Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

INTERTIDAL CLAM SURVEY DATA REPORT: FINAL

For submittal to

The US Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

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Table of Contents

1.0 Introduction

Data presented in this report were collected as part of the Phase 2 Remedial Investigation (RI) for the Lower Duwamish Waterway (LDW). These data will be used to derive site-specific clam consumption rates for the Phase 2 Human Health Risk Assessment. A future deliverable will describe the methods by which these data will be used in that effort.

The field procedures used to conduct these surveys are described in detail in the Quality Assurance Project Plan (QAPP) for the clam, crab, and shrimp survey of the LDW (Windward 2003b), and are also described briefly in Section 2.0 below.

2.0 Methods

2.1 RECONNAISSANCE SURVEYS

Windward conducted an initial reconnaissance survey on July 16, 2003 during a minus tide to identify the potential clam sampling areas in the LDW. Personnel present on this survey included Bob Complita and Maryann Welsch from Windward Environmental, Kevin Li from King County, Andy Dalton and Glen St. Amant from the Muckleshoot Tribe, and Lon Kissinger from EPA. The survey began at the upstream end of Harbor Island (RM 0) and continued upstream to the Boeing pedestrian bridge (RM 4.9). Exposed intertidal areas were identified and mapped (Global Positioning System [GPS] coordinates) as potential clam sampling locations along each bank according to appropriate elevation (i.e., area between the waterline and approximately +6 ft mean lower low water [MLLW]) and substrate. Appropriate substrate was defined as everything but riprap, concrete, or other debris or structures that would prevent digging for clams. All the intertidal areas previously identified in the Phase 1 RI (Windward 2003a) from aerial photos taken at a negative tide (-2 ft MLLW) were visited with the exception of those areas upstream of the Boeing pedestrian bridge where the water was too shallow for boat travel at a minus tide. Field notes from the July 16 reconnaissance survey are provided in Appendix A.

Windward conducted a second reconnaissance survey in the LDW on July 29 and 30, 2003 during a minus tide. Personnel present on this survey included Bob Complita and Maryann Welsch from Windward Environmental, Kevin Li from King County; Andy Dalton from the Muckleshoot Tribe, and Paul Williams from the Suquamish Tribe. Each beach identified by visual inspection during the July 16 reconnaissance survey was re-visited to assess relative clam presence and habitat. Each beach was ranked according to the number of clams, shows (i.e., siphon holes), and shells observed and the condition of the substrate. Beaches were given a high or good ranking if clams were found in the majority of both random and targeted holes (targeted based on presence of shows) and if the clam habitat was good relative to other areas in the LDW. Beaches were given a low or poor ranking if few clams, shells, or shows were observed and if the substrate was so soft that clam harvesters would sink deeper than approximately six inches while standing on the beach. Medium-ranked beaches were those with clam density and habitat type intermediate between the high and low-ranked beaches. Further description of the methods and results of this survey are in Appendix B.

2.2 INTERTIDAL CLAM SURVEY

Windward conducted the quantitative portion of the clam survey during minus tides from August 8 to August 13, 2003. The Windward field crew varied by day and included Maryann Welsch, Bob Complita, Derek Pelletier, Shannon Pierce, Megan Schedler, Cindy Jackson, Joanna Florer, Helle Anderson, Shawn Hinz, and Scott Shotwell, and Kevin Li from King County. Oversight was provided by John Nakayama from SAIC (also assisted in field work), Andy Dalton from the Muckleshoot Tribe, Paul Williams from the Suquamish Tribe, and Lon Kissinger from EPA. All high-ranked beaches identified in the second reconnaissance survey were re-visited and sampled for clams during this survey. One low and one medium beach were also sampled during the survey.

2.2.1 Survey design and sampling methodology

A random sampling design, based on WDFW guidance (Campbell 1996), was employed to survey each beach for clam abundance. Each beach was surveyed from the top of the designated clam habitat to the waterline. The top of the clam habitat was designated based on the results of test holes dug to reveal clam presence, the presence of shows or siphon holes, or in instances where clam presence was not obvious or consistent, to the approximate elevation of +6 ft MLLW. Elevation was estimated to the nearest foot using two staff gages, one positioned at the top of the sample area and one at the waterline. A third staff member estimated the change in elevation from a distance and the approximate elevation of the top of the sample area, relative to the waterline, and the time measured was recorded on the field survey sheet. Actual elevation of the top of the sample area was later adjusted to the known elevation of the waterline at the time of measurement. Vertical boundaries of the sample area were determined based on the lack of clam presence or the presence of impediments such as sea walls, piers, riprap or other structures that would prevent digging holes.

