HNF-56238
Revision 0

Hanford Site Freshwater Mussel Monitoring Report for Calendar Year 2013

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728

P.O. Box 650
Richland, Washington 99352

Approved for Public Release
Further Dissemination Unlimited

Printed in the United States of America

The cover photo is courtesy of Cole Lindsey.

HNF-56238
Revision 0

Hanford Site Freshwater Mussel Monitoring Report for Calendar Year 2013

C. Lindsey, J. Nugent, B. Tiller, and M. Filan
Mission Support Alliance

Date Published
December 2013

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728

P.O. Box 650
Richland, Washington 99352

APPROVED
By Julia Raymer at 3:50 pm, Dec 10, 2013

Release Approval Date

Approved for Public Release
Further Dissemination Unlimited

Contents

Figures

Tables

1.0 Introduction

The U.S. Department of Energy, Richland Operations Office (DOE-RL) conducts ecological monitoring on the Hanford Site to collect and maintain data needed to ensure compliance with an array of environmental laws, regulations, and policies governing DOE activities. Ecological monitoring data provides baseline information about the plants, animals, and habitat under DOE stewardship at Hanford that is required for decision-making under the *National Environmental Policy Act* (NEPA) and *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). In addition, ecological monitoring helps ensure that DOE, its contractors, and other entities conducting activities on the Hanford Site are in compliance with the Hanford Site Comprehensive Land Use Plan (DOE/EIS-0222-F). DOE places priority on monitoring those plant and animal species or habitats with specific regulatory protections or requirements, that are rare and/or declining (federal or state listed endangered, threatened, or sensitive species), or are of significant interest to federal, state, or tribal governments or the public.

Freshwater mussels are one of the most imperiled groups of organisms on the planet, including those species potentially occurring in the stretch of the Columbia River along the Hanford Site known as the Hanford Reach (Nedeau et al. 2009). Three genera of freshwater mussels occur or potentially occur on the Hanford Reach of the Columbia River: *Anodonta, Margaritifera,* and *Gonidea*. These genera contain several vulnerable species. The California floater (*Anodonta californiensis*) is a candidate for listing as Threatened or Endangered by the Washington Department of Fish and Wildlife (WDFW), and is a Federal Species of Concern. Three other species are documented to occur in Washington State, the Oregon floater (*A. oregonensis*), western floater (*A. kennerlyi*), and winged floater (*A. nuttalliana*); all three are listed as Monitor species by the WDFW. *Anodonta* are documented to be in decline across their range (NatureServe 2012). The western pearlshell (*Margaritifera falcata*) is also a Washington State Monitor species, and although it was once prevalent along the Hanford Reach, it may be extirpated from the Hanford Reach according to a survey completed in the area during 2004 (PNNL-19933). The western ridged mussel (*Gonidea angulate*) is a Monitor species for the WDFW. The species may exist in the Hanford Reach of the Columbia River but remains undocumented (PNNL-19933).

Freshwater mussels have long lifespans, are relatively immobile, and are relatively sensitive to changing environmental conditions, making them ideal sentinel/indicator species for environmental impacts such as contamination. The Public Safety and Resource Protection program at Mission Support Alliance (MSA) selected freshwater mussels for monitoring because of their listing status, sensitivity to changing environmental conditions, and their utility as sentinel/indicator species.

This survey focused on mussels in the genus *Anodonta*. *Anodonta*, like other freshwater mussels, produce larval glochidia that require a host fish for survival. The glochidia attach to the host's gills and are parasitic for a period of time prior to dropping off and spending the remainder of their lifespan on the substrate filter feeding. *Anodonta*, unlike other mussel species such as the Western Pearlshell (*Margaritifera falcata*) that can live over one hundred years, have relatively short lifespans of 10-15 years (Nedeau et al. 2009). *Anodonta* are commonly found in silt areas, but may inhabit other substrate types.

Mussels in the genus *Anodonta*, Latin for "without teeth", lack pseudocardinal hinge teeth characteristic of other mussel species (Nedeau et al. 2009). These teeth are critical for delineation of other mussel species, thus making the different species of *Anodonta* difficult to discern, contributing to the changing taxonomy of the genus. Species determination for *Anodonta* is based almost completely on shell shape and size, which can be highly variable, creating a continuum between species. Two clades are expected to be present in the Columbia River, as described by Nedeau et al. (2009). These consist of Clade 1, containing the California floater (*A. californiensis*) and winged floater (*A. nuttalliana*) and Clade 2, containing the Oregon floater (*A. oregonensis*) and the western Floater (*A. kennerlyi*).

Survey efforts conducted in 2004 (PNNL-19933) included the documentation of age, density, composition, and habitat characteristics of *Anodonta* found throughout the Hanford Reach of the Columbia River. The data obtained during the current survey effort (2013) were collected using a comparable approach along the same stretch of the Columbia River. A comparison of these two datasets was planned in order to document potential trends in the mussel age classes, densities, and composition occurring near the Hanford Site.

2.0 Methods

Self contained underwater breathing apparatus (SCUBA) was used to perform the 2013 surveys. With the use of SCUBA, transects could extend into deeper water [down to 9 meters (30 feet)] than previous survey efforts on the Hanford Reach in 2004 (PNNL-19933). Divers conducted surveys in close proximity to the riverbed, less than 1 meter (3 feet) from the river bottom, to minimize the chance of missing mussels, particularly those individuals deeply embedded in the river substrate. All surveys were conducted below the ordinary low-water mark to minimize the influence of dewatering events. Areas below the low-water mark can be identified by the persistent colonies of periphyton growing on rock surfaces. This continually inundated section of the river generally corresponds to a river flow of approximately 1,353 cubic meters (47,781 cubic feet) per second (Turner 2004).

Survey areas were selected based on the presence of fine-grained sediment, which is a preferred habitat of *Anodonta*. Freshwater mussels are good indicators of environmental quality due to their relative immobility and long lifespans (Nedeau et al. 2009). For this reason, mussels may be valuable sentinel/indicator species for Hanford Site contaminants. In order to address whether contaminants are influencing the distribution and abundance of mussels, survey areas were selected adjacent to and away from known contaminated groundwater plumes (DOE/RL-2013-18, WCH-380). Survey areas adjacent to groundwater contamination plumes included the 100-B/C, 100-K West, 100-K East, 100-N, 100-D, and 100-H survey areas. Sites away from groundwater contamination plumes included Walleye Bay, White Bluffs Slough, Hanford Townsite Slough, and Hanford Townsite Beach (Figure 1). The full extent of fine-grained sediment in these 10 areas was mapped from a boat using a Trimble Global Positioning System (GPS) and underwater video camera.

