# Native freshwater mussel surveys of the Bear and Snake Rivers, Wyoming.

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## *Abstract*

North America hosts the world's highest diversity of freshwater mussels and more than 70% have an imperiled conservation status. Wyoming has seven known native mussel species within two families: *Unionidae* and *Margaritiferidae*. Prior to 2011, little was known about native mussels in Wyoming. The western drainages of Wyoming host two species of native freshwater mussels: the California floater (CFM, *Unionidae:Anodonta californiensis*) and western pearlshell (WPM, *Margaritiferidae:Margaritifera falcata*). A total of 23 sites were surveyed for native mussels yielding a high number of individuals ($n$=3,723 WPM; $n$=13 CFM) at 11 sites in the Bear River and Snake River drainages, Wyoming. Timed surveys were performed to look for native mussels. Total shell length (TL, mm) was used to create length frequency histograms for live mussels. Empty shells of preferred specimens were collected and added to our collection at the University of Colorado Museum of Natural History. Sites were measured for stream channel parameters such as: bankfull depth, bankfull width, wetted width, and substrate. Mussel presence-absence was compared to the habitat parameters using binary logistic regressions and no significant ($p$>0.05) relationships were found. Juvenile recruitment of WPM was evident, while only larger, older CFM were found during our surveys. Many factors limit the presence-absence of native freshwater mussels including water chemistry, droughts, floods, substrate, and availability and age of host fish. Based on the findings in this report, a rank of NSS2 for CFM and a rank of NSS5 for WPM are recommended.

## *Introduction*

North America hosts the world's highest diversity of freshwater mussels (over 300 species) and more than 70% have an imperiled conservation status (Williams et al. 1993). In the Midwest alone, half of the freshwater mussel species are listed as threatened or endangered (Cummings and Mayer 1992). Unregulated exploitation, loss of obligate host fishes, habitat degradation, and a lack of management during the last century took a considerable toll on mussel populations, despite their high ecological value (Bogan 1993, Watters 2000). Native mussels continue to decline, including species in the western U.S. such as the western pearlshell in Montana (Stagliano 2010), California, and Idaho, and the imperiled California floater throughout its range (NatureServe 2012; Table 1). The headwater nature of Wyoming drainages limits suitable habitat and increases the risk of native mussel extirpation in the state.

TABLE 1. Conservation status rank for CFM and WPM at various scales (NatureServe 2012) are listed. The ranking key is as follows: (1) critically imperiled, (2) imperiled, (3) vulnerable, (4) apparently secure, and (5) secure; (G) global, (N) national, and (S) statewide; (SH) possibly extirpated in that state, (NR) unranked and/or not assessed, and (Q) questionable taxonomy that may reduce conservation priority. Instances with multiple ranks (G#G#, N#N# or S#S#) indicate a range of ranks due to uncertainty as to the exact rank. Statuses with a ? (S#?) denote an inexact numeric ranking.

| Scale | CFM | WPM |
|---|---|---|
| Global | G3Q | G4G5 |
| National-USA | N3 | N4 |
| National-Canada | N3 | N4N5 |
| Alaska | | SNR |
| Arizona | S1 | |
| California | S2? | S2S3 |
| Idaho | S2 | S3 |
| Montana | | S2 |
| Nevada | S1 | SNR |
| Oregon | S2 | S4 |
| Utah | S1 | SH |
| Washington | S2 | S3S4 |
| British Columbia, Canada | | S5 |

Wyoming currently has seven known native mussel species within two families: *Unionidae* and *Margaritiferidae* (Cvancara 2005). The western drainages of Wyoming host two species of native freshwater mussels: the California floater (CFM, *Unionidae:Anodonta californiensis*) and western pearlshell (WPM, *Margaritiferidae:Margaritifera falcata*). Prior to 2011, little was known about the native mussels in Wyoming. The few studies carried out were limited in scope and produced sparse information on mussels (Beetle 1989, Henderson 1924, Hoke 1979, Hovingh 2004) (Figure 1, Appendix A). During the 2011-2012 field seasons, much knowledge was gained about the native mussels in western Wyoming. Incidental observations from field personnel in the Green River, Pinedale, and Jackson Fisheries Management regions were critical in determining potential survey locations. Many of the incidental records that were acquired happened after 2000 due to the efforts and encouragement by Gordon P. Edwards, Jr. and Roy Whaley.

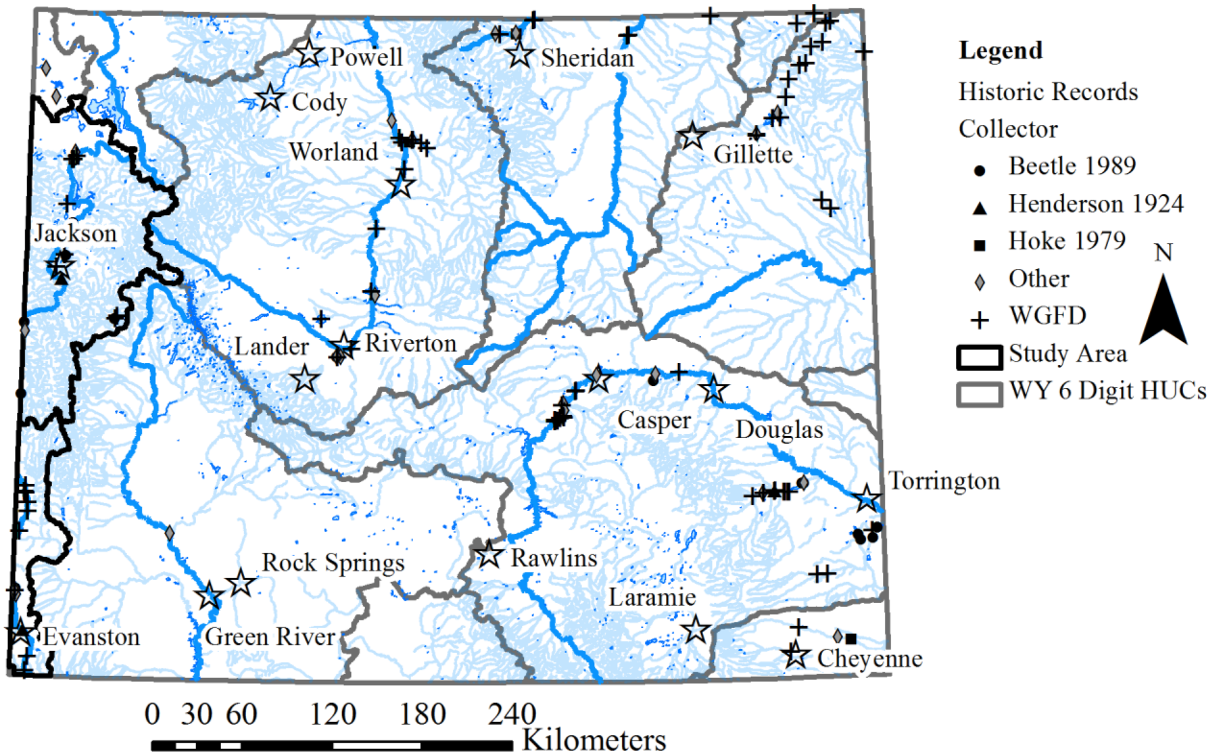


FIGURE 1. Map of Wyoming showing mussel observations from various studies (Beetle 1989, Henderson 1924, Hoke 1979) and incidental observations from WGFD personnel and various other sources.

Native mussels co-evolved with their fish hosts to increase the chance of upstream migration. Native mussel reproduction includes an encysted larval stage on a host fish, in which larval mussels (glochidia) attach themselves to a host fish's gills and fins. These mussel-bearing fish can travel extensively within rivers and among watersheds, and assist with dispersal. In the case of the WPM, it can use a multitude of hosts, most of which are salmonids: cutthroat trout, rainbow trout, brown trout, brook trout, sockeye salmon, Coho salmon, Chinook salmon, speckled dace, Tahoe sucker, and Lahontan redside (Nedeau et al. 2009). The CFM has fewer known species of host fish, which include mosquitofish (d'Eliscu 1972), speckled dace, margined sculpin, and longnose dace (O'Brien et al. 2013).

The CFM is a relatively short-lived mussel species, only living 10-15 years and reaching maturity at age-4 or -5 (Nedeau et al. 2009). Its native range originally included much of California north to British Columbia, Canada; east to western Wyoming and eastern Arizona; and south to Chihuahua, Mexico. For habitat, CFM prefers fine substrates (i.e., mud and sand) in rivers, reservoirs, and lakes. Irrigation diversions that cause water level fluctuations and water impoundment dams that act as migration barriers for host fish have contributed to major population declines throughout its native range. The CFM currently has a NatureServe rank of G3/N3 at the global and national scales (USA and Canada) and a ranking of S1 or S2 in all states where it is ranked (Table 1; NatureServe 2012, Nedeau et al. 2009).