A random sampling design was established at each beach by first laying a baseline transect parallel to the waterline along the entire length of the study area. Transects were laid perpendicular to this baseline along the width of the beach to the waterline and sampling locations or quadrats were flagged along each transect (Windward 2003b). Distances between transects and quadrats were designated for each beach based on the established sampling density or block size for that beach. For all high-ranked beaches, an average block size of 94 m^2 was used to establish the sampling grid. Following the first day of sampling, the suitability of this block size relative to the variability among samples for each beach was discussed by LDWG, EPA, and Tribal representatives using data analysis suggested by WDFW guidance (Campbell 1996). The results of this discussion are presented in Section 3.2. Larger block sizes were established for low and medium ranked beaches (370 m^2 and 188 m^2, respectively).

The distances from the sample area boundary to the first transect and to the first sample location on each transect were randomly chosen within the appropriate block size. The sample grid for each beach was mapped and recorded on the field survey form and included quadrat locations, GPS coordinates for each transect along the baseline, and bearings of the baseline and each transect. Changes in substrate and large obstacles were recorded on the field survey form.

After the sampling grid was established at each beach, a 0.093-m^2 hoop was centered on each quadrat flag and the area within the hoop was then excavated to a depth of 30 cm. All excavated substrate was placed into a sorting bin and all clams were sorted from the substrate by hand and stored in labeled Ziploc bags for identification and measurement in the lab (Section 2.4).

2.2.2 Interstitial salinity and percent fines measurements

A T-bar corer was used to collect several sediment samples to a depth of 30 cm at each beach. Samples were collected close to the waterline to ensure that the sediment was saturated. Samples were analyzed for interstitial salinity and percent fines in the laboratory. Interstitial salinity measurements were taken using methods from PERL (1990) in which each 30 cm sediment core was mixed over depth and a small subsample (approximately 2 g) was taken from the core for analysis. The subsample was placed into a 10-mL syringe and interstitial fluids were forced from the sediment into a filter holder containing #2 Whatman filter paper. A one-to-two-drop sample was expressed from the filter holder onto the plate of a refractometer (temperature-compensated, range 0-150 ppt) and the interstitial salinity was recorded. This procedure was replicated by two individuals of the field crew to test data reliability.

A rapid wet sieving technique (Gibson et al. 2000) was employed to estimate percent fines. A subsample from the composited sediment cores was washed through a 63-µm standard sieve using fresh water. Sediment remaining on the sieve was collected, placed into a 100-mL graduated cylinder and allowed to settle for approximately five minutes. Once the supernatant was clear, the volume of the coarse-grained fraction was recorded and subtracted from the original volume to obtain the fine-grained fraction, expressed as percent fines.

2.2.3 Incidental observations of mussels and other intertidal shellfish

Incidental observations of mussel presence on pilings, piers, and other structures were recorded throughout the LDW during the reconnaissance survey. Abundance and density was not quantified but assessed on a relative basis by noting the general location in the waterway where abundance decreased.

Incidental observations of other intertidal invertebrates made during the intertidal survey were recorded and included the number, identification, and location of organisms such as shore crabs. These observations were limited in effort (primary effort went to conducting clam survey) and do not reflect definitive presence of other intertidal organisms. Observations were made by lifting wood and other debris on the beach while conducting the intertidal survey and by chance during the catch rate exercise.

2.3 Catch Rate Exercise

On the last day of sampling, August 13, 2003, areas with the highest abundances of clams found during the intertidal survey were re-visited to assess potential catch rates. The Windward field crew for this survey consisted of Maryann Welsch, Bob Complita, Shannon Pierce, Helle Anderson, Cindy Jackson, Shawn Hinz, Derek Pelletier, and Joanna Florer, with oversight provided by Lon Kissinger of EPA and Andy Dalton of the Muckleshoot Tribe. Between 3 and 5 members of the field crew were assigned to each beach as harvesters and actively searched and collected clams for one hour during a minus tide. Efforts were made to find the areas with highest clam abundance, as determined by evidence of shows. Number and depths of holes were not specified or recorded. Clams were tallied per harvester and brought to the laboratory for measurement and identification.

