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Inorganic Arsenic Levels in Puget Sound Fish and Shellfish from 303(d) Listed Waterbodies and Other Areas

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Inorganic Arsenic Levels in Puget Sound Fish and Shellfish from 303(d) Listed Waterbodies and Other Areas

by
Art Johnson and Morgan Roose

Environmental Assessment Program
Olympia, Washington 98504-7710

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Waterbody Numbers: WA-15-0020, WA-15-0030, WA-15-0040, WA-15-0050

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Abstract

Total and inorganic arsenic were analyzed in eight fish and shellfish species to determine the appropriateness of placing five Puget Sound waterbodies on the 1998 303(d) list for exceeding EPA human health criteria in edible tissue. The waterbodies in question were Dyes Inlet, Port Washington Narrows, Sinclair Inlet, Port Orchard, and Eagle Harbor. The listings were based on total arsenic data.

Results showed the listing criterion of 0.006 ug/g inorganic arsenic was exceeded in all clam samples analyzed. However, this appears to be due to natural conditions in Puget Sound. All crab and fish samples were at or below the listing criterion. It is therefore recommended that these waterbodies be taken off the 303(d) list for arsenic exceedances in edible tissue (12 listings in all).

Acknowledgements

The authors thank the following individuals for assisting with this project:

- Washington Department of Fish and Wildlife biologists Sandie O'Neill, Jim West, and Greg Lippert for generously providing fish samples from the Puget Sound Ambient Monitoring Program archives.
- Dr. Roseanne Lorenzana of the U.S. Environmental Protection Agency Region 10 for providing helpful advice and information on arsenic speciation analysis.
- Karin Feddersen of the Ecology Manchester Environmental Laboratory for arranging contract laboratory services and for careful review of the data.
- Ecology employee Brandee Era-Miller for assistance with the clam sampling.

Introduction

Five Puget Sound waterbodies – Dyes Inlet, Port Washington Narrows, Sinclair Inlet, Port Orchard, and Eagle Harbor – have been listed by the Washington State Department of Ecology (Ecology) under Section 303(d) of the federal Clean Water Act for non-attainment of the EPA human health criteria for arsenic. The listings are based on total arsenic concentrations measured in edible tissues from various fish, clam, and crab species. These data are reported in Cubbage (1992); EA Engineering, Science, and Technology (1995); and Yake et al. (1984). There are no sediment or water listings for arsenic in any of these waterbodies, except for a sediment site near the Puget Sound Naval Shipyard in Sinclair Inlet.

Table 1 summarizes the Puget Sound listings for arsenic in edible tissue. Figure 1 shows locations of samples that resulted in listing Dyes Inlet, Port Washington Narrows, Sinclair Inlet, and Port Orchard. Figure 2 shows similar sites in Eagle Harbor.

Cubbage (1992) surveyed chemical contaminants in fish and clams from Dyes and Sinclair inlets. The fish samples consisted of pooled fillets from English sole, sand sole, C-O sole, rock sole, and flathead sole[1]. Total arsenic concentrations ranged from 3.3 to 21 ug/g (parts per million, wet weight basis). The clam samples were mixed species composites of the soft parts from native littlenecks, Japanese littlenecks, and butter clams. Total arsenic concentrations ranged from 1.2 to 3.5 ug/g in the clams.

The arsenic concentrations Cubbage reports for Sinclair Inlet fish appear to be biased high. In discussing these data, Cubbage noted that Crecelius et al. (1989) examined fish from 13 bays in Puget Sound (including Dyes and Sinclair inlets) and found little variation between sites in the concentrations of arsenic or other metals. Higher arsenic concentrations were, however, found in fish from Commencement Bay, likely due to contamination from the former ASARCO smelter. The arsenic concentrations in Cubbage's Sinclair Inlet fish samples averaged nearly twice the concentrations in fish from other parts of Puget Sound, except Commencement Bay. An earlier study in Sinclair Inlet found fish muscle had approximately the same arsenic concentrations as reference areas (Gahler et al., 1982). The reason for the high arsenic results in Cubbage's study is not known.

The Ostrich Bay (Dyes Inlet) 303(d) listings are based on a remedial investigation/feasibility study of Jackson Park by EA Engineering, Science, and Technology. Their 1995 report has data on total arsenic concentrations in littleneck clam soft parts and muscle tissue from the graceful crab. Concentration ranges were 1.3 to 4.5 ug/g in the clams and 5.8 to 37 ug/g in the crabs; the 37 ug/g value was an outlier.

Yake et al. (1984) investigated chemical contamination of Eagle Harbor clams and crabs from the Wyckoff wood-treating facility; only clams were analyzed for arsenic. Mixed species composites of native littlenecks, Japanese littlenecks, butter, and horse clams were collected from eight sites around the harbor. Total arsenic concentrations ranged from 1.5 to 4.4 ug/g.

[1] Species names are in Appendix A

Table 1. 1998 303(d) Listings for Arsenic in Fish and Shellfish from Puget Sound

Waterbody	Tissue	Latitude	Longitude	Basis for Listing
Dyes Inlet and Port Washington Narrows, Waterbody ID WA-15-0050				
Dyes Inlet	Clam	47.645	122.685	Cubbage (1992)
Chico Bay	Clam	47.605	122.705	Cubbage (1992)
Oyster Bay	Clam	47.565	122.675	Cubbage (1992)
Phinney Bay	Clam	47.585	122.665	Cubbage (1992)
Port Washington Narrows	Clam	47.585	122.645	Cubbage (1992)
Port Washington Narrows	Clam	47.575	122.625	Cubbage (1992)
Ostrich Bay	Crab and Clam	47.585	122.688	EA Engineering (1995)
Sinclair Inlet, Waterbody ID WA-15-0040				
Sinclair Inlet	Clam	47.535	122.645	Cubbage (1992)
Sinclair Inlet	Fish	47.545	122.625	Cubbage (1992)
Port Orchard, Waterbody ID WA-15-0030				
Port Orchard	Fish	47.565	122.605	Cubbage (1992)
Port Orchard	Fish	47.565	122.625	Cubbage (1992)
Eagle Harbor, Waterbody ID WA-15-0020				
Eagle Harbor	Shellfish	47.645	122.475	Yake et al. (1984)

The arsenic concentrations in the Ostrich Bay and Eagle Harbor shellfish samples mentioned above were similar to those in samples EA Engineering and Yake et al. collected from reference areas in Semiahmoo Bay and Port Blakely, respectively. As described in these reports, the arsenic levels in Ostrich Bay and Eagle Harbor clams and crabs are typical of Puget Sound.

