Suitability of two sand bars near the Native Village of Eyak for the enhancement of razor clams (*Siliqua patula*)

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1. Introduction. The Native Village of Eyak has traditionally harvested razor clams from nearby beaches and sandbars for subsistence and commercial purposes. The 1964 earthquake, which registered between 8.4 and 8.6 on the Richter Scale, raised most of the Copper River Delta 1.8 to 3.4 m (Thilenius, 1995). Razor clam populations in the Cordova area had begun declining before the earthquake. Barrett (1966) describes the uplifting that occurred in the Cordova area with significant losses of clam resources. Razor clam populations near Cordova have remained depressed every since. In 2004, the Village obtained funding under the USFWS Tribal Landowner Incentive Program for a razor clam rehabilitation project in an effort to revitalize this once important native fishery. As part of that project, Aquatic Environmental Sciences was retained to evaluate clam habitat in an effort to identify physicochemical characteristics that might be inhibiting recruitment, growth and/or survival of razor clams. This paper reports the results of the analysis of sediments for grain size distribution (SGS), total volatile solids (TVS), free sediment sulfides ($S^{=}$) and sediment redox potential (ORP). In addition, substrate elevations were determined using a theodolyte and stadium along selected transects laid out orthogonal to the waterline. An effort was also made to collect razor clams for use as brood stock in the hatchery-nursery phase of the rehabilitation project.

2. Background. Nickerson (1975) observed razor clams between ca. -30’ to + 4’ near Cordova (Table 31 of his paper). Highest clam densities occurred between -6’ and +3’. Few (0.4%) of the clams were found at +4.0’ and no clams were found at +5.0’ or above. Based on a literature search, Nickerson (1975 - Table 33) estimated an upper habitable tide level for razor clams that increased from a low of +1.97’ MLLW at Pismo, California to +6.26’ MLLW in Cook Inlet, Alaska. The estimated upper limit for Cordova was 4.50’ MLLW. He reported that the March 27, 1964 earthquake occurred at low tide when large portions of the tidal flats were exposed. An uplift of nearly 6 feet (2 m) was associated with the earthquake at Cordova. Tsunamis and seiches, as high as 24.6 feet (7.5 m) at Cordova, eroded at least 29.92 inches (76 cm) of surface sediment over large portions of the uplifted tidal flats (Reimnitz, op.cit.). He noted that clay layers were exposed on extensive tidal areas along Orca Inlet. These areas were located windward of poorly producing razor clam beds. It appeared that surface currents were removing clay fractions from exposed layers and re-depositing them in adjoining areas supporting marginal razor clam stocks.

Nickerson (1975) characterized silt as being <20 μm and clay <5 μm. On the Wentworth scale, silt particles are <0.63 μm and clay is <4 μm. However, in Table 36 of Nickerson (1975), he included particle sizes <74 μm. For 10 traditional razor clam beaches near Cordova, he found mean particle size diameters of 116 to 168 μm, all of which were characterized as fine sand. The percent silt and clay in these samples varied between 0.77% and 2.87%. If one adds the 20 to 74 μm fraction, these values are 1.17 to 8.3%. He estimated that maximum clay fraction (< 4 μm) tolerated by razor clams was 2.2% of the total particle size distribution because the clay was hypothesized to cause suffocation in the clam’s early life stages. This hypothesis was supported by the absence of one year old razor clams from Cordova bars where clay represented >2.0% of the substrate.

Lassuy and Simons (1989) described razor clam habitat as stable, open ocean, fully exposed, surf pounded, broad, flat, uniform, hard, and sandy. He quoted McMillin’s (1924) suggestion that fine-grained sand and gentle slopes aid in retaining pore water. The authors noted that good razor clam habitat has little organic carbon. This observation is consistent with that of Browning (1980) who suggested that razor clams, being highly active, require high concentrations of dissolved oxygen associated with fast currents and high surf. Hirschhorn's (1962) conclusion that highly productive razor clam beaches have fine grained sandy sediments with uniform particle sizes ranging from 160 to 190 μm adds to the consistency of these findings. He also noted that densities of razor clams were highest on beaches with <0.85% clay (<5 μm).

Bishop (2003) attributed the decline in Cordova area razor clam populations to a combination of factors including primarily over-harvesting and unspecified habitat changes. She concluded that the 1964 earthquake changed habitats but that their surveys revealed that "sufficient habitat is available in the area and thus is probably not limiting successful recruitment." Their study determined the percent sand and combined silt and clay. The values are given in Table (1) along with values observed during the surveys conducted in support of this report. Clam densities were estimated on Rock Quarry Bar at $0.41 \pm 0.40/m^2$ and $0.03 \pm 0.01/m^2$ on Bud's Bar. No clams were found at Hartney Bay or in the West Copper River Delta at Eyak or Pete Dahl. Point Steele, which had the lowest percent silt and clay, had the highest clam density ($0.62 \pm 0.12/m^2$).

Table 1. Sediment grain size distribution on six traditional razor clam beaches as measured by Bishop (2003) and Brooks (2004).

	Bishop (2004)		May 2004 Survey		
Site	% sand	% silt & clay	% fine sand	% silt	%clay
Hartney Bay	91	8			
Rock Quarry	90	6	87.57 to 91.37%	2.83 to 6.99%	3.16 to 9.21%
Bud's Bar. Named Grassy Island in this report.	90	6	84.33 to 91.86%	1.74 to 6.30%	3.64 to 7.11%
Pt. Steele Beach	99	<1			
Eyak	83	8			
Pete Dahl	52	23			

Ray (2002) quoted Rickard *et al's.* (1988) finding of high densities ($38,000/m^2$) of juvenile razor clams having a mean valve length of 2.0 mm in 12.2 m of water adjacent to Copalis Beach, Washington. They hypothesized that either the juveniles settle in deep water and migrate to shallower depths or that there is strong differential growth and mortality between intertidal and subtidal populations.

The results of this report will be interpreted in light of these previous studies, which suggest that razor clam recruitment and survival is inhibited when the clay content of sediments exceeds 2.2%; that fine sand sediments (160 to 190 μm mean particle size) having low organic content (TVS) are preferred; and that razor clams do not tolerate low dissolved oxygen (Redox) conditions. No information regarding the sulfide tolerance of razor clams was found and Brooks (2001a) observed that all of the mollusks for which data was available tolerated >135 $\mu M\ S^{=}$.

