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Some Effects of Suction Dredge Placer Mining on the Short-term Survival of Freshwater Mussels in Washington

Abstract

Suction dredge placer mining is an increasingly frequent activity that may affect the survival of mussels, however, the effect of suction dredge mining on freshwater mussels has received little attention. We quantified the effects of being entrained, exposed, and/or buried by suction dredge placer mining on the short-term survival of western ridged mussels (*Gonidea angulata*, Lea) and western pearlshell mussels (*Margaritifera falcata*, Gould) in the Similkameen River, Washington. The primary experimental treatments were entrainment by a suction dredge versus non-entrainment. The secondary experimental treatments were exposure and burial. No obvious physical damage to mussels was observed due to entrainment by the suction dredge and entrainment had no effect on the survival of mussels. All exposed mussels survived the 6-week experiment. However, burial by dredge tailings resulted in the death of a substantial percentage of mussels of each species and no mussels were able to excavate from experimental dredge tailings. Our results have significant conservation implications and emphasize the need for additional research.

Introduction

Freshwater mussels (Unionacea: bivalvia) are important components of many aquatic ecosystems. In some systems the biomass of mussels is greater than that of all other benthic organisms (Layzer et al. 1993). Where they are abundant, freshwater mussels can sequester large amounts of nutrients (Strayer et al. 1999) affecting system functions (Vaughn et al. 2004, Howard and Cuffey 2006) and providing food for aquatic and terrestrial species (Dillon, Jr. 2000). Unfortunately, many mussel species are imperiled (Master 1990, Strayer et al. 2004). Seventy of about 300 described species are listed as threatened or endangered under the Endangered Species Act of 1973 (USFWS 2002) and another 143 additional species are afforded some level of regulatory protection (Williams et al. 1992, Richter et al. 1997). Of the seven known native species of mussels in the Pacific Northwest, only the California floater (*Anodonta californiensis*, Lea) is currently a federal species of concern and a candidate for listing in Washington. However, the western ridged mussel (*Gonidea angulata*, Lea) is a species of special concern in British Columbia (COSEWIC 2003) and greater protection for this species in Idaho has been suggested (Frest and Johannes 2001). Western ridged mussels have been extirpated from some locations in the Columbia River and Snake River drainages (Bruce Lang, Eastern Washington University, personal communication). The western pearlshell mussel (*Margaritifera falcata*, Gould) does not appear to be imperiled in the Pacific Northwest, but the closely related freshwater pearl mussel (*Margaritifera margaritifera*, Linnaeus) is threatened with extinction (Bauer 1988) from several causes, including elevated water temperatures, droughts, floods, and loss of host fishes (Hastie et al. 2003). Little information is available describing the status of freshwater mussels in the Pacific Northwest.

Specific causes of mussel imperilment are often difficult to identify, but over-harvest, altered water quantity and quality, land use, introduced species, and physical disturbance have been cited as likely causes (Fuller 1974, Williams and Neves 1995, Watters 2000, Anthony and Downing 2001, Warren and Haag 2005). Suction dredge placer mining uses a hydraulic dredge to entrain substrate from the stream bottom using hydraulic pressure. Substrates (and mussels) are pulled through a hose and sorted in a sluice box allowing heavy objects,

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such as gold, to be separated from lighter objects, such as gravel. Substrate that is not retained in the sluice box is deposited as a tailing pile behind the dredge. Physical disturbance by suction dredge mining can affect the survival of aquatic organisms (Thomas 1985, Harvey 1986). For example, Griffiths and Andrews (1981) observed high mortality for salmonid eggs and fry due to entrainment by suction dredging. While little is known about the effects of suction dredging on freshwater mussels, concerns regarding the effects of dredging on mussels have been raised (Harvey and Lisle 1998).