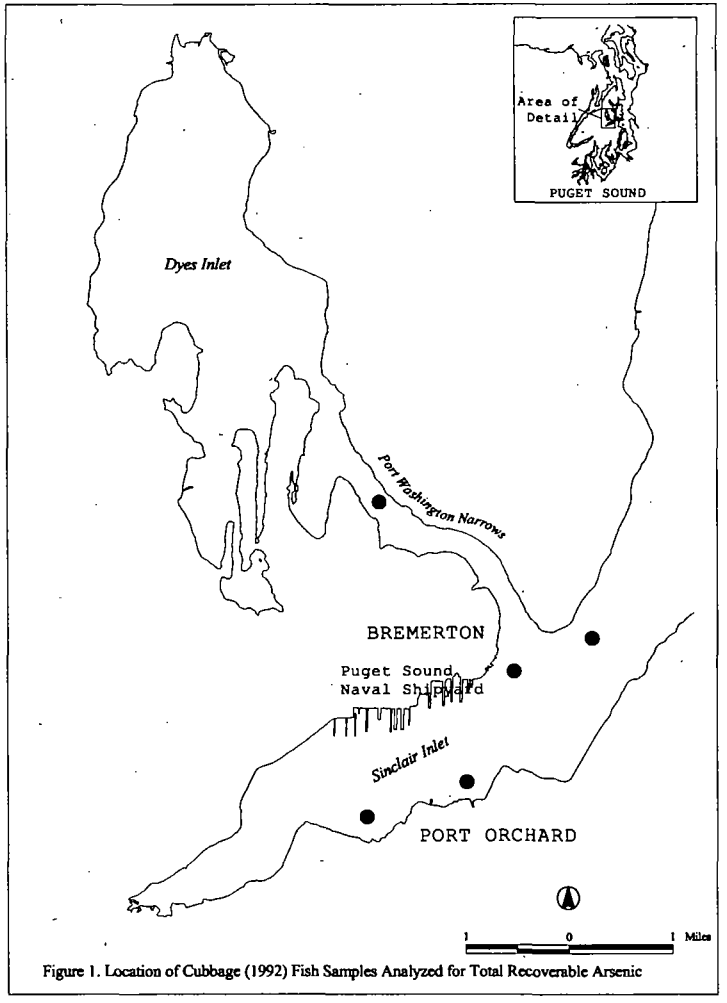

Figure 1. Location of Cubbage (1992) Fish Samples Analyzed for Total Recoverable Arsenic

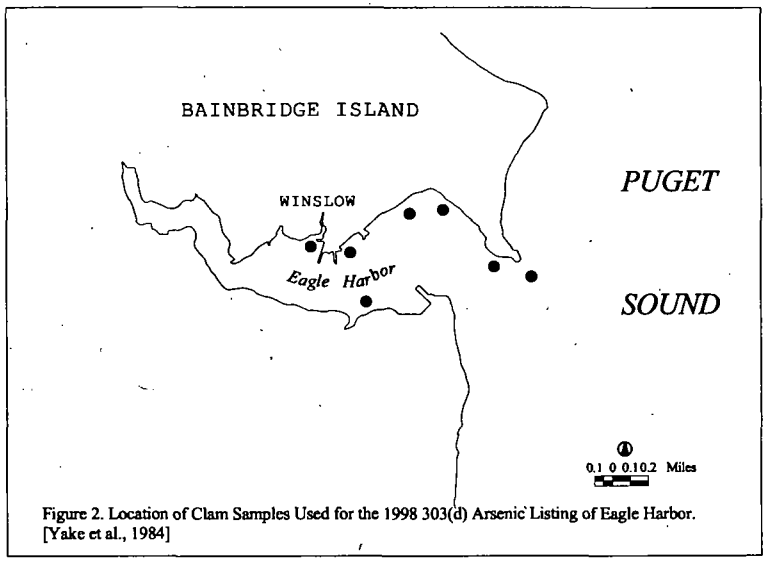

Figure 2. Location of Clam Samples Used for the 1998 303(d) Arsenic Listing of Eagle Harbor. [Yake et al., 1984]

Ecology's 303(d) listing criterion for arsenic in edible fish and shellfish tissue is 0.006 ug/g wet weight, calculated as the product of the U.S. Environmental Protection Agency (EPA) bioconcentration factor (44 L/Kg) and water column criterion (0.14 ug/L) (EPA, 1995). Although this criterion is for inorganic arsenic, it has been Ecology's practice to list waterbodies based on total arsenic data. The new listing policy for toxic pollutants requires that data must be for the specific isomer or chemical fraction that the criteria relate to (Ecology Water Quality Program Policy 1-11, September 2002).

In fish and shellfish tissues, arsenic is primarily in organic form as arsenobetaine (Ballin et al., 1994). The toxic species of most concern are inorganic arsenic, monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA), all of which are minor constituents. Information on the relative amounts of these forms in Puget Sound organisms is limited and of uncertain quality. The general picture emerging from local and national studies is that marine shellfish have the highest but also most variable concentrations of inorganic arsenic, followed by marine fish and freshwater fish, in that order (Donahue and Abernathy, 1999). Dietary exposure to arsenic via seafood and other food products is currently an issue of concern and research.

In order to determine the appropriateness of the 303(d) arsenic listings for Puget Sound, the Ecology Environmental Assessment Program analyzed total and inorganic arsenic in fish and shellfish collected from the listed waterbodies. Samples were also analyzed from unlisted waterbodies, including reference areas removed from known sources of arsenic contamination. The results of this effort are the subject of the present report.

MMA and DMA were included in the analysis at the request of EPA Region 10. Region 10 was interested in using the data to develop a human health risk assessment policy for arsenic in seafood. There are no state or EPA standards for MMA and DMA, so these compounds are not taken into consideration for 303(d) listings. The complete arsenic speciation data – total arsenic, inorganic arsenic, MMA, and DMA – are in Appendix B.

Two types of samples were analyzed for this investigation: 1) archived fish and crab tissues from the Puget Sound Ambient Monitoring Program (PSAMP), obtained through the Washington Department of Fish and Wildlife (WDFW); and 2) clams and crabs collected by Ecology specifically for the present study. The WDFW samples provided survey-type data on inorganic arsenic levels in harvested fish and crab around Puget Sound, while the Ecology samples were focused on 303(d) listed waterbodies.

The sample locations and species selected from the WDFW archives are shown in Figure 3. The only WDFW station located in a 303(d) listed waterbody was in Sinclair Inlet, and samples were limited to English sole and herring. Additional WDFW trawl sites were selected to give good spatial coverage over Puget Sound and include both urban/industrial and reference sites. Based on the total arsenic and other chemical data that have been collected for PSAMP, WDFW recommended Hood Canal and eastern Juan de Fuca Strait as reference sites for fish and crab tissue. English sole, quillback rockfish, Dungeness crab, coho salmon, and pacific herring were analyzed to represent a range of feeding types, habitats, and life histories. The coho were returning wild adults.

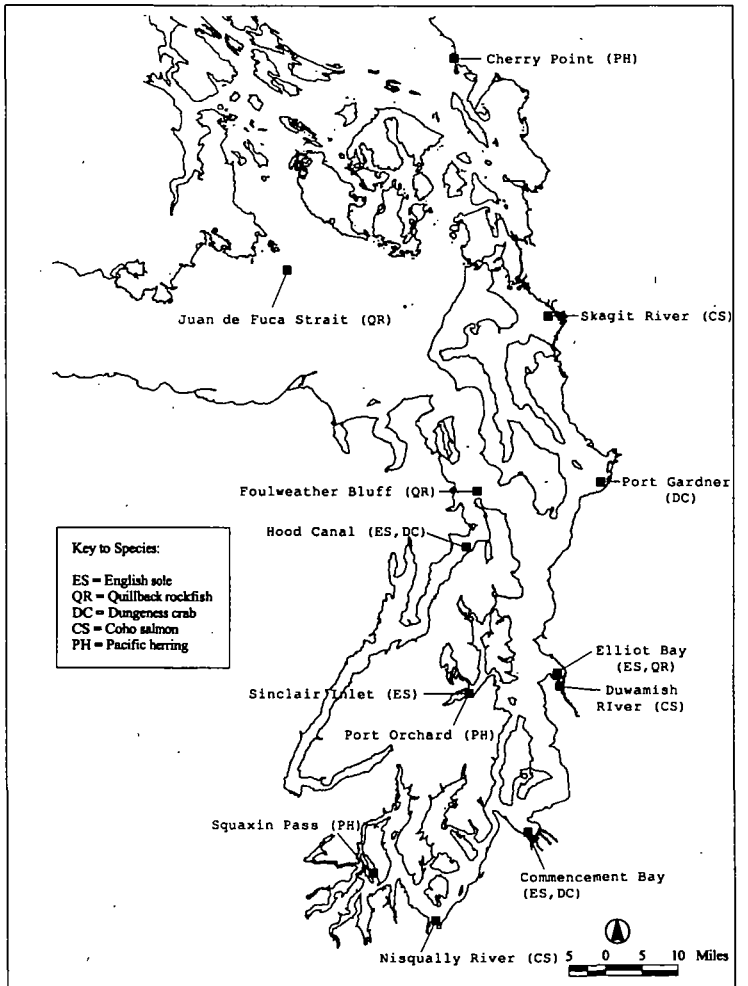

Figure 3. PSAMP Sampling Stations and Fish Species Selected for Arsenic Speciation Analysis

Figure 4 shows the location of Ecology's clam and crab samples. Tissues were obtained from most of the sampling sites used for the 1998 303(d) listings, except for Eagle Harbor where only two of the eight historical sites were sampled. Three separate sites were sampled along the west shoreline of Ostrich Bay to help the Washington State Department of Health (WDOH) reach a decision on allowing clam harvest by the Suquamish Tribe. Based on discussions with WDOH personnel who have monitored arsenic in clams for PSAMP and other studies, Twanoh State Park on Hood Canal and Sequim Bay State Park were selected as reference areas for clams.