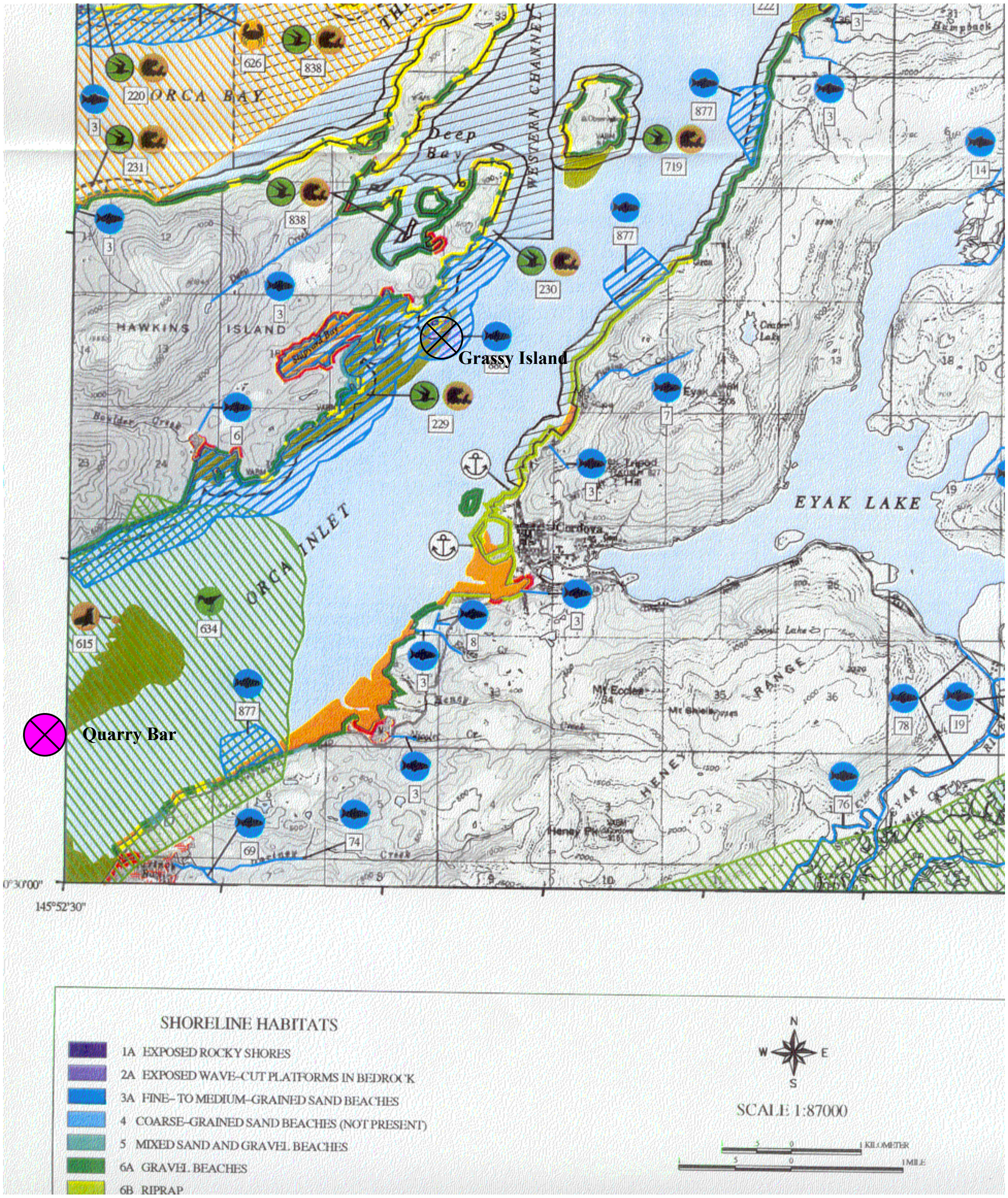

Figure 1. Site map depicting the location of two areas where razor clams and razor clam habitat was evaluate on May 18, 2004 (Quarry Bar) and May 19, 2004 (Grassy Island).

3. Materials and methods. Two sites, where razor clams were traditionally harvested, were chosen by Mr. Jeff Hetrick and Mr. Bud Janson prior to the sampling, which occurred on May 18, 2004 at Quarry Bar and on May 19, 2004 at Grassy Island during predicted low tides of -1.4 and -1.6' MLLW respectively. The locations of Quarry Bar and Grassy Island are provided in Figure 1. Quarry Bar currently has small numbers of razor clams and Grassy Island appears depauperate with respect to this species. The following sections describe specific protocols invoked for these surveys.

3.1. Sampling design. Razor clams occupy depths to 1.0 m. Due to equipment limitations, these surveys will rely on sediment cores to a depth of 60 cm. The systematic random sample strategy is defined in Figure 2. Upon arrival at each beach, a reconnaissance survey was initiated to identify areas with highest clam densities as evidenced by "shows." A baseline was then established to the left facing upland from the water's edge. A hand-held theodolyte and stadium were then used to estimate tidal elevations and the GPS coordinates of the south and northern ends of each transect recorded. A 300' fiberglass tape was laid out parallel to the waterline and red wire flags placed at the distances indicated in Figure 2.

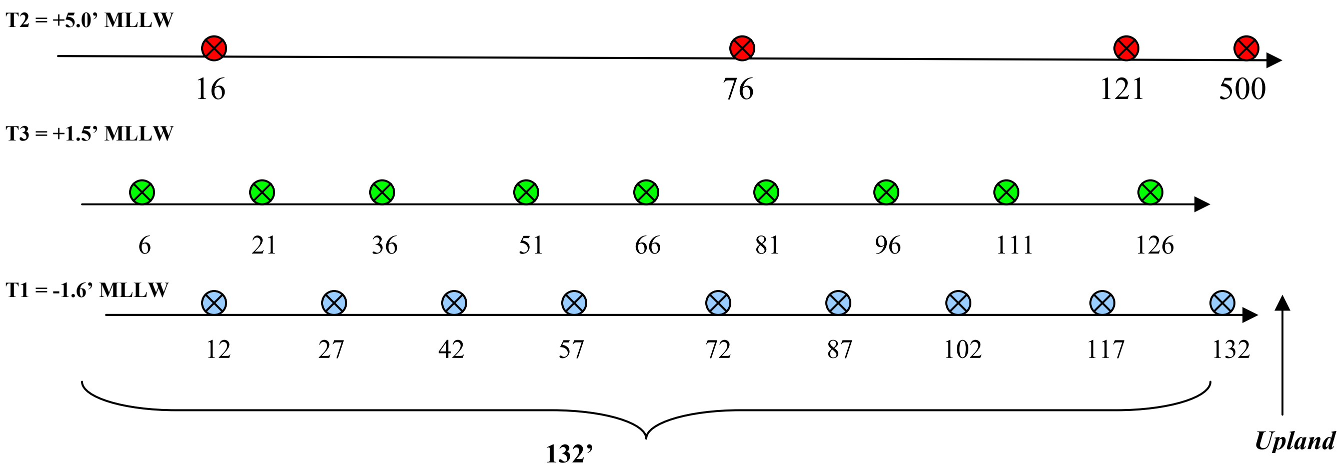

Figure 2. Systematic random sample design for sediment sampling at Quarry Bar near Cordova, Alaska. The samples are spaced 15' apart on T1 and T3 and 60' apart on T2 because of the exceptionally high tidal elevation.