The Washington Department of Fish and Wildlife (WDFW) is tasked to "preserve, protect, perpetuate, and manage the wildlife and food fish, game fish, and shellfish in state waters…" (Revised Code of Washington, RCW 77.04.012). The WDFW has developed rules for mineral prospecting to protect fish life, including mussels (WAC 220-110-200). However, the complex life history, limited ability to move, cryptic behavior, and longevity of freshwater mussels may make mussels particularly susceptible to extirpation and clearly makes them difficult to study (Bogan 1993). This research was designed to provide information to facilitate development of management guidelines to protect freshwater mussels while allowing suction dredge placer mining activities. The research questions involve a few of the most easily addressed and likely effects of suction dredge placer mining on the survival of individual freshwater mussels. Specifically, our research quantifies the effects of being entrained, exposed, and/or buried by suction dredge placer mining on the short-term survival of two species of freshwater mussels, the western ridged mussel and the western pearlshell mussel.

Methods

Mill Creek Preliminary Study

We conducted a preliminary study in a non-tidal reach of Mill Creek in Mason County, Washington in 2006 (Figure 1) to design experimental mussel enclosures, develop methods and assess the ability of western pearlshell mussels to reorient and excavate from burial in stream substrate. We conducted the preliminary study in Mill Creek because it afforded easy access to western pearlshell mussels. Cylindrical enclosures were constructed from a 0.9 x 0.6-m section of semi-rigid black plastic garden mesh with approximately 1.2-cm square mesh. We cut and overlapped one end of

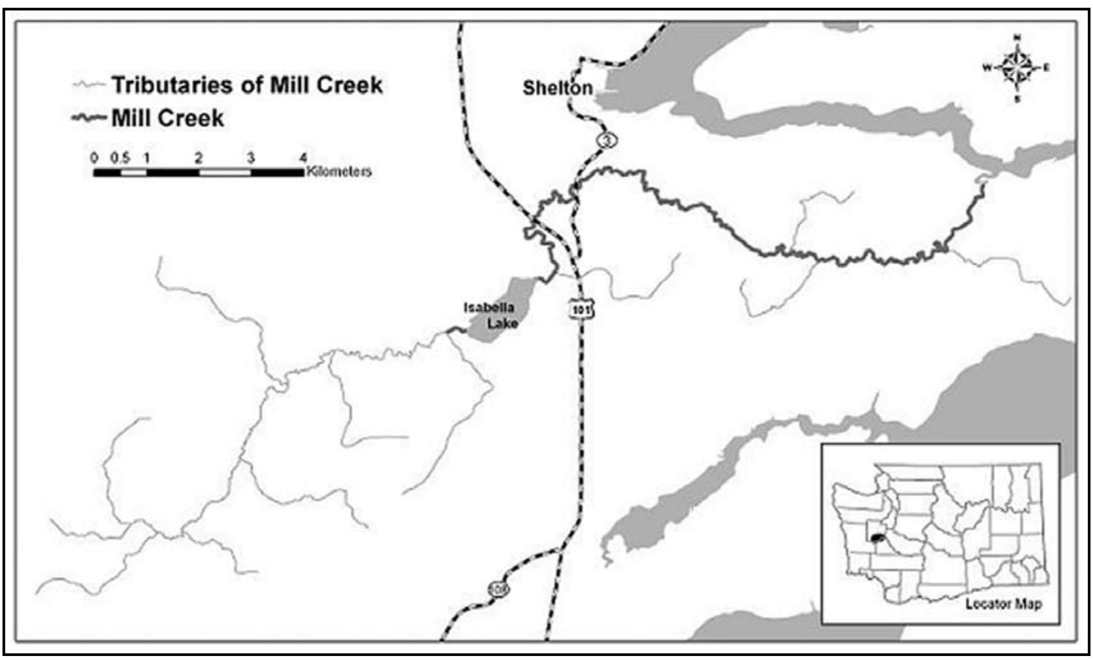

Figure 1. Map of Mill Creek in Mason County, Washington. The preliminary study area was located adjacent to and downstream (east) of the state highway 3 bridge over Mill Creek.

each cylinder to construct a flat bottom. The side and bottom of each cylinder were fastened using plastic electrical wire ties (zip ties). Each enclosure was approximately 50 cm high and 35 cm in diameter and held in place with wire ties attached to a 1.2-m section of reinforcing bar (rebar) that was driven into the stream bottom.