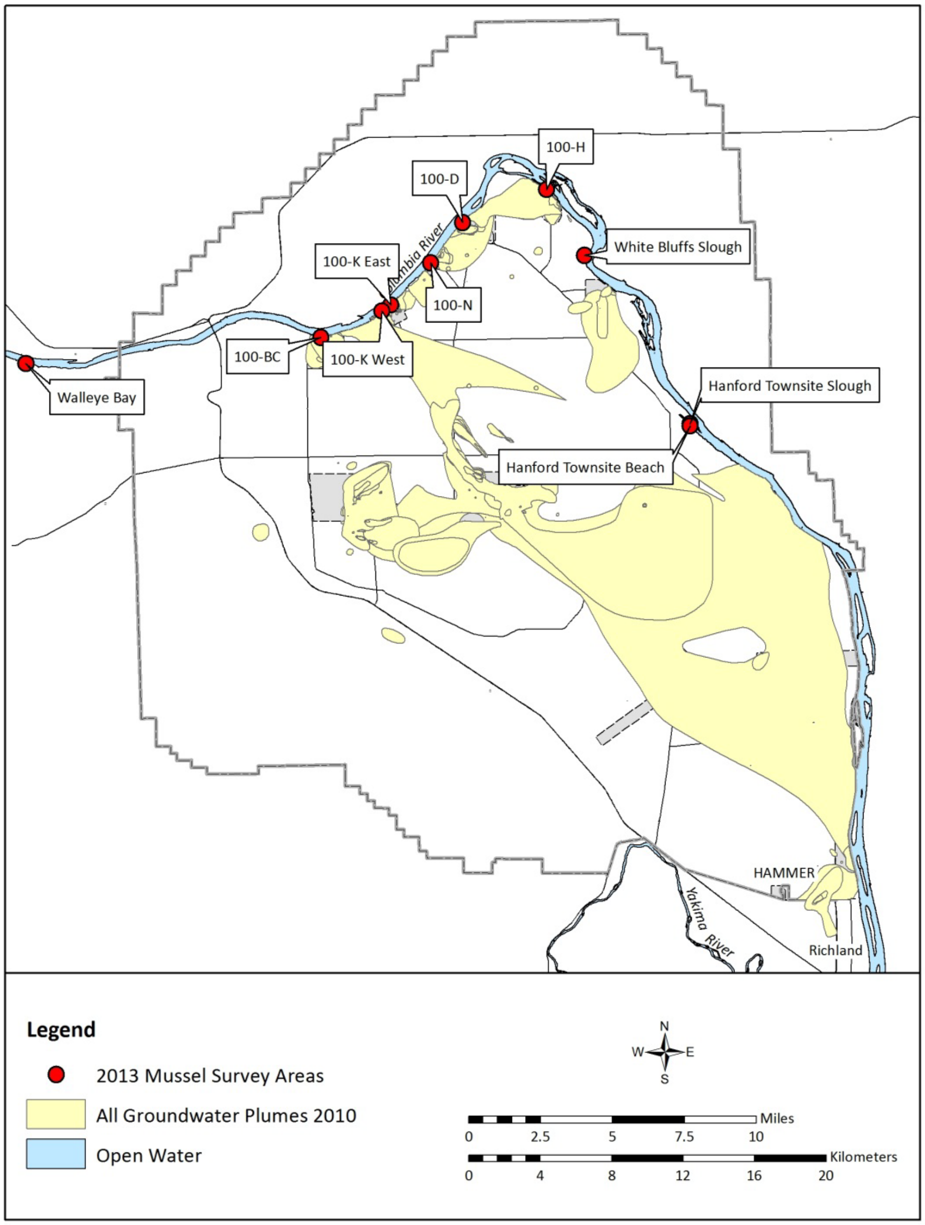

Figure 1. 2013 Mussel Survey Areas and All Groundwater Plumes from 2010

Once sediment areas were defined, each survey area was divided into grids with 6 x 6 meter cells. The cells were numbered and a random number generator was used to select a subset of cells to survey. The number of cells selected for survey in the larger survey area (e.g., White Bluffs Slough) were chosen to cover a minimum of one percent of each survey area, in smaller areas such as the reactor intake structures, a minimum of three cells were selected. A number of alternate sites were also randomly selected within each survey area, to use in the event that some primary sites did not meet survey criteria. Suitable sites were characterized by a fine-grained dominant substrate type and less than 75 percent vegetation cover. The 100-K East survey area is shown in Figure 2 as an example of the survey site selection process.