The red wire flags will be pre-labeled to indicate tidal height and sample number (i.e. –1.6 (1) through –1.6 (9). Numbers start on the left facing the upland with water at your back.

3.2. Sediment sampling. Each survey will begin with a reconnaissance survey in which cores will be collected without liners and laid out on the beach. Each core will be examined for buried organic debris, sulfidic conditions (darkening associated with iron sulfides or the smell of hydrogen sulfide), and gross characteristics of the sediment grain size distribution as a function of depth. Core samples for analysis were collected to a depth of 60 cm using a 1-1/8" x 24" AMS Unslotted Soil Recovery Probe.. The corer uses 1" x 24" Butyrate Plastic Liners (No. 7753). The lines are capped with Polyethylene Liner Caps (No.77536). The corer was pushed vertically into the substrate to the depth of the probe; turned 180 degrees to break the column and pulled straight out. Prelabeled caps were then placed on the ends of the inserts and they were stored on ice while in the field. Additional samples sufficient to fill prelabeled 125 ml urine specimen cups were collected from the top 2.0 cm of sediments.

3.3. Sample evaluation. The following observations were recorded on the field log sheet:

- Color
- Biological structures (shells, tubes, macrophytes)
- Presence and depth of debris (woody debris, macroalgae, eelgrass detritus, etc.

3.4. Sample processing. Samples were pushed from their Polyethylene Liners onto a cafeteria tray and sectioned into 20 cm intervals and placed in 125 ml urine specimen jars (four samples per core).The labels on the jars followed the code previously described with the addition of depth (i.e. 0 to 2 cm; 0 to 20 cm; 20 to 40 cm and 40 to 60 cm). The cups were held on ice or in a refrigerator until analyzed for TVS and SGS at Aquatic Environmental Sciences within two weeks of collection. Free sediment sulfides and redox potential were determined at a shore station within 6 hours of collecting each sample.

3.5. Physicochemical analyses. The following analyses were completed.

Total Volatile Solids (TVS) analysis. Approximately 35 ml of each sample was used for TVS analysis using Standard Method 2540.E. Samples were dried at 103 $\pm$ 2 ^{o}C in new aluminum boats that have been pre-cleaned by combusting at 550 ^{o}C for 30 minutes. Drying continued until there was no further weight loss in a 30 minute period. The samples were then weighed to the nearest 0.1 milligram on a four place precision balance and combusted at 550 ^{o}C for one hour or until there was no further weight loss in a 30 minute period. Total Volatile Solids were calculated as the percent difference between the dried and combusted weights.

Quality assurance required triplicate analyses on one of every 20 samples or on one sample per batch if fewer than 20 samples are analyzed. A maximum of 20 percent Relative Standard Deviation is established as the Data Qualification Control Limit for this study.

Sediment Grain Size (SGS) analyses will be conducted on an additional 35 grams of sediment using Plumb (1981). The samples were wet sieved on 0.064 mm sieves. The fraction retained on the sieve was then dried in an oven at 92 ^{o}C and dry sorted on 2.0, 0.89, 0.25 and 0.064 stainless steel sieves. Particles passing the 0.064 mm sieve during wet sieving were analyzed by sinking rates in a column of water (pipette analysis). Quality assurance required triplicate analyses on one of every 20 samples. A maximum of 20 percent Relative Standard Deviation (of the silt-clay fraction) is established as the Data Qualification Control Limit.

Redox potential. Redox potentials were determined at a shore station in Cordova assuming when they contained sufficient free water for the analysis. An Orion ™ advanced portable ISE/pH/mV/ORP/temperature meter model 290A with a Model 9678BN Epoxy Sure-Flow Combination Redox/ORP probe. The meter's accuracy in the ORP mode is $\pm$ 0.2 mV or $\pm$ 0.05% of the reading, whichever is greater. Calibration reagents will be prepared at the beginning of each day and held refrigerated. All reagents were pre-weighed into scintillation vials prior to deployment.

Redox Standard A requires:

- 4.22 g $K_4Fe(CN)_6$
- 1.65 g $K_3Fe(CN)_6$
- 100 ml of distilled water in an amber bottle

Standard B requires:

- 0.42 g $K_4Fe(CN)_6.3H_2O$
- 1.65 g $K_3Fe(CN)_6$
- 3.39 g $KF.2H_2O$
- 100 ml of distilled water in an amber bottle
- Orion600011 filling solution is used with a correction factor of +209 (15 ^{o}C) added to the meter's reading.

Redox standards are used to check the electrode readings at approximately four hour intervals. Standard A is transferred to a 150 l beaker and the electrode placed in the solution until the reading stabilizes with stirring (1 to 2 minutes). The potential of Standard A is +147 $\pm$ 9 mV. The electrode is then rinsed with distilled water and the measurement repeated with Standard B (potential = +216 $\pm$ 9 mV). The potential in Standard A is approximately +69 mV greater than in Standard B.

Measurement of sediment redox potential. After each 20 cm long section of sediment is placed in a urine specimen cup, the entire sample was gently homogenized with a stainless steel spatula and a 5 ml subsample was removed for sulfide analysis. The redox probe was then inserted approximately 2 cm deep into the sample and the mV reading recorded when the meter stabilized. The electrode was then removed and gently wiped free of sediment and placed directly in the next sample. The redox probe was rinsed and stored in distilled water between batches of samples. However, the probe's performance is enhanced if it is placed ambient seawater for approximately one hour before starting a new set of samples. Quality assurance for redox measurements requires triplicate analyses on one of every 20 samples. There is no Data Qualification Control Limit for this test at this time.

Free sediment sulfide analysis. Five ml sediment samples were analyzed as quickly as possible following collection.

Calibration of the total sulfide field probe. An Orion™ advanced portable ISE/pH/mV/ORP/temperature meter model 290A meter with a Model 9616 BNC *Ionplus* Silver/Sulfide electrode was used for these analyses. The meter has a concentration range of 0.000 to 19,900 μM $S^=$ and a relative accuracy of $\pm$ 0.5% of the reading.