We constructed 14 enclosures and filled each with approximately 30 cm of stream substrate. Only substrate that could be entrained by a suction dredge that met current WDFW guidelines was used. That is, the maximum length of all substrate was approximately 7.7 cm. The percent of substrate size classes was visually estimated for each enclosure following Peck et al. (2003). We opportunistically collected 14 western pearlshell mussels and marked them with numbered plastic tags. Tags were approximately 5 mm by 10 mm and were attached to the mussel using cyanoacrylate glue. Three western pearlshell mussels were haphazardly placed on the surface of the substrate (exposed) and 11 western pearlshell mussels were buried in approximately 30 cm of substrate. The movement and reorientation of the three exposed mussels and the movement to the surface (excavation) and reorientation of the 11 buried mussels was observed and recorded after 24 hours and every two days for approximately two weeks following the experimental treatment. At the end of the experiment all mussels were returned to their capture location.

Similkameen River Studies

We conducted spatially extensive surveys and dredging experiments in the Similkameen River in Okanogan County, Washington. The Similkameen River originates in British Columbia, Canada and is a 225-km-long tributary to the Okanogan River that flows into the Columbia River. Enloe Dam, located near Oroville, WA, is a barrier to upstream fish movement in the Similkameen River (Figure 2). Gold and other minerals were discovered in the river and its watershed in the 1850's. Commercial hard rock mineral mining occurred adjacent to the Similkameen River into the early 1900's at the Nighthawk and Kabba Texas mines in Washington and at several locations in Canada. Placer mining (mining alluvial deposits) for gold using suction dredges and other equipment has occurred and currently occurs in the Similkameen River at several locations, but data describing historical and current mining are scarce (Shaw and Taylor 1994).

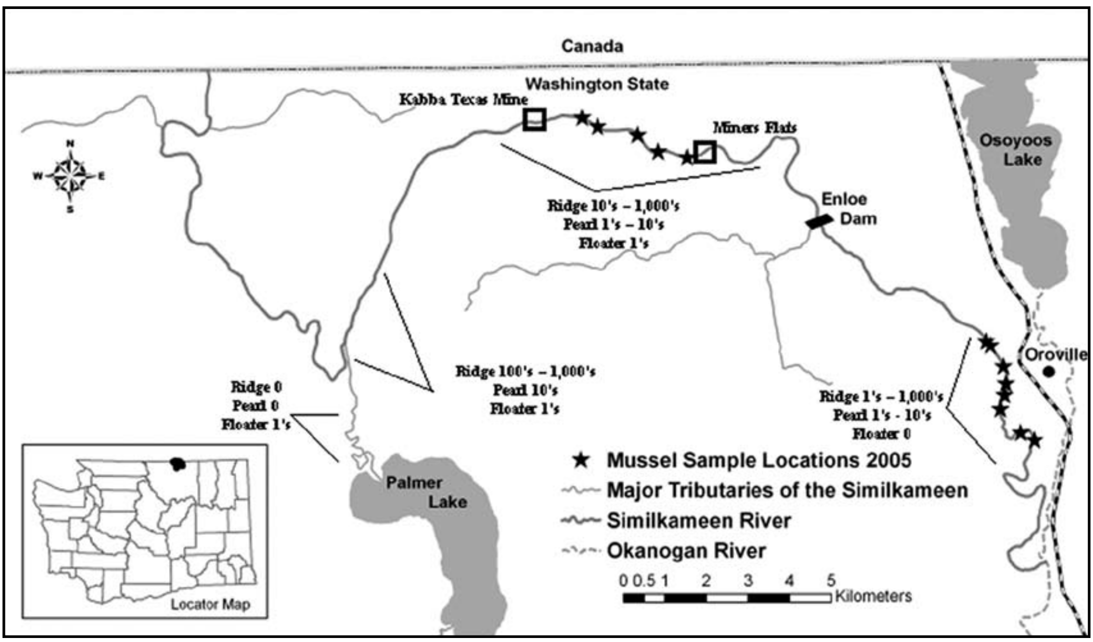

Figure 2. Map of the Similkameen River in Okanogan County, Washington. The location of Enloe Dam and mussel survey cross-sections (black stars) are identified. Sites of the dredging experiments are identified with unfilled rectangles. Mean range of relative abundance of western ridged mussels (Ridge), western pearlshell mussels (Pearl), and floater mussels (Floater) are presented for regions where surveys were conducted.

