), prickly sculpin (*Cottus asper*), shorthead sculpin (*Cottus confusus*), and black crappie (*Pomoxis nigromaculatus*) (Haley et al. 2007; O'Brien et al. 2013; Mageroy 2015; Brownlee et al. in prep).

For *Anodonta* spp., these include: rainbow trout/steelhead trout (*Oncorhynchus mykiss*), chiselmouth (*Acrocheilus alutaceus*), northern pikeminnow (*Ptychocheilus oregonensis*), longnose dace (*Rhinichthys cataractae*), margined sculpin (*Cottus marginatus*), peamouth (*Mylocheilus caurinus*), sucker (*Catostomus* sp.), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Oncorhynchus clarkii*), Dolly Varden (*Salvelinus malma*), brook stickleback (*Culaea inconstans*), golden shiner (*Notemigonus crysoleucas*), and mosquitofish (*Gambusia affinis*) (D'Eliscu 1972; Moles 1983; Lang 1998; Martel and Lauzon-Guay 2005; O'Brien et al. 2013; Barnhart, unpublished data, 2016; Maine and O'Brien, unpublished data, 2016).

For *Sinanodonta beringiana*, these include: threespine stickleback (*Gasterosteus aculeatus*), king salmon (*Oncorhynchus tshawytscha*), sockeye/kokanee Salmon (*Oncorhynchus nerka*), nine-spine stickleback (*Pungitius pungitius*), slimy sculpin (*Cottus cognathus*), and Alaska blackfish (*Dallia pectoralis*) (Cope 1959; Smith et al. 2005).

SPECIES PROFILES

Figure A2.5. Shells of the western pearlshell, *Margaritifera falcata*.

Western Pearlshell (*Margaritifera falcata*)

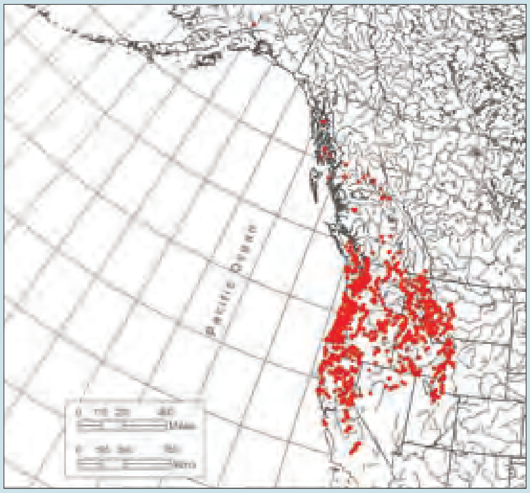
Margaritifera falcata, known as the western pearlshell (Figure A2.5 and A2.6), is our longest-lived mussel and is found in both urban and remote headwater river and stream habitats of many western states and into B.C. and Alaska (Figure A2.7). Size ranges up to 14 cm in length (perpendicular to the hinge). Though this species can occur in small numbers, it can also be found in dense mussel beds containing thousands of animals. Western pearlshell mussels may live to be as old as 100 years or more, and individuals as old as 60 years are often observed. This species is considered a host fish specialist on juvenile or resident salmonids including Chinook and coho salmon, cutthroat trout, and steelhead. Other host fish are listed in Table A2.1.

The species is typically found in perennial rivers, streams, and creeks and occurs at elevations from sea level up to nearly 8,000 feet. More stable river reaches with areas of low velocity, shear stress, and gradient are preferred habitat, often consisting of boulders, sand, gravel, silt or clay. Even within a reach, the species may inhabit diverse parts of a stream, ranging from undercut banks to the thalweg, and can be found in shallow fringes as well as at a depth of several meters.

The western pearlshell has the broadest range among our western mussel species and may be commonly encountered in areas targeted for salmon or stream restoration projects. Even though the species is still widely distributed and can be found in large beds, it has declined across its range. The IUCN Red List is a resource that provides ranks of extinction risk in species. Although these ranks are non-regulatory, they can be used to support conservation and protection efforts. The western pearlshell is ranked as *Near Threatened* on the IUCN Red List due to apparently non-reproducing populations consisting only of older individuals and populations that have declined dramatically in abundance. Mussel bed die-offs are also reported from multiple sites.

Figure A2.6. Distinct papillae of western pearlshell can vary in color but appear fleshy and "tree-like" along the inhalant aperture, which is generally only up to a few centimeters in length.

Figure A2.7. Map of historic and recent occurrence records from the Western Freshwater Mussel Database. The species has since been lost from portions of the range depicted here.



Western Ridged Mussel/Rocky Mountain Ridged Mussel (*Gonidea angulata*)

Gonidea angulata, known as the western ridged mussel or Rocky Mountain ridged mussel (Figure A2.8 and A2.9), is also a long-lived species and the only living species of the genus *Gonidea*. It is found in river and stream habitats, as well as in lakes from California to B.C. and east to Idaho and Nevada (Figure A2.10). Size ranges up to 14.5 cm in length (perpendicular to the hinge). This species may also occur in dense beds or in much smaller numbers. The species may live 30 years or more. Host fish are listed in Table A2.1.

The species has been reported from elevations at sea level up to nearly 7,000 feet. In both rivers and lakes, the western ridged mussel is found in well-oxygenated, stable areas and can be found among boulders, sand, silt, and cobble. This species can be difficult to observe because it may be burrowed flush with the stream or lake bottom. In rivers, the species is often found tightly wedged between boulders or cobble or against steeper banks, though it can also be found along sand and gravel bars.

Figure A2.8. Shells of the western ridged mussel, *Gonidea angulata*.

The western ridged mussel has the smallest range among our mussel species but may be encountered in areas targeted for stream restoration projects. Like the western pearlshell, this species has been ranked on the IUCN Red List. This species is considered the most imperiled of our western mussels and is ranked as *Vulnerable* due to declines across the species' range. Mussel bed die-offs are also reported from multiple sites.

Figure A2.10. Map of historic and recent occurrence records from the Western Freshwater Mussel Database. The species has since been lost from portions of the range depicted here.