The WPM is one of the longest-lived invertebrates known, with a life span that can exceed 100 years, but typically averages 60 to 70 years. The species reaches maturity at 9 to 12 years. Within the Pacific Northwest drainages it is the most common species of native freshwater mussel (Nedeau et al. 2009). Its native range includes Alaska, California, Idaho, Montana, Nevada, Oregon, Washington, Wyoming, and British Columbia; WPM is possibly extirpated in Utah (NatureServe 2012). The WPM is one of seven species of native mussels in North America known to be predominantly hermaphroditic (Thorp and Covich 2010), which allows for reproduction when few individuals are present at a site, such as in a headwater stream. The WPM prefers clean, cold streams with salmonids present. For substrate, WPM prefers stable sand, gravel, and cobble, and are often found in the slack water along the banks of rivers. As with the CFM, impoundments have caused major declines in the WPM throughout its range by preventing host fish movement and regulating stream flows.

Wyoming native species of greatest conservation need are those with a native species status (NSS) rank of U or 1-4 (Table 2). Both CFM and WPM are currently ranked NSSU in the 2010 State Wildlife Action Plan (SWAP) due to the lack of information on their distribution and abundance at that time (WGFD 2010). Recommendations from this report will be used to make a more informed decision on the NSS status of these species for the 2015 SWAP revision.

The objectives of this study were to (1) identify species distributions, habitat associations, and core populations of native mussels in the Bear and Snake River drainages of western Wyoming, initially focusing on top aquatic priority areas listed in the Department's Strategic Habitat Plan; (2) propose Native Species Status rankings, identify potential limiting factors, and suggest potential management actions for native mussels in Wyoming; and (3) complete a comprehensive collection of native mussel voucher specimens at the University of Colorado Museum of Natural History.

TABLE 2. Native Species Status (NSS) rankings and definitions (WGFD 2010).

| NSS Rank | Definition |
|---|---|
| U | Distribution and general abundance is unknown. |
| 1 (Aa) | Population size or distribution is restricted or declining and extirpation is possible. Limiting factors are severe and continue to increase in severity. |
| 2 (Ab) | Population size or distribution is restricted or declining and extirpation is possible. Limiting factors are severe and not increasing significantly. |
| 2 (Ba) | Population size or distribution is restricted or declining but extirpation is not imminent. Limiting factors are severe and continue to increase in severity. |
| 3 (Bb) | Population size or distribution is restricted or declining but extirpation is not imminent. Limiting factors are severe and not increasing significantly. |
| 4 (Bc) | Population size or distribution is restricted or declining but extirpation is not imminent. Limiting factors are moderate and appear likely to increase in severity. |
| 4 (Cb) | Population size and distribution is stable and the species is widely distributed. Limiting factors are severe and not increasing significantly. |
| 5 (Cc) | Population size and distribution is stable and the species is widely distributed. Limiting factors are moderate and appear likely to increase in severity. |

## *Study Area*

Two major drainages west of the continental divide in Wyoming comprised the study area: the Bear and Snake rivers (Figure 2). We sampled 11 sites in the Bear River drainage in southwest Wyoming and 12 sites in the Snake River drainage in northwest Wyoming. The streams we sampled in the Bear River drainage included the Smiths Fork River, Bear River, Yellow Creek, Sulphur Creek, LaChapelle Creek, and Mill Creek. Our Snake River drainage sites were in the following streams: Fall Creek, North Fork Fisherman Creek, Flat Creek, Spread Creek, Buffalo Fork River, Lizard Creek, Polecat Creek, Snake River, Lake Creek, and Bearpaw Creek.

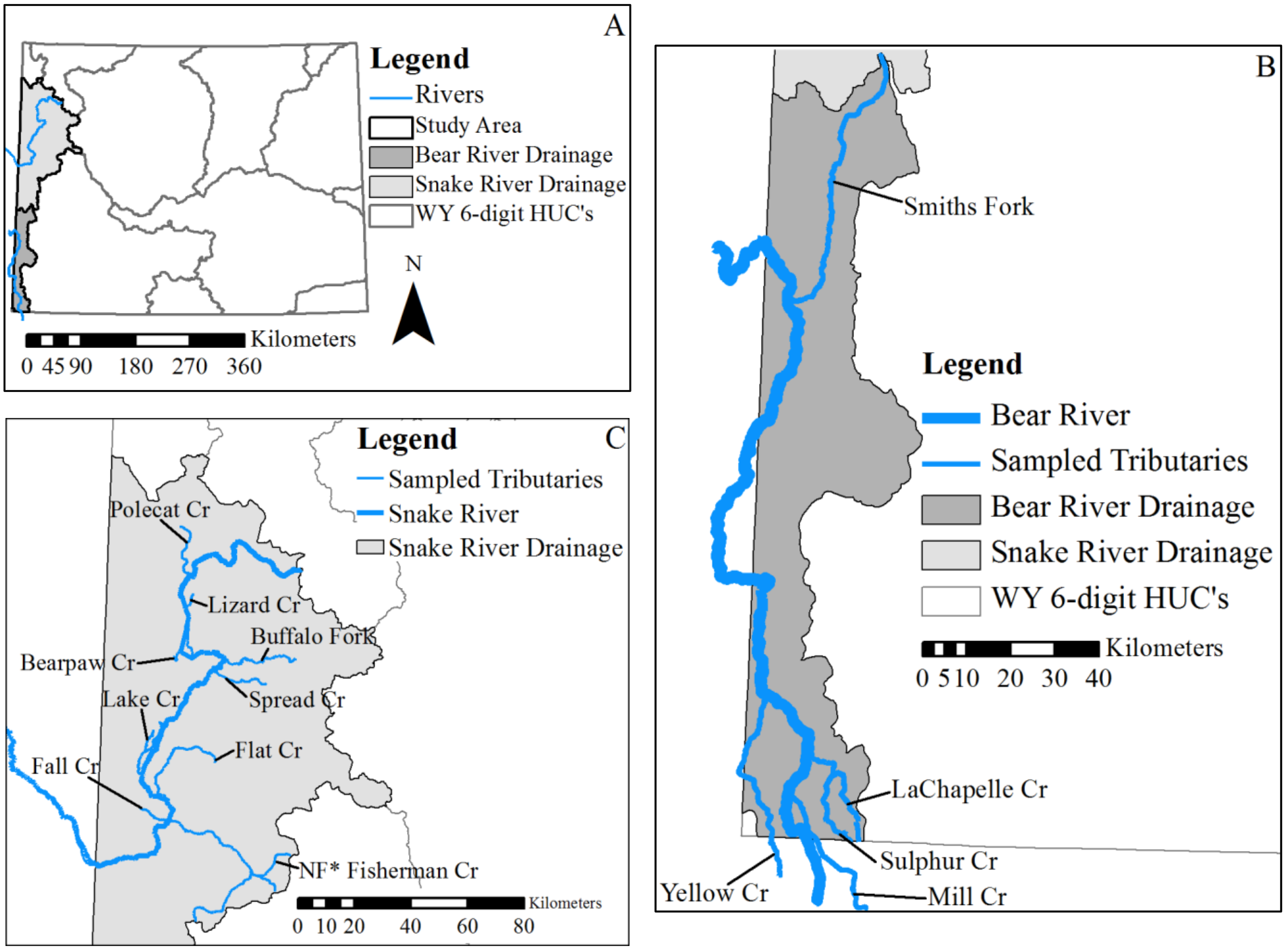


FIGURE 2. (A) Perspective map of the study area in Wyoming. (B) Map of the Bear River drainage in Wyoming with the sampled tributaries included. (C) Map of the Snake River drainage in Wyoming with the sampled tributaries included (*North Fork).

## *Methods*

### *Site Selection*

Our site selection had two major criteria: 1) the stream had to be perennial; and 2) we had to obtain property access from private landowners or find public access. Many of our sites were based on historical records, incidental reports from fisheries biologists, and recommendations from regional fisheries biologists. We then focused our sampling efforts on portions of streams where major habitat changes occur (i.e., diversions, dams, confluence of major perennial tributaries). We attempted to sample a site upstream and downstream of each major habitat change if possible and attempted to sample major tributaries within each drainage.

***Surveying for Native Mussels***

Once a site was chosen, we determined the best sampling method for that site. We began by walking the banks looking for hazards in and out of the water and evidence of shells along the banks. Many times, native mussel shells are deposited on the banks from high water flows and/or predators (e.g., muskrats or raccoons; Grabarkiewicz and Davis 2008). Deposited shells were collected as evidence that the species found are or were present in that section of stream. Based on our observation of the site (i.e., water clarity, depth, etc.), we used the most appropriate sampling technique: snorkeling, glass bottomed view buckets, polarized sunglasses (if clear and shallow enough to do so), and/or tactile searches. Each method was performed as a timed search, meaning that we recorded the total time sampled and the number of surveyors to calculate the overall person-hours and catch per unit effort (CPUE, number of live mussels per person-hour).

