# Infaunal Macroinvertebrate Diversity of East and West Sound Orcas Island: use of Multibeam and In-Situ sampling to characterize soft-sediment communities

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Final Paper
Spatial Ecol RA
Dec. 9, 2011

## Introduction

Marine soft-sediments comprise the largest and oldest habitat types on earth (Gray 1974). Species and communities within these habitats vary spatially and temporally; controlled by sediment composition, disturbance, primary production, and biotic interactions (Lenihan and Micheli, 2001). These variations can occur over a matter of meters and result in highly patchy sea floors (Snelgrove and Butman, 1994). A relationship between grain-size and faunal diversity was first identified by Peterson (1913) and further investigated by Johnson (1957) becoming a widely accepted supposition until the 90's (Snelgrove and Butman, 1994). Snelgrove and Butman's (1994) review of animal-sediment relationships noted no consistent relationship in the literature between fauna and grain size and questioned if other mechanisms are driving the apparent relationship.

Gray (2002) maintains the animal-sediment relationship and argues that many results cannot be considered characteristic of soft-sediment communities as a whole because most studies are small in spatial and temporal scale and lack extensive sampling. Regional scale diversity controls local species richness and environmental factors in turn determine regional richness. Environmental factors are grain-size diversity, temperature, and productivity. Gray (2002) further postulates that reduced richness may be the result of geologic history such as the Pleistocene glaciation of high latitudes. Benthic animals may not have had the time needed to fully colonize or establish stable communities in environs bound up or scraped clean by ice. Both reviews agree that further sampling controlling for a number of biologically relevant physical factors, including sediment grain size, need to be performed over larger temporal and spatial scales (Snelgrove and Butman, 1994; Lenihan and Micheli, 2001; Gray 2002).

### *Sedimentology*

Sedimentological analysis of marine substrate has predominantly been performed according to geologic techniques outlined in Folk (1980). Wet samples composed of greater than 30% clay are first chemically dispersed to break aggregates of material down into individual grains, then wet sieved, and lastly a technique called pipeting removes and fractionates the mud portion (Folk, 1980). However, this geological approach of dissaggregating sediments to individual grains may not be appropriate for ecological investigation. Snelgrove and Butman (1994) and others have noted that infaunal organisms do not interact with individual grains of sediment, but rather aggregates of sediment containing or coated with organic material (Watling, 1991; Snelgrove and Butman, 1994). It is this organic material that the organisms are feeding upon and aggregated sediments that they burrow through. However, grain size must play an indirect role as there is a limit to the extent and size of grains that can be bound by organic material (H.G. Greene, personal communication, 2011).

## Hypothesis

East Sound and West Sound, Orcas Island WA, are two glacially cut fjords dominated by mud and silty/mud substrates (Endris et. al., 2010). Fine grained substrates are typically dominated by deposit feeding organisms, specifically polychaetes (Lenihan and Micheli, 2001). Estuaries, with influx of fine grained material and alteration of water chemistry, exhibit lower overall diversity (Constable, 1999). This study aims to evaluate differences in the infaunal macroinvertebrate communities in East and West Sound Orcas Island Washington State. A possible controlling factor on the communities within East Sound is a glacially deposited partial sill at the mouth that restricts flow and likely creates differing physical conditions from West Sound. This question is addressed by 1) collecting and characterizing the infaunal macroinvertebrates within East and West Sound. 2) Measuring physical parameters such as dissolved oxygen, pH, temperature, and grain size distribution. 3) Using multibeam backscatter data and in-situ sampling to delineate the boundaries between different communities in the two sounds.