The species that figured most prominently in the 303(d) listings were collected. Clam samples consisted of mixed native and Japanese littlenecks. The graceful crab was collected in Ostrich Bay. Graceful crabs are small and not normally harvested. The more popular red rock and Dungeness crabs are rarely encountered in Ostrich Bay, and none were caught during the sample collections for this project.

Detailed descriptions of the WDFW trawl sites can be found in their groundfish survey sampling summaries (e.g., Quinnell et al., 2001). The Ecology sampling sites for clams and crabs are described in Appendix C.

A quality assurance project plan was prepared for this study (Johnson, 2002).

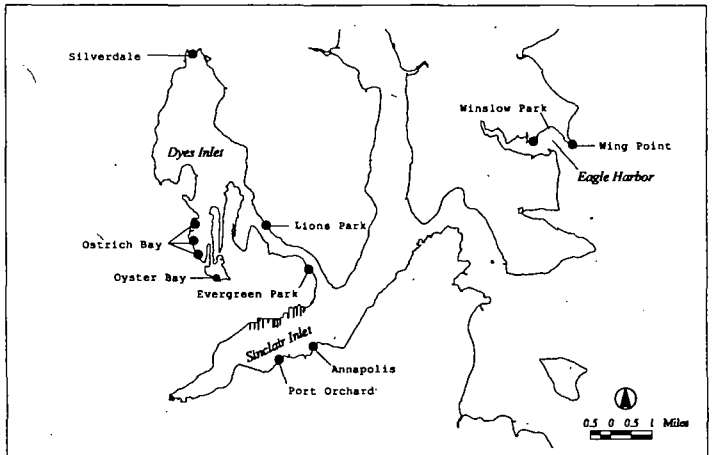

Figure 4A. Location of Shellfish Samples Collected for Arsenic Speciation Analysis: 303(d) Listed Areas

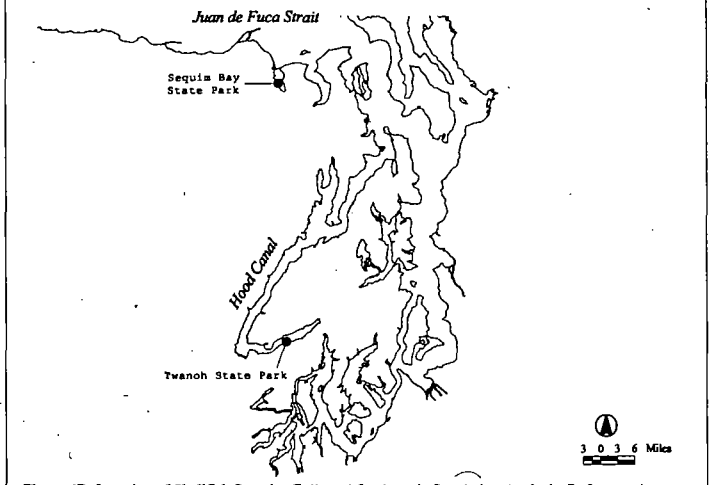

Figure 4B. Location of Shellfish Samples Collected for Arsenic Speciation Analysis: Reference Areas

Sampling Procedures

Sample collection and tissue preparation methods for the archived WDFW samples have been described by West et al. (2001). The samples were stored frozen at WDFW headquarters. Each sample consisted of composited muscle tissue from 5 to 15 individual organisms. To the extent possible, the fish and crabs in each composite were of similar size and age, and the numbers of male and female fish in each composite were approximately equal. All crabs were males, as per harvest rules. The fish muscle samples were skin-off. Length, weight, and age data for the specimens used in the composites are in Appendix D.

The clam sampling and tissue preparation procedures used by Ecology were based on unpublished guidelines prepared by Glen Patrick, WDOH Office of Toxic Substances (Johnson, 1997). These are modifications of procedures used for PSAMP shellfish monitoring. Clam diggers used clean rakes and shovels, uncontaminated by grease or oil. Prior to collection, stainless steel buckets were pre-cleaned by washing with detergent and rinsing with acetone and deionized water. Rakes, shovels, and buckets were washed with sea water between sampling sites.

The clams were rinsed thoroughly with on-site sea water to remove any adhering mud or sand, then placed in one-gallon glass jars with Teflon lid-liners, cleaned to EPA (1990) quality assurance/quality control (QA/QC) specifications. The clams were held on ice and returned the same day to Ecology headquarters where they were frozen in a secure freezer. The clams were not depurated.

Crab sampling and tissue preparation procedures used by Ecology were based on PTI (1991) and Puget Sound Water Quality Action Team (PSWQAT, 1997a,b). Crabs were collected using pots baited with salmon carcasses and set for 1-2 hours at depths ranging from 16-38 feet (MLLW). The largest male crabs were taken for samples. Care was taken to avoid contact between the crabs and engine fumes, fuel, oil, bilge water, or other contaminants.

Each crab selected for analysis was killed with a blow to the ventral nerve cord. The crabs were individually wrapped in aluminum foil, put in double plastic bags, and placed on ice. The crabs were kept dorsal side down so that body cavity liquids would drain away from muscle tissue. They were returned the same day to Ecology headquarters and frozen in a secure freezer.

All tissues were removed using techniques intended to minimize potential for sample contamination. Only non-corrosive stainless steel instruments were used. Persons preparing the samples wore non-talc polyethylene gloves and worked on aluminum foil. Gloves and foil were changed between samples. Resecting instruments and blender parts were cleaned by washing in hot tap water with Liquinox detergent, followed by sequential rinses with tap water, 1% reagent-grade nitric acid, deionized water, and pesticide-grade acetone. All items were then air dried on aluminum foil in a fume hood before use.

The clams were rinsed with tap water followed by deionized water to remove any adhering debris. The composites consisted of the entire soft parts from between 30 and 35 individuals.

Only clams that met the legal limit of $\geq 1\ \frac{1}{2}$ inches were used in the composites, and the number of small, medium, and large specimens was approximately equal. The soft parts were homogenized to uniform color and consistency in a plastic and stainless steel Kitchen-Aid blender and placed in 8-oz jars with Teflon lid-liners, cleaned to EPA (1990) QA/QC specifications. Shell fragments were not included.

The Ostrich Bay crabs were analyzed in two composites of nine crabs each. The range of carapace widths was 85-100 mm. After rinsing the crabs with tap water and deionized water, muscle tissue was removed from the claws, legs, and body and placed in 8-oz glass jars with Teflon lid-liners, cleaned to EPA (1990) QA/QC specifications

When removing body meat from the crabs, care was taken not to include hepatopancreas tissue or other organs. Shell fragments were not included in the samples. The resected samples were homogenized to uniform color and consistency by hand with stainless steel implements.

The clam and crab samples were re-frozen and taken by courier to the Ecology Manchester Environmental Laboratory (Manchester). The samples were stored frozen at Manchester until analyzed.