Preparation of the SAOB buffer. A sulfide antioxidant buffer solution (SAOB) was prepared at the beginning of each day and at four hour intervals. All components were premeasured into scintillation vials prior to deployment using a four place balance. Eighty grams of sodium hydroxide (NaOH) and 71.6 grams of EDTA ($Na_2C_{10}O_8N_2.2H_2O$) were added to 1,000 ml of distilled water upon arrival in Cordova. This SOB solution was dispensed into 250 ml brown HDPE bottles to which 8.75 grams of L-ascorbic acid was added just prior to use. SAOB buffer is stable for up to 4 hours and new batches were prepared at the end of this time. 5ml of this solution was used for each sample.

Preparation of sulfide standards. A 10,000 μM $S^=$ standard was made up once every 48 hours and kept cool (~4 ^oC). The stock solution was diluted to concentrations of 100 and 1000 μM just before use. Fresh diluted standards are made up when new SAOB buffer was made (about every four hours). The $S^=$ electrode was calibrated before and after each batch of samples. The probe was standardized at 100, 1000 and 10,000 μM at least once every four hours and checked against the 1,000 μM standard every two hours. A stock $S^=$ solution of 0.01 M Na_2S was prepared by weighing 0.2402 g $Na_2S.9H_2O$ into an amber glass bottle and diluting to 100 ml with distilled water. A 1000 μM $S^=$ standard (10^{-3} M) was prepared by transferring 10 ml of the 0.01 M Na_2S stock solution (10,000 μM) into an amber jar and diluting to 100 ml with distilled water. A 100 μM $S^=$ Standard is(10^{-4} M $S^=$) was then prepared by transferring 10 ml of the 1000 μM standard to another amber jar and diluting to 100 ml with distilled water. Both dilution standards were mixed thoroughly before use. A three-point calibration procedure was performed following the meter's instruction manual. Just before calibration of the $S^=$ electrode, 25 ml of each standard was transferred to a dark bottle and 25 ml of SAOB (containing ascorbic acid) added. The combined solution was kept tightly capped until used for standardizing the sulfide electrode.

Measurement of sediment total free sulfides. Five ml of the previously described SAOB buffer (to which L-ascorbic acid has been added) was pipetted into a 30 ml graduated beaker. Homogenized sediment was then added to the 10 ml marker on the beaker. A flat-tip stainless steel spatula was used to mix and homogenize the sediment sample with the SAOB buffer. Following this, the $S^{=}$ electrode was used to gently stir the sediment until a "ready" indication is achieved on the meter. The $S^{=}$ electrode typically stabilizes in 2 to 4 minutes. Electrodes were not cleaned or recalibrated between analyses of sediments from the same transect. However, after completing the analyses required, the electrode was wiped clean and rinsed in distilled water.

Triplicate analyses were completed on one of every 20 samples or on one sample per batch when fewer than 20 samples were analyzed. No data qualification control limit has been established for this procedure.

3.6. Photographic record. A digital photograph was taken of selected core samples using a Sony CD1000 camera in the macro mode. Additional photographs were taken to document the sites and their overall sediment characteristics.

3.7. Statistical analyses. The raw data was entered into an Excel™ spreadsheet (Appendix 1). This data was then imported into Statistica™ Version 6 for analysis. Proportional data was transformed (arcsin(sqrt(proportion))) prior to inferential tests. Tests of significance were conducted with a 5% probability of making a Type I error ($\alpha = 0.05$). Means are presented with $\pm$ 95% confidence intervals.

4.0. Results. Quarry Bar was examined on May 18, 2004 and Grassy Island on May 19, 2004 during low tides of -1.4' MLLW and -1.6' MLLW respectively. The weather was calm and overcast on both days. No significant problems were encountered. Results are provided, by beach, in the following paragraphs.

4.1. Quarry Bar. An Excel™ spreadsheet summarizing the results of measurements made at Quarry Bar is included as Appendix (1). Figure 3 describes the laying out of Transect 3 located 28' from the water's edge at a -1.4' MLLW tide. Samples were collected at 15' intervals along Transects 1 and 3 starting at a randomly chosen distance from the baseline. Fewer core samples were collected at random intervals on Transect 2 because of its extremely high elevation (+5.0' MLLW). Tidal heights characterizing the bar were measured using a hand-held theodolyte and stadium. The results are provided in Figure 4. At Quarry Bar, the beach rises quickly to +5.3' MLLW leaving only a 60' wide band of beach between MLLW and the upper limit of clam habitat (+4.5' MLLW). This does not mean that occasional clams will not occasionally be found above the band. However, the tidal elevation over most of the bar was above the maximum associated with historical razor clam populations. Sediment physicochemical statistics are summarized in Table (2). Quarry Bar is composed of primarily of sand (91.6 $\pm$ 0.4%) and most of this (89.62 $\pm$ 0.43%) was fine sand having a particle size of 64 to 250 μM. The fine sand component of the substrate is similar to that documented before the 1964 earthquake by Nickerson (1975) for ten razor clam beaches near Cordova. However, the mean clay content of 4.66 $\pm$ 0.49%) in existing sediments is twice the maximum clay content of 2.2% clay reported suitable for razor clams by Nickerson (1975) for.

Figure 3. Layout of T2 at Quarry Bar during a survey of sediment physicochemical properties on May 18, 2004. Buddy Jansen and Arron Van Armoun are preparing to collect cores in the foreground as Jeff Hetrick and David Petree (Alaska Department of Fish and Game) finish laying out the transect.