**Figure 1**

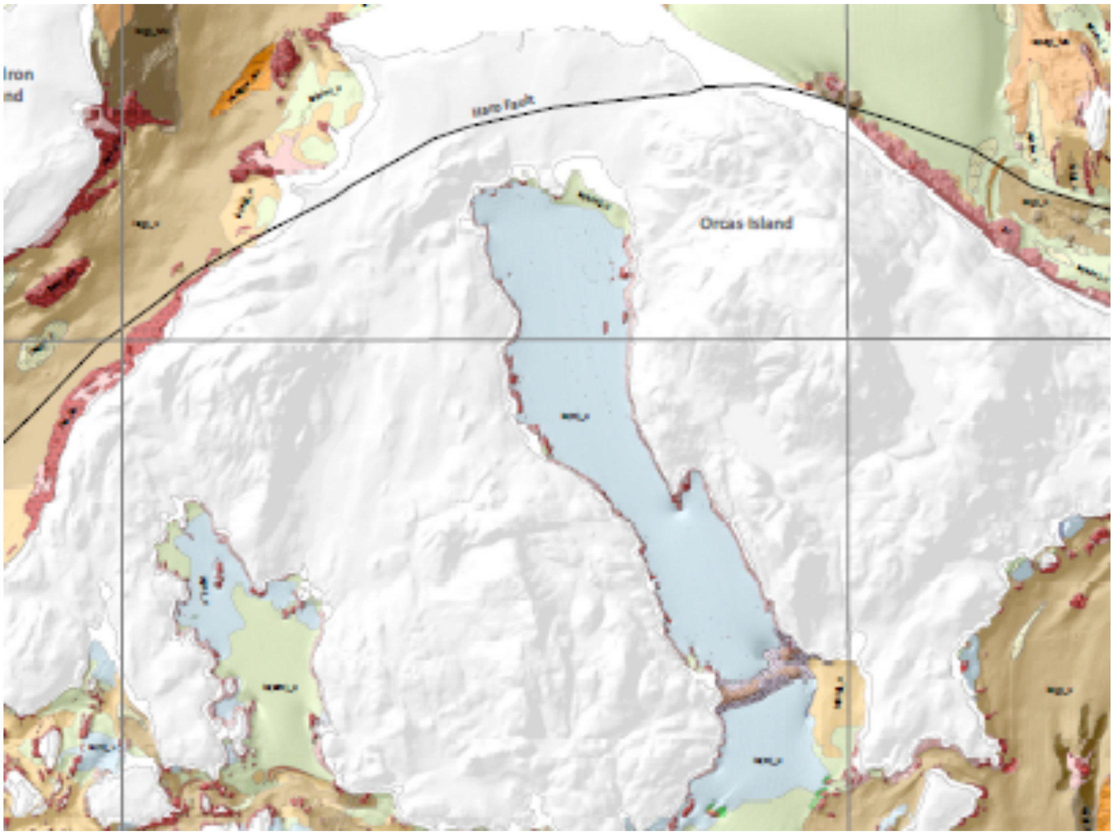


Figure 1: Geological Survey of Canada habitat map (Endris et al., 2011), sheet 3 of 5, Orcas Island (Endris et. al., 2010) designating two habitat types in West Sound, but only a single habitat in East Sound. Note the breached sill at the mouth of East Sound that is a glacial end moraine that restricts circulation.