2.4 Clam Species Identification and Size Measurements

All clams harvested during the intertidal surveys and the catch rate surveys were returned to the laboratory and frozen. The location of collection, length, and total wet weight (including shell) were recorded for each clam. Each clam was identified to the species level using several keys (Harbo 2001, Kozloff 1987, and Smith and Carlton 1975) and by comparing the characteristics of the internal and external surfaces of the shell. Voucher specimens of each species were retained and mailed to Camille Speck, shellfish biologist at the Point Whitney Shellfish Laboratory, for verification.

2.5 Deviations from the QAPP

The methods described in the QAPP to measure interstitial salinity were adjusted to aid in obtaining samples from beaches with high silt content. Sediment from these beaches frequently clogged the filter and made it difficult to obtain a clean sample as most of the drops expressed from these samples were not adequately filtered and cloudy and thus made it difficult to read the refractometer. In these cases, a glass pipette and pipette pump were employed to thin the sample by withdrawing less sediment and more fluid from the sample. This thinned sample was then placed into the syringe and filtered as described above in Section 2.2.2.

3.0 Results

3.1 RECONNAISSANCE SURVEYS

Twenty-three beaches were identified as potential clam habitat during the first reconnaissance survey on July 16, 2003. The field notes from this initial survey are found in Appendix A. The beaches were divided into three categories based on clam habitat quality during the second reconnaissance survey (Appendix B). Overall, eight beaches were ranked high, five beaches were ranked medium, and thirteen beaches were ranked low quality clam habitat. High- and medium-ranked beaches were found predominantly in the downstream (northern) regions of the waterway.

Prior to the quantitative survey, sample density was estimated for each high-ranked beach and for a subset of three medium- and three low-ranked beaches that were randomly chosen for inclusion in this survey (Appendix B). The area of each beach was estimated based on the exposed intertidal area of each beach identified from aerial photographs used in the LDW Phase 1 RI (Windward 2003a). The number of samples per beach was estimated based on the area and the designated sample density or block size of each beach. Sample density was the highest on high-ranked beaches with a block size of 94 m^2. Because the number of identified beaches exceeded the field team's capacity to sample them, sampling efforts on the low- and medium-ranked beaches were assigned a lower priority compared to efforts on high-ranked beaches. Thus, sample density on medium- and low-ranked beaches was lower (188 and 370 m^2, respectively) to accommodate the large sampling effort required on the high-ranked beaches.

In addition to identifying clam habitat, the presence of mussels on structures was noted throughout the LDW during the initial reconnaissance survey. Mussels were abundant on many piers, pilings and other structures in the lower regions of the waterway, but occurred in very low densities upstream of the 16th Avenue bridge. Photos in Appendix H illustrate the relative higher density of mussels closer to the mouth of the waterway (Photos 1 and 2) versus further upstream (Photo 3).

3.2 QUANTITATIVE SURVEY

Table 1 summarizes the sampling effort for each beach included in the quantitative survey. All eight high-ranked, one medium-ranked, and one low-ranked beaches were sampled. The remaining two medium-ranked and two low-ranked beaches originally selected for this survey could not be sampled because of time constraints associated with the four-hour sampling period per day and the amount of time necessary for moving between beaches.

The survey design for each beach is illustrated in Appendix C, Figures C-1 to C-6. The sample area of each beach was calculated based on the length of the baseline and each transect. In addition, a 3 m buffer was applied to the waterline and two vertical edges of each area to account for additional sample area covered by the block size of each quadrat location. The baseline of each sample area in most cases was a straight line parallel to the water. Minor adjustments of 5 to 10 degrees in the direction of the baseline occurred in response to slight curves on the beach. In addition, in some cases the baseline of the sample area was offset by up to 90 degrees to accommodate additional beach area, such as on beaches 1a and 8 (Appendix C, Figures C-1 and C-3). The sample area of each beach ranged from approximately 600 m^2 to 9,200 m^2 (Table 1). The mean block size for each quadrat was calculated by dividing the sample area by the number of samples. Block sizes ranged from 61 m^2 to 79 m^2 on the high-ranked beaches and 122 m^2 and 203 m^2 for the medium- and low-ranked beaches, respectively. The number of transects ranged from 4 to 42 per beach and the number of samples per beach ranged from 10 to 122. The field forms from the quantitative survey are shown in Appendix D.