Analytical Methods

Manchester contracted three private laboratories to analyze the samples. The Battelle Marine Sciences Laboratory in Sequim, WA did the initial arsenic speciation analysis of the WDFW samples. A subset of these samples was subsequently analyzed for inorganic arsenic by Frontier Geosciences Inc., Seattle, WA as a check on the accuracy of Battelle's determinations. The arsenic speciation analysis of Ecology's clam and crab samples was done by Brooks Rand LLC in Seattle. Manchester did the total arsenic analysis on these samples.

Battelle analyzed inorganic arsenic, MMA, and DMA by EPA Method 1632A - *Chemical Speciation of Arsenic in Water and Tissue by Hydride Generation Quartz Furnace Atomic Absorption Spectrometry*. The tissues were digested with 2N NaOH @ 80°C overnight. Method 1632A was developed by Battelle. Total arsenic was analyzed using Battelle's in-house ICP/MS method.

Frontier Geosciences employed a modification of Method 1632A to analyze inorganic arsenic by hydride generation-cryogenic trapping-gas chromatography-atomic absorption spectrophotometry. Sample digestion employed a cell disrupter and HCl leach procedure.

Brooks Rand's arsenic speciation analysis followed EPA Method 1632A and used an HCl digestion.

Manchester digested and analyzed total arsenic following EPA Method 200.8 (ICP/MS).

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Data Quality

Manchester staff prepared written QA reviews of the arsenic data generated for this project. The reviews included an assessment of sample conditions on receipt at the laboratory, compliance with holding times, instrument calibration, procedural blanks, laboratory control samples, standard reference material, precision, and matrix spike recoveries. Except as noted for Battelle below, no significant analytical difficulties were encountered during the analyses, and all QC parameters were within established control limits. The QA reviews and complete chemical data are available from the author.

The initial analysis of the WDFW fish samples did not meet contract requirements for detection limits low enough to compare to the 0.006 ug/g criterion for inorganic arsenic. Battelle re-analyzed the samples, making an effort to lower detection limits by injecting a larger volume. This resulted in an unstable baseline and poor peak resolution, leading in turn to uncertainty in the region of the chromatogram where inorganic arsenic normally elutes. A subset of the samples was subsequently analyzed for inorganic arsenic by Frontier Geosciences. Frontier's results corroborated Battelle's data (see Results and Discussion).

The precision of the arsenic data reported here can be gauged from results of analyzing selected tissue samples in duplicate and triplicate, as summarized in Table 2.

Table 2. Precision Data

Ecology Sample No.	Laboratory	Tissue	Analyte	Analysis #1		Analysis #2		Analysis #3	
498084	Battelle	fish muscle	total arsenic	0.915		0.915		0.915	
"	"	"	inorganic arsenic	0.00200	NJ	0.00111	NJ	0.0310	NJ
"	Frontier	"	"	0.004	U	0.004	U	0.004	U
498089	Battelle	crab muscle	total arsenic	3.80		3.84		3.83	
"	"	"	inorganic arsenic	0.00287	NJ	0.00282	NJ	0.00142	NJ
238080	Manchester	clam soft parts	total arsenic	3.48		3.29		--	
"	Brooks Rand	"	inorganic arsenic	0.040		0.030		--	
238088	Manchester	clam soft parts	total arsenic	2.83		2.68		--	
"	Brooks Rand	"	inorganic arsenic	0.030		0.020		--	

NJ = There is evidence that the analyte is present. The associated numerical result is an estimate.
U = The analyte was not detected at or above the reported result.

As indicated later in this report, some of the tissue samples from the WDFW archives had been collected more than one year before subsamples were taken for arsenic speciation analysis. Holding time does not affect the stability of arsenic in frozen or freeze-dried samples (Crecelius, 2001). However, it is possible that certain samples were desiccated during the long storage period. If so, the results on those samples would be biased high.

Results and Discussion

WDFW Fish and Crab Samples

The total and inorganic arsenic concentrations measured by Battelle in the WDFW fish and crab samples are summarized in Table 3. Battelle reported inorganic arsenic concentrations ranging from 0.00047 to 0.044 ug/g. Inorganic arsenic accounted for 0.2% or less of the total arsenic in most samples (12 of 16).

Table 3. Results of Battelle Marine Sciences Laboratory's Analysis of Total and Inorganic Arsenic in Archived WDFW Fish and Crab Composites [ug/g wet weight; parts per million]

Species and Location	Date Collected	No. of Individuals	Ecology Sample No.	Total Arsenic	Inorganic Arsenic		Percent Inorganic
English sole							
Sinclair Inlet	2000	15	498080	10	0.0013	NJ	0.01
Commencement Bay	2000	15	498081	12	0.00086	NJ	0.01
Elliott Bay	2000	15	498082	8.5	0.044	NJ	0.5
Hood Canal	2000	15	498083	10	0.0035	NJ	0.04
Quillback rockfish							
Elliott Bay	1998	12	498084	0.89	0.011	NJ	1.2
Foulweather Bluff	1997	12	498085	2.4	0.032	NJ	1.3
E. Juan de Fuca Str.	2001	8	498086	2.0	0.0013	NJ	0.1
Dungeness crab							
Hood Canal	2001	11	498087	5.0	0.0026	NJ	0.1
Port Gardner	2001	11	498088	3.3	0.0013	NJ	0.04
Commencement Bay	2001	12	498089	3.8	0.0024	NJ	0.1
Coho salmon							
Skagit River	2000	12	498090	0.35	0.00062	NJ	0.2
Duwamish River	2000	12	498091	0.29	0.0018	NJ	0.6
Nisqually River	2000	12	498092	0.34	0.00073	NJ	0.2
Pacific herring							
Cherry Point	2001	15	498093	0.98	0.00080	NJ	0.1
Port Orchard	2001	15	498094	1.8	0.00047	NJ	0.03
Squaxin Pass	2001	15	498095	2.0	0.00099	NJ	0.05

NJ = There is evidence that the analyte is present. The associated numerical result is an estimate.

The only 303(d) listed waterbody represented by the WDFW samples was Sinclair Inlet. Inorganic arsenic concentrations in the Sinclair Inlet English sole and herring were 0.0013 and 0.00047 ug/g, respectively, well below the 303(d) listing criterion of 0.006 ug/g.

Three of the 16 WDFW samples appeared to exceed the criterion. The three samples were English sole and quillback rockfish from Elliott Bay, and quillback rockfish from Foulweather Bluff. These exceedances are probably not significant. A triplicate analysis of the Elliott Bay quillbacks showed poor precision. Two of three results on this sample were well below 0.006 ug/g (sample number 498084, Table 2). Foulweather Bluff, at the entrance to Hood Canal, is far removed from known arsenic sources. There were no apparent exceedances in samples from Commencement Bay, which has the highest sediment and water column levels of arsenic in Puget Sound (Ecology SEDQUAL database; Crecelius, 1975, 1998).

Table 4 shows Frontier Geosciences' results from re-analyzing seven of the WDFW samples. The re-analysis included the English sole from Elliott Bay, and the sole and Dungeness crab from Commencement Bay. Inorganic arsenic was not detected in any of these samples at or above 0.004 ug/g. Again, these results are below the listing criterion.

Table 4. Comparison of Inorganic Arsenic Concentrations Measured by Battelle Marine Sciences Laboratory and Frontier Geosciences Inc. [ug/g wet weight; parts per million]

Species and Location	Ecology Sample No.	Battelle Results		Frontier Results	
English sole					
Sinclair Inlet	498080	0.0013	NJ	0.004	U
Commencement Bay	498081	0.00086	NJ	0.004	U
Elliott Bay	498082	0.044	NJ	0.004	U
Hood Canal	498083	0.0035	NJ	0.004	U
Dungeness crab					
Commencement Bay	498089	0.0024	NJ	0.004	U
Coho salmon					
Duwamish River	498091	0.0018	NJ	0.004	U
Pacific herring					
Port Orchard	498094	0.00047	NJ	0.004	U

NJ = There is evidence that the analyte is present. The associated numerical result is an estimate.
U = The analyte was not detected at or above the reported result.