**Figure 2**

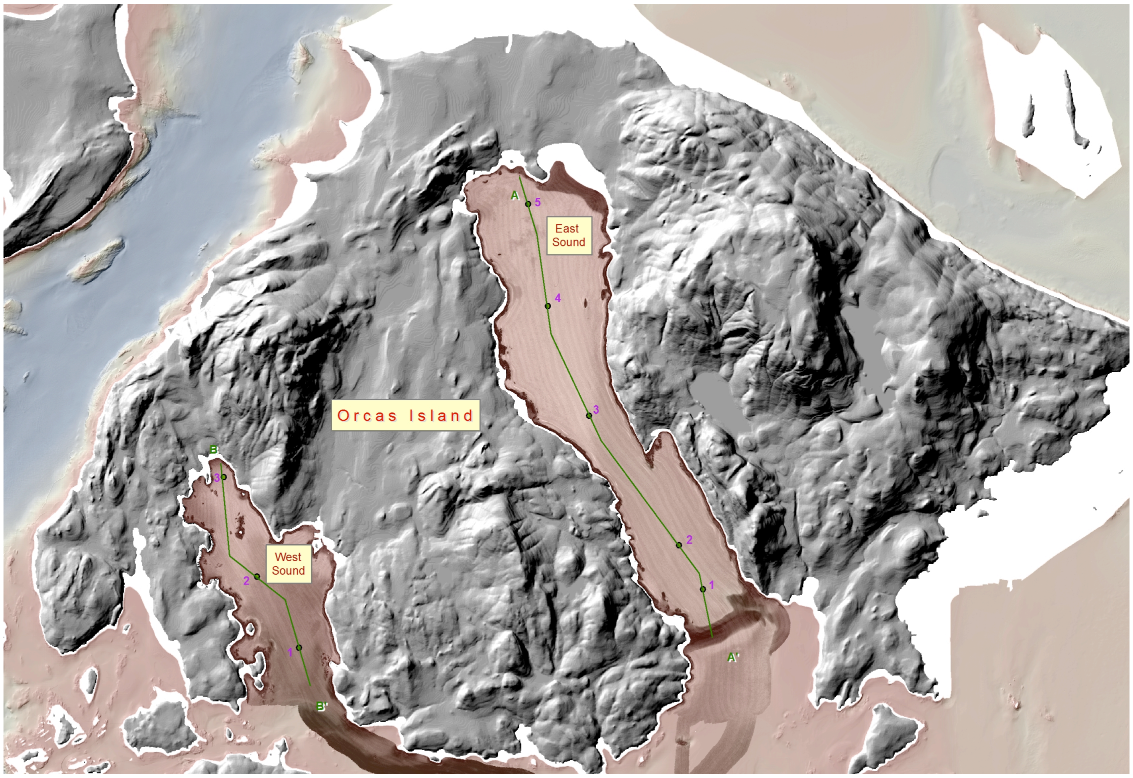


Figure 2. Map of Orcas Island generated in ArcGIS 10. Gray hill shade is LIDAR of Orcas Island, red indicates shallow depth, and backscatter is mapped within the two sounds. Lighter shade indicates fine grained substrates. Note change in intensity that implies variation in substrate composition. Bathymetric data provided by H. Gary Greene, LiDAR data from Puget Sound LiDAR Consortium.