We conducted spatially extensive surveys that identified freshwater mussel species and described their geographic distribution in 2005 and 2006 in the Similkameen River and its tributaries. In 2005 mussels were counted in seven 0.25-m^2 quadrats evenly spaced on stream cross-sections at 14 randomly selected locations on the mainstem of the Similkameen River (Figure 2). The mesohabitat unit type (i.e., pool, riffle, or glide) in which each cross-section was located was identified and the relative abundance of mussels in the mesohabitat unit was visually estimated for each species. Estimates of abundance were recorded as 0, 10's, 100's, or 1000's within the mesohabitat unit. Additionally, in 2005 and 2006 we surveyed approximately 13 km of the mainstem of the Similkameen River. Two or more surveyors located and identified mussel species and noted signs of mining activity in mesohabitat units in several stream reaches defined by tributary junctions as they snorkeled downstream. These data were used to describe the geographic distribution of mussel species and to locate potential experiment sites.

Dredging experiments were conducted at two sites on the mainstem of the Similkameen River in August and September 2006. The lower site, referred to as Miners Flats, was located on the downstream right bank at -119° 32.565 longitude 48° 58.776 latitude. The upper site, referred to as the Kabba Texas Mine site, was located on the downstream right bank at -119^0 38.863 longitude 48^0 57.31629 latitude (Figure 2). Western ridged mussels were abundant at both sites, but western pearlshell mussels, although present at both sites, were not abundant. Because western pearlshell mussels were scarce at the Kabba Texas Mine study site we collected individuals approximately 600 m upstream of the Kabba Texas Mine site and transported them to the site of the experiment. The lengths of all mussels were measured (mm) using a calipers and each mussel was marked with two numbered tags to facilitate the detection of size effects on survival and excavation and to ensure accurate repeated measures of movement and survival. Prior to inclusion in the experiment each mussel was visually inspected for physical damage (e.g., cracks and chips). Damaged mussels were excluded from the experiment.

The primary experimental treatments were entrainment by a suction dredge versus non-entrainment and secondary experimental treatments were exposure and burial. Mussels to be entrained were first placed in a natural orientation in substrate and not disturbed for one hour. These mussels were then entrained along with substrate by two experienced miners using a Keene suction dredge with a 10.2-cm diameter nozzle and a 7.7-cm reducer ring. Mussels were collected as they exited the dredge (i.e., from the sluice box) and held in a submerged enclosure until dredging was completed. Immediately upon completion of dredging, entrained mussels were examined for physical damage and then randomly assigned to secondary treatments of exposure or burial. Mussels that were not entrained were also randomly assigned to exposure or burial secondary treatments. Mussels that were not entrained, exposed, or buried were used as experimental controls.

Buried mussels were placed on 2 to 5 cm of gravel in the bottom of the enclosure and buried with approximately 40 cm of gravel found in or adjacent to the study site. We selected this burial depth because it approximated the height of several tailing piles observed in the Similkameen River and it allowed experimentation in relatively shallow water while reducing the risk of falling water levels dewatering the enclosures. An exposed mussel was haphazardly placed on the surface of the substrate in each enclosure. Control mussels were placed in a natural orientation; partially buried in gravel substrate with dorsal side facing upstream at the surface of gravel filled enclosures. Gravel used to fill the enclosures was selected to be similar to that where mussels were collected and was small enough to be entrained by a dredge. The composition of substrate (percent by size class) was visually estimated for each enclosure following Peck et al. (2003). Gravel was allowed to equilibrate to ambient water temperature before initiating experimental treatments.

Logistical constraints and difficulty collecting sufficient numbers of individuals limited the number of experimental replicates and number of species used in the experiment. We collected 45 western ridged mussels at Miners Flats on August 9, 2006. Three mussels were placed in each of 15 enclosures, one mussel each for the control, exposure and burial treatments. None of these 45 mussels was entrained by a dredge. On August 13, 2006 we collected an additional 45 western ridged mussels and 15 were treated as controls and 30 were treated with dredge entrainment. Of the entrained mussels, 15 were exposed and 15 were buried using the protocol described above.