Ecology Clam and Crab Samples

Results from analyzing total and inorganic arsenic in the clam and graceful crab samples Ecology collected from 303(d) listed waterbodies and two reference areas are summarized in Table 5. The levels of inorganic arsenic were higher than in the WDFW fish and Dungeness crab samples.

Table 5. Results of Brooks Rand's Analysis of Inorganic Arsenic in Clam and Crab Edible Tissue Composites; Total Arsenic Analysis by Ecology Manchester Laboratory
[ug/g wet weight; parts per million]

Location	Species	Date Collected	No. of Individuals	Ecology Sample No.	Total Arsenic	Inorganic Arsenic	Percent Inorganic
Dyes Inlet							
Silverdale	Clam*	5/15/02	30	238087	2.4	0.020	0.8
Ostrich Bay NW	Clam	6/13/02	34	238084	3.2	0.017	0.5
Ostrich Bay W	Clam	6/13/02	35	238085	4 2	0.018	0.4
Ostrich Bay SW	Clam	6/13/02	31	238086	2.9	0.018	0.6
Ostrich Bay	Crab**	9/6/01	9	428086	12	0.008	0.1
"	"	9/6/01	9	428087	8.4	0.009	0.1
Oyster Bay	Clam	7/19/01	30	428082	4.2	0.021	0.5
Port Washington Narrows							
Lions Park	Clam	7/19/01	30	238090	2.2	0.015	0 7
Evergreen Park	Clam	8/31/01	20	428085	1.9	0.022	1.2
Sinclair Inlet							
Port Orchard	Clam	5/1/02	30	238088	2.8	0.025	0 9
Annapolis	Clam	5/1/02	30	238089	2.3	0.022	1 0
Eagle Harbor							
Wing Point	Clam	4/28/02	30	238082	3.0	0.021	0.7
Winslow Park	Clam	4/28/02	30	238083	2.1	0.020	1.0
Hood Canal (reference area)							
Twanoh State Park	Clam	5/29/02	30	238081	2.3	0.015	0.7
Sequim Bay (reference area)							
Sequim Bay State Park	Clam	4/29/02	30	238080	3.4	0.035	1.0

* mixed native and Japanese littleneck clams
**graceful crab

Concentrations of inorganic arsenic in clam tissues were confined to a relatively narrow range of 0.015 to 0.035 ug/g. Lower concentrations of 0.008 and 0.009 ug/g were found in the two graceful crab samples analyzed from Ostrich Bay. Within individual waterbodies, inorganic arsenic concentrations varied by 12% or less in most cases.

Total arsenic concentrations ranged from 1.9 to 4.2 ug/g in clams and 8.4 to 12 ug/g in crabs. Inorganic arsenic was 0.4 - 1.2 % of total arsenic in clams, but only 0.1% of the total in crabs.

All clams from 303(d) listed waterbodies exceeded the 0.006 ug/g inorganic arsenic criterion. However, clams collected from the Hood Canal and Sequim Bay reference areas had 0.015 and 0.035 ug/g inorganic arsenic, respectively, bracketing the concentrations found in 303(d) waterbodies. This finding suggests that inorganic arsenic concentrations in this range are naturally occurring in Puget Sound clams.

The inorganic arsenic concentrations reported in the Ostrich Bay graceful crab samples (0.008 and 0.009 ug/g) slightly exceeded the listing criterion. There is enough uncertainty associated with inorganic arsenic measurements at this low level to question whether the criterion was truly exceeded. As shown in Table 2, results from two samples (238080 and -88) analyzed in duplicate in conjunction with the crab tissues differed by 0.01 ug/g.

Other Local Data

Yilmazer et al. (2001) summarized the existing data on inorganic arsenic concentrations in Puget Sound fish and shellfish (Table 6). These samples were analyzed by Battelle using the same methods as in the present report.

Table 6. Inorganic Arsenic Data for Puget Sound Fish and Shellfish Composite Samples
[ug/g wet weight; parts per million]

Species	Location	N =	Total Arsenic	Inorganic Arsenic	% Inorganic
Sand dab	Commencement Bay	18	4.5	0.01	0.2
Rock sole	Commencement Bay	2	17	0.05	0.3
Red rock crab*	Commencement Bay	4	3.6	0.03	0.8
Littleneck clam	Marrowstone Island	12	2.2	0.02	0.9
Cockle clam	Marrowstone Island	9	1.1	0.02	1.8
Oyster	Marrowstone Island	1	2.1	0.01	0.5
Littleneck clam*	Sequim Bay	3	6.9	0.02	0.3

Median value as summarized by Yilmazer (2001)
*cooked

The inorganic arsenic levels Yilmazer et al. report for clam and oyster tissues are in the same range as the clam samples analyzed for the present study. Substantially higher concentrations, however, are reported in fish and crab than in similar samples from the WDFW archives. This could be because different species were analyzed and that the samples came from arsenic contaminated Commencement Bay. It should be noted that several of Battelle's results for the present study were in the same range as the higher concentrations shown for Commencement Bay rock sole and red rock crab in Table 6, but these were discounted for reasons described above.

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Conclusions and Recommendations

Among the eight Puget Sound fish and shellfish species evaluated in the present study, clams had the highest levels of inorganic arsenic, followed by crabs and fish, in that order. Inorganic arsenic was 0.4 - 1.2 % of total arsenic in clams, and typically 0.2% or less of the total in crabs and fish.

The 303(d) listing criterion of 0.006 ug/g inorganic arsenic was exceeded in all clam samples analyzed. This appears to be due to natural conditions in Puget Sound, based on a comparison with reference areas used in the study. All crab and fish samples were at or below the listing criterion.

It is therefore recommended that the following Puget Sound waterbodies be removed from the 1998 303(d) list for arsenic exceedances of the EPA human health criterion:

- Dyes Inlet and Port Washington Narrows (WA-15-0050) – 7 listings
- Sinclair Inlet (WA-15-0040) – 2 listings
- Port Orchard (WA-15-0030) – 2 listings
- Eagle Harbor (WA-15-0020) – 1 listing

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Appendices

Appendix A. Scientific Names of Species Referred To in This Report

Fish
C-O sole *Pleuronichthys coenosus*
English sole *Pleuronectes vetulus*
Sand sole *Psettichthys melanostictus*
Flathead sole *Hippoglossoides elassodon*
Quillback rockfish *Sebastes maliger*
Coho salmon *Oncorhynchus kisutch*
Pacific herring *Clupea harengus pallasi*

Clams
Japanese littleneck *Tapes japonica*
Native littleneck *Protothaca staminea*
Butter clam *Saxidomus giganteus*
Horse clam *Tresus nuttalli*

Crabs
Dungeness crab *Cancer magister*
Graceful crab *Cancer gracilis*

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Appendix B-1. Battelle Arsenic Speciation Data (Original Results)

[Note. Data flags U, J, UJ, NJ added by Ecology Manchester Environmental Laboratory]
Project: WDOE (Washington State Dept of Ecology)
CF: 1753
Add#: Kit
Matrix: Tissue digested in 2N NaOH @ 80 C overnite