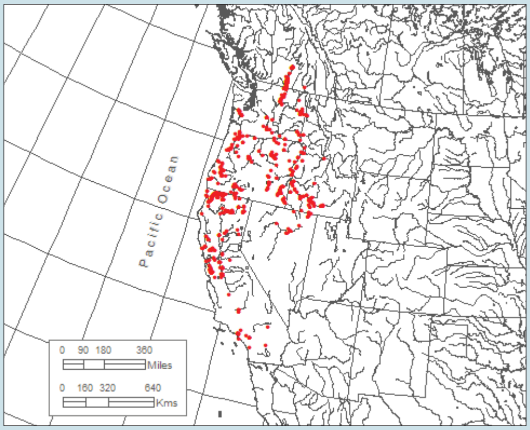


Figure A2.9. Distinct papillae of western ridged mussels are branched and non-uniform along the inhalant aperture, which is generally only up to a few centimeters in length.

Floater Mussels (genus *Anodonta* or *Sinanodonta*)

Mussels belonging to the genus *Anodonta* and *Sinanodonta* (Figure A2.11 and A2.12) are difficult to identify to species because obvious shell characteristics, such as hinge teeth and shape, are lacking or variable within species. Luckily, distinguishing species is often not necessary for those conducting restoration projects, and populations should be conserved regardless of species. Size ranges up to 18.5 cm in length (perpendicular to the hinge). Floater species appear to overlap in range (which includes multiple western states and provinces; Figure A2.13) and often co-occur in a waterbody. Like other western mussels, floaters can reach high densities at sites but can also occur in much smaller numbers. Floaters typically live between 10 and 20 years, and use a variety of host fish (Table A2.1). They are commonly found in low elevation or floodplain ponds, in reservoirs and lakes, and in rivers and creeks. These species prefer muddy and sandy sediment where they can easily burrow (Hemphill 1891; Taylor 1981; Nedeau et al. 2009).

Understanding the distribution of floaters is complicated by misidentifications, although genetic analyses can be used to distinguish species. Floater species from western North America are now understood to belong to three distinct clades (Table A2.2). The winged/California floater clade

Figure A2.11. Shells of various floater species (*Anodonta and Sinanodonta*).

Figure A2.12. Distinct papillae of floater mussel appear singular and "finger-like" along the inhalant aperture, which is generally only up to a few centimeters in length.

Table A2.2: Floater Species by Clade Membership (Chong et al. 2008)

Clade	Species	Common Name
Anodonta clade 1	*Anodonta nuttalliana*	winged floater
	Anodonta californiensis	California floater
Anodonta clade 2	*Anodonta oregonensis*	Oregon floater
	Anodonta kennerlyi	western floater
[*Sinanodonta*] clade 3	*Sinanodonta beringiana*	Yukon floater

(*Anodonta nuttalliana/Anodonta californiensis),* which once occurred across a greater area in California, Arizona, and elsewhere, is ranked on the IUCN red List as *Vulnerable*, and the Oregon/western (*Anodonta oregonensis/ Anodonta kennerlyi)* floater clade is ranked as *Least Concern*. The Yukon floater ([Lopes-Lima et al. 2017; Williams et al. 2017] *Sinanodonta beringiana*, formerly recognized as *Anodonta beringiana)* is also ranked *Least Concern*, though many fewer records exist for the species and range information is incomplete. Floater mussels often occur in areas that may be targeted for restoration or management activities.

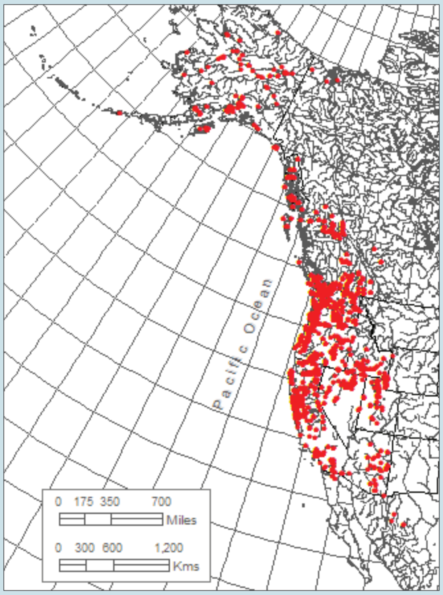


Figure A2.13. Map of historic and recent occurrence records from the Western Freshwater Mussel Database. Mussels in these genera have since been lost from portions of the range depicted here.

Appendix 3. Surveying for Mussels

Handling and Identifying Freshwater Mussels

If you are not able to secure a permit in advance of surveys, which may be necessary to handle freshwater mussels (see Determining if You Need a Permit [page 22]), it is still possible to conduct a survey. You should be able to see mussels without handling them under good conditions, and they can be identified by differences in their papillae, shell color, and shell shape (Figure A3.1 and examples in Appendix 2 [page 82]). Avoid surveying during high flows or turbid or cold conditions, when visibility may be poor (making detectability low), conditions may be unsafe, or mussels may burrow deeper. Instead, conduct surveys in warmer months during the lowest flow. USGS maintains an online resource for stream gaging stations (https://waterdata.usgs.gov/nwis). If your waterbody is not gaged, you can still look at nearby stations or even consult white-water rafting or kayaking forums for information about flows.

If you will handle mussels to practice identification skills or to estimate density or abundance of mussels (which will require excavation of the substrate to count buried mussels or juveniles), you may need to acquire a permit. If you do handle mussels, gently place them flat on the surface where you found them (see Placement [page 62]). Also, place any disturbed substrate back as you found it. If you know in advance of handling mussels that they will eventually be relocated (especially if you excavate the

Figure A3.1. The papillae on this mussel can help you determine which mussels are present (in this case, a floater). Differences in papillae are covered further in Appendix 2.

sediment to estimate density; see Estimating Density [page 98]), you may want to limit your disturbance.

If you need to collect a voucher specimen to document the presence of mussels, you generally should not collect live animals. Instead, photos of the animal or of shells (internal and external if empty) and notes regarding measured dimensions and other characteristics should be sufficient to identify mussels to genus. Empty shells can also be collected for vouchers.