These 45 mussels were placed in enclosures using the protocol described above.

We repeated this experimental protocol with western ridged mussels at the Kabba Texas Mine site. On August 10, 2006 three mussels were placed in each of 15 enclosures. In each enclosure one mussel was used as a control, one mussel was exposed, and one mussel was buried. None of these 45 mussels were entrained. On August 14, 2006 we collected an additional 45 western ridged mussels and 15 were treated as controls and 30 were entrained. Of the entrained mussels, 15 were exposed and 15 were buried. These 45 mussels were placed in enclosures using the protocol described above.

On August 15, 2006 we collected 45 western pearlshell mussels from a location approximately 600 m upstream of the Kabba Texas Mine site. Of these mussels, we treated 15 as controls and 30 were entrained by a dredge. Of the entrained mussels, 15 were exposed and 15 were buried. This group of 45 mussels was then placed in enclosures using the protocol described above.

We assessed the condition of all mussels approximately 24 hours after the initial treatment and approximately every seven days thereafter for the duration of the experiment. The condition (e.g., siphoning water), orientation, and location of mussels visible in the enclosures were noted using a viewbox or dive mask and snorkel. Mussels and substrate were minimally disturbed for monitoring. Buried mussels were observed only if they moved to the side or top of the enclosure during the experiment.

We concluded the experiment after 6 weeks (September 29, 2006) when enclosures were emptied and the survival of each mussel was assessed. At the conclusion of the study, living mussels in the buried treatment were haphazardly placed at the substrate surface of an enclosure for an additional 48 hours. We recorded whether these formerly buried mussels reoriented to a natural position and began siphoning water within 48 hours to determine their condition. At the end of this additional 48 hours we attempted to manually open the mussel by gently applying force to the valves. Mussels were assumed to be dying if they did not reorient to a natural position and/or could be easily opened. All surviving mussels were carefully returned to the river near where they were collected.

Results

Mill Creek Pilot Study

In Mill Creek the three exposed and 11 buried western pearlshell mussels survived the study. All exposed mussels recovered to their normal orientation within 24 hours and all buried mussels were able to excavate to the surface, most (64%) within 24 hours of burial. Two buried mussels escaped the enclosure and all mussels moved. The western pearlshell mussels used in the pilot study were relatively large compared to those used in the Similkameen River experiment (mean length = 110 mm, SD = 9.5, range = 85 – 122 mm; Figure 3). Gravel substrate used in this experiment was relatively fine, with about 70% fine gravel (2 to 16 mm), 30% coarse gravel (16 to 64 mm), and little silt or clay.

Similkameen River Studies

We found at least three mussel species, western ridged mussels, western pearlshell mussels, and one or two species of floater of the genus *Anodonta*, during spatially extensive surveys. The floater was likely the western floater (*A. kennerlyi*, Lea), but the taxonomy of *Anodonta* is unresolved and the Oregon Floater (*A. oregonensis*, Lea), might also have been collected. Hereafter, we refer to the floater species as *Anodonta spp*. Mussels were present in all 24 surveyed reaches and in all 14 mesohabitat units in which cross-section samples were made (Figure 2). Individual species occurrence and abundance varied along a longitudinal gradient and among mesohabitat units. Western ridged mussels were the most abundant species, followed by western pearlshell mussels, and *Anodonta spp.* Western ridged mussels were present in all 24 reaches surveyed and in all 14 mesohabitat units in which cross-section samples were made. Although ubiquitous throughout the mainstem, western ridged mussel abundance was often low (10's of individuals observed in a mesohabitat unit), but increased in downstream reaches and were evidently highest in downstream riffle mesohabitat units (1000's of individuals in a mesohabitat unit). Western pearlshell mussels were relatively rare (10's of individuals per mesohabitat unit) and most frequently found in a few upstream riffles and glides. *Anodonta spp.* were rare throughout the mainstem of the Similkameen River. Only three individuals were found in upstream glides.