				Original results reported			
MSL Code	Client ID	Analysis Date	Analyte	Conc ug/g Wet Wt Flag	MDL	% Recv /RPD	MS/MSD RPD
1753 Blank		1/11/02	inorg As	0 >	0.0135		
1753 Blank		1/11/02	MMA	0 >	0.0071		
1753 Blank		1/11/02	DMA	0 >	0.0056		
1753 Blank		2/6/02	Total As	0.014 >	0.0915		
1753-1	498080	1/11/02	inorg As	0 UJ	0.1259		
1753-1	498080	1/11/02	MMA	0 UJ	0.0666		
1753-1	498080	1/11/02	DMA	0.0511 J	0.0526		
1753-1	498080	2/6/02	Total As	10.4	0.0915		
1753-2	498081	1/11/02	inorg As	0.0090 NJ	0.0514		
1753-2	498081	1/11/02	MMA	0 UJ	0.0272		
1753-2	498081	1/11/02	DMA	0.0284 J	0.0215		
1753-2	498081	2/6/02	Total As	12.3	0.0915		
1753-3	498082	1/11/02	inorg As	0 UJ	0.0499		
1753-3	498082	1/11/02	MMA	0 UJ	0.0264		
1753-3	498082	1/11/02	DMA	0.0214 J	0.0208		
1753-3	498082	2/6/02	Total As	8.45	0.0915		
1753-4	498083	1/11/02	inorg As	0 UJ	0.0483		
1753-4	498083	1/11/02	MMA	0 UJ	0.0256		
1753-4	498083	1/11/02	DMA	0.0187 J	0.0202		
1753-4	498083	2/6/02	Total As	9.99	0.0915		
1753-5 R-1	498084	1/11/02	inorg As	0 UJ	0.0525		
1753-5 R-1	498084	1/11/02	MMA	0 UJ	0.0278		
1753-5 R-1	498084	1/11/02	DMA	0 UJ	0.0219		
1753-5 R-1	498084	2/6/02	Total As	0.915	0.0915		
1753-5 R-2	498084	1/11/02	inorg As	0 UJ	0.0523		
1753-5 R-2	498084	1/11/02	MMA	0 UJ	0.0277		
1753-5 R-2	498084	1/11/02	DMA	0 UJ	0.0218		
1753-5 R-2	498084	2/6/02	Total As	0.907	0.0915		
1753-5 R-3	498084	1/11/02	inorg As	0 UJ	0.0518		
1753-5 R-3	498084	1/11/02	MMA	0 UJ	0.0274		
1753-5 R-3	498084	1/11/02	DMA	0 UJ	0.0216		
1753-5 R-3	498084	2/6/02	Total As	0.843	0.0915	4%	

				Original results reported			
MSL Code	Client ID	Analysis Date	Analyte	Conc ug/g Wet Wt. Flag	MDL	% Recv /RPD	MS/MSD RPD
1753-5 MS	498084	1/14/02	inorg As	1.55 J	0.2528	83%	
1753-5 MS	498084	1/14/02	MMA	1.60 J	0.1338	86%	
1753-5 MS	498084	1/14/02	DMA	2.16 J	0.1055	116%	
1753-5 MS	498084	2/6/02	Total As	6.68	0.0915	97%	
1753-5 MSD	498084	1/14/02	inorg As	1.53 J	0.2531	82%	1%
1753-5 MSD	498084	1/14/02	MMA	1.55 J	0.1339	84%	3%
1753-5 MSD	498084	1/14/02	DMA	2.20 J	0.1056	118%	2%
1753-5 MSD	498084	2/6/02	Total As	6.21	0.0915	89%	
1753-6	498085	1/14/02	inorg As	0 UJ	0.0520		
1753-6	498085	1/14/02	MMA	0 UJ	0.0275		
1753-6	498085	1/14/02	DMA	0.0143 J	0.0217		
1753-6	498085	2/6/02	Total As	2.38	0.0915		
1753-7	498086	1/11/02	inorg As	0 UJ	0.0519		
1753-7	498086	1/11/02	MMA	0 UJ	0.0275		
1753-7	498086	1/11/02	DMA	0.0112 J	0.0217		
1753-7	498086	2/6/02	Total As	2.03	0.0915		
1753-8	498087	1/14/02	inorg As	0 UJ	0.0496		
1753-8	498087	1/14/02	MMA	0 UJ	0.0262		
1753-8	498087	1/14/02	DMA	0.123 J	0.0207		
1753-8	498087	2/6/02	Total As	4.96	0.0915		
1753-9	498088	1/14/02	inorg As	0 UJ	0.0498		5%
1753-9	498088	1/14/02	MMA	0 UJ	0.0264		
1753-9	498088	1/14/02	DMA	0.119 J	0.0208		
1753-9	498088	2/6/02	Total As	3.29	0.0915		
1753-10 R-1	498089	1/14/02	inorg As	0 >	0.0526 UJ		
1753-10 R-1	498089	1/14/02	MMA	0 >	0.0278 UJ		
1753-10 R-1	498089	1/14/02	DMA	0.108 J	0.0220		
1753-10 R-1	498089	2/6/02	Total As	3.80	0.0915		
1753-10 R-2	498089	1/14/02	inorg As	0 >	0.0516 UJ		
1753-10 R-2	498089	1/14/02	MMA	0 >	0.0273 UJ		
1753-10 R-2	498089	1/14/02	DMA	0.106 J	0.0215		
1753-10 R-2	498089	2/6/02	Total As	3.84	0.0915		
1753-10 R-3	498089	1/14/02	inorg As	0 >	0.0546 UJ	0%	
1753-10 R-3	498089	1/14/02	MMA	0 >	0.0289 UJ	0%	
1753-10 R-3	498089	1/14/02	DMA	0.122 j	0.0228	1%	
1753-10 R-3	498089	2/6/02	Total As	3.83	0.0915	1%	

Original results reported

MSL Code	Client ID	Analysis Date	Analyte	Conc ug/g Wet Wt.	Flag	MDL	% Recv /RPD	MS/MSD RPD
1753-11	498090	1/14/02	inorg As	0	>	0.0537 UJ		
1753-11	498090	1/14/02	MMA	0	>	0.0284 UJ		
1753-11	498090	1/14/02	DMA	0.0258	J	0 0224		
1753-11	498090	2/6/02	Total As	0.350		0 0915		
1753-12	498091	1/14/02	inorg As	0	>	0.0504 UJ		
1753-12	498091	1/14/02	MMA	0	>	0.0267 UJ		
1753-12	498091	1/14/02	DMA	0	>	0 0210		
1753-12	498091	2/6/02	Total As	0.293		0.0915		
1753-13	498092	1/14/02	inorg As	0	>	0.0493 UJ		
1753-13	498092	1/14/02	MMA	0	>	0.0261 UJ		
1753-13	498092	1/14/02	DMA	0	>	0.0206		
1753-13	498092	2/6/02	Total As	0.336		0 0915		
1753-14	498093	1/14/02	inorg As	0	>	0.0485 UJ		
1753-14	498093	1/14/02	MMA	0	>	0.0267 UJ		
1753-14	498093	1/14/02	DMA	0.0554	J	0 0202		
1753-14	498093	2/6/02	Total As	0.982		0 0915		
1753-15	498094	1/14/02	inorg As	0	>	0.0485 UJ		
1753-15	498094	1/14/02	MMA	0	>	0.0256 UJ		
1753-15	498094	1/14/02	DMA	0 224	J	0 0202		
1753-15	498094	2/6/02	Total As	1.82		0 0915		
1753-16	498095	1/14/02	inorg As	0	>	0.0526 UJ		
1753-16	498095	1/14/02	MMA	0	>	0.0278 UJ		
1753-16	498095	1/14/02	DMA	0.270	J	0 0219		
1753-16	498095	2/6/02	Total As	2 04		0 0915		

Battelle data qualifiers:
- > Reported below MDL
- V Interferring peaks
- NA Not available
- NR Results not reported

Ecology data qualifiers:
U = The analyte was not detected at or above the reported result.
J = The analyte was positively identified. The associated numerical result is an estimate.
UJ = The analyte was not detected at or above the reported estimated result.
NJ = There is evidence that the analyte is present. The associated numerical result is an estimate.