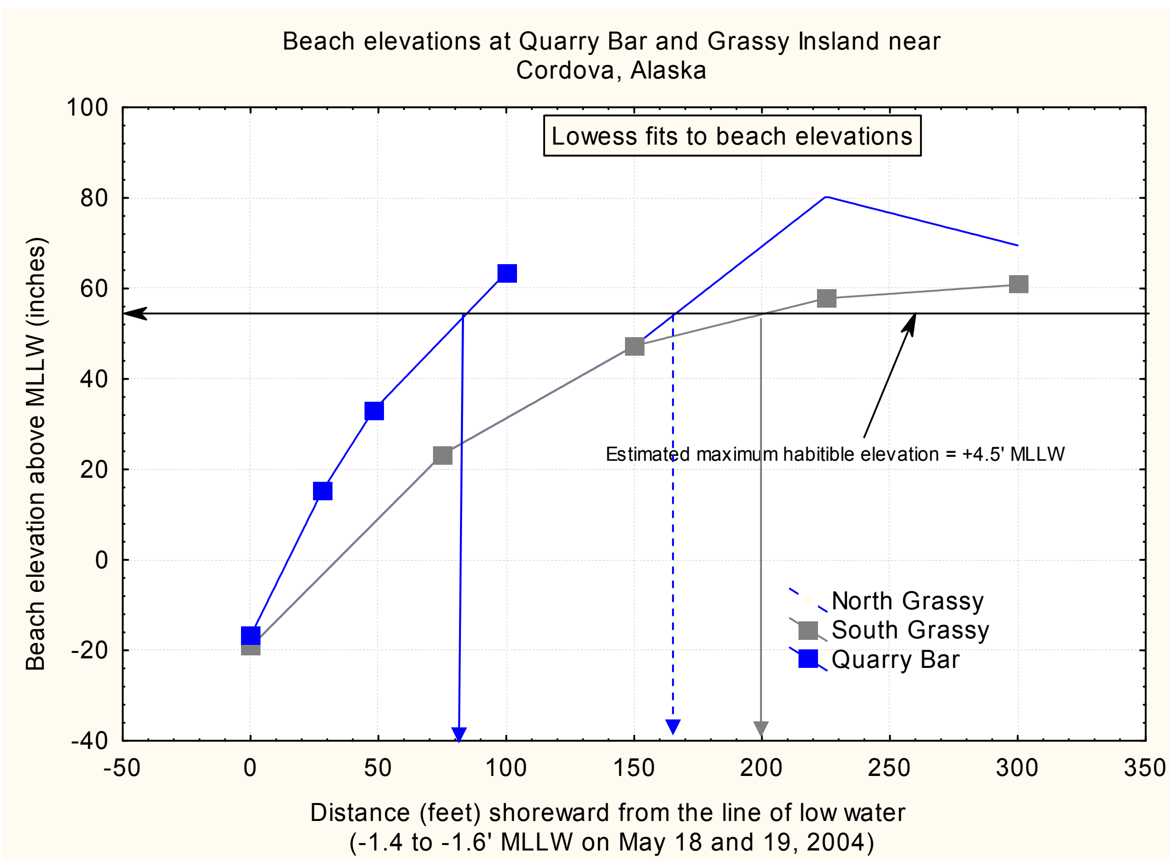

Figure 4. Beach elevations at Quarry Bar near Cordova, Alaska.

The minimum clay content in the current sediment samples (3.13%) is 50% higher than the maximum identified by Nickerson (1975) for razor clams and none of the sampled sediments on Quarry Bar were suitable for healthy clam populations. Based on the work of Brooks (2001a), the very low sulfide concentrations (0.274 $\pm$ 0.067 μM) should not inhibit the recruitment or survival of invertebrates at any depth >60 cm in Quarry Bar sediments. Total Volatile Solids (TVS) is low at 0.69 $\pm$ 0.03% and redox potential high at 233.0 $\pm$ 19.8 mV in all of these samples and these values have no conceivable affects on razor clams or other invertebrates – excepting the low TVS might inhibit deposit feeders due simply to a lack of food in the sediments.

Table 2. Statistics describing overall sediment physicochemical variables at Quarry Bar.

Variable	Descriptive Statistics (Eyak Datasheet) Valid N	Mean	Confidence -95.000%	Confidence +95.000%	Minimum	Maximum
TVS	35.000	0.692	0.663	0.722	0.530	0.830
Sand	27.000	91.564	91.173	91.956	89.650	93.130
Sulfide	71.000	0.274	0.207	0.342	0.001	1.270
Redox	64.000	233.031	213.276	252.786	-22.000	322.000
Clay	27.000	4.659	4.167	5.152	3.130	9.210
Silt and Clay	27.000	8.436	8.045	8.828	6.870	10.350

No significant differences in percent sand, clay or silt and clay, redox potential, TVS or free sulfides were found as a function of tidal height or core depth ($\alpha = 0.05$). In other words, the beach was homogeneous with respect to these variables (Table 3).

Table 3. Statistics describing sediment physicochemical variables as a function of tidal height and core depth on Quarry Bar and results of an analysis of variance examining differences in these variables.

Breakdown Table of Descriptive Statistics (Eyak - Quarry Bar - Datasheet)
Smallest N for any variable: 27

Depth	EleCode	TVS Means	TVS N	TVS Minimum	TVS Maximum	Sand Means	Sand N	Sand Minimum	Sand Maximum	Clay Means	Clay Minimum	Clay Maximum
1	-1	0.705	4	0.580	0.820	92.320	2	91.640	93.000	5.535	4.070	7.000
1	1	0.723	3	0.600	0.810	91.090	1	91.090	91.090	4.810	4.810	4.810
1	5	0.585	2	0.530	0.640	91.720	1	91.720	91.720	4.980	4.980	4.980
11	-1	0.672	4	0.530	0.780	91.373	3	91.260	91.510	4.660	4.230	5.130
11	1	0.737	3	0.700	0.770	91.397	3	89.650	93.030	4.473	3.840	5.350
11	5	0.640	2	0.610	0.670	91.065	2	90.950	91.180	6.695	4.180	9.210
30	-1	0.670	4	0.540	0.830	92.257	3	91.090	93.130	4.297	3.460	4.810
30	1	0.723	3	0.680	0.750	91.710	3	91.090	92.320	4.323	3.180	4.980
30	5	0.645	2	0.590	0.700	90.565	2	89.850	91.280	3.890	3.160	4.620
50	-1	0.738	4	0.710	0.810	91.210	3	89.650	93.030	4.220	3.130	5.350
50	1	0.705	2	0.690	0.720	91.265	2	91.020	91.510	4.930	4.230	5.630
50	5	0.695	2	0.640	0.750	92.580	2	92.030	93.130	3.995	3.460	4.530
All Grou		0.692	35	0.530	0.830	91.564	27	89.650	93.130	4.659	3.130	9.210

Analysis of Variance (Eyak Datasheet)
Marked effects are significant at p < .05000

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
TVS	0.01	3	0.004	0.02	4	0.005	0.811195	0.550393
Sand	4.49	3	1.497	1.65	3	0.551	2.714545	0.216948
Sulfide	0.06	3	0.018	0.11	10	0.011	1.672508	0.235238
Redox	23931.83	3	7977.275	65501.87	9	7277.985	1.096083	0.399768
Clay	10.13	3	3.375	14.29	3	4.763	0.708605	0.608044
Silt and Clay	4.53	3	1.508	1.63	3	0.542	2.783803	0.211398

Summary for Quarry Bar. Nearly all of Quarry Bar lies above 4.5’ MLLW, considered the maximum height for healthy razor clam populations (Figure 5). Clam populations above ca. 3.0’ MLLW are inhibited by reduced feeding times and loss of pore water during low tides. This assertion is substantiated by the lack of pore water and low compaction in sediments on top of the bar (Figure 5 inset). In addition, all of the sediments sampled at Quarry Bar contained too much clay to support healthy razor clam populations. These two factors appear responsible for the reduced razor clam population on this bar. There is a narrow band of sediments at suitable tidal elevations along the perimeter of the bar. However, sediments descend quickly in this zone and likely lose pore water rapidly, which further inhibits razor clams. Sediments below -1.6’ MLLW appeared to have an even higher proportion of fines. Because of these factors, the bar is not recommended for enhancement – even though small numbers of razor clams (cover photo) were found in compacted sand in a few areas on top of the bar. Figure 6 describes a typically uniform sediment core from Quarry Bar. No evidence of stratification or of a reduction oxidation potential discontinuity (evidence of anaerobic conditions) were observed in any core.