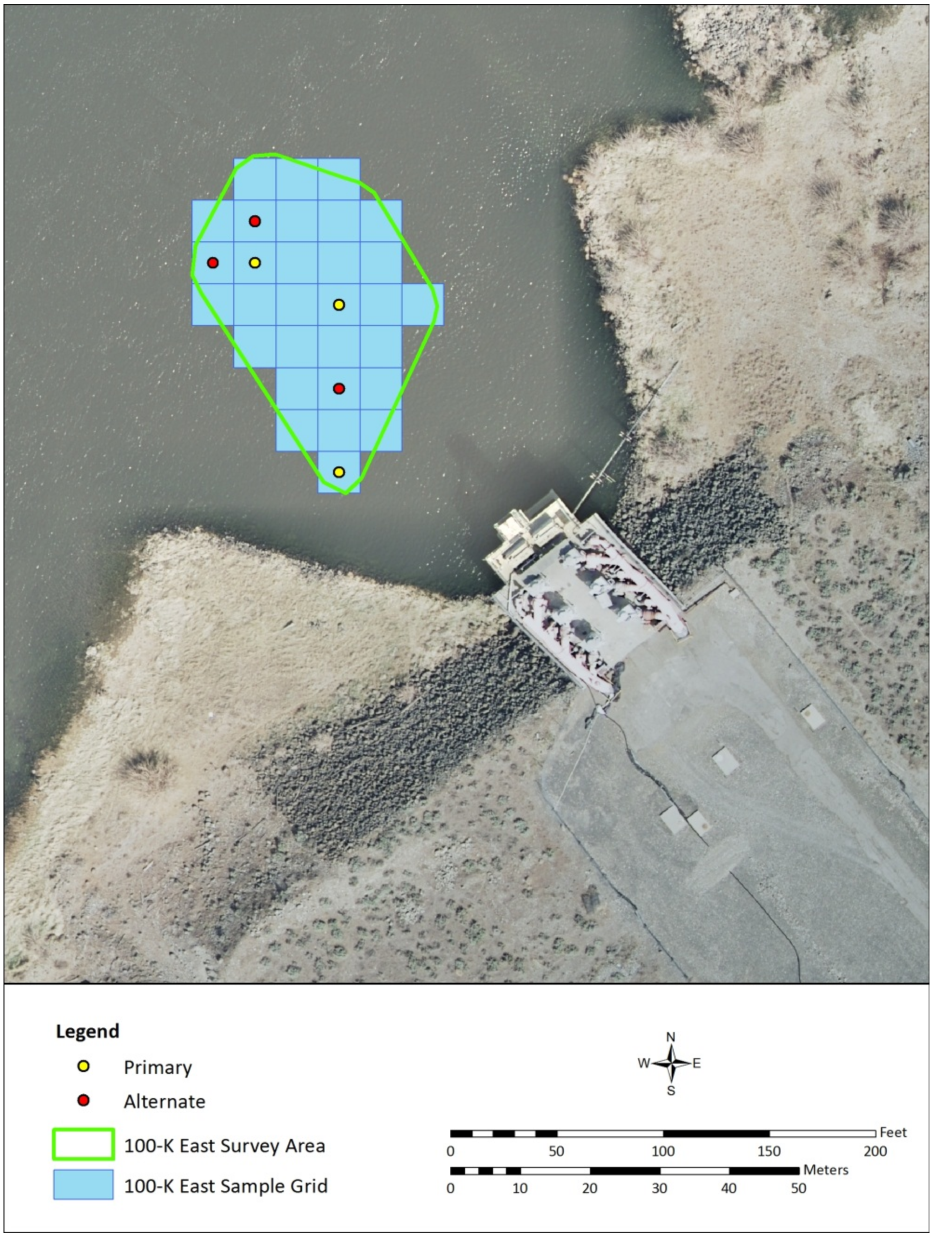

Figure 2. 100-K East Survey Area with Primary and Alternate Transect Locations

A four meter (13 foot) radius, circular sample plot was centered on each of the chosen cells. Two surveyors each surveyed a circular, two meter (seven foot) wide swath of the river bottom. This resulted in 100 percent coverage of the sample plot (Figure 3). A Trimble GPS unit with sub-meter accuracy was used from a boat to place a small anchor at the center of each transect. A 4 meter (13 foot) long rope tied to the anchor was used to delineate the sample plot radius. A float was tied to the end of the rope to aid in marker retrieval. Upon reaching the river bottom, divers used an underwater writing slate to record the transect characteristics including the dominant and subdominant substrate types, embeddedness level, and abundance of aquatic vegetation (Table 1). Surveyors placed a pinflag at the start/end of each sample plot to prevent recounting mussels. Upon locating a mussel, surveyors remained underwater and used a caliper to measure the length, width, and height of the mussel, recording the data to the nearest millimeter (mm) (Figure 4). The mussel was then placed back into the substrate in the location and orientation it was found. Upon completion of each survey, the equipment was removed to be used at the next location.

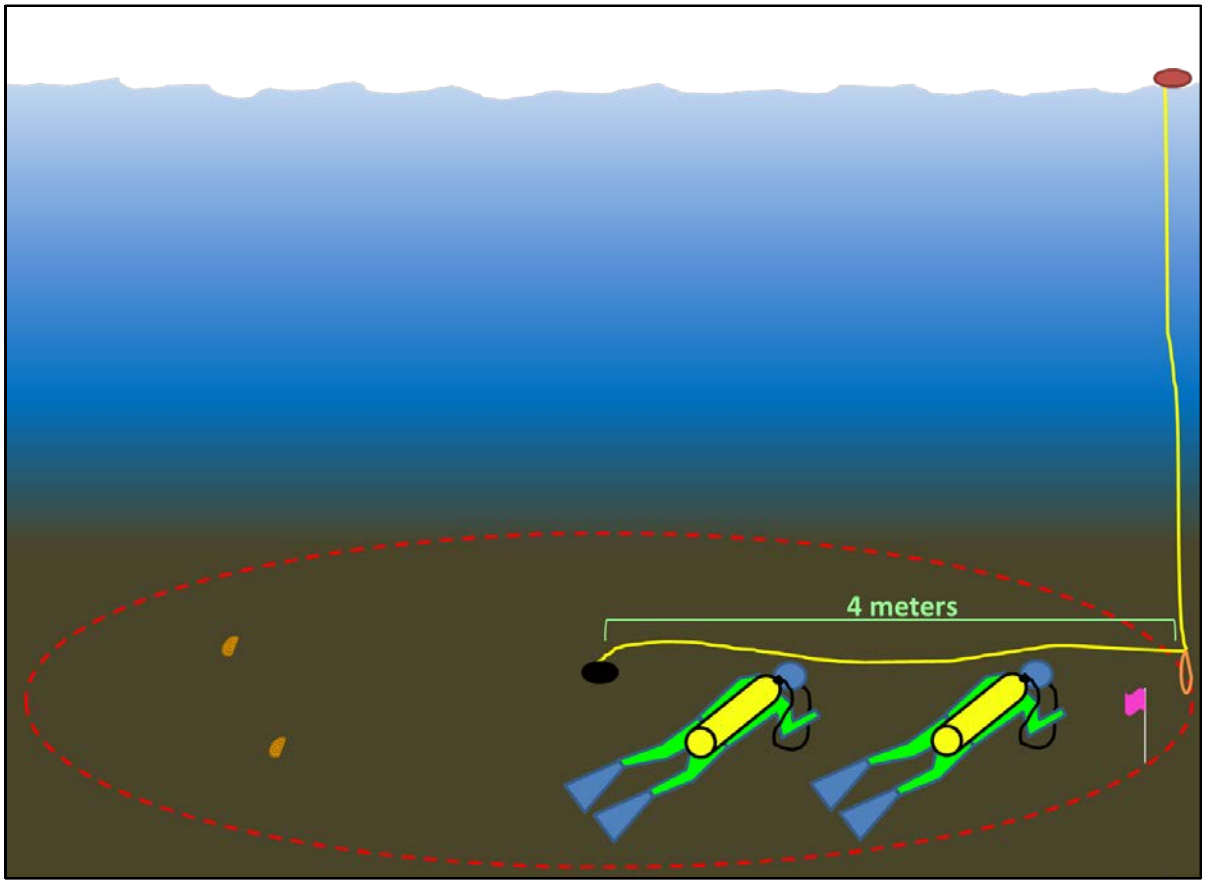

Figure 3. Circular Mussel Survey Design Performed Using SCUBA

Table 1. Substrate Classification Criteria Used During 2013

Dominant Substrate	Subdominant Substrate	Embeddedness	Aquatic Vegetation
1) Fines, sand, silt, and mud	1) Fines, sand, silt, and mud	1) 0-25 % fines	1) No vegetation present
2) Gravel-medium cobble	2) Gravel-medium cobble	2) 26-50% fines	2) Sparse vegetation, substrate completely evident
3) Large cobble	3) Large cobble	3) 51-75% fines	3) Vegetation common, substrate partially obscured
4) Boulder/bedrock	4) Boulder/bedrock	4) 76-100% fines	4) Dense vegetation, substrate nearly or completely obscured