Sites were first measured for an average wetted width. The average wetted width was multiplied by 40 and rounded up to the nearest 50 m (164 ft) to determine the site length, up to 600 m (1969 ft). Our protocol was based on the U.S. EPA Environmental Monitoring and Assessment Program (Lazorchak et al. 2006). Timed visual and tactile surveys began at the downstream portion of the site and we worked upstream to reduce turbidity issues. Substrates were not excavated to find buried mussels, giving a bias to less cryptic and larger, and thus older, individuals and species (Hornbach and Deneka 1996, Metcalfe-Smith et al. 2000, Obermeyer 1998). We measured the total length (TL, mm) of approximately the first 100 live mussels observed at each site. Additional mussels were left undisturbed, and were visually counted and tallied at the end of the survey. Measuring live mussels for TL gave a relative population age structure. If there was a large diversity of sizes, especially with small individuals present, it confirmed that recruitment was occurring as TL is relative to age. After live mussels were measured and photographed, they were returned to their approximate original locations and placed in the substrate in the correct orientation (anterior portion of the shell in the substrate). We collected the empty shells for our voucher collection at the University of Colorado Museum of Natural History.

***Habitat Measurements***

After we surveyed for mussels, the streams were measured for basic habitat parameters. The site was divided into 11 equispaced transects. We first measured the wetted width, bankfull width, and approximate bankfull depth. Bankfull depth was approximated by locating the stream elevation at the greenline (first line of perennial vegetation), suspending the measuring tape across the stream at the greenline, and measuring the vertical distance downward to the bottom of the wetted-channel at five positions across the stream (left bank, left-center, center, right-center, and right bank; left is to the surveyor's left as he faces downstream). Bankfull width and bankfull depth were used in our analysis because we assumed these measurements to be the maximum hydrologic pressure a site would regularly experience (Gangloff and Feminella 2006). Substrate was also categorized at each position that the bankfull depth was measured. Substrate was categorized as: fines (silt, clay, muck, not gritty), sand (< 2 mm, gritty to ladybug size), fine gravel (2-16 mm, ladybug to marble size), course gravel (16-64 mm, marble to tennis ball size), cobble (64-250 mm, tennis ball to basketball), boulder (250-4,000 mm, greater than basketball), hardpan, bedrock (> 4,000 mm, larger than car), wood, and other (Lazorchak et al. 2006). Between transects, we identified the dominant habitat type as a pool, riffle, or run. We also recorded basic site information: UTM (NAD27) upstream/downstream (downstream is used as the UTM for the site), elevation, property owner, nearest town, county, date, time start/stop, site name, site code, river, drainage, management region, surveyors, and data recorder.

We coordinated with the Wyoming Department of Environmental Quality (WYDEQ) to obtain water quality records from locations near our survey sites. Many of the records provided were not relevant for a variety of reasons (i.e., distance from sites, chemical parameters included, consistency, etc.) and therefore were not used in our analyses. More long-term, site-specific chemical parameters were needed to see if there was an influence on mussel presence.

***Species-Habitat Associations***

Binary logistic regressions were used to assess the relationship between the presence and absence of native mussels in the Bear and Snake River drainages (R 3.0.2, R Commander; R Core Team 2013, Fox 2005) to the habitat data taken at each site (Appendices C & D). Pearson correlation analyses were first conducted to identify redundant habitat variables for all sites and CFM only sites (Appendix D). Dominant substrate was not correlated ($p \geq 0.05$) with any other variables (mean bankfull depth, mean bankfull width, drainage area ($km^2$), and Stahler's stream order).

Drainage area was calculated using mosaiced 10 m (32.8 ft) resolution National Elevation Dataset (NED) files to create 10 m (32.8 ft) contour lines in ArcMap 10.1. The closest contour line to each site was used to split the HUC12 polygon that each site was located in. The drainage area was then calculated for the split polygon. The area of the split polygon was added to the additional HUC12s upstream of the split polygon to get the total drainage area ($km^2$) upstream of each site.

Two different sets of binary logistic regressions were run. The first set included all sites in the Bear River and Snake River drainages (Appendix B). Using all sites within both drainages allowed for the explanation of habitat associations for both WPM and CFM. In Wyoming, CFM is only found in the Bear River drainage. I removed sites from the Snake River drainage and sites where only live WPM were found to run a CFM-specific model (Appendix C).

***Length Frequency Histograms***

For sites with more than 30 live mussels present, the TLs of the measured individuals were used to create size frequency histograms. The histograms can suggest recruitment if smaller individuals are present and there is a broad range of TL (Miller and Payne 1988).

## Results

We sampled 23 sites across the two drainages, yielding 3,736 native mussels at 11 sites (Tables 3 & 4, Figure 3). Field efforts in 2011 were hampered by high flows, which made for a short field season, high turbidity at several sites, and unusually high seasonal flows. Of the sites yielding mussels, five were within the Bear River drainage and six were within the Snake River drainage. We did not find mussels at six sites in each of the drainages. The Snake River drainage is host to a single species, WPM, while the Bear had both CFM and WPM present (Table 4).

TABLE 3. Survey locations and dates for the 25 sites surveyed in 2011 and 2012. The site code, HUC5 code, and WGFD WaterID (WaterID) are listed for each site. All sites are in UTM Zone 12 (NAD27). The landownership (Owner) is also included.

| Drainage/ Water body | Site | HUC5 | WaterID | Date | UTM Easting | UTM Northing | Owner |
|---|---|---|---|---|---|---|---|
| **Bear River** | | | | | | | |
| Smiths Fork R. | BR01 | 1601010202 | PE8B1400LN | 09/16/11 | 509470 | 4665363 | Private |
| Bear R. | BR02 | 1601010201 | PE8B1020LN | 08/22/11 | 503667 | 4647337 | USFWS |
| Bear R. | BR03 | 1601010108 | PE8B1020LN | 08/23/11 | 500780 | 4641433 | USFWS |
| Bear R. | BR04 | 1601010103 | GR8B1040UA | 08/03/11 | 499467 | 4594971 | BLM |
| Lower Yellow Cr. | BR05 | 1601010104 | GR8B2690UA | 08/08/11 | 500118 | 4569451 | Private |
| Bear R. | BR06 | 1601010102 | GR8B1040UA | 09/14/11 | 505747 | 4567220 | State |
| Lower Sulphur Cr. | BR07 | 1601010102 | GR8B2780UA | 08/06/11 | 510800 | 4561147 | Private |
| LaChapelle Cr. | BR08 | 1601010102 | GR8B2790UA | 08/04/11 | 517539 | 4553514 | Private |
| Upper Sulphur Cr. | BR09 | 1601010102 | GR8B2780UA | 08/05/11 | 514878 | 4546287 | Private |
| Upper Yellow Cr. | BR10 | 1601010104 | GR8B2690UA | 08/05/11 | 502804 | 4542466 | Private |
| Mill Cr. | BR11 | 1601010101 | GR8B2870UA | 08/04/11 | 511988 | 4539180 | Private |
| **Snake River** | | | | | | | |
| Fall Cr. | SN01 | 1704010301 | JN8S3270TN | 10/28/11 | 518039 | 4796328 | USFS |
| NF Fisherman Cr. | SN02 | 1704010303 | JN8S3850SE | 10/25/11 | 557360 | 4779453 | USFS |
| Flat Cr. | SN03 | 1704010302 | JN8S4050TN | 10/26/11 | 522018 | 4820276 | USFWS |
| Spread Cr. | SN04 | 1704010105 | JN8S5255TN | 10/12/11 | 543556 | 4845995 | USFS |
| Buffalo Fork R. | SN05 | 1704010106 | JN8S5450TN | 09/30/11 | 552727 | 4853787 | USFS |
| Lizard Cr. | SN06 | 1704010103 | JN8S6300TN | 10/12/11 | 525733 | 4872589 | NPS |
| Polecat Cr. | SN07 | 1704010103 | JN8S6375TN | 10/01/11 | 525284 | 4883738 | NPS |
| Snake R. | SN08 | 1704010102 | JN8S6001TN | 09/29/11 | 527472 | 4886080 | NPS |
| Snake R. | SN09 | 1704010103 | JN8S6001TN | 09/28/11 | 527472 | 4886080 | NPS |
| Flat Cr. | SN10 | 1704010302 | JN8S4050TN | 09/19/12 | 518893 | 4814178 | Private |
| Lake Cr. | SN11 | 1704010301 | JN8S4240TN | 09/18/12 | 517325 | 4827830 | NPS |
| Bearpaw Cr. | SN12 | 1704010103 | JN8S6010TN | 09/20/12 | 521660 | 4852796 | NPS |