The elevation of the top of the sampling area was determined based on the presence of shows or clams, but in those instances where shows and clams were not apparent, an approximate elevation of +1.8 m (+6 ft) MLLW was used. In most cases, the top of the sample area was determined by the presence of physical constraints, such as riprap, seawall, vegetation, or fenced restoration areas. Elevation of the top of the sample area ranged from 0.2 m (0.6 ft) to 2.7 m (9 ft) (Table 1).

Interstitial salinity and percent fines measurements varied widely among beaches, ranging from 10 ppt to 27 ppt interstitial salinity and 0% to 56% fines. Interstitial salinity did not appear to consistently decrease with distance from the mouth of the waterway as expected. Instead, interstitial salinity varied widely, ranging from 10 ppt at beach 1 (T105) to 27 ppt at beach 2a island (Kellogg Island). The variability in interstitial salinity may also be attributed to surface water runoff, which was observed at some beaches. Percent fines also varied widely among beaches, ranging from 0% at beaches 1a and 7 to 56.4% at beach 13a. Percent fines also appeared to vary within a beach where, based on observations made during the survey, patches of coarse gravel and fine silty substrates were intermixed throughout many of the sites.

Following the first day of sampling (August 8, 2003), a conference call between LDWG, EPA, and Tribal representatives occurred to discuss the suitability of the survey design based on the results from that day's sampling. Using equations described in the QAPP that are based on WDFW data analysis methods (Campbell 1996), Windward analyzed the sampling variance for the first two high-ranked beaches sampled, beaches 1a and 8 (Appendix E). For the purposes of WDFW sampling of popular beaches for recreational clam harvesting, the block size is considered adequate if the ratio of the error of the population estimate (B) to the population estimate (T) is 0.3 or less. The calculated ratio of B to T was 0.69 for beach 1a (T-105) and 0.55 for beach 8 (1st Avenue South Bridge). Because the sampling effort necessary to complete the survey design described in Appendix B was already anticipated to require all the remaining hours of minus tides during the survey period, the conference call participants agreed to accept the proposed block size rather than reduce the number of beaches sampled. During the call, it was agreed that additional sampling would not necessarily reduce the variance appreciably because of the patchiness of clam abundance in the LDW.

Sample variance for the rest of the beaches included in this survey is described in Table 2. For these calculations, area in m^2 was converted to ft^2 to facilitate calculating mean number of clams per 1 ft^2 instead of per 0.093 m^2. Based on the mean number of clams per square foot, the total population estimate ranged from approximately 2,000 clams at beach 11 to 87,000 clams at beach 2a-island (Kellogg Island). However, the ratio of B to T was greater than 0.3 at most of the beaches. Beaches 2a-island and 2a-mainland (Kellogg Island and adjacent beach on mainland) were the only two beaches where the ratio of B to T was approximately 0.3 (Table 2).