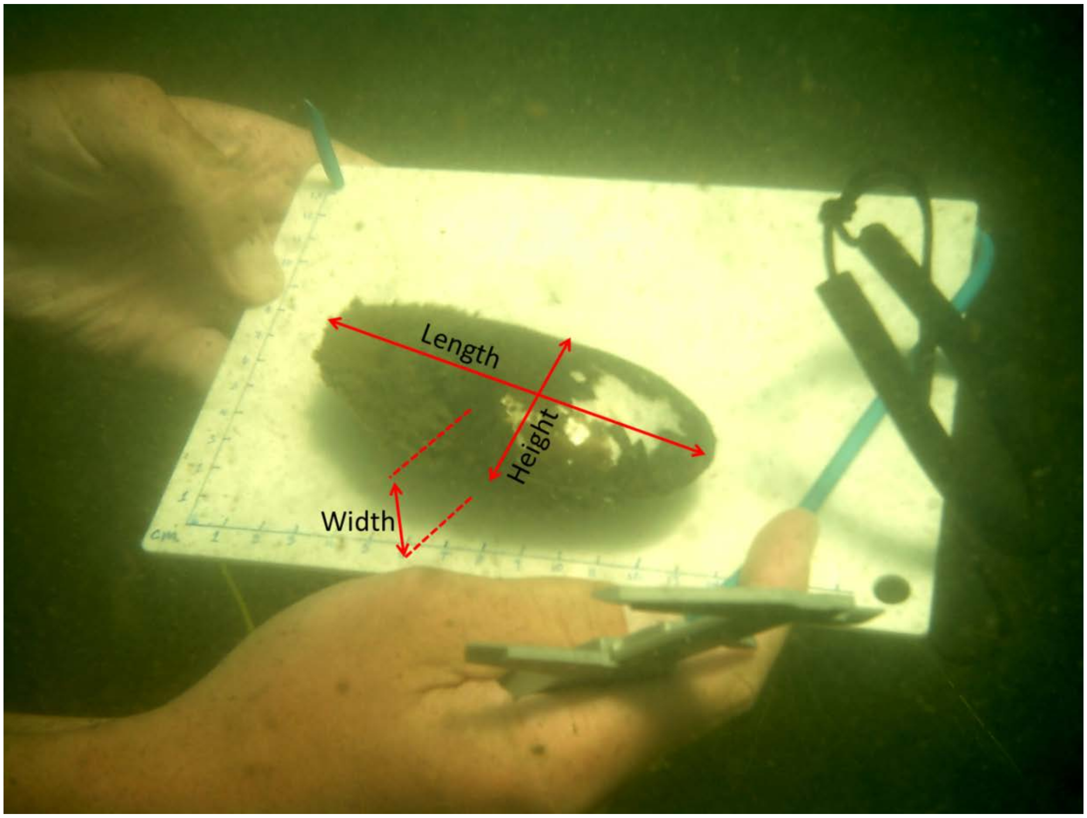

Figure 4. Mussel Morphometrics Recorded During 2013

3.0 Results

Mussel surveys began on August 27 and concluded on September 5, 2013. A total of 50 sample plots were examined across the ten selected survey areas, covering a total of 2,563 square meters (27,588 square feet). Survey depths ranged from one to nine meters (three to 30 feet). Several of the primary points selected for surveys did not meet survey criteria either due to dense aquatic vegetation that obscured the river substrate, or lack of fine-grained sediment. When a primary survey point was deemed unsuitable, it was replaced with an alternate randomly selected point. There were four instances when surveyors rejected all primary and randomly generated alternate points without completing the required number of survey plots for a survey area. In those cases a suitable location was selected as near as possible to the first unsuitable randomly generated survey point and a new GPS point was recorded.

Surveyors examined 50 circular survey plots and located a total of 75 mussels, all from the genus *Anodonta*. These mussels ranged in length from 60 mm up to 129 mm (2.4 to 5.1 inches). The total number of mussels within a single survey plot ranged from 0 to 12 individuals. The calculated number of mussels per 100 square meters (1,076 square feet) within a survey area ranged from 0 to 9 individuals, with an average density across all surveys of 2.9 mussels per 100 square meters. A summary of the survey results, along with population estimates for each of the surveyed areas are provided in Table 2.

Table 2. Survey Results Including Estimated Populations in Surveyed Areas

Survey Area	Total Area Surveyed (m^2)	Mussels/100m^2*	Estimated Habitat Area (m^2)	Surveyed Area Population Estimate*
100-BC	151	3.3 ± 1.1	6429	213 ± 74
100-D	151	0	4583	0
100-H	151	0	908	0
100-K East	151	2.7 ± 1.1	1038	28 ± 12
100-K West	151	3.3 ± 4.1	2216	73 ± 92
100-N	151	0	622	0
Hanford Townsite Beach	151	4.0 ± 2.0	4542	181 ± 90
Hanford Townsite Slough	302	1.3 ± 2.4	21141	280 ± 509
Walleye Bay	201	8.9 ± 10.3	12484	1117 ± 1290
White Bluffs Slough	955	3.5 ± 3.5	67844	2343 ± 2372
*Density and Population Estimates ± 1 Standard Deviation				

Nedeau et al. (2009) described the method for determining whether an individual belongs to Clade 1 (California Floater/Winged Floater) or Clade 2 (Oregon Floater/Western Floater), with Clade 1 having a shell length to height ratio "usually less than 1.5" and Clade 2 having a length to height ratio "close to or exceeding 2.0". The data collected during 2013 indicated a continuum of shell length to height ratios between 1.3 and 2.3. Therefore, using the methods described by Nedeau et al. (2009), a large proportion of the mussels collected during 2013 fell outside of either clade description. Only two individuals had a shell length to height ratio of less than or equal to 1.5, and 40 had a ratio equal or greater than 2. This left 33 mussels with a shell length to height ratio between 1.5 and 2 (Figure 5). Examples of a Clade 1 and Clade 2 mussels collected during 2013 are shown in Figure 6.

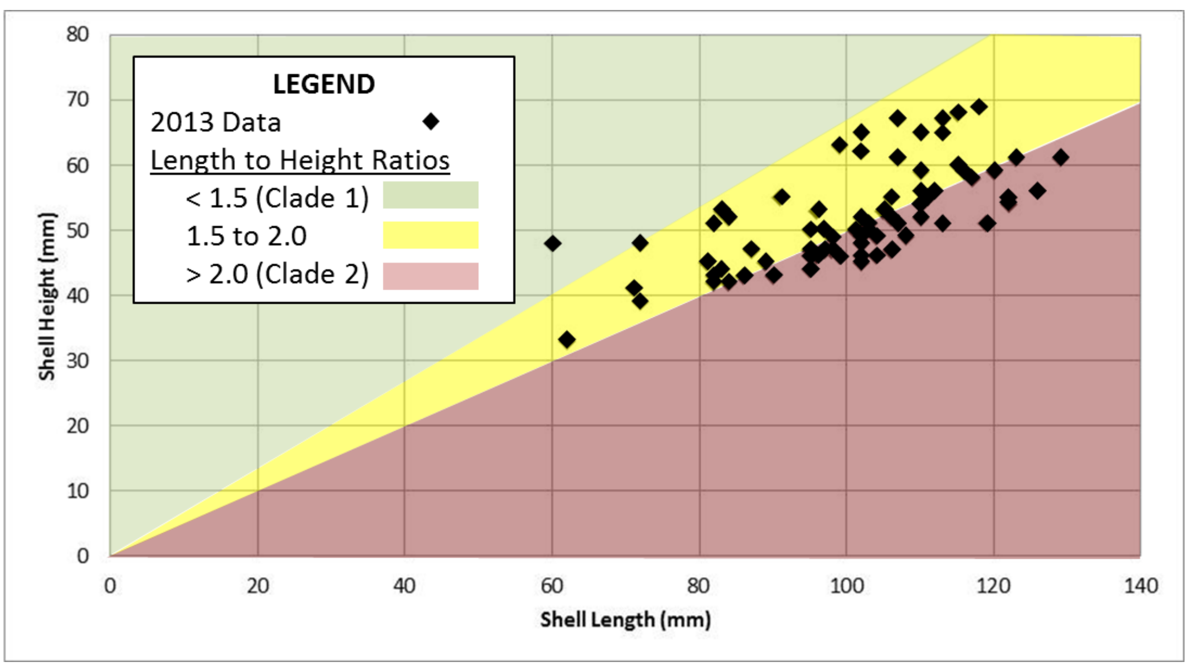

Figure 5. Shell Length and Height Data from 2013 with Corresponding Length to Height Ratios

Figure 6. Examples of Clade 1 (Above) and Clade 2 (Below) Mussels Collected During 2013

4.0 Discussion

Due to the similarities between the survey performed in 2004 (PNNL-19933), and the 2013 survey, several factors of the two datasets were compared to determine if trends could be discerned in the populations of *Anodonta* along the Hanford Reach. These datasets were collected nine years apart, representing the majority of the lifespan (10-15 years) of an individual *Anodonta*, allowing for a review of certain trends in the mussel population over nearly one full life cycle. The minimum and maximum mussel shell lengths collected in 2004 were 47mm (1.9 inches) and 143mm (5.6 inches), respectively (PNNL-19933). The 2004 survey efforts documented a slightly larger range than that found during the 2013 surveys [60mm up to 129mm (2.4 to 5.1 inches)], but the 2004 dataset was based on a larger sample number (2004 n = 196, 2013 n = 75). Although many individuals collected during 2013 fit the length to height ratios describing Clade 1 and Clade 2 *Anodonta*, all mussels collected during 2013 were grouped together for data analysis purposes due to the continuum of shell length to height ratios observed. The length distribution of *Anodonta* collected by the 2004 study and those collected during 2013, are shown in Figures 7 and 8 to compare size-classes as an indicator of possible demographical trends.