TABLE 4. Survey results and techniques listed by site in the Snake River and Bear River drainages. Length is site length, which was measured in meters (m). Techniques are defined as visual (V), view bucket (B), snorkel (S), and tactile (T). Total length (TL) was measured in millimeters (mm). Catch per unit effort (CPUE) is the number of live mussels per person-hour.

| Drainage/ | | | | Occurrences | | Live (TL) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Length | Technique | Species | Live | Dead | Min | Max | Mean | CPUE |
| **Bear River** | | | | | | | | | |
| BR01 | 600 | S/V | WPM | 524 | Y | 28 | 75 | 52 | 16.0 |
| BR02 | 600 | T/B | CFM+WPM | 0 | Y | | | | 0.0 |
| BR03 | 600 | T/B | CFM | 2 | Y | 93 | 103 | 98 | 0.2 |
| BR04 | 600 | B/S | CFM+WPM† | 10 | Y | 60 | 70 | 64 | 0.5 |
| BR05 | 300 | V/B | CFM | 1 | Y | 58 | 58 | | 0.3 |
| BR06 | 600 | B/S | | 0 | Y | | | | 0.0 |
| BR07 | 600 | V/B | | 0 | N | | | | 0.0 |
| BR08 | 200 | V/B | | 0 | N | | | | 0.0 |
| BR09 | 150 | V/B | | 0 | N | | | | 0.0 |
| BR10 | 150 | V/B | | 0 | N | | | | 0.0 |
| BR11 | 375 | V/B | WPM | 2 | N | 52 | 53 | 53 | 0.5 |
| **Snake River** | | | | | | | | | |
| SN01 | 400 | V/B | | 0 | | | | | 0.0 |
| SN02 | 200 | V/B | WPM | 828 | Y | 18 | 81 | 44 | 138.0 |
| SN03 | 400 | S | | 0 | N | | | | 0.0 |
| SN04 | 600 | V/B | | 0 | N | | | | 0.0 |
| SN05 | 600 | S/V | | 0 | N | | | | 0.0 |
| SN06 | 100 | V/B | | 0 | N | | | | 0.0 |
| SN07 | 600 | S | WPM | 537 | Y | 27 | 75 | 67 | 83.9 |
| SN08* | 600 | S/V | WPM | 30 | N | | | | 7.5 |
| SN09 | 600 | S/V | WPM | 608 | Y | 31 | 81 | 67 | 80.0 |
| SN10 | 200 | S/B/V | WPM | 9 | Y | 66 | 77 | 72 | 1.8 |
| SN11 | 600 | B/V | | 0 | N | | | | 0.0 |
| SN12 | 250 | B/V | WPM | 1,185 | Y | 42 | 81 | 66 | 263.3 |

†No live WPM, only shells. Live and dead CFM found.
* No shell measurements made as site was directly adjacent to SN09.

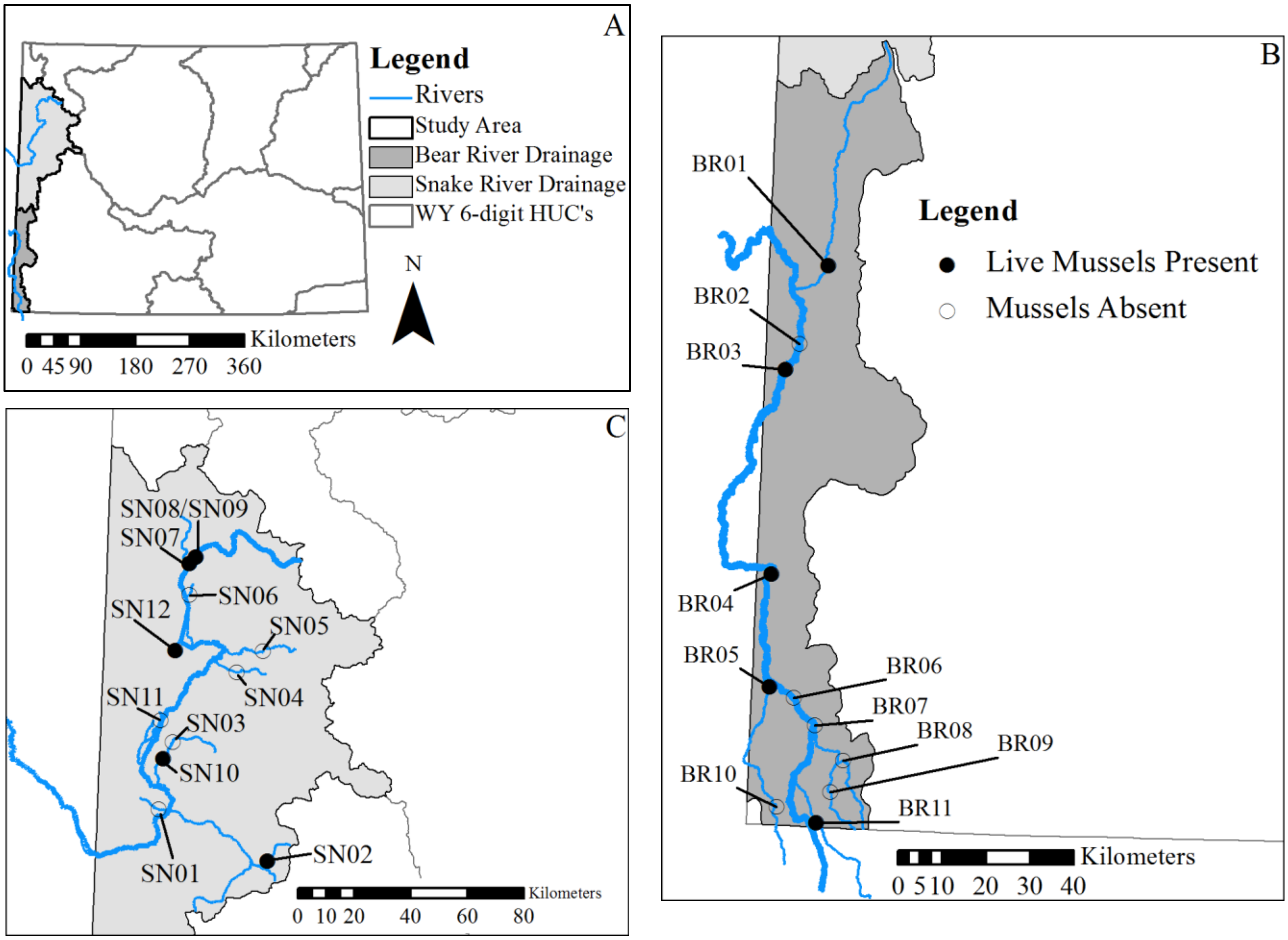


FIGURE 3. (A) Perspective map of the study area in Wyoming. (B) Bear River drainage map with survey sites included. (C) Snake River drainage map with survey sites included.

***Bear River Drainage (HUC 1601)***

Though both CFM and WPM are present in the Bear River drainage, we did not find live individuals of both at the same site. We did find live CFM with empty WPM shells at site BR04 and site BR02 had only empty shell evidence of the two species together.

Live CFM were found at three sites (BR03, BR04, and BR05; *n*=13). Site BR04 had numerous whole empty shells of CFM present that were found embedded in the bank in life position with tissue still in them. At site BR03, we found two live occurrences of CFM during a tactile search, which was necessary at this site due to low visibility. We discovered one live CFM and many relic shells at site BR05. Site BR05 in Yellow Creek is the most upstream population of CFM known in the Bear River drainage of Wyoming, upstream of Woodruff Narrows Reservoir.

Live WPM were found at two sites in the Bear River drainage. Site BR11 (*n*=2) was the highest elevation that we have found WPM (2,350 m; 7,710 ft). WPM were most abundant at site BR01 (*n*=524). All individual WPM were collected and measured at BR01 resulting in diverse TL’s among individuals.

At several sites in the Bear River drainage, we found empty shells only. Site BR02 contained the shells of two species; there were whole and fragment CFM and only the right valve of a WPM.  Site BR06 had a single WPM valve found on the riverbank.

No evidence of live or dead mussels was found in the Sulphur Creek drainage (sites BR07, BR08, and BR09) or at site BR10 in Yellow Creek.  The landowner for site BR10 had mentioned that the stream had gone dry in the past.