Figure 5. Quarry Bar near Cordova Alaska. The inset depicts poorly consolidated sediments found in some areas on top of the bar where there is little or no pore water.

Figure 6. 60 cm core from Quarry Bar.

4.2. Grassy Island (Figure 7) is an expansive bar that local knowledge indicates was once an important razor clam beach. No razor clams or clam shows were observed on Grassy Island. Figure 8 describes the stratified (by tidal elevation) systematic random sample design used to assess sediment conditions on Grassy Island. Transect lines were 150' apart and samples along each transect were spaced 100' apart. The coarse spacing was chosen because of the apparent homogeneity of the substrate.

Figure 7. Grassy Island looking southwest.

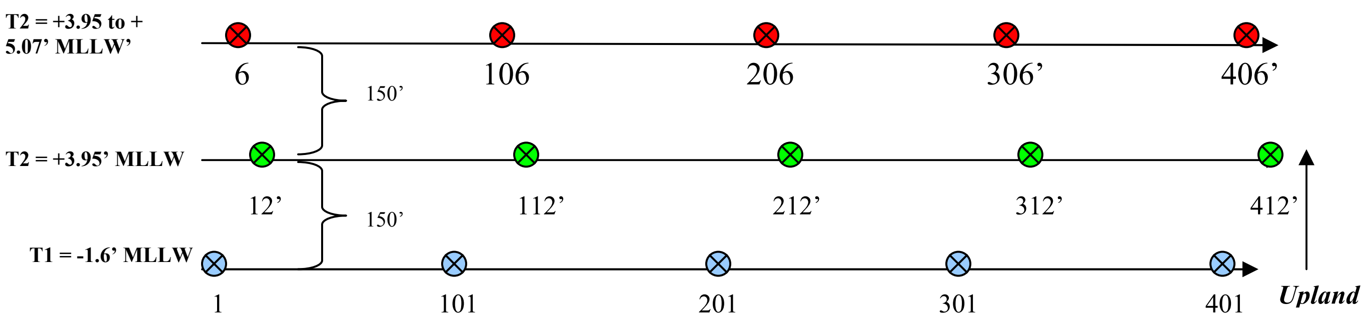

Figure 8. Systematic random sample design for sediment sampling at Grassy Island near Cordova, Alaska. The samples were spaced 100' apart on each transect.

A distinct hydrogen sulfide odor was present and it appeared to originate in a depositional area located to the northwest behind the bar (Figure 9). This area was organically enriched by macroalgae detritus which is generally refractory and not associated with high biological oxygen demand leading to sulfide generation (Brooks 2001a). It can be hypothesized that there was an unidentified source of more labile organic matter, such as animal waste, to this backwater that was responsible for the high BOD; reducing conditions; and generation of hydrogen sulfide. However, this was not investigated. Figure 4 indicates that the distance from MLLW to the

+4.5’ MLLW upper limit for razor clams was 130’ to 165’ wide in the area of the Grassy Island survey. The remainder of the bar was too high to support viable clam populations of any species (Brooks 2001b). No clams were observed in the band of suitable tidal height. Sediment physicochemical characteristics measured during this survey at Grassy Island are summarized in Table 4. Total Volatile Solids (TVS = 0.84 $\pm$ 0.4%) was relatively low, but higher than observed at Quarry Bar, and the proportion fine sand (88.8 $\pm$ 0.7%) appeared suitable for razor clams; and sediments were aerobic with a mean redox potential of 167.5 $\pm$ 24.2 mV. However, the proportion clay in all samples (4.94 $\pm$ 0.36%) was higher than the upper tolerable limit of 2.2% clay given by Nickerson (1975).

Figure 9. Organically enriched area lying to the northwest behind Grassy Island. A distinct odor of hydrogen sulfide was present on the bar and appeared to emanate from this general location.

Table 4. Statistics describing overall sediment physicochemical variables at Grassy Island near Cordova, Alaska on May 19, 2004.

	Descriptive Statistics (Eyak Datasheet)					
Variable	Valid N	Mean	Confidence -95.000%	Confidence +95.000%	Minimum	Maximum
TVS	40.000	0.836	0.797	0.874	0.570	1.090
Sand	29.000	91.069	90.492	91.647	87.230	93.280
Sulfide	60.000	23.865	14.722	33.008	0.000	159.000
Redox	38.000	167.526	143.365	191.687	54.000	317.000
Clay	28.000	4.944	4.582	5.306	3.350	7.110
Silt and Clay	28.000	8.794	8.270	9.318	6.720	12.770
Fine sand	28.000	88.800	88.097	89.502	84.330	91.860

Table 5 describes the distribution of TVS, free sediment sulfides, redox potential and percent clay as a function of transect and core depth at Grassy Island. The results of an analysis of variance is provided in Table 6 demonstrating significant differences ($\alpha = 0.05$) associated with sulfides, but not with the other variables. Post hoc testing using Duncan’s test with multiple ranges is also provided in Table 6 demonstrating that sulfides generally increased with depth in Grassy Island sediments. This is graphically presented in Figure 10, which suggests significant sulfide clines for Transects 1 and 3, but not for Transect 2. Brooks (2001a) presented sulfide tolerance data for a large number of invertebrate taxa – but razor clams were not included. Wang and Chapman (1999) provided a 96 hr LC_{50} of 187 µM $S^{=}$ for *Macoma sp.* (a clam) and a few tens of µM for two amphipod species. Observed sulfide concentrations of up to 159 µM in Grassy Island sediments likely exclude numerous taxa, but their affect on razor clams is unknown and would require specific information developed through either empirical evidence or laboratory bioassays. Having said that, it should be noted that free sediment sulfide concentrations at Grassy Island were generally low enough (23.9 $\pm$ 9.1 µM) that a generally affect over the entire bar would not be expected.

Table 5. Statistics describing sediment physicochemical variables as a function of tidal height and core depth at Grassy Island.