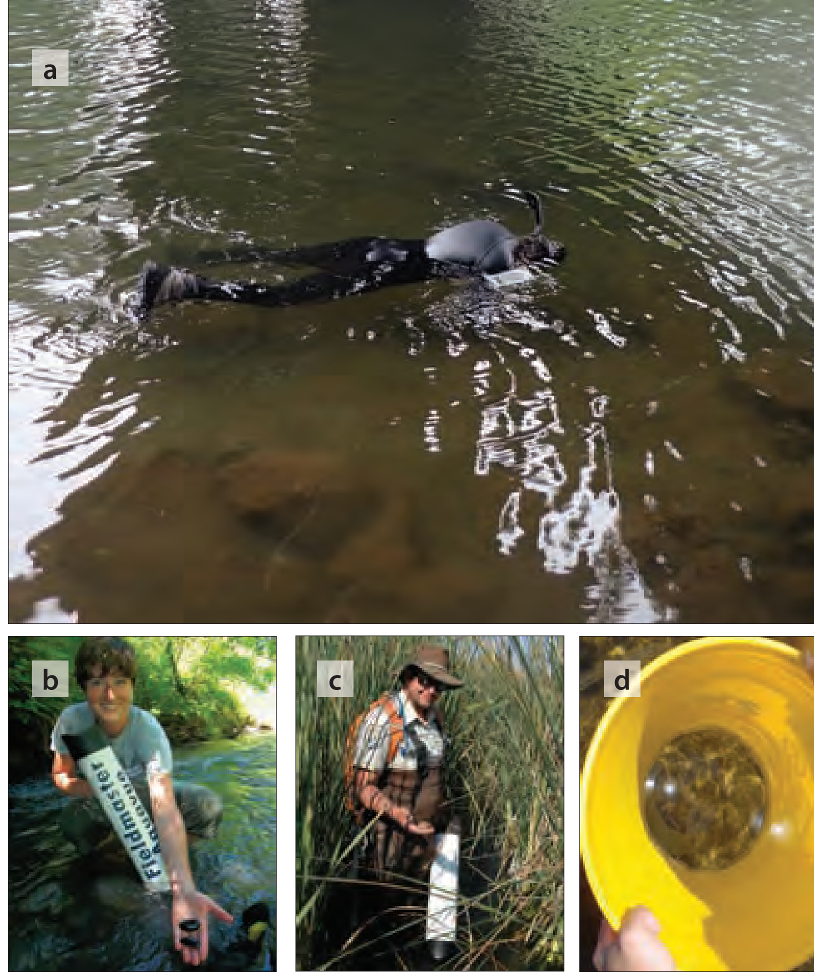


Figure A3.2. a: Snorkel surveys are appropriate where water is deep enough to float above mussels; where water is still shallow enough, this method also allows surveyors to examine habitat. b–d: View scopes (can be purchased from a lab and field equipment supply company) or homemade viewing buckets (the bottom has been cut out, leaving a ~1-inch rim; screws and aquarium sealant are used to attach plexiglass to the bottom of the bucket) are useful for shallow water surveys where mussels may be difficult to observe from above.

Equipment

To complete surveys, the following basic equipment is recommended:

- a permit, if needed (see Determining if You Need a Permit [page 22])
- maps of your site, especially depicting the area of potential impact or planned salvage and relocation areas
- printed field sheets (see example below)
- waterproof markers and pencils
- appropriate clothing, including waders or water shoes for shallow water, and wetsuits or drysuits and snorkel and mask for deeper water (Figure A3.2 a)
- viewing bucket or view scope (Figure A3.2 b–d)
- waterproof flashlight for surveying under vegetation or banks
- measuring tape for measuring stream width and habitat area, or setting transects
- gloves to protect against sharp objects
- GPS to record the location of mussels (with extra batteries)

Other equipment that may be useful includes:

- dive slate to record observations in water
- calipers or ruler to measure mussels
- 0.25 m^2 or 1 m^2 quadrat constructed of PVC pipe, with holes drilled, making them neutrally buoyant, or with weights inside, like rebar, to keep them in place under stronger currents (Figure A3.3 a)
- waterproof camera to document observations
- watch to keep track of time
- dredge net for surveying floaters in mucky habitat (Figure A3.3 b)

- multi-tool and knife for cutting any fishing line encountered
- flagging tape to visually mark sites
- thermometer
- mesh bags or mussel rafts if relocating mussels or estimating population size (Figure A3.3 c–e)
- stakes, rebar, or poles to mark locations, hold mesh bags or mussel rafts, or use for walking

Disinfecting your Equipment

Proper disinfection of equipment is critical to efforts to avoid introduction or further transport of nonindigenous aquatic species. At minimum, all equipment used in more than one waterbody or in distant areas within the same river should be cleaned, drained, and dried. You should also keep an eye out for invasive species at your site, reporting your observation to the state or provincial fish and wildlife agency (e.g., www.wdfw.wa.gov/ais/reporting) or the USGS Nonindigenous Aquatic Species site (https://nas.er.usgs.gov/default.aspx).

- Cleaning: Remove any debris such as plant materials or mud from equipment before leaving a site. Use a high pressure spray or scrubbing brush to remove materials that are stuck on or in cracks or seams. Disinfect equipment using the following:
    - Materials that would be damaged by a bleach solution: Use a mild disinfectant like Virkon® Aquatic (see http://www.syndel.com/products/biosecurity-supplies-disinfectants/virkon-auqatic/virkon-aquatic-10-lb-tub-virkdlb0010.html for description), following