***Snake River Drainage (HUC 1704)***

We only found WPM in the Snake River drainage.  Twelve sites were sampled in the drainage, both above and below Jackson Lake, and we observed 3,197 WPM across six sites. We observed 608 WPM at site SN09 and measured the TL of the first 212 individuals.  Site SN08 had 30 live WPM.  Sites SN08 and SN09 were originally combined, but were surveyed for mussels and the habitat data were taken separately, warranting two separate sites.  Site SN08 was the main channel of the Snake River and SN09 was a slack water/side channel in the Snake River.  We did not collect or measure any live mussels at SN08 since we had collected and measured 212 individuals at site SN09 and they were geographically at the same location.  We found 537 live WPM at site SN07 and measured the TL of the first 95 individuals.  Mussels were found throughout the stream channel, mainly upstream of a large bend in the river and the confluence with a tributary coming from a hot spring.  The mussels at SN07 were found in the substrate and embedded in macrophytes.  We observed 828 WPM at site SN02 and measured the TL of the first 105 mussels.  We observed 1,185 WPM at site SN12, measuring the TL of the first 176 individuals.  This was our most abundant site to date in the Snake River drainage.  Site SN10 had only 9 live WPM present.

At our other six sites in the Snake River drainage (SN01, SN03, SN04, SN05, SN06, SN11), we did not find any evidence of mussel presence.  Sites SN01, SN03, and SN06 had very compacted substrate, while sites SN04 and SN05 were very wide (bankfull widths were greater than 100 m; 328 ft) and had unstable substrates.  During high spring flows these sites would not support live mussels, as they have a higher chance of being pulverized.

***Species-Habitat Associations***

No significant predictors or models were determined using the habitat data.  All *p*-values were >0.05, which was greater than our *a priori* $\alpha$ of 0.05 (Appendix E).  The logistic regressions performed in this report did not reveal a relationship between the parameters measured and the presence-absence of CFM or WPM in Wyoming.  Further analyses were unnecessary because of a lack of statistically significant results.

***Length Frequency Histograms***

The length of a native mussel is relative to its age.  Looking at the age/length structure of a population allows us to determine if recruitment is occurring, whether there is low adult survival, and/or if one age class is dominating that site (Miller and Payne 1988).

*Bear River Drainage*

Only one site (BR01) in the Bear River drainage had more than 30 individual WPM. Western pearlshell mussels from site BR01 contained a wide total length range including smaller individuals (Figure 4).  All sites with CFM had very small size ranges, trending towards larger, older individuals (Table 4).

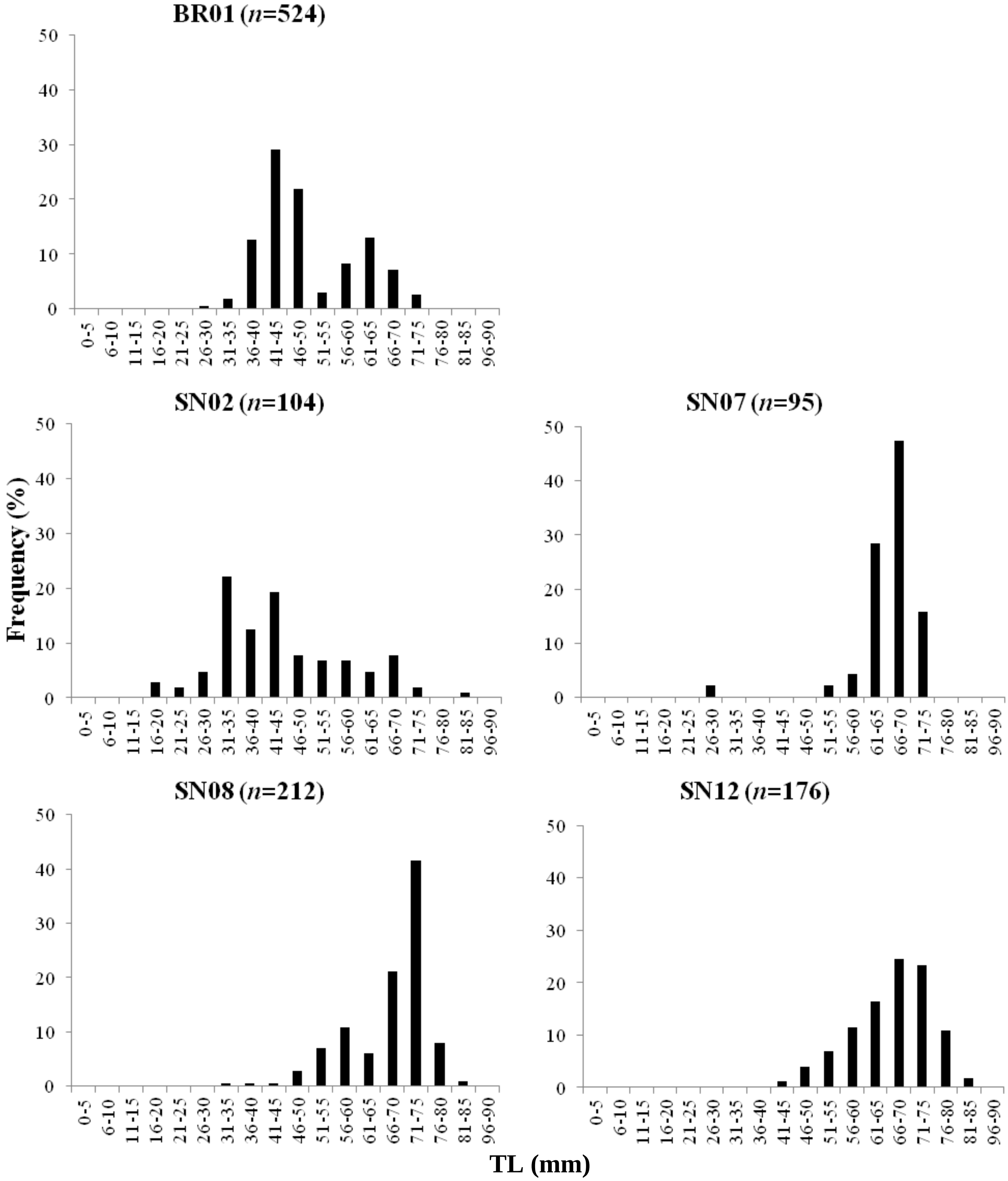


FIGURE 4. Shell length frequencies of WPM for sites with more than 30 individuals present in the Bear River (BR) and Snake River (SN). Values are percent of the total number (*n*) of individuals collected and measured for total length (TL). The maximum TL for WPM is 127 mm (5.0 in; Nedeau et al. 2009).

*Snake River Drainage*

All sites within the Snake River drainage that had over 30 individual WPM present (SN02, SN07, SN08, and SN12) had a wide variety of sizes and in most cases smaller individuals were present (Figure 4). The smallest detectable mussels using our methods appeared to be around 20 mm (0.8 in) TL.

## Discussion

During the 2011-2012 field seasons, much knowledge was gained about the native mussels in western Wyoming. The surveys in this project have documented expansions of the known ranges of CFM and WPM, provided age structure information, and produced systematic survey methods that can be used in the future. Western pearlshell were found in large numbers in both the Bear River and Snake River drainages. Healthy recruitment of juvenile WPM was also observed at multiple locations. Site BR05 is the furthest upstream in the Bear River drainage in Wyoming that CFM has been recorded live.

### *Habitat and Water Quality*

Many factors limit the presence and absence of native freshwater mussels. Populations that were once viable may be extirpated as a result of stochastic events (e.g., floods, droughts, chemical changes, etc.). These populations may never recolonize that site despite a return to previous habitat conditions. Wyoming is a headwater state that can experience fluvial changes both rapidly and drastically due to large snowmelts and high gradient streams. The loss and decline in host fish populations can also have major effects on the viability of native mussel populations (Haag and Warren 2008, Hastie et al. 2001, Nicklin and Balas 2007).

Mussels are long-lived sedentary filter feeders; they cannot simply relocate to more favorable conditions. They spend their entire lives filtering the water column and bioaccumulating whatever chemicals enter their gills. Absence of native mussels may be caused by several chemical conditions that include high ammonia, low pH, high calcium, and low dissolved oxygen levels (Nicklin and Balas 2007). In laboratory studies, many chemical factors can play a major role in the decline of mussel populations (e.g., ammonia, pH, copper, cadmium, chlorine, zinc, mercury, etc.); the effects are most drastic on glochidia and juvenile mussels (Augspurger et al. 2003, Cheney et al. 2008, Mummert et al. 2003, Wang et al. 2010). Large, old mussels have much higher tolerances of these chemical parameters than the glochidia and juvenile mussels (Cope et al. 2008). Exposure time is also an important factor in determining the lethal effects of environmental chemicals on mussels, along with the interactions of life history, hydrology, and geology of each stream (Cope et al. 2008). Utilizing a single water chemistry reading on one day will not give an accurate description of the chemical levels and their effect on these long lived organisms throughout the year. Few field studies have been performed assessing the effects of water quality on freshwater mussels (e.g., Ward et al. 2007), and most are laboratory based, translating poorly to the field. Concerning in situ studies, Nicklin and Balas (2007) found no correlation between mussel densities and chemical parameters from the EPA rapid water assessment protocols. Additionally, Geist and Auerswald (2007) found that water chemistry was insufficient for assessing streambed quality for *Margaritifera margaritifera*, a sister species to WPM. The erratic changes in chemical parameters as a result of spring runoffs, mid-summer droughts, rain events, fertilizer applications, etc. can all temporarily influence the chemical parameters at a specific locale. Thus, daily, weekly, monthly, and yearly chemical readings would be more effective for an accurate assessment compared to a one-time measurement.