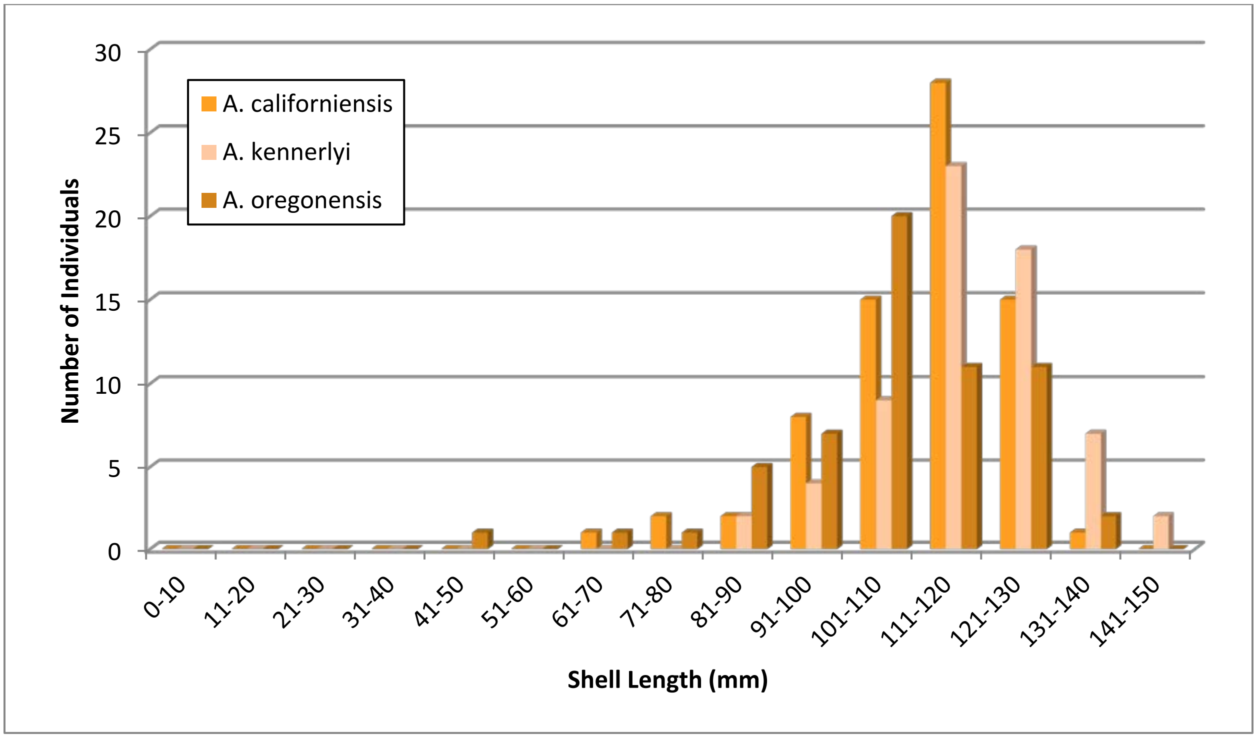

Figure 7. Size Distribution of Anodonta Species Collected During 2004 (PNNL-19933)

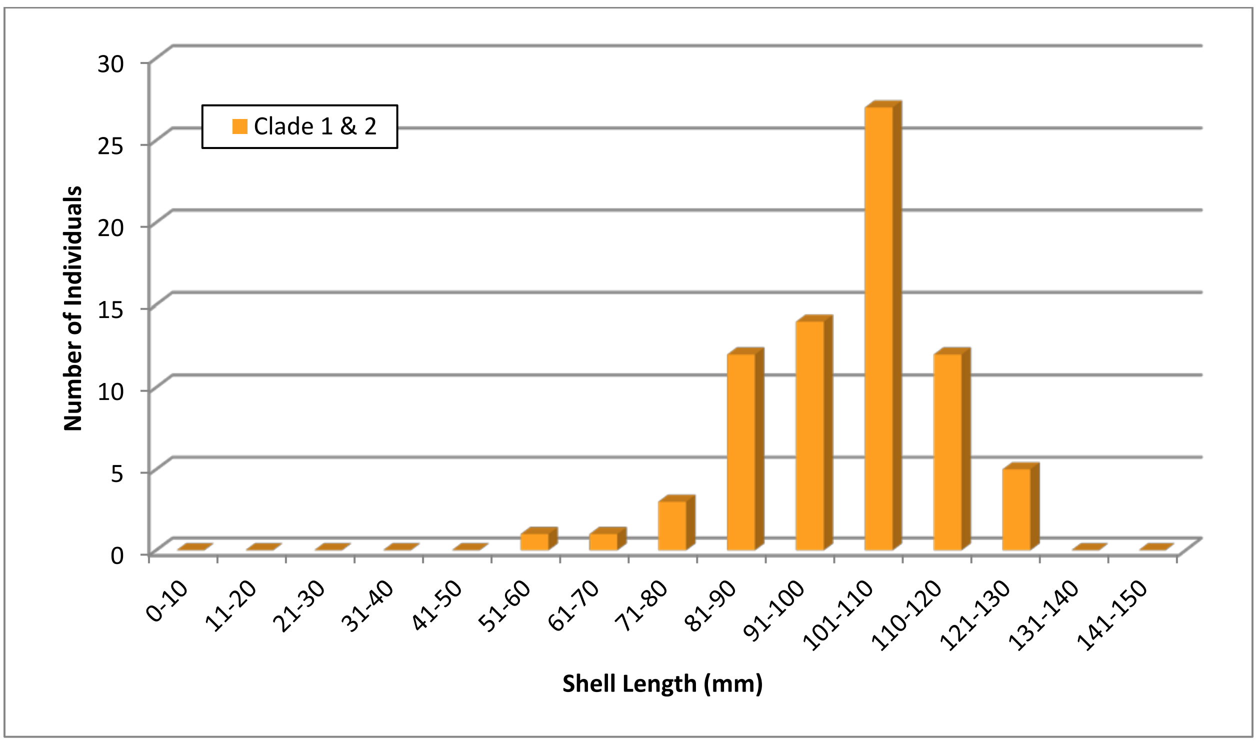

Figure 8. Size Distribution of All Anodonta Collected During 2013

All statistical tests performed on the datasets for this report were t-Tests assuming unequal variance with a significance criteria of less than or equal to 0.05 ($p \leq 0.05$). Shell lengths were compared between 2004 [Mean (M) = 111.6, Standard Deviation (SD) = 15.0] and 2013 (M = 100.5, SD = 14.5) and the mussels from 2004 were found to be significantly larger than those collected during 2013, t (5.8), df = 269, $p < 0.001$. Additional tests were conducted to help determine factors potentially contributing to this observed difference. The length to height ratios of all mussels collected during 2004 (M = 1.90, SD = 0.27) were compared to the length to height ratios of all mussels collected during 2013 (M = 1.95, SD = 0.22) and no significant difference was found between the datasets, t (-1.5), df = 163, $p>0.05$. In other words, the differences in shell ratios between years did not explain the differences observed between years for shell length. Mussels collected during 2004 in White Bluffs Slough (M = 118.4, SD = 10.3) had significantly greater shell length than the mussels collected there during 2013 (M = 103.2, SD = 14.0), t (5.6), df = 49, $p < 0.001$. Therefore, even when controlling for collection location, the mussels surveyed during 2004 were longer than those surveyed during 2013.