Figure A3.3: Mussel Sampling Equipment

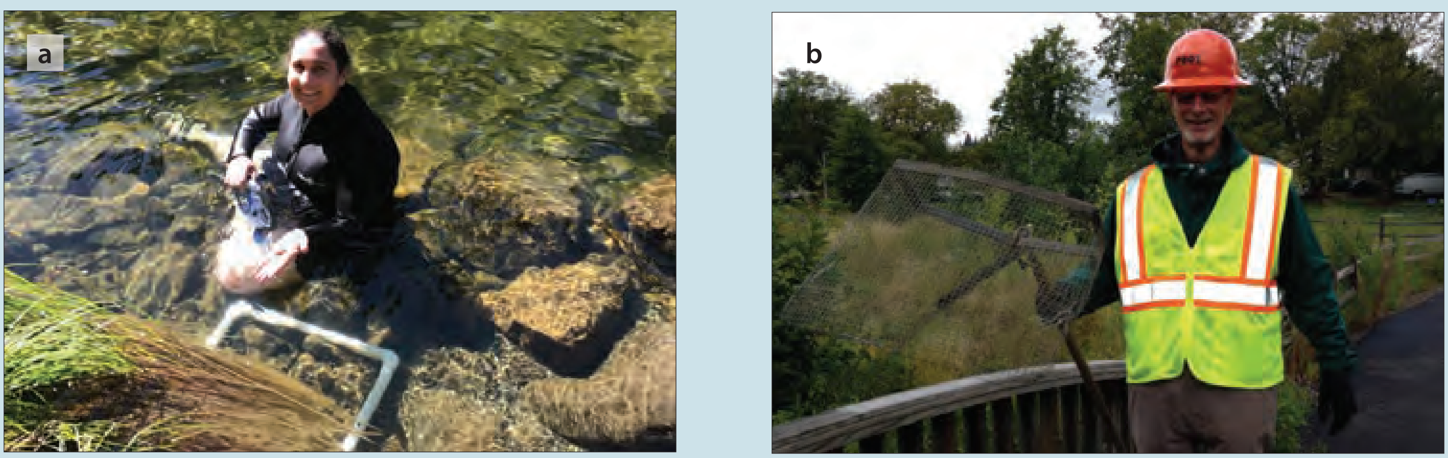


Figure A3.3. a: Quadrats are useful to determine mussel density in a subset of habitat; the small western pearlshell in hand was collected from sandy habitat between these boulders. b: A large dredge net, like this one, can efficiently collect many floater mussels from thick sediment, including those buried deeply. This method is useful for determining density of floaters in mucky or deep habitat or for salvage and relocation of floaters, but is damaging to other mussels and habitats.

label guidelines for treatment. This is the preferred method for Washington Department of Fish and Wildlife (WDFW 2012), which recommends that gear is soaked in a 1% solution for at least 10 minutes, making sure it is totally saturated.

  - WDFW also recommends that "decontamination for larger aquatic organisms such as New Zealand Mudsnails and zebra/quagga mussels requires soaking gear thoroughly with 2% solution so that it is completely saturated for a minimum of 20 minutes. Rinse thoroughly in a contained area and dispose of rinse water down a sewage drain, not a storm drain" (WDFW 2012).
  - Materials that can be exposed to a bleach solution: Soak equipment in a 10% bleach solution for 10 minutes.

- Draining: Drain water from containers before leaving a site. If relocating mussels to a new waterbody, limit additional transfer of water during relocations. For example, do not pour water from coolers into new waterbodies. Instead, return water to the original site or dispose of water upland and far away from waterbodies.
- Drying: Allow equipment to dry before use in new waterbodies.

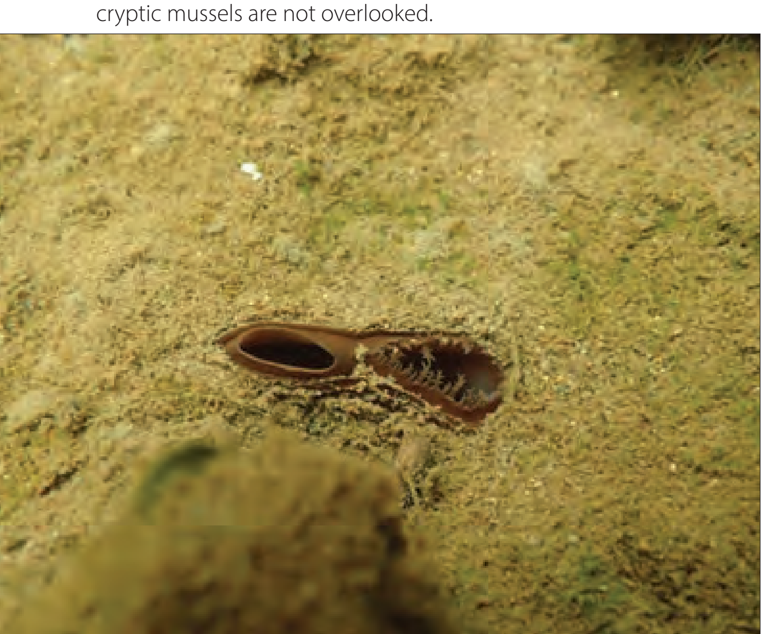
These recommendations are adapted from those developed by Texas Parks and Wildlife Department (TPWD 2017; https://tpwd.texas.gov/publications/pwdpubs/media/pwd_lf_t3200_1958_arrp_guidelines_packet.pdf) for aquatic resource relocation plans for freshwater mussels. Multiple agencies and organizations have developed disinfection protocols and should be consulted for recommendations or requirements. See also Washington state's protocol (WDFW 2012; http://wdfw.wa.gov/publications/01490/wdfw01490.pdf).

Figure A3.3: c–d: This "mussel raft" was designed using a plastic box with holes punched through to allow water to flow over mussels. The pool noodles ensure that the device floats, enabling mussels to stay cool and submerged if they are collected for species identification or density estimates (design and construction of mussel raft by Patrick Norton). e: Mesh bags are also commonly used to temporarily hold mussels.

Figure A3.4. These western pearlshell mussels look much like the rocks they are wedged between. Even after you find several, it can be difficult to count how many are actually in an area.

Figure A3.5. When floater mussels are open and filtering in murky environments, you can more easily see their distinctive papillae among the muck and algae.

Figure A3.6. This western ridged mussel is only visible when it is open and filtering. Care should be taken during surveys to ensure that cryptic mussels are not overlooked.



Surveying Methods

When surveying, work from downstream to upstream or otherwise limit disturbing water or sediment in the area you will be searching. If mussels are disturbed, they may close up and become more difficult to see, particularly if they are flush with the sediment. Mussels may also have accumulated algae or aquatic fauna on their shells, further camouflaging them (Figures A3.4–6).

Shallow Water Habitat

In some cases, water may be clear and shallow enough to conduct shoreline or wading visual surveys but not deep enough for snorkel surveys. Shoreline and wading methods are preferred only in these conditions because walking shorelines generally does not enable you to thoroughly survey habitat, and wading has the potential to crush mussels or otherwise disturb mussels and their habitat. Polarized sunglasses may reduce glare, and view scopes or viewing buckets may provide a better view, but otherwise little equipment is necessary.

In other shallow water habitats, conditions may be too murky or mucky to see mussels easily. Water may also be too turbulent as it flows over rocks. Tactile searches and substrate excavation may also be necessary in these conditions, but as with other shallow water surveys, the potential to disrupt or damage mussels and their habitat is somewhat higher. Take care also with tactile searches, during which you could encounter glass or other damaging objects. Dredging can be used to survey for floater mussels in mucky habitat, but this method is not appropriate for other species or habitats because it can be especially damaging.