Many sites with WPM present in the Snake River drainage and site BR01 in the Bear River drainage had individuals with highly eroded shells and empty shells that were dissolved completely except for their periostracum (outer covering on the shell, normally yellow to brown). The erosion of native mussels' shells is usually most prominent at their umbo, as this is the oldest portion of the shell. Once the periostracum is worn through and the calcareous portion of the shell is exposed, there is no defense against this portion of the shell being chemically eroded. Shell dissolution of *Corbicula fluminea* has been shown to be a leading cause of mortality (Kat 1982). This dissolution is caused by low pH levels (pH 5.6) and usually occurs in individuals older than three. Juveniles may not experience these effects as much because the physical erosion of their periostracum has not occurred as much and therefore, the chemical erosion is not as drastic. A more detailed chemical analysis in the Snake River and Bear River drainages would need to be performed to see if the water chemistry was causing the shell dissolution.

Hydrological conditions and stream geomorphology can affect presence of unionids on both a reach and drainage scale (Gangloff and Feminella 2007). Little work has been done to predict mussel presence-absence on a large-scale but many studies have focused on microhabitats. Native freshwater mussels have unique microhabitats that are both species-specific and population-specific (Nicklin and Balas 2007). Due to these microhabitats, detecting a relationship between habitat and native mussels proved to be difficult at the scale that we measured. In future native mussel surveys, survey techniques could include quadrat surveys with a substrate component to potentially determine microhabitat correlations.

After transformation from glochidia to juvenile mussel, it is essential for the transformed individual to be deposited on suitable substrate. Though both CFM and WPM have habitat preferences, the scale at which we took our habitat variables (equispaced, not where individual mussels were found), likely did not allow us to delineate a relationship between substrate type and the presence-absence of mussels, but still allowed for a general comparison among sites. An individual mussel's location in a mussel bed is not simply influenced by a particular substrate type, but rather a combination of stream velocity and the stream's ability to sort the substrate, water depth, the number of different types of substrate available, and recent alterations of fluvial dynamics (Huehner 1987). With limited time available for native mussel surveys, these parameters could not be recorded for more than a one-time event.

Native mussel communities may better be explained by host fish communities and reproductive ability than by the microhabitat variations at a site (Haag and Warren 1998). Haag and Warren (1998) also found that mussel assemblages were similar among sites towards the mouths of rivers, while the headwaters varied widely. Mussel communities with host fish-specific mussels are often dependent on host fish densities and the stability in the number of host fish available (Haag and Warren 1998). However, sites with unstable host fish assemblages, such as headwaters, tend to have mussels that are not dependent on host fish densities (Haag and Warren 1998). Barriers to host fish (i.e. dams, diversions, waterfalls, etc.) prevent upstream colonization or recolonization of native mussels within a drainage. The age structure of the host fish community also plays an important role. Populations with younger (0+) fish are the most important age group for mussel populations, while older fish may be less susceptible from a potential immunity developed from previous exposures (Hastie and Young 2001). Both CFM and WPM are not limited to a single host, but they can use many species within a family (Nedeau et al. 2009). If conditions were ideal (e.g., chemical parameters, host fish availability and age, fluvial dynamics, and substrate), declining and less-abundant sites might have a chance to receive higher recruitment.

***Bear River Drainage***
*CFM*

Historically, there were many more live CFM present at site BR04 than we found. Finding shells in life-position with tissue inside along the dry banks suggests the mussels migrated to the lower velocity bank areas to avoid the higher flows. The water then receded faster than the mussels could return to the thalweg, thus desiccating and killing them. Site BR05 also experienced high water during 2011. This site had exposed hardpan and many empty shells present. We found one live individual at the site, but the condition of the empty shells suggests that the population was recently much more robust. Site BR05 in Yellow Creek is an important site for CFM since it is the furthest upstream population in the Bear River drainage in Wyoming. Another site in Yellow Creek, BR10, did not have evidence of mussels. The landowner mentioned that the portion of stream we surveyed had gone dry in the past, and thus would not support native mussel populations (Haag and Warren 2008).

Site BR03 was sampled using a tactile search due to the turbidity. Tactile searches are even more biased towards larger individuals than visual searches since searchers have to feel the mussels and a large proportion of substrate area can be missed. We found our two largest CFM at this site and no juvenile mussels, which suggests that there was no detectable, active recruitment occurring at this site. Sites BR04 and BR05 did not show signs of recruitment and the variability in size classes was minimal.

*WPM*

Site BR01 had both smaller WPM individuals and a large diversity of sizes of, suggesting recent recruitment of WPM. Shells of WPM were found in conjunction with CFM at BR04, but no live individuals were found. Site BR04 was a very wide site and if only a few live WPM were present it is possible that they were overlooked. Our most upstream site for WPM in Wyoming was BR11. There were two live individual WPM found at BR11. Mill Creek, site BR11, had native cutthroat restoration work done on it prior to our native mussel surveys. The stream was treated with rotenone to remove non-native trout. In a laboratory setting, the sister species to WPM, *Margaritifera margaritifera*, had a rotenone tolerance that was six times greater than what is typically used for removing fish in the wild (Dolmen et al. 1995); WPM likely has the same resistance to rotenone, since it is closely related.

Historic records in the Bear River drainage (Appendix A) were limited for both WPM and CFM. Most observations only had one or two individuals present and most were empty shells. Our records date back to 1979 for CFM and 1895 for WPM, however, most observations were made since 2003. The highly migratory Bonneville cutthroat (BRC) are found in the Bear River drainage. Historically, the migration patterns of the BRC could have likely distributed WPM throughout large portions of the drainage, especially headwater streams. Today, there are lower numbers of BRC and numerous man-made barriers throughout the drainage, thus lowering the chances of colonizing/recolonizing headwaters. With more man-made barriers than historically, host fish encounters and widespread movement throughout the drainage have been severely hindered.

***Snake River Drainage***

The Snake River drainage had high numbers of WPM individuals (*n*=3,197) in a wide range of sizes. Larger WPM individuals usually dominated populations but this may be because juvenile mussels are much more cryptic than adults and will completely bury themselves in the substrate. Without excavating the substrate during a typical qualitative field survey, juveniles can be missed, even in healthy, unstressed populations (Hastie 2011). The length frequency histograms show trends toward larger, and thus older, individuals, however individuals as small as 18-20 mm (0.7-0.8 in) were found at SN02. Juveniles may have been present more often than our surveys portrayed and our systematic visual surveys merely overlooked them. Despite the low detectability of juveniles through qualitative visual surveys, sites SN07 and SN08 both revealed smaller individuals, but at very low abundances. Site SN07 had dense macrophytes, making the detection of juvenile mussels more difficult. Following our sampling methods, we only measured 176 of the 1,185 WPM at site SN12. These 176 WPM were within the first 100 m (328 ft) of the stream, leaving the remaining 150 m (492ft) of stream and 1,009 WPM unmeasured (only observed and tallied). It is possible that within the unmeasured length of stream there may have been juveniles present. In Montana, Stagliano (2010) used a semi-quantitative approach to sample juveniles. He used 0.25m$^2$ (2.7 ft$^2$) quadrats at sites with high abundances of WPM to determine if juveniles were present. Using 0.25m$^2$ (2.7 ft$^2$) quadrats allows for a more detailed survey since the sediment is excavated and that is where juveniles may be buried and overlooked during visual surveys. This approach would work well at most of the sites with WPM in Wyoming. High water levels during 2011 greatly reduced the length of our field season. With the limited time we had, we focused on more sites rather than more details at a few sites, thus not performing the semi-quantitative sampling and likely leading to juveniles being missed.

The Snake River drainage in Wyoming has two major dams on the main stem. One dam forms Jackson Lake and the other forms Palisades Reservoir. Both of these act as upstream barriers for WPM's host fish. Between and upstream of these major dams, there is relatively little development within the drainage compared to the rest of the Snake River and the Columbia River drainages. Many of the tributaries to the Snake River in Wyoming remain unregulated besides a few irrigation withdrawals. Much of the undeveloped land is managed by the USDA, USFS, USFWS National Elk Refuge, and NPS. The protection of this habitat benefits not only WPM, but their host-fish as well, which may be evidenced by the presence of juvenile mussels among these populations.