**Figure 3**

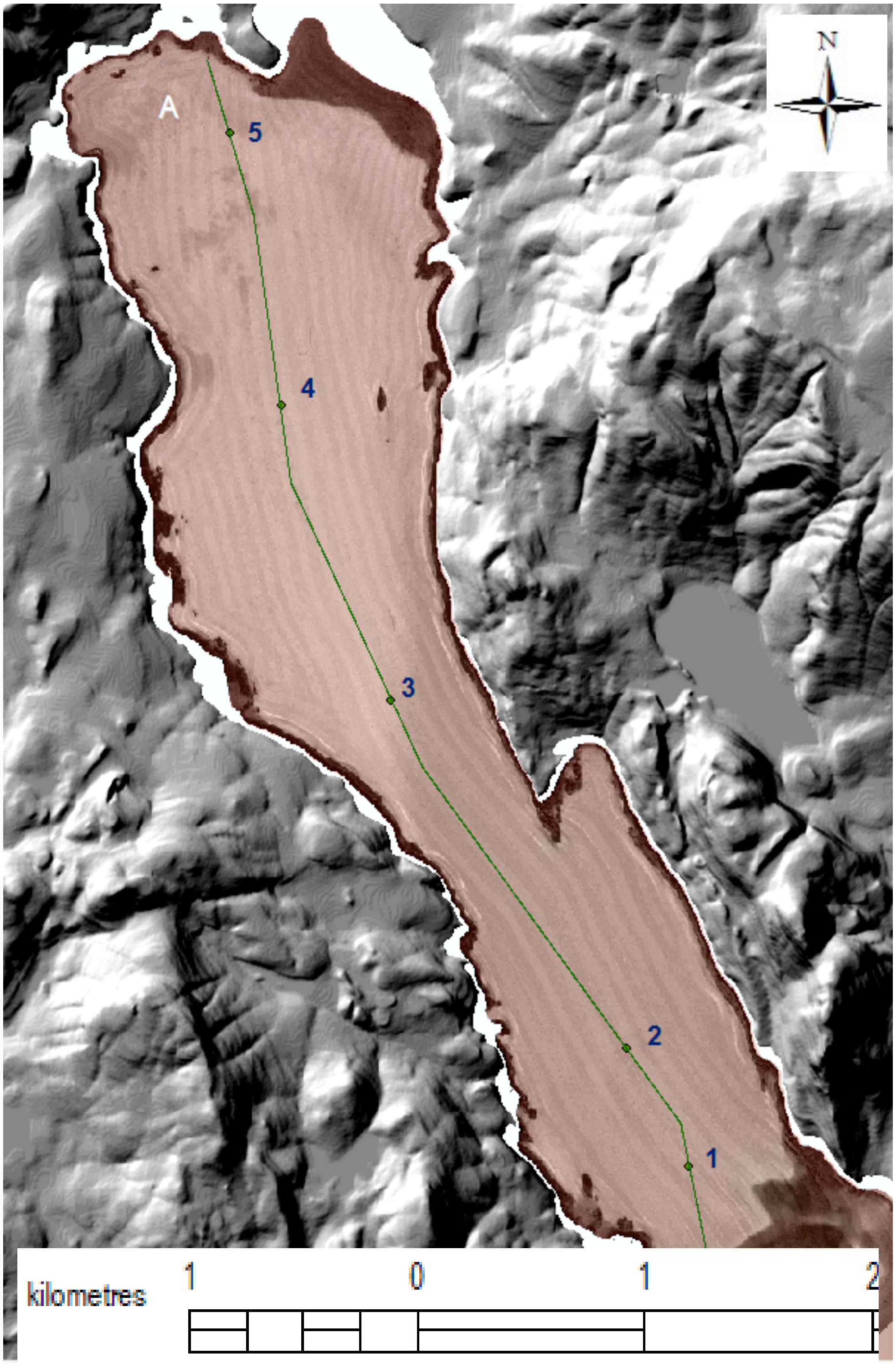


Figure 3: Detail of East Sound, brown shade indicates all depths are less than 30 m and overlays backscatter. Note change in backscatter intensity from mouth to head at Site 3. A – A' represents transect with station numbers.

## Study Area

The San Juan Islands are a part of an archipelago centrally located within the Salish Sea. The structural geology is complex as the islands are exotic tectonostratigraphic terranes. Formed as volcanic arcs and associated terranes in the Pacific, the islands represent accretion onto the North American continent beginning in the Mesozoic and continuing through the Cenozoic. The area was then glaciated during the Pleistocene, which scoured bedrock, cut fjords, and deposited sediments ranging in size from erratic boulders to mud banks (Edriz et. al., 2010). These glacially deposits comprise much of the sediment in the Salish Sea (H.G. Greene, personal communication, 2011).

### *Orcas Island*

Orcas Island is the largest of the San Juan archipelago. Although the Strait of Georgia and Juan de Fuca Strait are north and west of the Island and concentrate current flow, the southern portion of the island experiences restricted flow because the geometry of surrounding islands. On the southern shore are the mouths of three glacially cut fjords, Deer Harbor, West Sound, and East Sound (Figure 1) (McLellan, 1927). East and West Sounds are the larger of the three and shall be the focus of this study due to their differing bathymetries (Figure 4). Both embayments are shallow, experience the same atmospheric conditions, have similar geologic history, and subject to the same water. However, bathymetries differ such that circulation within East Sound is restricted due to the presence of a partial sill, where as West Sound is open and experiences greater flushing.