Swimmable Habitat

Where water is deep enough to float, flow is slow enough to conduct surveys, and visibility permits a clear view of the substrate, snorkeling is the preferred method for surveying. Diving in deeper water (generally >2–3 m, depending on water clarity) similarly enables habitat to be more thoroughly surveyed. These methods have the benefit of improving access to deeper sites without disturbing mussels or their habitat but may require additional personnel and greater skill, as well as carrying additional risks. As with all in-water activities, care should be taken in areas of deep or swift water, poor visibility, obstructions, or otherwise dangerous conditions. Use of wetsuits or drysuits may be necessary even on the warmest days in colder waters of the Pacific Northwest.

Survey Area

The area to be surveyed will depend on your site, as well as the type of planned restoration or construction activity. Identify your target search area, including areas of potential impact, a diversity of microhabitat sites, and areas downstream of project activities. For basinwide or multi-site restoration projects, plan for surveys to span the entire project area or watershed. Before conducting your survey, design a data sheet, use the one provided here, or download the West Virginia DNR data sheet (http://www.wvdnr.gov/Mussels/Main.shtm). After completing your surveys, submit data (including absence data) to the Western Freshwater Mussel Database managed by the Xerces Society.

Initial Surveys

If more than one survey is possible at the site, first conduct a time-based survey and target areas where mussels are most likely to occur or project activities will take place. Conducting sweeps with one or more surveyors will ensure that habitat is more fully surveyed. If you do not yet have a project footprint, target surveys for areas that provide potential mussel habitat and/or are generally within the area for which a project or management activity is planned. Plan your survey day(s) to ensure that you adequately balance the time spent searching with the area that needs to be searched to maximize detectability. Follow-up surveys may be necessary to help you identify project impacts, estimate population size, and determine the extent of mussel habitat. You will also need to survey for potential relocation sites if mussels will need to be moved prior to project implementation (see Relocation Site [page 59]).

Pre-implementation Surveys

If you only have time to survey once in advance of implementing your project, you can follow the recommendations below. Recommendations by Piette (2005) include surveying 200 m or 4 person-hours for waterbodies with mean stream width (MSW) less than 15 m and 300 m or 8 person hours for waterbodies MSW more than 15 m (Table A3.1). MSW is based on ten measurements of stream width (bank to bank) throughout the project area.

Table A3.1: Survey Recommendations for Projects Based on Time

Adapted from Piette (2005), CVCWA (2015), and Clayton et al. (2016).

MSW	Total Person-hours	Minimum Distance to Cover	Survey Locations
<15 m	4	200 m	Within the anticipated project area
>15 m	8	300 m	Within the anticipated project area
Projects involving water outfalls	See above	See above	2 locations upstream and 2 downstream of outfall, including mixing zone

Additional surveys are necessary for projects that include physical alteration of habitat, particularly if initial surveys do not specifically target the area of potential effect or the project footprint. Virginia state guidelines for a full survey include 200 m upstream and 800 m downstream of a project (USFWSVFO/VDGIF 2015), while minimum survey distances recommended by USFWS/GDOT (2008) include 100 m upstream and 300 m downstream of the project's footprint (Table A3.2). The project footprint is inclusive of the area where an activity will take place, as well as any area downstream that may experience sedimentation and/or changes to hydraulic conditions. If you are unable to survey such a large area or the project is expected to have a much smaller footprint, surveys should at minimum aim for covering 10–50 m upstream, downstream, and lateral to the project footprint; refer to Table 3 of Clayton et al. (2016) for project-specific guidelines.

Table A3.2: Survey Recommendations for Projects Based on Distance

Distances should be in addition to surveys of the actual project footprint. Adapted from USFWS/GDOT (2008), USFWSVFO/VDGIF (2015) and Clayton et al. (2016).

Activity or Project Footprint	Upstream Survey Area	Downstream Survey Area	Lateral Survey
Extensive and/or large physical impact	100–200 m	300–800 m	Bank to bank
Smaller and/or limited physical impact	10–50 m	10–50 m	10–50 m
Projects involving water outfalls	10 m	Mixing zone + 100 m	10 m

Conducting the Survey

Because western freshwater mussel communities have many fewer species compared to those in the eastern United States, species accumulation curves are not as informative for determining the appropriate level of search effort. Instead, search the largest variety of microsites and allow adequate time to see mussels. To conduct your search, survey at least ~20 seconds over a square meter of habitat (Clayton et al. 2016) if you are able to adequately see the substrate and move through habitat. If you must navigate obstructions, like large rocks or wood, take as much time as you need to and are able. Use multiple techniques, such as tactile, substrate excavation, and snorkel.

When multiple surveyors are present, transects provide a more systematic method for surveys as compared to meandering while snorkeling or wading. You may be able to cover your whole site, but if it is not possible to adequately cover your survey area using the recommendations for distance and time,

1. Establish regularly spaced transects across your site, perpendicular to flow to ensure that you sample a variety of habitats. Record observations of mussels in a transect.
2. Spot check additional areas outside of your transects, including habitat that looks promising that may have been missed by your transects. This will help you refine knowledge of where mussels occur within your site.
3. Place quadrats within areas where you identified mussels to get a better idea of which species occur and their abundance. If you are permitted to handle mussels, carefully excavate within plots to get a more accurate count of mussels (but see next section).

Estimating Density

You may wish to estimate density or abundance of mussels, whether to evaluate project impacts or help you prepare for a salvage and relocation effort. You should consult Strayer and Smith (2003) for greater detail regarding how to estimate density and abundance. However, if you must quickly assess the approximate number of mussels at your site or within a project footprint, you can easily place a quadrat and count both the number of visible mussels and the number buried in the substrate. To do this, you must excavate the substrate by digging until you reach a hardpan layer. Sieving sediment through mesh (~6 mm is sufficient) will help with collecting juveniles.

Density estimates can particularly help with assessing your project impacts (see Mussels at Your Site [page 13]) and targeting your salvage and relocation efforts (see Salvage Area [page 59]). If you must later prioritize areas from which to salvage mussels, it can help to document zones of density at your site.

eDNA Surveys

Another method of surveying also has potential to identify waterbodies and sites where mussels are present, even when mussels are not observed. eDNA is short for environmental DNA, and refers to the collection of DNA from water or sediment that may contain small amounts shed from species present in an area. DNA primers for western mussel eDNA studies have been developed and are being field tested in California, Utah, and other western states. eDNA methods are well-suited to identifying mussel presence on a larger spatial scale, but you might also want to sample for eDNA at your site to evaluate if mussels are present. However, this method is not sufficient for determining the specific locations where mussels are present within a site and should be combined with visual surveys to identify the precise locations of mussels. This method will require collaboration with researchers or specialized training.