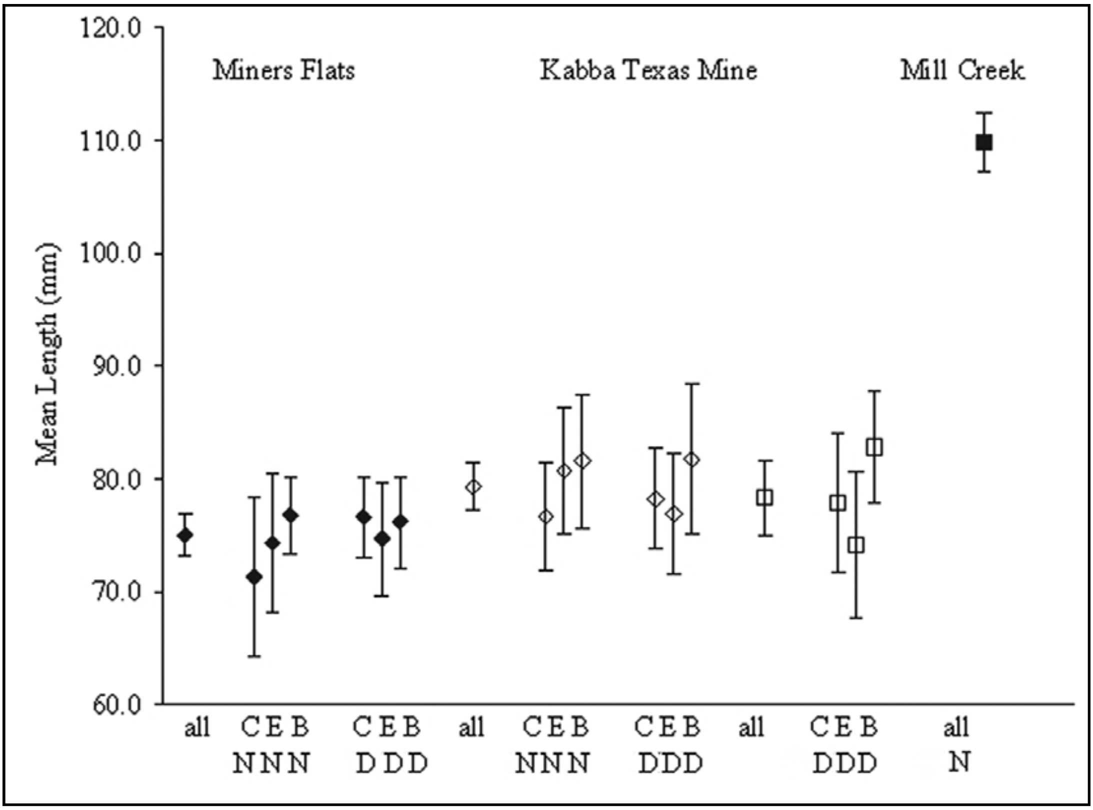

Figure 3. Mean and 95% confidence intervals of the length (mm) of western ridged mussels (diamonds) and western pearlshell mussels (squares) used in dredging experiments at the Miners Flats (filled) and Kabba Texas Mine (unfilled) sites on the Similkameen River and on Mill Creek (filled square), Washington. Statistics are calculated for all individuals of a species at a site (all), and individuals treated as controls (C), exposed (E), and buried (B) secondary treatments nested within primary treatments of not entrained by a dredge (N) and entrained by a dredge (D).

Particularly near public access points and in riffles we observed many large (> 1-m^3) holes in the stream bed and piles of coarse gravel and small boulder substrate that were evidently the results of mining activity.