Some of the survey areas were deeper during 2013 than in 2004 [up to nine meters (30 feet) versus up to two meters (seven feet)]. This factor was tested to see if it affected mussel lengths within the 2013 dataset. The length of mussels collected from transects deeper than 2 meters during 2013 (M = 101.2, SD = 5.0) were not significantly different than mussels collected at two meters or less (M = 97.1, SD=11.3), t (1.09), df = 19, $p > 0.05$. Similarly, Mussel length to height ratios [>2 meter depth (M = 2.0, SD = 0.2), ≤2 meter depth (M = 1.9, SD = 0.2)] did not vary significantly due to depth within the 2013 dataset, t (0.9), df = 15, $p > 0.05$. Thus, the wider range of sampling depths from 2013 did not appear to explain the mussel length difference observed between 2004 and 2013 datasets. It is important to note that the depths listed are those recorded at the time of the surveys, but that the depth in a particular location along the Hanford Reach can vary up to 5.5 meters (18 feet) in a given location due to seasonal flow fluctuations and upstream dam operations. Both the 2004 and 2013 surveys were conducted during the fall which is typically one of the lowest flow periods of the year.

Scenarios that could explain the observed length difference between surveys include the possibility that mussels are not growing as large in 2013 as they did during 2004, that there is a larger proportion of young, small mussels in 2013 than there was in 2004, or that the detectability of small mussels was lower during the 2004 study than during 2013. Repeating the study performed in 2013 at a later date would control for effects of sampling technique and could indicate whether the average mussel length is changing over time on the Hanford Reach.

An average of 2.9 mussels per 100 square meters was found across all sites in 2013. The data needed to assess whether a statistical difference in mussel density existed between the two datasets was not readily available for the 2004 study, and could be skewed by sampling design. Trends in population densities may be revealed by repeating the 2013 study at a later date.

Mussel density (mussels per 100 square meters) was compared between areas that are adjacent to contaminated groundwater plumes (M = 1.4, SD = 2.2) and areas away from contaminated groundwater plumes (M = 3.8, SD = 4.8) and the areas surveyed away from known contaminant plumes had significantly higher mussel density, t (-2.3), df = 45, $p = 0.03$. In addition to the presence of adjacent groundwater contamination plumes, many factors such as substrate characteristics could potentially influence mussel occupancy rates. Additional information documenting the presence of contaminated groundwater upwelling within survey areas, the concentration of contaminants present, and the concentration of contaminants in mussel tissues may be useful to assess the role these factors play on mussel populations in the Hanford Reach. A site identified as "Walleye Bay" was selected as a reference location, and was the only area surveyed upstream of the Hanford Site. Mussel density observed at Walleye Bay (M = 8.9, SD = 10.3) was not significantly different from the density observed along the remainder of the Hanford Site (M = 2.5, SD = 2.9), t (-1.4), df = 2, $p > 0.05$. However, the strength (i.e., power) of this comparison was limited by the single location and low number of transects completed upstream of the Hanford Site (n = 4). Additional surveys in reference areas would be necessary to determine whether mussel density varies between reference areas and the suitable habitat found adjacent to the Hanford Site.

Although substrate particle size distribution was not a parameter extensively measured in this study, this factor was suspected by observers to potentially affect mussel occupancy and density. Although areas were marked generically as substrate Category 1 (fines, sand, silt, and mud), substrate particle size distribution classified within this category may range widely with respect to suitability for *Anodonta* occupation. For example, although the Hanford Townsite Slough location is in close proximity to the Hanford Townsite Beach location, the Slough location had a much lower density of *Anodonta* than the Beach location (1.3/100m^2 and 4.0/100m^2, respectively). Although both sites were recorded as Category 1 (fines, sand, silt, and mud) dominant substrate type, the Slough was observed to be extremely fine-grained and unconsolidated compared to the coarser, consolidated mud at the Beach. This level of detail, as well as the documentation of additional habitat characteristics such as the presence or absence of groundwater upwelling (WCH-380), and environmental contaminant levels may contribute to the understanding of habitat requirements for *Anodonta* on the Hanford Reach and the reasons for the variation of mussel density observed across transects.

As noted previously, several survey points were deemed unsuitable due to the lack of fine-grained sediment or abundant aquatic vegetation. It is unknown how aquatic vegetation affects mussel density, but surveys conducted in the winter when vegetation is less abundant, especially within survey plots where dense vegetation was documented during the 2013 survey, could help determine how this factor influences mussels. A more accurate substrate map would better define habitat availability for mussels and improve mussel abundance estimates.

The time that an individual mussel was removed from the substrate in 2013 typically lasted less than one minute. Mussels were observed resuming filter feeding within minutes of being returned to the substrate, indicating the low level of stress induced by the prompt return to the river substrate following collection of morphometrics (Figure 9). This technique is extremely important for these locations to be viable as long-term monitoring plots. Due to the use of a high accuracy GPS unit, and the low impact nature of the monitoring protocol, these same locations can be revisited in the future to monitor for changes to the populations without concern for mortality or significant sub-lethal impacts to the sampled individuals that could occur with longer-duration removal from the river bottom, exposure to air, and relocation from microhabitats that would be associated with bringing mussels to the surface to collect morphometrics.