Further Resources for Mussel Surveys

The next two pages provide an example data sheet for documenting your freshwater mussel pre-implementation surveys. You may also wish to conduct more detailed mussel surveys at a site, perhaps to determine the demography of a population or precisely estimate population size. Other protocols for surveying mussels have been developed by states and can be accessed at http://molluskconservation.org/Mussel_Protocols.html. Detailed information on survey techniques, gear, safety, and other considerations, can also be found in Duncan et al. (2008) and Strayer and Smith (2003).

Remember, at the minimum you should ensure that you have conducted a thorough search using methods that are appropriate for your site (Figure A3.7)**.** If you suspect that relocation will be necessary in advance of project implementation, be sure to review the Salvage and Relocation BMPs [page 55] in this document well in advance of the relocation effort. These BMPs include important considerations for identifying relocation sites and planning activities prior to implementation.

Figure A3.7. Example of a thorough site search that included surveys of upper project boundary (dashed line), diagonal, bank to bank transect lines (arrows), mussel bed areas with >1 mussel/m^2 (white ovals). The initial surveys were conducted with view buckets and identified areas of higher *M. falcata* density. These areas of higher density will be prioritized during upcoming salvage efforts in preparation of in-channel restoration activities.

Figure A3.8: Freshwater Mussel Data Sheet

Page __/__

Date: _________________________________	**Location:** _________________________________
Time begin/end: ____________/___________	____
Lead/observers: ___________________________	**Waterbody:** ________________________________
Contact email/phone: ______________________	**Site/transect/plot:** __________________________
# surveyors: ______________________________	**Township:** _____ **Range:** _______ **Section:** ____
Coordinate source: _________________________	**Lat: N** ___________________________________
UTM Zone: _______ **Northing** ________________	**Long: W** ____________________________________
Easting: _________________	**Elevation:** __________ **GPS Accuracy:** ________
Survey method *(Select all applicable)*	**Survey type** *(Select all applicable)*
snorkel or dive wading visual view scope or bucket shoreline visual tactile substrate excavation dredge net	timed search area-based search plot transect incidental
Survey extent *(Select all applicable; orient downstream)*	**Abundance estimate/observation**
Distance/area surveyed: ____ River habitat surveyed: upstream downstream left-shore right-shore midchannel	Catch per unit effort (CPUE; mussels/person hour): ____ Total number observed: Live _______________ Fresh Dead ___________ Shell _______________
Instream features *(Specify units of measurement)*	**Evidence of recent reproduction**
wetted width: ________ water depth (at thalweg): _______	Multiple size/age classes? Y N Juvenile mussels observed? Y N
Substrate composition *(% estimated, 100% total)*	**Water clarity/quality**
bedrock (contin.): ____ gravel (0.6-2.5 in.): _____ boulder (>12 in.): ____ sand (<0.6 in.): ______ cobble (2.5-12 in.): ____ silt/clay/muck: ______ large woody debris: ______ other: ______	clear turbid muddy tannic green/algae white/milky Water temp: _____ °C Air temp: ______ °C
Additional wildlife observed *(species and count)*	**Other comments**
Fish: Other:	

Freshwater Mussel Data Sheet

Page __/__

Mussel ID Number	**Transect/ Plot Number**	**Genus code**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Condition (live, fresh dead, weathered shell, other)**	**Comments**

Genus code: MF: *Margaritifera falcata*; AN: *Anodonta* or *Sinanodonta*; GA: *Gonidea angulata*

Appendix 4. Case Studies in Restoration Projects that Include or Protect Freshwater Mussels

Incorporating Freshwater Mussel Conservation into River Restoration

Confederated Tribes of the Umatilla Indian Reservation First Foods Initiative and the Freshwater Mussel Project

Contributed by: Beth Glidewell, Donna Nez, and Alexa Maine, Confederated Tribes of the Umatilla Indian Reservation

Freshwater mussels were a traditional staple of the diet for Plateau Indian people since time immemorial. In ancient times, mussels were plentiful in the Columbia Basin and were gathered in the winter months when other food was scarce. In addition to the mussels' importance as "First Foods," the shells were used as adornment and for trade purposes (Figure A4.1). Freshwater mussels are among those First Foods that are of cultural importance to the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), and are recognized as a vital aspect of a healthy aquatic ecosystem.

The cultural and ecological importance of these First Foods, and the reserved Tribal Treaty rights to harvest, have informed a First Foods based approach to river restoration, described as the Umatilla River Vision (Jones et al. 2008). The Umatilla River Vision incorporates system physical and ecological processes–referred to as 'key touchstones'—hydrology, geomorphology, connectivity, riparian vegetation, and aquatic biota, that characterize a functional and sustainable aquatic system into a framework to help guide holistic restoration activities.

The mission of the CTUIR Department of Natural Resources (DNR) is

> *To protect, restore, and enhance the First Foods - water, salmon, deer, cous and huckleberry – for the perpetual cultural, economic and sovereign benefit of the CTUIR. We will accomplish this using traditional ecological and cultural knowledge*

Figure A4.1. Wampum necklace made of freshwater mussel shells from the Tamástslikt Cultural Institute, Confederated Tribes of the Umatilla Indian Reservation.

Figure A4.2. Left: CTUIR Freshwater Mussel Project staff Beth Glidewell and Donna Nez conducting surveys in the Middle Fork John Day River. Right: CTUIR Mussel Project staff member Alexa Maine working at the aquatic propagation lab.

and science to inform: 1) population and habitat management goals and actions; and 2) natural resource policies and regulatory mechanisms.

and the CTUIR DNR Fisheries Program mission is

To provide sustainable harvest opportunities for aquatic species of the First Food order by protecting, conserving, and restoring native aquatic populations and their habitats.