We observed no obvious damage to the valves of either species upon exiting the dredge. All control and all exposed western ridged mussels and western pearlshell mussels survived the experiment at both study sites in the Similkameen River. Many control mussels of both species (47%) changed their location or orientation in enclosures. One entrained and exposed western ridged mussel escaped the enclosure, and was found alive in a natural orientation near the enclosure. All entrained and exposed mussels recovered a natural orientation and resumed siphoning water within 1 week, many (36%) recovered within 24 hours. Of the three western ridged mussels entrained by the suction dredge and deposited with dredge tailings, two remained exposed downstream of the tailing pile and one was deposited in the tailing pile, suggesting that some, but not all, mussels may be buried in tailing piles. Burial killed between 6% and 13% of western ridged mussels at both sites and 6% of western pearlshell mussels at the Kabba Texas Mine site. Several of the dead mussels were heavily decayed (e.g., no soft tissue remained) at the termination of the study, indicating that they had died early in the study. Being entrained by the suction dredge did not increase the percent of buried mussels that died (Table 1). Approximately 15% of the buried mussels were located between 15 cm and 25 cm above the enclosure bottom when the experiment was terminated, indicating that they may have been attempting to excavate. In addition to the observed deaths of buried mussels, two western

TABLE 1. Percent of mortalities at two study sites in the Similkameen River, Washington of two freshwater mussel species; western ridged mussels (ridge) and western pearlshell mussels (pearlshell). Primary treatments are no entrainment and entrainment by a suction dredge. Secondary treatments included a control (C), exposure (E), and burial (B) of mussels. We used 15 enclosures for each combination of species, primary treatment, and secondary treatment with one mussel treated as a C, E, and B in each enclosure.

Miners Flats						Kabba Texas								
western ridge						western ridge						western pearlshell		
no entrainment			entrainment			no entrainment			entrainment			entrainment		
C	E	B	C	E	B	C	E	B	C	E	B	C	E	B
0	0	13	0	0	6	0	0	13	0	0	13	0	0	6

ridged mussels were unable to recover a natural orientation within 48 hours of exhumation at the termination of the experiment.

The western ridged mussels and western pearlshell mussels used in the experiments were relatively small (mean length = 77 mm, SD = 9.7, range = 47 – 98 mm for western ridged mussels and mean length = 78 mm, SD = 11.0, range = 45 – 95 mm for western pearlshell mussels) compared to those described by Vannote and Minshall (1982) for living and extinct populations in Idaho. Mean lengths of western ridged mussels were similar among study locations and experimental treatments (Figure 3). Mean lengths of western pearlshell mussels were similar among control and burial treatments at the Kabba Texas Mine site, but western pearlshell mussels were significantly larger in Mill Creek than at the Kabba Texas Mine site (Figure 3).

Discussion

Mussels were widely distributed throughout the mainstem of the Similkameen River, but their abundance was variable among species and locations. Mussel abundance varied along the longitudinal stream gradient, among mesohabitat units, and across many stream cross-sections. We located mussel in all reaches and mesohabitat units that we surveyed. However, mussel abundance differed among reaches and mesohabitat units and was often highest in riffles and glides, some of which evidently had recent mining activity based on observations of tailing piles and excavations. Western ridged mussels were most abundant in downstream reaches, whereas western pearlshell mussels were most abundant in upstream reaches of the study area. Both species were most abundant between the stream margin and thalweg, perhaps because these areas remain wet and have relatively low stream power (Layzer and Madison 1995, Strayer 1999). However, both species were often found throughout stream cross-sections, especially where the channel margin was well-defined by steep banks.

The cryptic behavior, shape, and color of mussels made them difficult to locate. Visual surveys to count freshwater mussels often locate only a small percentage of the mussels present (Hastie and Cosgrove 2001, Strayer and Smith 2003), suggesting that failure to locate mussels when they are present is a common problem. For example, of the 90 mussels that we entrained with the suction dredge, one was entrained without the dredge operator's knowledge, even though it was marked with two yellow numbered tags. Like many fishes (Angermeier et al. 2002), freshwater mussels are often discontinuously distributed within and among rivers (Green and Young 1993), suggesting that failure to find mussels in a mesohabitat unit or stream reach is poor evidence of their absence at larger spatial extents.