**Figure 4**

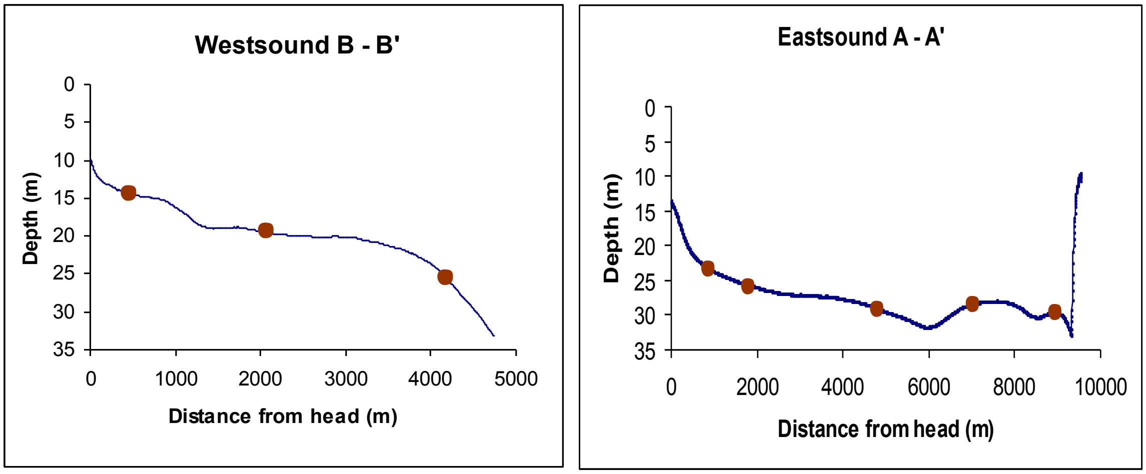


Figure 4. Depth profiles of East and West Sound showing differing bathymetries. Profile taken along transects in Figure 2. Head of bay is zero. Note glacially deposited sill at mouth of East sound that restricts flow of bottom currents. Orange dots represent sampling sites.

### *East Sound*

Located near the center of Orcas Island, East Sound is a glacially cut fjord that trends N 30° W and is the largest and deepest of the two sounds. Due to a partial sill, a breached terminal or recessional moraine, that restricts more than half of the mouth, East Sound experiences a reduced tidal range of 0.3 to 3.5 m (McLellan, 1927; Roesler et al., 1989; Dekshenieks et al 2001). East Sound averages 1 to 2 km wide and maintains close to a 30 m depth along most of its 12 km length (Dekshenieks et al., 2001; Rines et al., 2002)(Figure 3). Salinity drops in the spring due to increased runoff from the Fraser River on the Canadian mainland through the Strait of Georgia (Roesler et al., 1989; Rines et al., 2002). Although a number of phytoplankton studies have been carried out in East Sound, providing a wealth of water chemistry and circulation data, little has been done to investigate the benthic infauna in the center of the sound.

### *West Sound*

West Sound is the smaller of the two sounds and located approximately 5 km west of East Sound. It is of similar width and trends parallel to East Sound, but is only 7 km long. It is shallow and rocky at the northern end, maintains a 20m depth for much of its length, and slopes to a maximum depth of 40m at the mouth (McLellan, 1927). West sound does not have a restrictive sill at the mouth and presumable experiences increased circulation compared to East sound (Figure 4).

## Past Work

### *Multibeam and Backscatter*

Multibeam echosounder (MBES) data are typically used to generate bathymetric maps, but some of the acoustic signal is refracted and not collected by the transducer.  This results in a change in intensity of the signal termed “backscatter” and can be used to infer seabed composition.  For example, smooth and consolidated sediments return more acoustic signal generating higher intensity backscatter and poorly sorted or rough sea beds refract more signal resulting in lower intensity backscatter (Brown, 2007).