Table 1. Beaches included in the LDW quantitative survey

Beach #	Location (RM)	Ranking	Date sampled	Low tide height (m)	Area (m^2)	Number of Samples	Mean block size (m^2)	Upper sample area elevation (m)	Interstitial salinity (ppt)	Percent Fines (%)
1a	0.1	high	8/8/2003	-0.49 (-1.6 ft)	2,664	39	68	2.7 (9.0 ft)	10	0
2a-island	0.5	high	8/11/2003	-0.71 (-2.3 ft)	8,029	102	79	0.17 (0.57 ft)	27	11.3
2a-mainland	0.5	high	8/11/2003- 8/12/2003	-0.71 (-2.3 ft) -0.60 (-2.0 ft)	7,394	94	79	1.7 (5.5 ft)	22	32.1
2b-mainland	0.5	med	8/12/2003	-0.60 (-2.0 ft)	1,463	12	122	1.7 (5.5 ft)	22	32.1
2c-mainland	0.5	low	8/12/2003	-0.60 (-2.0 ft)	2,026	10	203	1.7 (5.5 ft)	22	32.1
7	1.8	high	8/9/2003	-0.65 (-2.1 ft)	1,925	28	69	1.6 (5.4 ft)	22	0
8	2.1	high	8/8/2003	-0.49 (-1.6 ft)	3,495	49	71	2.0 (6.7 ft)	15	7.7
11	2.6	high	8/9/2003	-0.65 (-2.1 ft)	611	10	61	0.80 (2.6 ft)	na[a]	48.1
13a	2.9	high	8/9/2003	-0.65 (-2.1 ft)	1,085	17	64	0.14 (0.50 ft)	25	56.4
12	2.8	high	8/9/2003	-0.65 (-2.1 ft)	913	14	65	1.1 (3.6 ft)	15	12.8
16	3.5	high	8/9/2003- 8/10/2003	-0.65 (-2.1 ft) -0.73 (-2.4 ft)	9,241	123	75	1.2 (3.9 ft)	17	26.8

a- Interstitial salinity of this sample was not determined because of the inability to extract a clear sample for analysis with the refractometer.

Table 2. Population estimates and sample variance for beaches included in the quantitative survey

Beach	Ranking	Sample area (ft^2)	Mean number of clams per 1 ft^2 sample	Total population estimate (T)	One-half of the 95% confidence interval (B)	Ratio of B to T
1a	high	28,673	0.28	8,028	5,428	0.68
2a- island	high	86,427	1.0	87,291	24,144	0.28
2a- mainland	high	79,592	0.67	53,327	17,757	0.33
2b-mainland	low	21,808	0.70	15,266	14,611	0.96
2c-mainland	med	15,747	0.17	2,677	3,539	1.3
7	high	20,723	0.46	9,533	8,929	0.94
8	high	37,620	0.94	35,363	19,428	0.55
11	high	6,576	0.30	1,973	2,807	1.4
12	high	9,829	0.71	5,600	4,926	0.88
13a	high	11,680	0.47	5,490	4,531	0.83
16	high	99,472	0.18	17,905	13,399	0.75

Over half the clams collected during this survey were identified as *Macoma balthica* (60%), followed by *Mya arenaria* (20%) and *Macoma nasuta* (18%) (Table 3). Other less common macoma species included *Macoma inquinata* and *Macoma secta* (both <1%). *M. balthica* were the smallest clams collected on all beaches with a mean total wet weight of 0.7 g (range of <0.1 g to 3.4 g), whereas *M. nasuta* were on average larger in size (mean total wet weight of 5.2 g, range of 0.3 g to 16 g). *M. inquinata* and *M. secta* were similar in size to *M. balthica*. *M. arenaria* clams were the largest clams collected (mean total wet weight of 15.2 g); however, this species also had the widest range in weight (0.3 g to 54 g).

Based on the approximate sample area and number of clams collected at each beach, the highest number of clams per area (m^2) was estimated for beaches 8 and 2a-island (10 and 11 clams/m^2, respectively; Table 3). However, the greatest total clam biomass per area was estimated for beach 13a (79 g/m^2). The least number of clams and total biomass per area were estimated for beaches 2a-mainland (medium-ranked) and 16 (1.8 and 1.9 clams/m^2, and 12 and 5.2 g/m^2, respectively).

Table 3. Summary of clams identified at each beach in the quantitative survey

Beach	Ranking	Clam Species	Total Number of Individuals/ Species	Total number and Wet Weight (g)[a] of Each Clam Species per m^2	Mean (min, max) Wet Weight (g)[a] per Species
8	high	*Macoma balthica*	39	8.6 (12)	1.5 (0.3, 3.4)
		Macoma secta	1	0.22 (0.48)	2.5
		Mya arenaria	6	1.3 (20)	14.9 (1.0, 41.6)
		Total	46	10 (33)	3.3 (0.3, 41.6)
1a	high	*Macoma balthica*	6	1.6 (0.44)	0.3 (<0.1, 0.5)