Sites SN01, SN03, and SN06 had compacted substrates that may have influenced the absence of WPM since mussels may not be able to properly burrow and withstand high flows. Sites SN04 and SN05, on the other hand, had very unstable streambeds, which are not conducive to mussels in high flows as the shells would be crushed by cobble and boulders moving along the stream bed. Anecdotal records of WPM in Lake Creek (SN06) have been reported to the Jackson Region Fisheries Biologists. Those reports combined with the seemingly suitable substrate, flow, and gradient made the site seem suitable for WPM, but no evidence of mussels was found during our surveys.

Historic records throughout the Snake River drainage (Appendix A) were helpful in determining survey site locations. As with the Bear River drainage, the records note very low numbers of individuals, but whether this indicates low abundances is uncertain since the historic surveys were likely not as thorough. Our survey efforts allowed us to greatly increase our knowledge of WPM. There were several streams that were not surveyed, but historic records of WPM exist. With the limited time available to survey the Snake River drainage, we still found high abundances of WPM.

***NSS Rankings***

*CFM*

The challenges present for native mussels are already high in Wyoming—being a headwater state for the Bear River. The impoundments and irrigation diversions throughout the Bear River drainage present even more challenges for native mussels to reproduce. These barriers prevent downstream populations of CFM from using the migration capabilities of their host fish (Watters 1996). Utah ranks the CFM as S1 and states that populations of CFM that are present are very small (NatureServe 2012, Sutter et al. 2005). Idaho has the CFM ranked as imperiled (S2) with a reduced distribution and declining populations range-wide, all of which make it vulnerable to statewide extirpation (IDFG 2005). Limited populations in downstream states and within Wyoming make the source populations limited. Woodruff Narrows Reservoir restricts two-way genetic exchange between upstream and downstream populations due to the large dam. In addition, the sites on the Cokeville Meadows National Wildlife Refuge (BR02 and BR03) have several large irrigation diversion dams that limit the ability of CFM to recolonize from downstream and upstream populations. If these isolated populations of CFM experience more severe drought years and increased anthropogenic disturbances, it may cause a rapid decline in their existing population numbers, making their recovery very difficult (Haag and Warren 2008). The short-lived nature of CFM reduces their chances of recolonization in the absence of immigration from downstream populations, (Haag and Warren 2008). Given the low numbers of CFM found in this survey and considering the impacts of water development (e.g., stream dewatering and the presence of barriers to fish movement); the CFM may be more imperiled in Wyoming than what was once thought. Three of 11 sites yielded a total of 13 CFM. Using WGFD's 2010 SWAP NSS Matrix and the description of limiting factors, I recommend assigning CFM a rank of NSS2.

*WPM*

Populations of WPM appear to be doing well, except for the populations of WPM upstream of Woodruff Narrows Reservoir (BR11) and in Flat Creek (SN10), each of which had marginal habitat. Most populations show signs of recruitment and high numbers of individuals. With a large proportion of protected land (i.e., national parks and national forests) surrounding the populations of WPM in western Wyoming, the threats to their populations are minimal. Additionally, the historic and present stocking of native host fish throughout WPM's range likely benefited the species. The populations appear stable, and in future years, continued sampling may determine if the populations are expanding. Using WGFD's 2010 SWAP NSS Matrix and in combination with the favorable conditions and factors noted here, I recommend assigning a rank of NSS5 for WPM.

## Recommendations

- Regional Fisheries crews are encouraged to continue to report incidental findings, especially live individuals. If possible, UTM's and photos of live mussels should be sent to the Aquatic Assessment Crew (AAC). Collection of empty shells is also encouraged; empty shells and site information can also be sent to the AAC.

***Bear River Drainage***

- More records of both CFM and WPM from the Bear River drainage would be extremely valuable. If time allows and resources are available, thorough systematic surveys where live mussels are present should be performed. Surveying for CFM (average lifespan of 10-15 years) is recommended more frequently than for WPM (average lifespan of 60-70 years). It is recommended to sample sites with CFM present (BR03, BR04, and BR05) every five years and sites with WPM (BR01 and BR11) every 10 years to observe if their populations are increasing, decreasing, or stable. High flows throughout 2011 hindered sampling abilities in the main stem Bear River, therefore any new sites in the main stem Bear River would be critical in determining a more refined NSS ranking.

***Snake River Drainage***

- More records of WPM from the Snake River drainage would be extremely valuable. If time allows and resources are available, thorough systematic surveys where live mussels are present should be performed. Since WPM is a long-lived species, surveys would only need to be performed once a decade per site (SN02, SN07, SN08, SN09, SN10, and SN11) to observe if there are population increases and decreases. At sites with large abundances of WPM, 0.25$m^2$ or $m^2$ quadrat sampling should be used to determine if recruitment is occurring, following the methods described in Stagliano (2010). Large data gaps still occur in the Salt River, Hoback River, Gros Ventre River, and Greys River drainages.

***NSS Rankings***

- It is recommended that the CFM be ranked as an NSS2 in the 2015 SWAP revision.
- It is recommended that the WPM be ranked as an NSS5 in the 2015 SWAP revision.

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APPENDIX A. Historic records of CFM and WPM in Wyoming from various studies (Beetle 1989, Henderson 1924, Hoke 1979) and from incidental observations from WGFD personnel and others. All UTMs are in zone 12 (NAD27). Dead shells are recorded as fractions of the whole. A single valve (left or right) was recorded as 0.5. Fragments of shells are also indicated (*).

| Drainage/ | | | UTM | | | | | |
|---|---|---|---|---|---|---|---|---|
| Water Body | HUC | Date | Easting | Northing | Collector | Species | Live | Dead |
| **Missouri River (Yellowstone NP)** | | | | | | | | |
| Madison R | 1002000702 | 9/23/1979 | 504171 | 4943689 | Other | WPM | 1 | |
| Little Firehole R | 1002000701 | 8/24/1988 | 511714 | 4925304 | Other | WPM | 1 | |
| **Bear River** | | | | | | | | |
| Bear R | 1601010103 | 09/15/1979 | 498700 | 4592000 | Other | CFM | | 2 |
| Bear R | 1601010103 | 09/15/1980 | 498700 | 4592000 | Other | CFM | | 10 |
| Bear R | 1601010103 | 1988 | 498331 | 4596272 | Beetle | CFM | | 1 |
| Woodruff Narrows Res | 1601010103 | 09/28/2003 | 497914 | 4594496 | Other | CFM | | 1 |
| Bear R | 1601010201 | 10/14/2005 | 501472 | 4660838 | WGFD | CFM | | 0.5 |
| Woodruff Narrows Res | 1601010103 | 08/11/2006 | 497747 | 4594592 | WGFD | CFM | | 1.5 |
| Bear R | 1601010201 | 10/22/2008 | 503981 | 4653955 | WGFD | CFM | 1 | 2.5* |
| Bear R | 1601010201 | 10/22/2008 | 501788 | 4659972 | WGFD | CFM | 2 | 4 |
| Bear R | 1601010108 | 05/05/2010 | 499225 | 4634527 | WGFD | CFM | | 0.5 |
| Bear R | 1601010201 | 05/06/2010 | 502111 | 4664851 | WGFD | CFM | | 1* |
| Bear R | 1601010201 | 08/19/2010 | 503980 | 4647977 | WGFD | CFM | 9 | 9 |
| Bear R | 1601010102 | 07/30/1895 | 504188 | 4568519 | Henderson | WPM | 1 | |
| Bear R | 1601010201 | 10/22/2003 | 501713 | 4660453 | WGFD | WPM | 1 | |
| Bear R | 1601010201 | 08/08/2005 | 501789 | 4659972 | WGFD | WPM | | 1 |
| Bear R | 1601010201 | 10/14/2005 | 501472 | 4660838 | WGFD | WPM | | 2 |
| Smith's Fork | 1601010201 | 10/22/2008 | 502489 | 4659954 | WGFD | WPM | | 2 |
| Bear R | 1601010201 | 10/22/2008 | 503981 | 4653955 | WGFD | WPM | | * |
| Bear R | 1601010201 | 10/22/2008 | 501788 | 4659972 | WGFD | WPM | 2 | 6.5* |
| Bear R | 1601010102 | 08/18/2010 | 507608 | 4551062 | WGFD | WPM | | 1 |
| Bear R | 1601010102 | 08/19/2010 | 506602 | 4541323 | WGFD | WPM | 1 | |
| Bear R | 1601010201 | 08/19/2010 | 503980 | 4647977 | WGFD | WPM | | 0.5* |