Breakdown Table of Descriptive Statistics (Eyak Grassy Island Datasheet)
Smallest N for any variable: 28

Transect	Depth	TVS Means	Confidence +95.000%	TVS N	Sand Means	Confidence +95.000%	Sand N	Sulfide Means	Confidence +95.000%	Sulfide N	Redox Means	Confidence +95.000%	Redox N	Clay Means	Confidence -95.000%	Confidence +95.000%	Clay N
T1	1	0.890	1.077	5	89.425	117.315	2	13.000	49.094	5	208.750	345.591	4	5.200			1
T1	11	0.910	1.018	3	89.507	94.563	3	31.120	84.418	5	109.000		1	6.297	4.536	8.058	3
T1	30	0.810	1.079	3	90.830	91.584	3	39.240	74.045	5	82.000	437.774	2	5.470	3.927	7.013	3
T1	50	0.917	1.004	3	91.407	93.829	3	72.864	143.680	5	171.600	236.598	5	4.723	2.993	6.453	3
T3	1	0.782	0.940	5	90.600	105.085	2	0.155	0.445	5	149.000	178.212	5	4.595	0.084	9.106	2
T3	11	0.710	0.964	2	92.735	99.660	2	12.562	21.097	5	155.333	401.618	3	4.410	-5.374	14.194	2
T3	30	0.847	1.085	3	92.455	99.380	2	46.620	81.243	5	163.400	258.570	5	4.500	0.307	8.693	2
T3	50	0.685	2.146	2	92.015	103.895	2	65.760	107.656	5	125.400	178.288	5	4.770	-1.202	10.742	2
T2	1	0.922	1.091	5	90.600		1	0.006	0.020	5	289.000	644.774	2	5.740			1
T2	11	0.753	0.857	3	91.997	92.393	3	1.128	3.073	5			0	4.440	1.575	7.305	3
T2	30	0.830	1.009	3	90.987	95.607	3	1.688	3.988	5	168.000	1120.965	2	4.913	1.278	8.548	3
T2	50	0.823	1.196	3	90.590	93.957	3	2.233	6.213	5	207.750	360.692	4	4.473	2.065	6.882	3
All Group		0.836	0.874	40	91.069	91.647	29	23.865	33.008	60	167.526	191.687	38	4.944	4.582	5.306	28

Table 6. Results of a one-way analysis of variance examining the significance of differences in sediment physicochemical variables observed on Grassy Island on May 19, 2004. A summary of post hoc testing using Duncan's test with multiple ranges is included.

Analysis of Variance (Eyak Datasheet)
Marked effects are significant at p < .05000

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
TVS	0.203	11.000	0.018	0.364	28.000	0.013	1.419	0.219
Sand	28.375	11.000	2.580	36.186	17.000	2.129	1.212	0.350
Sulfide	39084.391	11.000	3553.126	34821.919	48.000	725.457	4.898	0.000
Redox	72039.707	10.000	7203.971	127877.767	27.000	4736.214	1.521	0.186
Clay	9.863	11.000	0.897	13.665	16.000	0.854	1.050	0.452

Duncan test; Variable: Sulfide (Eyak Datasheet)
Marked differences are significant at p < .05000

Transect Depth	{1} M=13.000	{2} M=31.120	{3} M=39.240	{4} M=72.864	{5} M=.15516	{6} M=12.562	{7} M=46.620	{8} M=65.760	{9} M=.00628	{10} M=1.1280	{11} M=1.6878	{12} M=2.2328
T1 1 {1}		0.293	0.152	0.002	0.517	0.980	0.076	0.007	0.518	0.543	0.552	0.557
T1 11 {2}	0.293		0.636	0.031	0.122	0.311	0.397	0.068	0.125	0.129	0.130	0.128
T1 30 {3}	0.152	0.636		0.076	0.053	0.160	0.667	0.148	0.054	0.057	0.057	0.057
T1 50 {4}	0.002	0.031	0.076		0.000	0.002	0.152	0.679	0.000	0.000	0.000	0.000
T3 1 {5}	0.517	0.122	0.053	0.000		0.525	0.022	0.001	0.993	0.955	0.934	0.916
T3 11 {6}	0.980	0.311	0.160	0.002	0.525		0.079	0.007	0.527	0.548	0.553	0.547
T3 30 {7}	0.076	0.397	0.667	0.152	0.022	0.079		0.267	0.023	0.024	0.024	0.024
T3 50 {8}	0.007	0.068	0.148	0.679	0.001	0.007	0.267		0.001	0.001	0.001	0.001
T2 1 {9}	0.518	0.125	0.054	0.000	0.993	0.527	0.023	0.001		0.952	0.932	0.911
T2 11 {10}	0.543	0.129	0.057	0.000	0.955	0.548	0.024	0.001	0.952		0.974	0.953
T2 30 {11}	0.552	0.130	0.057	0.000	0.934	0.553	0.024	0.001	0.932	0.974		0.975
T2 50 {12}	0.557	0.128	0.057	0.000	0.916	0.547	0.024	0.001	0.911	0.953	0.975	