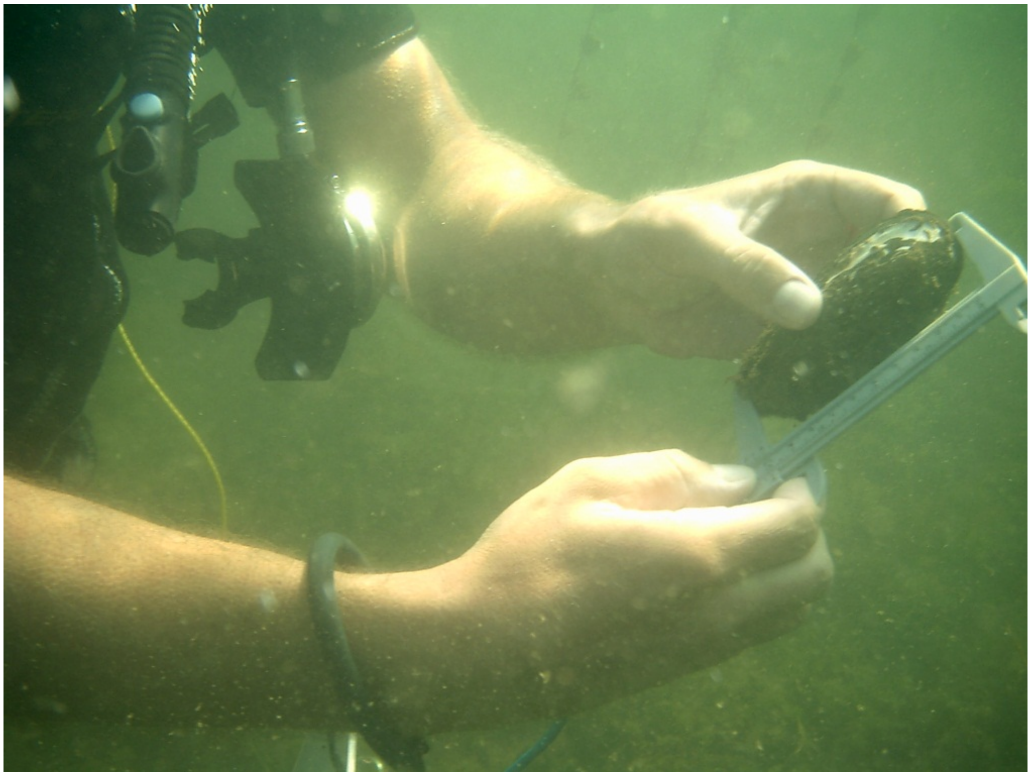

Figure 9. Field Team Member Measures an Anodonta at the River Bottom Prior to Release

At first glance, the lack of small mussels collected during the 2004 and 2013 studies, shown in Figures 7 and 8, could appear to indicate populations on the verge of collapse. However, the 2013 data showed a similar population curve to the 2004 data, indicating population stability over the nine year timeframe between the surveys despite the lack of small age-class individuals in either dataset. This observation is supported by Miller and Payne (1993), who observed that moderate-lifespan mussel assemblages with a stable population show positively skewed, unimodal frequency distributions, of age (x-axis) related to amount (y-axis) (Miller and Payne, 1993). A distribution of this shape corresponds to a moderately long-lived unionid community whose growth slows with age, which describes the *Anodonta* that were the focus of this study (Miller and Payne, 1993). This results in a large proportion of the population existing in the medium size range, and a smaller proportion of very small and very large individuals. This does not, however, explain the complete lack of small individuals observed during both the 2004 and 2013 studies. Visual inspection of the river bottom does not appear to be a suitable survey technique to detect small *Anodonta* (<50mm [two inches]). Even individuals that are significantly smaller than 50mm should have been readily visible using the SCUBA techniques employed during this study if they were exhibiting the same filtering strategy as adults (i.e. shell beak or siphon slightly exposed out of the riverbed substrate). Smaller individuals of other freshwater mussel genera have been documented to burrow into sediments, thus resulting in the potential for under-representation by sampling procedures that do not involve excavation (Allen and Vaughn 2009). A mussel in the same genera *Anodonta anatina* has been documented burrowing into the substrate, with smaller individuals showing a greater tendency to burrow completely below the surface of the substrate than larger individuals which were typically exposed above the substrate (Annie et al. 2013). However, we were unable find any documentation of this behavior for the groups of *Anodonta* studied during 2013. Thus, we propose the potential that juvenile *Anodonta* present along the Hanford Reach, (presumably belonging Clade 1 or Clade 2 from Nedeau et al. 2009) remain below the surface of the river substrate and only emerge to filter-feed once reaching a particular size threshold. This hypothesis could be tested by excavating and sieving fine-grained sediments, beginning in areas with high adult mussel density to increase the likelihood of detection. This could help explain the lack of small size classes of mussels observed on the Hanford Reach, and would give a more accurate picture of population health.

Although questions remain, the comparison of the 2013 dataset to the data collected in 2004 indicates that the population of *Anodonta* present along the Hanford Site appears to be relatively stable. This may not be the case for the other mussel species, the western pearlshell and western ridged mussels, potentially occurring on the Hanford Reach. These species were not detected alive during the 2004 or 2013 surveys but were historically present in the Hanford Reach (PNNL-19933, WCH-029). Additional surveys focusing on the preferred habitats of other freshwater mussel species that were historically present along the Hanford Reach would help determine their status in the Columbia River along the Hanford Site. Additional surveys along the opposite shoreline and in reference areas upstream of the Hanford Site would further characterize and provide a more complete understanding of the populations of *Anodonta* along the Hanford Reach.

5.0 References

Allen, D.C., C.C. Vaughn, 2009, *Burrowing Behavior of Freshwater Mussels in Experimentally Manipulated Communities*, Journal of the North American Benthological Society, 28(1):93-100.

Annie, J., B. Ann, R. Mats, 2013, *Spatial Distribution and Age Structure of the Freshwater Unionid Mussels Anodonta anatina and Unio tumidus: Implications for Environmental Monitoring*, Hydrobiologia, 711(1):61-70.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601-9675. (P.L. 96-510).

DOE/EIS-0222-F, 1999, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, U.S. Department of Energy, Washington, D.C. Online at: http://energy.gov/nepa/downloads/eis-0222-final-environmental-impact-statement-0.

DOE/RL-2013-18 Rev. 0, 2013, *Hanford Site Environmental Report for Calendar Year 2012*, U.S. Department of Energy, Richland, Washington. Online at: http://msa.hanford.gov/page.cfm/environmentalreports2001-latest

Miller, A.C., B.S. Payne, 1993, *Qualitative versus Quantitative Sampling to Evaluate Population and Community Characteristics at a Large-river Mussel Bed*, American Midland Naturalist, 130(1):133-145.

National Environmental Policy Act of 1969, 42 U.S.C. 4321, et seq. (P.L. 91-190).

NatureServe, 2012, *NatureServe Explorer: An Online Encyclopedia of Life* [web application]. Version 7.1. NatureServe, Arlington, Virginia. Online at: http://natureserve.org/search-results.jsp?q=anodonta

Nedeau, E. J., A. K. Smith, J. Stone and S. Jepsen, 2009, *Freshwater Mussels of the Pacific Northwest Second Edition*, The Xerces Society for Invertebrate Conservation. Online at: http://www.xerces.org/wp-content/uploads/2009/06/pnw_mussel_guide_2nd_edition.pdf

PNNL-19933, 2011, *Assessment of the Species Composition, Densities, and Distribution of Native Freshwater Mussels along the Benton County Shoreline of the Hanford Reach, Columbia River, 2004*, R.P. Mueller, B.L. Tiller, M.D. Bleich, G.K. Turner, and I.D. Welch, Prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy, Richland, Washington. Online at: http://www.pnl.gov/main/publications/external/technical_reports/pnnl-19933.pdf

Turner G.K., 2004, *Factors Affecting the Distribution of Vascular Vegetation, Non-Vegetated Substrate,Periphyton, Asiatic Clams, Crayfish, and Sculpin in the Hanford Reach of the Columbia River*. Master's Thesis, Eastern Washington University, Cheney, Washington.