The CTUIR's Freshwater Mussel Project applies this First Foods resource management ideology to the conservation of the region's freshwater mussels. Since 2003, the Mussel Project has conducted research designed to understand the biology and ecology of freshwater mussels, with the goal of using this knowledge to conserve native fauna and to restore freshwater mussels to the Umatilla River and its tributaries (Figure A4.2). As part of this work, the Freshwater Mussel Project is working with the Xerces Society to further freshwater mussel conservation and restoration goals, both as part of Tribal aquatic restoration efforts and across the Pacific Northwest. Upcoming collaborative efforts will focus on implementing, monitoring, and evaluating freshwater mussel conservation efforts using the BMPs described in this document. The Freshwater Mussel Project is also conducting research designed to address knowledge gaps in freshwater mussel conservation biology.

For more on the CTUIR Umatilla River Vision and First Foods Initiative, consult:

Jones, K., G. Poole, E. J. Quaempts, S. O'Daniel, and T. Beechie. 2008. Umatilla River Vision. Available at: https://www.researchgate.net/publication/259100537_Umatilla_River_Vision

CASE STUDY

Implementing and Monitoring Salvage and Relocation Efforts

U.S. Forest Service and the Upper Truckee Relocation Project

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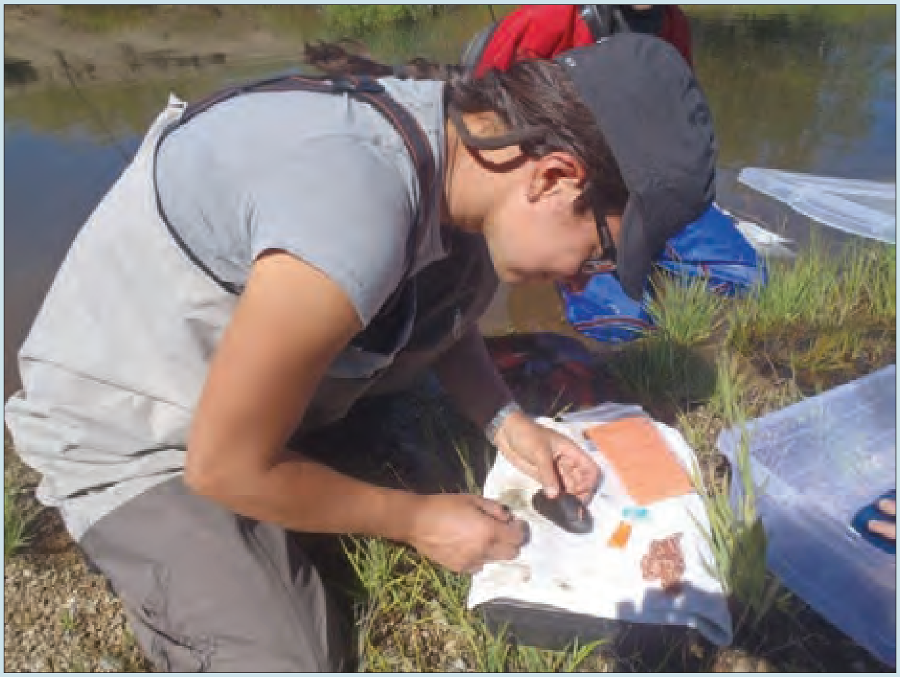
The western pearlshell (*Margaritifera falcata*) is present in the Lake Tahoe Basin, although recent observations suggest that it is not widespread. Still, thousands of mussels have been observed in densely packed beds in the Upper Truckee River. In advance of a 2011 project to restore a reach of this river, which included plans to dewater and backfill an existing channel and construct a new channel, freshwater mussels were salvaged and relocated. However, follow-up monitoring in 2013 revealed that only ~20% of the 5,000 salvaged mussels remained at the relocation site (Howard 2013).

Additional restoration projects are being implemented on the Upper Truckee River, and as part of this work, additional mussel salvages have been planned. Because the 2011 salvage had limited success, and because the Upper Truckee River is the only waterbody in the Lake Tahoe Basin known to have extant populations of the western pearlshell, the Lake Tahoe Basin Management Unit (LTBMU) developed a pilot study to identify habitat attributes important for western pearlshell and field test potential relocation sites with a subset of salvaged mussels. This pilot study was conducted several years in advance of a full mussel salvage and relocation at a planned restoration site (Figure A4.3 and A4.4). By planning, testing, and monitoring mussels through the pilot study, staff were able to:

1. plan and refine salvage and relocation techniques,
2. better estimate and prepare for the number of mussels to be salvaged,
3. identify potential relocation sites in a basin with few other populations of western pearlshell, to where mussels would generally be relocated, and
4. evaluate methods for sampling and monitoring at relocation sites.

Figure A4.3. Mussels are collected, measured, and marked before being relocated to pilot sites.



Staff investigated the following questions during the pilot phase:

1. Is survival influenced by relocating individuals to sites with existing mussel beds?
2. What stream/habitat characteristics influence survival of relocated mussels?
3. Does mussel size influence success, defined as survivorship and persistence?
4. Do actions associated with relocation (e.g., marking and measuring) influence relocation success?

In 2014, 925 mussels were collected from the population of ~25,000. Mussels were tagged, weighed, measured, and relocated into 37 plots in 8 reaches in the Upper Truckee River, Trout Creek, Cold Creek, and Truckee River. Data were collected on 13 habitat variables at each plot, and monitoring occurred during the spring and fall in 2015, 2016, and 2017. Of the 654 mussels (71%) relocated in fall 2015, only 2 (0.22%) have been confirmed dead. Initial results indicate that success (based on presence and length) was not significantly different between reaches, although median weight differed between reaches. Initial size was not correlated with survivorship and growth. Monitoring is ongoing, but preliminary data suggest that relocation sites with lower cover of aquatic vegetation, lower elevation, and lower minimum and maximum water depth are correlated with increased mussel weight, possibly indicating more suitable habitat for mussels.

In order to evaluate key habitat characteristics for the large scale salvage, staff had to determine what could be considered success. This preliminary analysis identified initial success of mussel translocation as plots where 75% or more of the tagged mussels could be found (≥19 mussels out of 25). Success was further refined by identifying how many plots were considered successful at retention. A plot was identified as a good retention plot when 75% or more of the mussels stayed in plots identified as successful and did not move/travel outside of the plot. However, it is unknown if the threshold of 75% is biologically meaningful to define this short-term success. Clear thresholds of success are not scientifically documented, and therefore this value became more of a value judgement because there are varying gradients of success (i.e., a plot with 18 mussels is clearly more successful than a plot with only 4). Success is ideally measured over the long term and is evaluated based both on numbers and on successful reproduction that maintains the population.