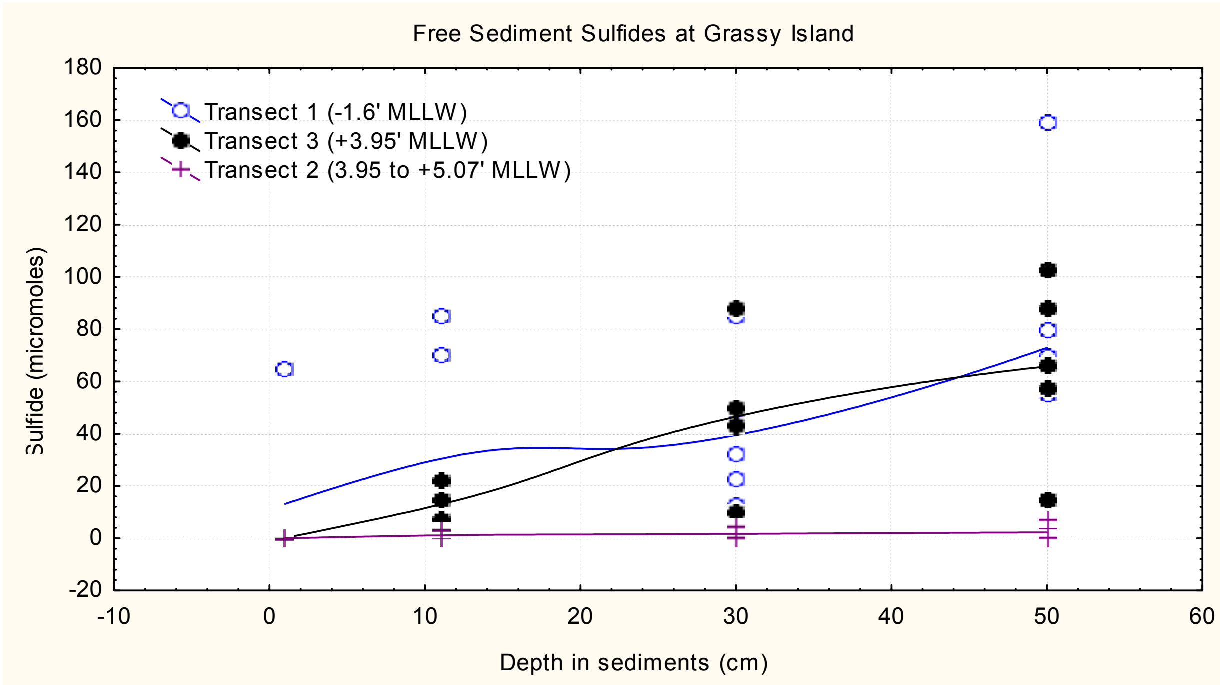

Figure 10. Scatter plot demonstrating increasing sulfide concentrations with depth in sediments on Transects 1 and 3 at Grassy Island, but not on Transect 2.

Summary for Grassy Island. This sand bar is expansive and historically supported a viable commercial fishery for razor clams. However, no razor clams were observed on this bar during this survey. There are likely two primary reasons for this. Most of the bar is well above the maximum upper tidal elevation estimated for razor clams. In addition, Grassy Island sediments contain more clay than Nickerson (1975) found suitable for razor clams. The reduced redox potential and increased sulfide concentrations are likely the result of increased sediment organic content. Because razor clams are active animals, it is assumed that they require high porewater oxygen concentrations. However, specific redox conditions have not been documented and the redox potential observed in this survey was generally positive. The affects of increased sulfide on razor clams is also unknown. However, the sulfide distribution is patchy and there are areas of sediment where sulfide concentrations are lower than any documented effects threshold. Therefore, it does not appear that either sulfide or redox are excluding razor clams from this beach. The problem is tidal elevation and the high clay content of the sediments.

4.3. Comparison of sediment physicochemistry on Quarry Bar and Grassy Island during the May 2004 surveys. Small, but statistically significant differences were observed in the physicochemistry of Grassy Island and Quarry Bar during these surveys (Table 7). The significantly increased sulfide and decreased redox potential on Grassy Island appear in response to significantly increased concentrations of organic matter (TTVS). Clay content on Grassy Island was slightly higher than on Quarry Bar, but the differences were not significant. A determination of cause and effect was not a part of this study. However, it should be noted that a small population of razor clams exists on Quarry Bar and that no clams or clam shows were observed on Grassy Island. In either case, the high clay content in the sediments of both sites –

and the high tidal elevations of the majority of the substrate are likely preventing establishment of viable razor clam populations.

A distinct hydrogen sulfide odor was observed on Grassy Island. The back side of the bar is depositional and supports a vibrant invertebrate population as evidenced by the numerous burrows seen in Figure 11. Much of the observed detritus was of terrigenous origin or was fragmented macroalgae. This material is somewhat refractory and it is not usually associated with high biological oxygen demand and sulfide generation (Brooks 2001a). The origin of the sulfides is more likely a labile source such as animal waste. However, this was not investigated in these surveys.

Table 7. Results of an analysis of variance investigating the significance of differences in sediment physicochemical endpoints on Quarry Bar and Grassy Island near Cordova, Alaska in May 2004.

	T-tests; Grouping: Beach (Eyak Datasheet) Group 1: Quarry Group 2: Grassy										
Variable	Mean Quarry	Mean Grassy	t-value	df	p	Valid N Quarry	Valid N Grassy	Std.Dev. Quarry	Std.Dev. Grassy	F-ratio Variances	p Variances
Sulfide	0.274	23.865	-5.620	129.000	0.000	71.000	60.000	0.286	35.393	15361.509	0.000
Redox	233.031	167.526	4.150	100.000	0.000	64.000	38.000	79.085	73.506	1.158	0.640
TTVS	0.083	0.091	-5.858	73.000	0.000	35.000	40.000	0.005	0.007	1.638	0.146
Clay	4.659	4.944	-0.963	53.000	0.340	27.000	28.000	1.245	0.933	1.778	0.144
Fine sand	89.616	88.800	2.014	53.000	0.049	27.000	28.000	1.090	1.812	2.763	0.011

Figure 11. Organically enriched sediments on the back side of Grassy Island showing evidence of a rich annelid community.

5.0. Summary. Contrary to previous surveys, this effort indicates that Quarry Bar and Grassy Island do not presently represent suitable razor clam habitats. These bars were elevated about eight feet during the 1964 earthquake. Since then, they have eroded, but tidal elevations remain too high to support viable clam populations of any species (Brooks 2001b). Remnitz (op. cit.) noted that the 1964 earthquake exposed clay layers on extensive tidal areas along Orca Inlet and that surface currents were removing clay fractions from these exposed layers and re-depositing them in adjoining areas supporting marginal razor clam stocks. That process appears to have increased the proportion of clay on these two bars, resulting in elevated clay content in sediments that according to Nickerson (1975) is inimical to juvenile razor clams because the clay clogs their gills. It is the author's opinion that razor clam enhancement could be attempted at suitable tidal elevations on the sides of these bars, but that the high clay content would likely result in excessive mortality of juvenile razor clams. These bars will continue to erode and eventually the lighter clay will be selectively washed out and deposited in depositional areas – most likely in deep water. Thus, at some point in the future, Grassy Island and Quarry Bar will once again provide suitable razor clam habitat – but not now.

6.0. Recommendations. The purpose of these surveys was to examine differences in the physicochemical attributes of two historic razor clam beaches including Quarry Bar, which currently hosts a small population of razor clams; and Grassy Island, which historically supported razor clams, but which is currently depauperate of this species. Two factors inhibiting razor clams were identified – unsuitably high substrates and excessive clay content in the sediments. The following recommendations should be considered prior to future attempts to enhance razor clam populations in the Cordova area:

6.1. Tidal heights were measured using a hand-held theodolyte during this survey. These elevations should be confirmed and refined using a more accurate tripod mounted surveyor's level or a laser level.

6.2. A survey of intertidal areas should be initiated in the Cordova area to identify sand-bars or beaches with suitable relatively flat areas located at tidal heights of ca. -1.5 to +3.0' MLLW.

6.3. The sediment grain size distribution on these beaches should be determined, with emphasis on the proportion clay (<4 μM particle size). Those beaches having <2.2% clay should be identified as suitable for enhancement.

6.4. Only those beaches having suitable habitat (fine sand containing <2.2% clay at tidal elevations of -1.5 to +2.0' MLLW) should be considered for enhancement.

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