WCH-380 Rev. 0, 2010, *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling*, L.C. Hulstrom, and B.L. Tiller, Washington Closure Hanford, Richland, Washington. Online at http://pdw.hanford.gov/arpir/index.cfm/viewdoc?accession=0093555

WCH-29 Rev. 0, 2006, *Radionuclides, Trace Metals, and Organic Compounds in Shells of Native Freshwater Mussels Along the Hanford Reach of the Columbia River: 6000 Years Before Present to Current Times*, B.L. Tiller, and T. E. Marceau Washington Closure Hanford, Richland, Washington. Online at: http://www.wch-rcc.com/pgs/readroom/WCH/wch29.pdf

ATTACHMENT A

Hanford Site Freshwater Mussel Monitoring 2013
Mussel Morphometrics

Date	Area	Transect#	Mussel Morphometrics		
			Length (mm)	Height (mm)	Width (mm)
9/4/2013	100-BC	100BC-161	120	59	35
9/4/2013	100-BC	100BC-161	87	47	26
9/4/2013	100-BC	100BC-29	97	50	32
9/4/2013	100-BC	100BC-29	89	45	26
9/4/2013	100-BC	100BC-17	102	50	30
8/29/2013	100-D	100D-45	-	-	-
8/29/2013	100-D	100D-121	-	-	-
8/29/2013	100-D	100D-122	-	-	-
8/29/2013	100-H	100H-23	-	-	-
8/29/2013	100-H	100H-24	-	-	-
8/29/2013	100-H	100H-new	-	-	-
9/4/2013	100-K East	100KEAST-10	98	47	31
9/4/2013	100-K East	100KEAST-10	95	46	30
9/4/2013	100-K East	100KEAST-17	117	58	38
9/4/2013	100-K East	100KEAST-30	99	46	34
9/4/2013	100-K West	100KWEST-new1	106	52	31
9/4/2013	100-K West	100KWEST-new1	116	59	47
9/4/2013	100-K West	100KWEST-new1	95	50	31
9/4/2013	100-K West	100KWEST-new1	126	56	43
9/4/2013	100-K West	100KWEST-41	106	55	36
9/4/2013	100-K West	100KWEST	-	-	-
8/29/2013	100-N	100N-13	-	-	-
8/29/2013	100-N	100N-8	-	-	-
8/29/2013	100-N	100N-5	-	-	-
9/3/2013	Hanford Townsite Beach	HTB-99	104	49	33
9/3/2013	Hanford Townsite Beach	HTB-99	101	50	31
9/3/2013	Hanford Townsite Beach	HTB-108	103	51	29
9/3/2013	Hanford Townsite Beach	HTB-108	82	43	23
9/3/2013	Hanford Townsite Beach	HTB-108	104	46	31
9/3/2013	Hanford Townsite Beach	HTB-new	110	56	35
9/3/2013	Hanford Townsite Slough	HTS-16	-	-	-
9/3/2013	Hanford Townsite Slough	HTS-89	-	-	-
9/3/2013	Hanford Townsite Slough	HTS-272	112	56	31
9/3/2013	Hanford Townsite Slough	HTS-270	102	49	32
9/3/2013	Hanford Townsite Slough	HTS-270	72	48	20
9/3/2013	Hanford Townsite Slough	HTS-270	99	63	31
9/3/2013	Hanford Townsite Slough	HTS-496	-	-	-
9/3/2013	Hanford Townsite Slough	HTS-558	-	-	-
9/5/2013	Walleye Bay	WALLBAY-36	122	55	37
9/5/2013	Walleye Bay	WALLBAY-36	122	54	37
9/5/2013	Walleye Bay	WALLBAY-36	97	47	32

Date	Area	Transect#	Mussel Morphometrics		
			Length (mm)	Height (mm)	Width (mm)
9/5/2013	Walleye Bay	WALLBAY-36	110	59	37
9/5/2013	Walleye Bay	WALLBAY-36	71	41	24
9/5/2013	Walleye Bay	WALLBAY-36	72	39	23
9/5/2013	Walleye Bay	WALLBAY-36	102	48	35
9/5/2013	Walleye Bay	WALLBAY-36	86	43	29
9/5/2013	Walleye Bay	WALLBAY-36	62	33	20
9/5/2013	Walleye Bay	WALLBAY-36	113	65	36
9/5/2013	Walleye Bay	WALLBAY-36	105	53	32
9/5/2013	Walleye Bay	WALLBAY-36	82	42	27
9/5/2013	Walleye Bay	WALLBAY-242	83	44	28
9/5/2013	Walleye Bay	WALLBAY-242	96	53	34
9/5/2013	Walleye Bay	WALLBAY-242	95	47	33
9/5/2013	Walleye Bay	WALLBAY-242	82	51	27
9/5/2013	Walleye Bay	WALLBAY-210	95	47	35
9/5/2013	Walleye Bay	WALLBAY-149	98	49	34
8/27/2013	White Bluffs Slough	WBS-44	118	69	36
8/27/2013	White Bluffs Slough	WBS-44	102	65	35
8/27/2013	White Bluffs Slough	WBS-44	107	51	33
8/27/2013	White Bluffs Slough	WBS-44	60	48	20
8/27/2013	White Bluffs Slough	WBS-44	110	54	38
8/27/2013	White Bluffs Slough	WBS-405	113	67	40
8/27/2013	White Bluffs Slough	WBS-405	115	68	32
8/27/2013	White Bluffs Slough	WBS-405	83	53	25
8/27/2013	White Bluffs Slough	WBS-449	107	51	33
8/27/2013	White Bluffs Slough	WBS-449	115	60	37
8/27/2013	White Bluffs Slough	WBS-534	113	51	34
8/27/2013	White Bluffs Slough	WBS-948	107	67	32
8/27/2013	White Bluffs Slough	WBS-948	129	61	43
8/28/2013	White Bluffs Slough	WBS-1240	-	-	-
8/28/2013	White Bluffs Slough	WBS-1320	-	-	-
8/28/2013	White Bluffs Slough	WBS-1545	106	47	33
8/28/2013	White Bluffs Slough	WBS-1725	96	46	32
8/28/2013	White Bluffs Slough	WBS-1727	111	55	35
8/28/2013	White Bluffs Slough	WBS-1813	102	46	32
8/28/2013	White Bluffs Slough	WBS-1813	102	45	31
8/28/2013	White Bluffs Slough	WBS-1813	90	43	26
8/28/2013	White Bluffs Slough	WBS-610	95	44	26
8/28/2013	White Bluffs Slough	WBS-610	81	45	25
8/28/2013	White Bluffs Slough	WBS-566	-	-	-
8/28/2013	White Bluffs Slough	WBS-28	-	-	-
8/28/2013	White Bluffs Slough	WBS-672	-	-	-

			Mussel Morphometrics		
Date	**Area**	**Transect#**	**Length (mm)**	**Height (mm)**	**Width (mm)**
8/28/2013	White Bluffs Slough	WBS-1305	119	51	45
8/28/2013	White Bluffs Slough	WBS-1305	123	61	33
8/28/2013	White Bluffs Slough	WBS-1389	108	49	36
8/28/2013	White Bluffs Slough	WBS-1389	91	55	30
8/28/2013	White Bluffs Slough	WBS-1389	107	61	35
8/28/2013	White Bluffs Slough	WBS-1389	84	52	28
8/28/2013	White Bluffs Slough	WBS-1389	110	52	32
9/3/2013	White Bluffs Slough	WBS-1033			
9/3/2013	White Bluffs Slough	WBS-1039	103	50	30
9/3/2013	White Bluffs Slough	WBS-1039	110	65	39
9/3/2013	White Bluffs Slough	WBS-1039	102	62	31
9/3/2013	White Bluffs Slough	WBS-1039	84	42	22
9/3/2013	White Bluffs Slough	WBS-1039	102	52	32

This page intentionally left blank.