NOTE: Total arsenic results reported from ICP-MS, Batch ID# 020602-6100A

Appendix B-1. Battelle Arsenic Speciation Data (Re-analysis)

[Note Data flags U, J, UJ, NJ added by Ecology Manchester Environmental Laboratory]
Project WDOE (Washington State Dept of Ecology)
CF: 1753
Add#. Kit
Matrix: Tissue digested in 2N NaOH @ 80 C overnite

Re-analysis at increased sample volume (2 mL)

MSL Code	Analysis Date	Conc ug/g Wet Wt.	Flag	MDL	% Recv /RPD	MS/MSD %Recv
1753 Blank	2/7/02	0.000798	J	0.00043		
1753 Blank	2/7/02	0.002	U	0 00085		
1753 Blank	2/7/02	NR		0.00184		
1753 Blank						
1753-1	2/8/02	0.00132	NJ	0.00184		
1753-1	2/8/02	0.0019	J	0.000402		
1753-1	2/8/02	NR				
1753-1						
1753-2	2/8/02	0.000862	NJ	0.00188		
1753-2	2/8/02	0.00178	NJ	0 00041		
1753-2	2/8/02	NR				
1753-2						
1753-3	2/8/02	0.044	NJ	0.00182		
1753-3	2/8/02	0.00167	NJ	0.000397		
1753-3	2/8/02	NR				
1753-3						
1753-4	2/8/02	0.00352	NJ	0.00176		
1753-4	2/8/02	0.00101	NJ	0.000384		
1753-4	2/8/02	NR				
1753-4						
1753-5 R-1	2/8/02	0.00200	NJ	0.00191		
1753-5 R-1	2/8/02	0.00187	J	0.000418		
1753-5 R-1	2/8/02	NR				
1753-5 R-1						
1753-5 R-2	2/8/02	0.00111	NJ	0.00190		
1753-5 R-2	2/8/02	0.00211	J	0.000414		
1753-5 R-2	2/8/02	NR				
1753-5 R-2						
1753-5 R-3	2/8/02	0.031	NJ	0.00189	NA	
1753-5 R-3	2/8/02	0.00196		0 000413	6%	
1753-5 R-3	2/8/02	NR				
1753-5 R-3						

	Re-analysis at increased sample volume (2 mL)				
MSL Code	Analysis Date	C+M69onc ug/g Wet Wt. Flag	MDL	% Recv /RPD	MS/MSD %Recv
1753-5 MS	2/8/02	0 00993 NJ	0.00189		73%
1753-5 MS	2/8/02	0.00519 NJ	0.000413		24%
1753-5 MS	2/8/02	NR			
1753-5 MS					
1753-5 MSD		NA	NA		
1753-5 MSD		NA	NA		
1753-5 MSD		NA	NA		
1753-5 MSD					
1753-6	2/8/02	0.0317 NJ	0.00190		
1753-6	2/8/02	0.00310	0.000414		
1753-6	2/8/02	NR			
1753-6					
1753-7	2/8/02	0 00133 NJ	0 00190		
1753-7	2/8/02	0.00344	0.000414		
1753-7	2/8/02	NR			
1753-7					
1753-8	2/8/02	0.00264 J	0.00181		
1753-8	2/8/02	0.00057 J	0.000395		
1753-8	2/8/02	NR			
1753-8					
1753-9	2/12/02	0.00133 NJ	0.00183		
1753-9	2/12/02	0.00133 J	0.000398		
1753-9	2/12/02	NR			
1753-9					
1753-10 R-1	2/12/02	0.00287 J	0.00192		
1753-10 R-1	2/12/02	0.000835 J	0.000418		
1753-10 R-1	2/12/02	NR			
1753-10 R-1					
1753-10 R-2	2/12/02	0.00282	0.00188		
1753-10 R-2	2/12/02	0.000626	0.000410		
1753-10 R-2	2/12/02	NR			
1753-10 R-2					
1753-10 R-3	2/12/02	0.00142 NJ	0.00192	35%	
1753-10 R-3	2/12/02	0.00135	0 000418	40%	
1753-10 R-3	2/12/02	NR			
1753-10 R-3					

	Re-analysis at increased sample volume (2 mL)				
MSL Code	Analysis Date	Conc ug/g Wet Wt. Flag	MDL	% Recv /RPD	MS/MSD %Recv
1753-11	2/12/02	0.000621 NJ	0.00195		
1753-11	2/12/02	0.000485 J	0.000426		
1753-11	2/12/02	NR			
1753-11					
1753-12	2/12/02	0.00176 NJ	0.00184		
1753-12	2/12/02	0 00208 NJ	0.000402		
1753-12	2/12/02	NR			
1753-12					
1753-13	2/12/02	0.000734 NJ	0.00179		
1753-13	2/12/02	0.000495 J	0.000391		
1753-13	2/12/02	NR			
1753-13					
1753-14	2/12/02	0.000795 NJ	0.00177		
1753-14	2/12/02	0.000449 J	0 000387		
1753-14	2/12/02	NR			
1753-14					
1753-15	2/12/02	0.00047 NJ	0.00177		
1753-15	2/12/02	0.000224 NJ	0.000387		
1753-15	2/12/02	NR			
1753-15					
1753-16	2/12/02	0.000989 NJ	0.00192		
1753-16	2/12/02	0.000638 J	0.000418		
1753-16	2/12/02	NR			
1753-16					

> Reported below MDL
V Interferring peaks
NA Not available
NR Results not reported

Ecology data qualifiers:
U = The analyte was not detected at or above the reported result.
J = The analyte was positively identified. The associated numerical result is an estimate.
UJ = The analyte was not detected at or above the reported estimated result.
NJ = There is evidence that the analyte is present. The associated numerical result is an estimate.

NOTE: Total arsenic results reported from ICP-MS, Batch ID# 020602-6100A

Appendix B-2. Brooks Rand Arsenic Speciation Data (ug/g, wet weight)