Adult western ridged mussels and western pearlshell mussels are evidentley robust to entrainment and exposure, at least for the short temporal extent of this experiment. We observed no evidence of injury to the valves of any mussels that were entrained by the dredge. Additionally, entrained and exposed mussels are able to reorient themselves in stream substrate after disturbance. However, several studies including ours demonstrate that burial can kill mussels. Marking and Bills (1979) found variable but frequently high mussel mortality due to experimental burial in gravel and Ellis (1942) found high (90%) mussel mortality resulted from experimental burial in silt. Further, Vannote and Minshall (1982) postulated that large numbers of western pearlshell mussels died in the Salmon River, Idaho as a result of burial. We observed relatively low mortality (10%) of buried mussels, but no individual of either species was able to excavate from experimental burial in the Similkameen River and several buried individuals did not fully recover within 48 hours of excavation. Our results suggest that additional mortalities would have occurred if we had continued the experiment.

Burial depth, substrate size, and mussel size may be important determinants of the mortality of buried mussels. Western pearlshell mussels from Mill Creek were able to excavate from burial, in contrast to our results in the Similkameen River and the findings of Vannote and Minshall (1982) who observed no movement by western pearlshell mussels. However, the mussels used in the preliminary study in Mill Creek were larger than those found and used in the Similkameen River. Furthermore, the mussels in the Similkameen River were buried deeper under larger substrate than those in Mill Creek. Differences in study outcomes demonstrate that the effects of dredging may vary among locations, probably due to differences in the size of mussels, the size of substrate, and the depth of burial.

Our results should be interpreted and applied carefully. The complex life history, limited ability to move, longevity, and cryptic behavior of freshwater mussels make them particularly susceptible to extirpation and difficult to study (Bogan 1993). Because female mussels filter gametes from the water column, their reproductive success depends on the density and distribution of male mussels. Amyot and Downing (1998) found that individuals of certain mussel species moved closer together during the breeding season and Shelton (1997) found that some mussels may form male-female pairs. The effect of moving or exposing mussels on their fertilization success is not known, but low density may reduce reproductive success (Downing et al. 1993). Most freshwater mussels have an obligatory parasitic life stage (glochidia), often requiring a specific species of fish as a host. Successful reproduction requires the release of glochidia at the proper time to allow infestation of the fish host. Physical disturbance can have sublethal detrimental effects on freshwater mussels, such as early release of glochidia and subsequent failure to reproduce (Hastie and Young 2003, Dr. William Henley, Virginia Tech, Blacksburg, VA, personal communication). Whether suction dredge mining affects such disturbances and whether entrainment and exposure of glochidia or juvenile mussels results in their mortality is not known. This research only studied the effects of suction dredge mining on the short-term survival of relatively large, likely adult, mussels. However, suction dredging does affect the survival of other aquatic organisms (Thomas 1985, Harvey 1986), especially some early life stages of fish and invertebrates (Griffiths and Andrews 1981), suggesting that juvenile mussels might be more-affected by dredging than the relatively large mussels we studied.

Management Implications

The WDFW is responsible for protecting individual mussels and mussel populations in Washington. Given the extremely high percentage of imperiled freshwater mussels in North America (Master 1990, Strayer et al. 2004), the long history of anthropogenic disturbance to the Similkameen River, and concerns over possible declines in abundance and distribution of western ridged mussels in the Columbia basin, precautionary management of mussels in Washington is warranted.

We know very little about the life history, geographic distribution, and population persistence of freshwater mussels in Washington (Nedeau et al. 2005). This paucity of information contributes to uncertainty regarding the appropriateness of management alternatives. Our research provides limited, but valuable information that can be used to develop management actions and guide additional research, especially regarding suction dredge placer mining. The frequent occurrence and usually low abundance of freshwater mussels in the Similkameen River suggests that avoiding mussels may be difficult during placer mining. This may be a concern for areas of riverbed that are entrained or where tailing are deposited. It may be possible to avoid locations (e.g., some riffles or rivers) with known high abundance of adult mussels. Our results demonstrate no effect of entrainment and/or exposure of mussels by a suction dredge on their short-term survival, but burial in dredge tailings often results in mussel mortality. Further, we do not know how suction dredge mining will affect small individuals or thin-shelled mussels such as *Anodonta spp*. Finally, we do not know how mining affects mussel behavior or demographic performance. Managers should be aware that we have little knowledge of the long-term or sub-lethal effects on mussels of entrainment and exposure by suction dredging.

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