East and West Sound have been mapped at 200% coverage with MBES data. These data have been used by the Geologic Survey of Canada to generate a habitat map that define two habitats in West Sound, but only a single unconsolidated muddy habitat for East Sound (Figure 1)(Endris et. al., 2010). Reexamination of the data reveals two and possibly three changes in the backscatter that could result from changes in substrate and habitat (Figure 3).  In concert with in-situ sampling, this study aims to determine if East Sound contains more than one habitat.

### *Sediment Quality Assessment*

The Washington State Department of Ecology carried out a sediment quality assessment in 2002 and 2003 to evaluate levels of toxicity throughout the Salish Sea.  Included in their study were four sites in East sound and one in West sound (Figure 5).  Sediment quality was assessed by measuring biological and physical parameters.  At each site Van Veen grabs recovered samples of the bottom sediment and subsamples were taken for water chemistry, sedimentary analysis, and benthic infauna studies.  East Sound was designated as an area of concern due to toxicity levels within the sediments and low faunal diversity and abundance.

**Figure 5**

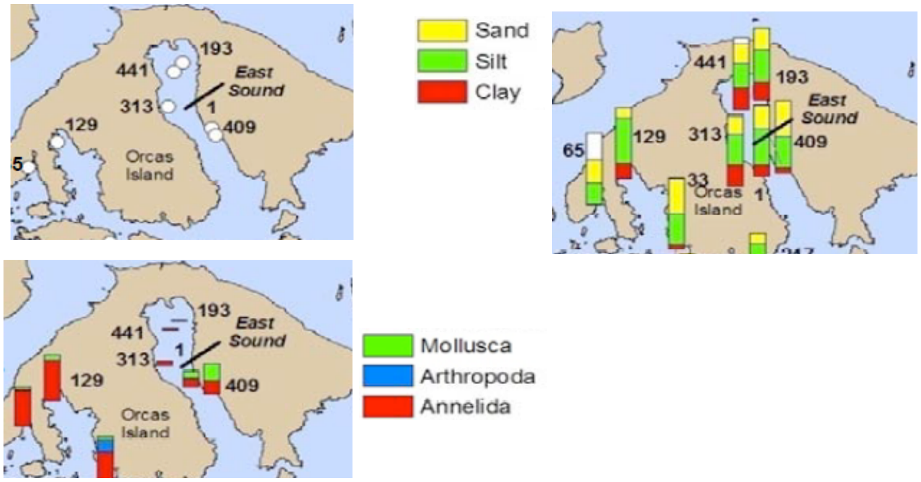


Figure 5. Results from Washington State Department of Ecology's Sediment Quality Assessment. Note sample sites located near shore, which may explain larger sand size fraction than collected for this study. Faunal abundances and diversity are consistent with this study.

### *Macrofauna and backscatter*

Self et. al. (2001) working in West Sound found that low-angle acoustic backscatter can be used to map some types of macrofauna, specifically those with hard parts or large air bladders. These authors experimentally placed several species of benthic macroinvertebrates on the sea floor and set out bait to attract mobile fauna. The sites were then monitored and re-sampled for changes in acoustical properties, or backscatter. When infauna were concentrated, especially those with hard parts, or significantly altered the sediments in such a way as to change consolidation of the sediments, it was possible to identify a signal in the backscatter.

### *Phytoplankton and Thin Layer water studies*

Dekshenieks et al. (2001) found that both local and regional physical processes control water mass movement in East Sound. Surface waters are influenced by wind, where as deeper waters are influenced by tidal currents, which caused the development of a thin layer between the differing densities of surface and deep water. Differing water chemistries of the Strait of Georgia and Juan de Fuca seasonally influence the Sound. High spring runoff from the Fraser River into the

Strait of Georgia during neap tide introduces a plume of low salinity water into the Sound creating strong density gradients. Additional studies confirm a season influx of freshwater into East sound (Roesler et al., 1989; Rines et al., 2002).