Tracking	Client ID	Collection Date	Analysis	Analysis Date	Batch	Result	Qualifier
02BR539	02238080	4/29/02	As(Dimethyl)	10/18/02	02-275	1.87	
02BR539	02238080	4/29/02	As(III)	10/16/02	02-274	0.033	
02BR539	02238080	4/29/02	As(Inorganic)	10/21/02	02-273	0.035	
02BR539	02238080	4/29/02	As(Monomethyl)	10/21/02	02-272	0.005	B
02BR539	02238081	5/29/02	As(Dimethyl)	10/18/02	02-275	0.928	
02BR539	02238081	5/29/02	As(III)	10/16/02	02-274	0.017	B
02BR539	02238081	5/29/02	As(Inorganic)	10/21/02	02-273	0.015	
02BR539	02238081	5/29/02	As(Monomethyl)	10/21/02	02-272	0.003	B
02BR539	02238082	4/28/02	As(Dimethyl)	10/18/02	02-275	1.27	
02BR539	02238082	4/28/02	As(III)	10/16/02	02-274	0.023	B
02BR539	02238082	4/28/02	As(Inorganic)	10/21/02	02-273	0.021	
02BR539	02238082	4/28/02	As(Monomethyl)	10/21/02	02-272	0.003	B
02BR539	02238083	4/27/02	As(Dimethyl)	10/18/02	02-275	0.555	
02BR539	02238083	4/27/02	As(III)	10/16/02	02-274	0.025	B
02BR539	02238083	4/27/02	As(Inorganic)	10/21/02	02-273	0.02	
02BR539	02238083	4/27/02	As(Monomethyl)	10/21/02	02-272	0.002	B
02BR539	02238084	6/13/02	As(Dimethyl)	10/18/02	02-275	0.956	
02BR539	02238084	6/13/02	As(III)	10/16/02	02-274	0.018	B
02BR539	02238084	6/13/02	As(Inorganic)	10/21/02	02-273	0.017	
02BR539	02238084	6/13/02	As(Monomethyl)	10/21/02	02-272	0.006	
02BR539	02238085	6/13/02	As(Dimethyl)	10/18/02	02-275	1.22	
02BR539	02238085	6/13/02	As(III)	10/16/02	02-274	0.021	B
02BR539	02238085	6/13/02	As(Inorganic)	10/21/02	02-273	0.018	
02BR539	02238085	6/13/02	As(Monomethyl)	10/21/02	02-272	0.006	
02BR539	02238086	6/13/02	As(Dimethyl)	10/18/02	02-275	0.686	
02BR539	02238086	6/13/02	As(III)	10/16/02	02-274	0.016	B
02BR539	02238086	6/13/02	As(Inorganic)	10/21/02	02-273	0.016	
02BR539	02238086	6/13/02	As(Monomethyl)	10/21/02	02-272	0.003	B
02BR539	02238087	5/15/02	As(Dimethyl)	10/18/02	02-275	0.647	
02BR539	02238087	5/15/02	As(III)	10/16/02	02-274	0.023	B
02BR539	02238087	5/15/02	As(Inorganic)	10/21/02	02-273	0.02	
02BR539	02238087	5/15/02	As(Monomethyl)	10/21/02	02-272	0.003	B
02BR539	02238088	5/1/02	As(Dimethyl)	10/18/02	02-275	1.11	
02BR539	02238088	5/1/02	As(III)	10/16/02	02-274	0.028	
02BR539	02238088	5/1/02	As(Inorganic)	10/21/02	02-273	0.026	
02BR539	02238088	5/1/02	As(Monomethyl)	10/21/02	02-272	0.003	B
02BR539	02238089	5/1/02	As(Dimethyl)	10/18/02	02-275	0.75	
02BR539	02238089	5/1/02	As(III)	10/16/02	02-274	0.026	
02BR539	02238089	5/1/02	As(Inorganic)	10/21/02	02-273	0.022	
02BR539	02238089	5/1/02	As(Monomethyl)	10/21/02	02-272	0.002	B
02BR539	02238090	7/19/02	As(Dimethyl)	10/18/02	02-275	0.7	
02BR539	02238090	7/19/02	As(III)	10/16/02	02-274	0.018	B
02BR539	02238090	7/19/02	As(Inorganic)	10/21/02	02-273	0.015	
02BR539	02238090	7/19/02	As(Monomethyl)	10/21/02	02-272	0.002	B
02BR539	01428082	7/19/02	As(Dimethyl)	10/18/02	02-275	1.23	
02BR539	01428082	7/19/02	As(III)	10/16/02	02-274	0.023	B
02BR539	01428082	7/19/02	As(Inorganic)	10/21/02	02-273	0.021	
02BR539	01428082	7/19/02	As(Monomethyl)	10/21/02	02-272	0.005	
02BR539	01428085	8/31/02	As(Dimethyl)	10/18/02	02-275	0.538	
02BR539	01428085	8/31/02	As(III)	10/16/02	02-274	0.023	B
02BR539	01428085	8/31/02	As(Inorganic)	10/21/02	02-273	0.022	
02BR539	01428085	8/31/02	As(Monomethyl)	10/21/02	02-272	0.002	B
02BR539	01428086	9/5/02	As(Dimethyl)	10/18/02	02-275	0.25	
02BR539	01428086	9/5/02	As(III)	10/16/02	02-274	0.01	B
02BR539	01428086	9/5/02	As(Inorganic)	10/21/02	02-273	0.008	
02BR539	01428086	9/5/02	As(Monomethyl)	10/21/02	02-272	0.002	U
02BR539	01428087	9/5/02	As(Dimethyl)	10/18/02	02-275	0.32	
02BR539	01428087	9/5/02	As(III)	10/16/02	02-274	0.011	B
02BR539	01428087	9/5/02	As(Inorganic)	10/21/02	02-273	0.009	
02BR539	01428087	9/5/02	As(Monomethyl)	10/21/02	02-272	0.002	U

B = Detected above Method Detection Limit but less than Practical Quantitation Limit. Measured result is reported and considered an estimate

Appendix C. Location of Ecology Clam and Crab Samples Collected for Arsenic Speciation Analysis

Waterbody / Location	Species	Latitude*	Longitude*	Description
Dyes Inlet				
Silverdale	Clam**	47 38.592	122 41.713	Silverdale Waterfront Park 40' west of boat ramp
Ostrich Bay NW	Clam	47 35.39	122 41.20	North 175' of outfall pipe; down beach from stairs
Ostrich Bay W	Clam	47 35.06	122 41.27	Housing complex on waterfront
Ostrich Bay SW	Clam	47 34.80	122 41.10	At end of Shorewood Road
Ostrich Bay	Crab***	47 35 30 - 47 34.766	122 41.10- 122 41.083	Off west shore in vicinity of Jackson Park
Oyster Bay	Clam	47 34.185	122 40.393	In front of Oyster Bay Inn
Port Washington Narrows				
Lions Park	Clam	47 35.173	122 38.70	Beach on northwest side of boat launch
Evergreen Park	Clam	47 34.497	122 37.572	Beach on north side of boat launch
Sinclair Inlet				
Port Orchard	Clam	47 32.51	122 38.35	East of public boat ramp
Annapolis	Clam	47 32.90	122 36.86	Southeast of public piers
Eagle Harbor				
Wing Point	Clam	47 37.200	122 29.317	North side of wing point sand spit
Winslow Park	Clam	47 37.317	122 31.000	Just north and south of park dock
Hood Canal				
Twanoh State Park	Clam	47 22 651	122 58.550	Beach in front of concessions stand, east of roped-off swim area
Sequim Bay				
Sequim Bay State Park	Clam	48 02.583	123 01.600	A few feet south of the wooden bulkhead at the boat ramp

*NAD 83
** mixed native and Japanese littleneck clams
***graceful crab

Appendix D. Biological Data for WDFW Fish and Crab Samples

Species	Ecology Sample No	N=	Age Avg	Age Min	Age Max.	Length (mm) Avg	Length (mm) Min.	Length (mm) Max.	Length Type*	Weight (g) Avg.	Weight (g) Min.	Weight (g) Max
English sole	498080	15	5.1	4	6	354	296	412	TL	--	--	--
English sole	498081	15	5 1	4	6	287	222	421	TL	--	--	--
English sole	498082	15	5 1	4	6	300	246	392	TL	--	--	--
English sole	498083	15	4.9	3	6	280	247	322	TL	--	--	--
Quillback rockfish	498084	12	13.9	8	20	312	280	361	TL	--	--	--
Quillback rockfish	498085	12	7 0	4	12	320	246	370	TL	--	--	--
Quillback rockfish	498086	8	20 8	7	42	399	275	449	TL	--	--	--
Dungeness crab	498087	11	--	--	--	177	153	203	CW	--	--	--
Dungeness crab	498088	11**	--	--	--	177	157	195	CW	--	--	--
Dungeness crab	498089	12				160	150	169	CW	--	--	--
Coho salmon	498090	12	3.0	3	3	595	495	676	FL	2659	1598	4341
Coho salmon	498091	12	3.0	3	3	566	468	613	FL	2448	1508	3183
Coho salmon	498092	12	3 0	3	3	585	512	670	FL	2812	1711	4845
Pacific herring	498093	15	2 8	2	3	173	152	198	SL	74	54	95
Pacific herring	498094	15	2 8	2	3	172	163	195	SL	64	51	100
Pacific herring	498095	15	2 8	2	3	155	149	161	SL	47	42	54

*TL = total length, CW = carapace width, FL = fork length, SL = standard length
**biological data missing for one specimen