Beach	Ranking	Clam Species	Total Number of Individuals/ Species	Total number and Wet Weight (g)[a] of Each Clam Species per m^2	Mean (min, max) Wet Weight (g)[a] per Species
		Macoma spp.	1	0.27 (0.11)	0.4
		Mya arenaria	4	1.1 (22)	20.6 (1.2, 45.2)
		Total	11	3.0 (23)	6.6 (<0.1, 45.2)
7	high	*Macoma balthica*	4	1.5 (1.5)	1.0 (0.5, 1.5)
		Mya arenaria	9	3.5 (42)	12 (0.9, 26.7)
		Total	13	5.0 (44)	8.7 (0.5, 26.7)
11	high	*Macoma balthica*	2	2.2 (3.2)	1.5 (1.3, 1.7)
		Mya arenaria	1	1.1 (51)	47.5
		Total	3	3.2 (54)	16.8 (1.3, 47.5)
13a	high	*Macoma balthica*	2	1.3 (1.5)	1.2 (1.0, 1.4)
		Macoma nasuta	3	1.9 (14)	7.2 (2.2, 15.6)
		Mya arenaria	3	1.9 (64)	33.8 (27, 43.3)
		Total	8	5.1 (79)	15.7 (1.0, 43.3)
12	high	*Macoma balthica*	6	4.6 (4.3)	0.9 (0.5, 1.6)
		Mya arenaria	4	3.1 (48)	15.8 (0.9, 23.5)
		Total	10	7.7 (53)	6.9 (0.5, 23.5)
16	high	*Macoma balthica*	19	1.7 (1.6)	1.0 (0.3, 1.6)
		Macoma spp.	1	0.088 (na)	broken
		Mya arenaria	2	0.18 (3.7)	20.9 (0.9, 40.8)
		Total	22	1.9 (5.2)	2.9 (0.3, 40.8)
2a-island	high	*Macoma balthica*	75	7.9 (2.9)	0.4 (<0.1, 1.0)
		Macoma nasuta	12	1.3 (8.7)	6.9 (2.6, 14.4)
		Macoma secta	1	0.11 (0.074)	0.7
		Macoma spp.	1	0.11 (0.074)	0.7
		Mya arenaria	14	1.5 (15)	9.9 (0.3, 51.6)
		Total	103	11 (26)	2.5 (<0.1, 51.6)
2a-mainland	high	*Macoma balthica*	17	2.0 (0.64)	0.3 (<0.1, 1.9)
		Macoma inquinata	1	0.12 (0.15)	1.3
		Macoma nasuta	32	3.7 (17)	4.6 (0.3, 11.7)
		Macoma spp.	1	0.12 (0.046)	0.4
		Mya arenaria	12	1.4 (20)	14.4 (0.3, 53.5)
		Total	63	7.2 (38)	5.2 (<0.1, 53.5)
2b-mainland	low	*Macoma balthica*	2	2.2 (1.2)	0.6 (0.4, 0.7)
		Macoma nasuta	4	4.3 (13)	3.1 (0.8, 5.7)
		Mya arenaria	1	1.1 (8.4)	7.8
		Total	7	7.5 (23)	3.0 (0.4, 5.7)
2c-mainland	med	*Macoma balthica*	1	0.90 (0.54)	0.6
		Mya arenaria	1	0.90 (11)	12.2
		Total	2	1.8 (12)	6.4

Beach	Ranking	Clam Species	Total Number of Individuals/ Species	Total number and Wet Weight (g)[a] of Each Clam Species per m^2	Mean (min, max) Wet Weight (g)[a] per Species
All		*Macoma balthica*	173	3.7 (2.7)	0.75 (0.05, 3.4)
		Macoma inquinata	1	0.022 (0.028)	1.3
		Macoma nasuta	51	1.1 (5.7)	5.2 (0.3, 16)
		Macoma secta	2	0.043 (0.063)	1.5 (0.7, 2.2)
		Macoma spp.	4	0.086 (0.032)	0.5 (0.4, 0.7)
		Mya arenaria	57	1.2 (19)	15.2 (0.3, 54)
		Total	**288**	**6.2 (27)**	**4.5 (0.05, 54)**

[a] All wet weights are whole clam wet weights (including shells).