Figure A4.4. Staff transport mussels to sites in carefully packed and secured coolers.

During the larger salvage and relocation efforts in 2015 and 2016, 8,233 and 17,020 mussels were relocated, respectively. Of the mussels salvaged in 2016, 5,622 were salvaged and relocated thanks to follow-up surveys in the 2015 salvage area, indicating that mussels occurred in high density at the site and many were buried and therefore unseen in 2015. Had surveyors not returned to the 2015 salvage site in advance of implementation, these mussels would likely have been killed during implementation, but as recommended, conducting multiple survey sweeps in different years drastically reduced the number of mussels sacrificed at the relocation project.

Already this project has provided important, quantifiable insight regarding:

1. the need for multiple mussel surveys at sites in advance of restoration,
2. the importance of planning to relocate many more mussels than originally estimated, and
3. the importance of multiple years of data to identify mussel-habitat trends.

CASE STUDY

Protecting Freshwater Mussels During Sediment Remediation Projects

Johnson Lake Sediment Remediation

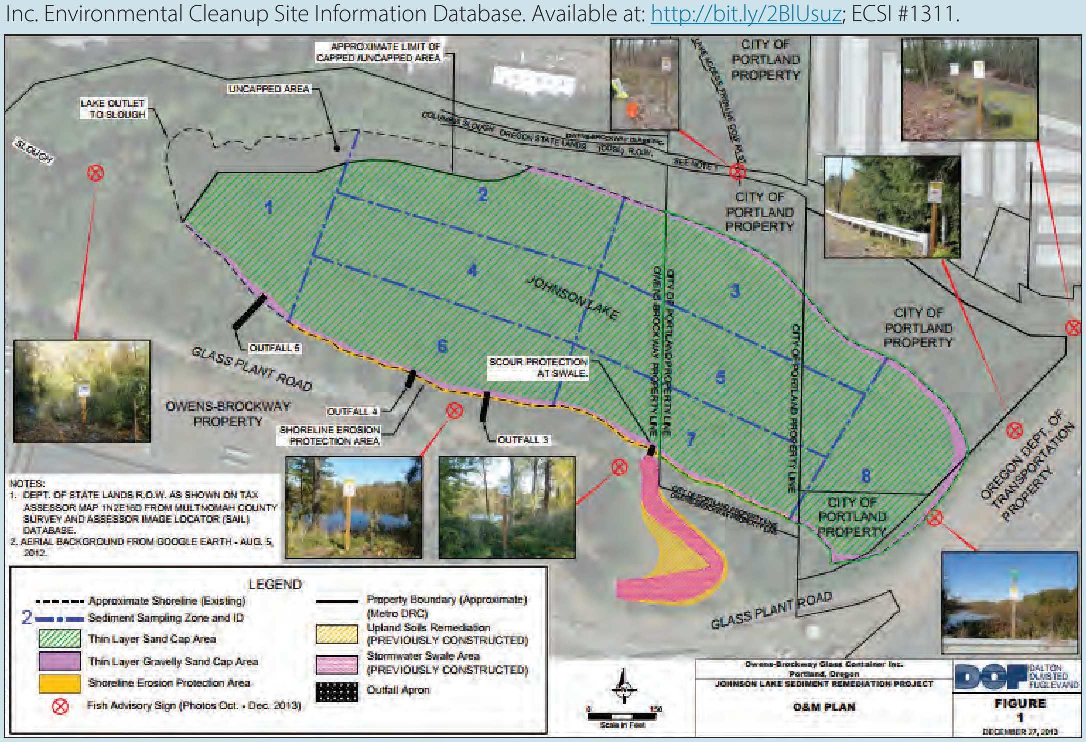
Contributed by: Laura Guderyahn, City of Portland, and Emilie Blevins, The Xerces Society

Floater mussels were present in Johnson Lake in Portland, Oregon prior to a capping project that was undertaken in 2012. This project consisted of applying a sand and topsoil layer 16 to 24 cm deep, with a target carbon percentage of 0.5–2% (see In Situ Chemical Remediation, page 53), to a contaminated lakebed. Gravelly sand was also applied to the outer perimeter, while coarser rock was placed along one shore to minimize erosion from waves. Scour aprons consisting of crushed angular rock and geotextile fabric were also placed at several wastewater outfalls. The northwest corner of the lake, away from the original source of contamination, was left uncapped to retain some habitat for benthic species, including mussels, with the potential for those animals to serve as a source population for the capped area (Sutter 2012; Figure A4.5). Prior to implementation, freshwater mussels were salvaged and relocated from the area of the lake to be capped. With a total of nine-person hours of salvage, only four mussels were found (Berry 2011).

A brief resurvey of the site in July 2017, five years after the remediation project, suggested that floater mussels have not recolonized capped portions of the lake. However, many mussels were found in the uncapped portion of the lake that was retained as natural habitat. When surveyors examined the northwest corner of the lake, many empty mussel shells were found on and adjacent to logs, forming a loose midden. Live mussels of various sizes were also readily observed and collected from the substrate. Because mussels appear to occur in greater number than previously observed at the site, but only within the uncapped area, it is unclear whether sediment caps can provide sufficient habitat or resources for floaters, even though they commonly inhabit sandy substrate elsewhere. Nutrient limitation within the capping material (much like other newly created habitat), substrate composition, or other factors may limit the ability of juvenile mussels to establish in new areas, and adult mussels may choose natural lakebed substrate over capped materials.

Further investigation into the formulation or consistency of the cap would improve understanding of what factors may impact habitat quality and usability of sediment caps by freshwater mussels. The nutrient composition, thickness, and mobility of capping sediment might then be better engineered to provide stable burrowing habitat for mussels. Information from this project is also being used to inform plans at another sediment remediation project in the area.

Figure A4.5. Map of Johnson Lake remediation plan. The northwest corner of the lake, which was retained as natural habitat, supports freshwater mussels. Map reproduced from: Sutter, J. 2012. State of Oregon Department of Environmental Quality Memorandum: No Further Action Recommendation Owens-Brockway Glass Container Inc. Environmental Cleanup Site Information Database. Available at: http://bit.ly/2BlUsuz; ECSI #1311.



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