APPENDIX A. Continued

| Drainage/ Water Body | HUC | Date | UTM Easting | UTM Northing | Collector | Species | Live | Dead |
|---|---|---|---|---|---|---|---|---|
| **Snake River** | | | | | | | | |
| Flat Cr | 1704010302 | 1934 | 520491 | 4804163 | Henderson | WPM | | 1 |
| Polecat Cr | 1704010103 | 08/02/1954 | 525770 | 4883591 | Beetle | WPM | 1 | |
| Polecat Cr | 1704010103 | 10/27/1973 | 525609 | 4883924 | Beetle | WPM | 1 | |
| Polecat Cr | 1704010103 | 1978 | 525369 | 4883923 | Hoke | WPM | 1 | |
| Crawfish Cr | 1704010102 | 08/15/1984 | 526031 | 4888524 | Other | WPM | 1 | |
| Snake R | 1704010105 | 1988 | 526578 | 4841722 | Beetle | WPM | | 1 |
| Flat Cr | 1704010302 | 1988 | 522626 | 4819496 | Beetle | WPM | | 1 |
| NF Slide Cr | 1704010303 | 1988 | 556907 | 4778820 | Beetle | WPM | | 1 |
| Crow Cr | 1704010501 | 1988 | 496723 | 4726177 | Beetle | WPM | | 1 |
| Child Cr | 1704010503 | 1988 | 496685 | 4774175 | Beetle | WPM | | 1 |
| Polecat Cr | 1704010103 | 06/26/2000 | 525322 | 4883667 | Other | WPM | | 1 |
| NF Fisherman Cr | 1704010303 | 07/26/2004 | 557200 | 4778900 | WGFD | WPM | | 1 |
| Flat Cr | 1704010302 | 09/08/2004 | 516500 | 4811600 | WGFD | WPM | | 1 |
| Salt R | 1704010503 | 07/21/2005 | 497510 | 4768228 | Other | WPM | | 1.5 |
| Polecat Cr | 1704010103 | 09/01/2005 | 524368 | 4883928 | WGFD | WPM | 3 | 3 |
| Bearpaw Cr | 1704010103 | 08/15/2006 | 522073 | 4853676 | WGFD | WPM | | 2 |
| NF Fisherman Cr | 1704010303 | 08/14/2009 | 558374 | 4780895 | WGFD | WPM | 1 | 4 |
| Flat Cr | 1704010302 | 10/08/2009 | 521805 | 4819891 | WGFD | WPM | | 1 |
| Polecat Cr | 1704010103 | 11/05/2009 | 525032 | 4883994 | WGFD | WPM | | 3 |
| Snake R | 1704010103 | 11/05/2009 | 527156 | 4886242 | WGFD | WPM | | 1 |
| Polecat Cr | 1704010103 | 11/19/2009 | 525022 | 4883994 | WGFD | WPM | 2 | |

APPENDIX B. Data used in binary logistic regressions for all sites. Presence/Absence (P/A) is defined as live mussels present (P); sites with no live mussels or only relic evidence of mussels were treated as absent (A). Width (m) and depth (cm) are the mean bankfull width and depth at each site. Dominant substrate is the dominant substrate type within the wetted width [silt (0), sand (1), fine gravel (2), course gravel (3), cobble (4), or boulder (5)]. Stream order is Stahler's stream order. Drainage area is the calculated drainage area ($km^2$) upstream of the survey site.

| Site | P/A | Width | Depth | Dominant Substrate | Stream Order | Drainage Area |
|---|---|---|---|---|---|---|
| BR01 | P | 16.71 | 63.33 | 4 | 4 | 700.756 |
| BR02 | A | 42.66 | 175.93 | 1 | 5 | 5387.681 |
| BR03 | P | 38.52 | 161.55 | 1 | 5 | 5203.028 |
| BR04 | P | 28.44 | 42.96 | 4 | 5 | 2050.479 |
| BR05 | P | 4.24 | 63.80 | 0 | 3 | 534.524 |
| BR06 | A | 31.00 | 103.16 | 4 | 5 | 1146.248 |
| BR07 | A | 8.35 | 51.56 | 4 | 4 | 905.725 |
| BR08 | A | 5.96 | 38.91 | 4 | 3 | 92.364 |
| BR09 | A | 2.42 | 37.75 | 0 | 3 | 54.196 |
| BR10 | A | 3.70 | 26.58 | 1 | 3 | 112.762 |
| BR11 | P | 10.33 | 51.20 | 4 | 3 | 152.489 |
| SN01 | A | 10.03 | 23.53 | 4 | 1 | 120.552 |
| SN02 | P | 4.17 | 19.87 | 3 | 2 | 112.080 |
| SN03 | A | 8.35 | 59.36 | 2 | 2 | 304.948 |
| SN04 | A | 59.05 | 173.71 | 4 | 3 | 252.794 |
| SN05 | A | 67.04 | 178.91 | 3 | 4 | 689.588 |
| SN06 | A | 2.30 | 14.98 | 3 | 1 | 20.934 |
| SN07 | P | 29.15 | 41.64 | 0 | 2 | 62.879 |
| SN08 | P | 50.36 | 172.24 | 4 | 5 | 1241.788* |
| SN09 | P | 20.13 | 114.50 | 4 | 5 | 1241.788* |
| SN10 | P | 11.89 | 55.58 | 4 | 3 | 384.094 |
| SN11 | A | 10.96 | 50.04 | 3 | 2 | 100.594 |
| SN12 | P | 3.68 | 11.13 | 2 | 1 | 80.757 |

*SN08 and SN09 had the same upstream and downstream locations, but were surveyed and measured as two individual sites since one was a side channel (SN09) and one was in the mainstem (SN08) of the stream. Since they had the same downstream location, the drainage area upstream and stream order were the same.

APPENDIX C. Data used in binary logistic regressions for sites with only CFM. Presence/Absence (P/A) is defined as live CFM present (P); sites with no live CFM or only relic evidence of CFM were treated as absent (A). Width (m) and depth (cm) are the mean bankfull width and depth at each site. Dominant substrate is the dominant substrate type within the wetted width [silt (0), sand (1), fine gravel (2), course gravel (3), cobble (4), or boulder (5)]. Stream order is Stahler's stream order. Drainage area is the calculated drainage area ($km^2$) upstream of the survey site.

| Site | P/A | Width | Depth | Dominant Substrate | Stream Order | Drainage Area |
|---|---|---|---|---|---|---|
| BR02 | A | 42.66 | 175.93 | 1 | 5 | 5387.681 |
| BR03 | P | 38.52 | 161.55 | 1 | 5 | 5203.028 |
| BR04 | P | 28.44 | 42.96 | 4 | 5 | 2050.479 |
| BR05 | P | 4.24 | 63.80 | 0 | 3 | 534.524 |
| BR06 | A | 31.00 | 103.16 | 4 | 5 | 1146.248 |
| BR07 | A | 8.35 | 51.56 | 4 | 4 | 905.725 |
| BR08 | A | 5.96 | 38.91 | 4 | 3 | 92.364 |
| BR09 | A | 2.42 | 37.75 | 0 | 3 | 54.196 |
| BR10 | A | 3.70 | 26.58 | 1 | 3 | 112.762 |

APPENDIX D. Pearson correlation analysis results (*p*-values) for all sites and CFM only sites.

All Sites

| | Width | Depth | Dominant Substrate | Stream Order | Drainage Area |
|---|---|---|---|---|---|
| Width | | 0.000 | 0.547* | 0.006 | 0.033 |
| Depth | | | 0.787* | 0.000 | 0.002 |
| Dominant Substrate | | | | 0.469* | 0.353* |
| Stream Order | | | | | 0.001 |
| Drainage Area | | | | | |

*Uncorrelated variables ($p$>0.05)

CFM Sites

| | Width | Depth | Dominant Substrate | Stream Order | Drainage Area |
|---|---|---|---|---|---|
| Width | | 0.001 | 0.863* | 0.000 | 0.001 |
| Depth | | | 0.447* | 0.015 | 0.000 |
| Dominant Substrate | | | | 0.551* | 0.667* |
| Stream Order | | | | | 0.016 |
| Drainage Area | | | | | |

*Uncorrelated variables ($p$>0.05)

APPENDIX E. Results from binary logistic regressions for all sites and CFM only sites. The models included dominant substrate (DS), mean bankfull width (W), mean bankfull depth (D), and Stahler's stream order (O), and drainage area (A; $km^2$).

All Sites

| Model | SE | *p*-value |
|---|---|---|
| DS+W | 0.983 | 0.779 |
| DS+D | 1.017 | 0.955 |
| DS+O | 1.272 | 0.528 |
| DS+A | 1.006 | 0.782 |

CFM Sites

| Model | SE | *p*-value |
|---|---|---|
| DS+W | 1.315 | 0.580 |
| DS+D | 1.628 | 0.680 |
| DS+O | 2.756 | 0.700 |
| DS+A | 1.395 | 0.529 |