Clam identification and measurement data for each clam in the quantitative survey are found in Appendix F. *M. arenaria* shells are very brittle and break easily upon collection resulting in the loss of fluids and pieces of shell. To correct the weights of broken clams, a power relationship was used, based on the recommendation of WFDW shellfish biologists (Speck 2003), to express the length-to-weight ratio of unbroken *M. arenaria* clams collected in this survey and the catch rate survey (Section 3.3). A power curve and equation were fit to this relationship using the trendline function in Microsoft Excel® and resulted in the following equation:

Wet weight (g) = 0.1066 * (shell length (cm))$^{2.9944}$ with an r-squared value of 0.940

This equation was applied to broken clams to obtain corrected clam wet weights, which were then used to summarize the results of this survey (Table 3).

3.3 Catch Rate Exercise

The four beaches included in the catch rate survey were beaches 1 (T-105), 2a-island and 2a-mainland (Kellogg Island and adjacent mainland), and 8 (under 1st Avenue bridge; Appendix C, Figures C-1 to C-3). The latter 3 beaches had the highest abundances of clams collected during the quantitative survey. Clam abundance on beach 1a (T-105) was approximately average among the remaining beaches sampled and was included because it was the furthest downstream and possibly more salt-water influenced than the other beaches. Also, many shows were observed during the quantitative survey.

Among the four beaches surveyed, the greatest harvest was collected on beach 2a-island (Kellogg Island; approximately 3,300 g wet weight of whole clam biomass, including shells, collected by harvester 1), followed by beaches 1a (T-105), 8 (under 1st Avenue bridge), and 2a-mainland (approximately 2,700 g, 900 g, and 700 g, respectively; Table 4). More than 98% of the total biomass was for *Mya arenaria*. Total biomass of other species, predominantly macoma species, was greatest at beach 8 (87 g biomass), which is consistent with the findings of the quantitative clam survey (Table 3), and lowest at beach 1a (2.8 g biomass). Similar to the intertidal survey, *M. balthica* was the most common macoma species harvested, followed by *M. nasuta*. One *Protothaca staminea* clam was harvested on beach 2a-island.

Although differences in clam harvest among the beaches may be related to clam abundances at each beach, harvester-specific effort, training, familiarity with clam distributions on each beach, and skill also greatly influence the biomass harvested at each beach and are a source of uncertainty for this exercise. Shows were targeted at each beach to identify the location of clams for harvesting; however, this method did not consistently yield the greatest harvest at each beach. For example at beach 1a (T105), anecdotal evidence collected during the catch rate exercise suggested more clams were harvested in areas not targeted on shows, but in areas shaded during the hottest part of the day by pilings and other large debris. The effort, and subsequent harvest, on this beach may have been improved if this information was available to the field crew prior to the exercise. Any additional catch rate exercise efforts would benefit by surveying the patchy distribution of clams on each beach and providing staff with beach-specific information as to where clams are likely to be found.

All macoma clams were similar in size to the macomas collected during the intertidal clam survey; the overall mean wet weight from both portions of the survey was 1.8 g. However, *M. arenaria* clams differed in mean size between the quantitative survey and the catch rate survey. Mean wet weight of *M. arenaria* clams collected during the catch rate survey was double that of clams collected during the intertidal survey (29.0 g and 15.2 g, respectively). Effort during the catch rate survey was concentrated on collecting large clams versus the intertidal survey where all clams regardless of size were collected.

Clam identification and measurement data for each clam collected during the catch rate survey are found in Appendix G. Broken clam weights were adjusted using the equation described in Section 3.2. During this catch rate exercise, *M. arenaria* clams broke easily on retrieval and several clams broke apart, preventing individual clam weight and length measurements. These fragments, referred to as *Mya* fragments in Appendix G, were lumped for a total fragment wet weight measurement and were not included in the mean wet weight and total biomass calculations in Table 4.

3.4 OTHER INTERTIDAL ORGANISMS OBSERVED IN THE LDW

Several shore crabs were incidentally observed during the intertidal survey at beach 12, and during the catch rate survey on beach 1a. All individuals were identified as *Hemigrapsus* spp. One individual was observed at beach 12 after a piece of wood was moved during the quantitative survey. At beach 1a (T-105), several individuals (5-10) were observed under rocks and wood debris among the remnant pilings on the south end of the beach. Other than shore crabs, polychaetes were also observed burrowing in the sediment on several beaches during both surveys.

3.5 VOUCHER VERIFICATION

Individuals from each species collected in both surveys were retained as voucher specimens. Camille Speck, shellfish biologist at Point Whitney Shellfish Laboratory in Brinnon, WA, conducted the voucher verification and reported that all species were correctly identified (Speck 2003).

Table 4. One-hour catch rates for *Mya arenaria* and other clam species[a] on four beaches in the LDW, August 13, 2003

Beach	Harvester	Total number of clams per harvester		Mean (SD) Wet Weight[a] (g) per Harvester		Total Biomass (g)[a] per Harvester	
		M. arenaria	Other species[b]	*M. arenaria*	Other species[b]	*M. arenaria*	Other species[b]
8	1	12	40	33.9 (18.0)	2.2 (0.8)	406.3	86.7
	2	27	23	30.6 (13.6)	1.6 (0.7)	826.4	35.8
	3	27	55	33.5 (13.6)	1.5 (0.6)	904.5	84.5
8 Overall		**66**	**118**	**32.4 (14.3)**	**1.8 (0.8)**	**712.4[c]**	**69.0[c]**
2a-island	1	97	7	33.9 (18.4)	0.8 (0.5)	3,289.3	4.0
	2	20	12	21.3 (17.5)	0.5 (0.2)	426.5	4.8
	3	49	9	20.7 (15.1)	0.5 (0.2)	1,012.3	4.6
	4	25	7	22.1 (17.0)	0.5 (0.2)	551.3	3.5
	5	96	8	33.4 (20.7)	5.2 (7.7)	3,206.3	36.1
2a-island Overall		**287**	**43**	**29.6 (19.3)**	**1.8 (3.6)**	**1,697.1[c]**	**10.6[c]**
2a-mainland	1	18	5	26.6 (11.6)	3.7 (4.8)	478.2	18.3
	2	31	3	21.7 (17.1)	3.5 (2.8)	671.6	10.5
	3	29	1	19.1 (12.2)	0.4	554.6	0.4
	4	12	4	22.0 (8.8)	6.5 (5.3)	265.3	25.8
2a-mainland-Overall		**90**	**13**	**21.9 (13.6)**	**4.2 (4.4)**	**492.4[c]**	**13.8[c]**
1a	1	69	2	29.8 (18.2)	0.7 (0.2)	2,053.2	1.3
	2	86	5	31.7 (14.9)	0.6 (0.1)	2,722.7	2.8
	3	12	3	21.8 (11.7)	1.0 (0.2)	261.1	3.0
	4	42	5	29.8 (16.7)	0.7 (0.4)	1,251.6	3.3
1a Overall		**209**	**15**	**30.1 (16.3)**	**0.7 (0.3)**	**1,572.1[c]**	**2.6[c]**
All beaches		**652**	**189**	**29.0 (17.4)**	**1.8 (2.2)**	**1,180.1[c]**	**20.3[c]**

[a] All wet weights are whole clam wet weights (including shells, but excluding clam fragments).

[b] The majority of other clam species present were macoma species. One *Protothaca staminea* clam was identified by harvester 5 on beach 2a-island

[c] Mean biomass per harvester per beach (total biomass for all harvesters per beach divided by the number of harvesters)

4.0 References

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Appendix A. Field notes from initial reconnaissance survey (July 16, 2003)

Appendix B. Clam sampling locations memo, August 1, 2003

Appendix C. Intertidal clam survey design at each beach

Appendix D. Field survey forms from the intertidal clam survey in the LDW, August 8-12, 2003

Appendix E. Preliminary analysis of clam sampling variance, August 8, 2003

Appendix F. Identification and size measurements of clams collected in the LDW during the intertidal clam survey, August 8-12, 2003

Appendix G. Identification and size measurements of clams harvested during the catch rate survey, August 13, 2003

Appendix H. Site photographs