## Methods

A single transect was run the length of the embayments in each of East and West sounds, Orcas Island, mouth to head on Nov. 4, 2011 aboard the R/V Centennial. Transects were mapped using ArcGIS 10 and located approximately mid sound, avoiding nearshore boulders and steep slope changes where possible (Figure 1). Sample sites were identified from changes in intensity on the backscatter map that may indicate changes in substrate (Figure 3). Five sites were selected in East Sound, but only three sites in West Sound, as it is shorter in length. Site 1 East Sound and Site 6 West Sound are located near the mouth and sample ID numbers increases incrementally along each transect towards the head of the sounds. Site 1 and 2 East Sound and Site 8 in West Sound are in higher intensity substrate as indicated by the darker shade. Site 3 East Sound and Site 7 West Sound are in a transitional zone from higher to lower intensity. Site 4 East Sound and Site 8 West Sound are in lower intensity, and Sample 5 East Sound is located in a "mottled" area of high and low intensity backscatter (Figure 2). Sampling began at 0950 hrs local time at site 1 in East sound and continued through site 5, the Centennial then transited to West Sound where sampling began at site 6 at 1350 hrs local time.

### *Sediment and infaunal sampling*

At each site, three Van Veen grabs were collected from which two, two liter size bag sub-samples were taken to be analyzed in the lab. While Van Veens were being deployed off the starboard side of the vessel, a niskin bottle was deployed twice off the port side to collect water samples for lab analysis.

In the laboratory bagged samples were wet sieved for infaunal organisms within 48 hrs of the time of collection. Samples were first washed through a 2mm sieve and then a 1mm sieve. Organisms were hand picked off sieves with soft forceps and placed in 95% alcohol to await identification.

200 mL of slurry were reserved from sample bag "a", corresponding to the first Van Veen grab at each site, for sediment grain size analysis. Standard geologic analysis of sediment samples containing more than 30% mud fraction employ the pipette method or a cell (Coulter) counter. Time and facilities prohibited the use of these two methods so samples were simply wet sieved, dried, and weighed. Samples were only sieved to 4phi to separate the sand from the silt and mud fraction. The 200 mL sub-sample was split into two sets, one set was treated

according to standard geologic methods as in Folk (1980) and the second set was untreated and left aggregated as this may be more ecologically relevant. Disaggregated sample was dispersed with a 1% Calgon solution, mechanically agitated, and sieved. The aggregated sample was wet sieved as collected with sea water.

*Water Sampling*

To sample near the sediment-water interface, a niskin bottle was hand deployed until it felt bottom and then pulled back 1 meter, allowed to drift to allow sediment to settle, and then a messenger deployed to close the bottle. Temperature, Salinity, and Dissolved Oxygen were measured on board the vessel using an YSI probe. Two samples were collected in $O_2$ bottles and delivered to the Friday Harbor Labs' Carbonate Chemistry Lab to measure total carbon, total alkalinity, and confirm salinity. The pH was then calculated in CO2Calc with Mehrbach et. al. (1973) constants for CO2. A Conductivity, Temperature, and Depth sampler (CTD) was run to within 5 m of bottom at Site 1, 3, and 5 in East Sound and Site 6 and 8 in West Sound to characterize the water column.

*Interpretive process*

Comparisons between abundances, site by grab and physical factors were analyzed using non-parametric multivariate statistics (PRIMER 6.1.13, PRIMER-E Ltd. Plymouth, UK; Clarke and Warwick 2001). Nonmetric multidimensional scaling (nMDS) was used to determine the significance of spatial trends in community structure between a) percent mud aggregated, b) temperature, c) dissolved oxygen, and d) pH. Tests were based on Bray-Curtis similarity matrices (Kruskal fit scheme 1; restarts=50; minimum stress=0.01), derived from square-root transformed point intercept data. All results were further tested for significance using one-way analysis of similarity (ANOSIM).

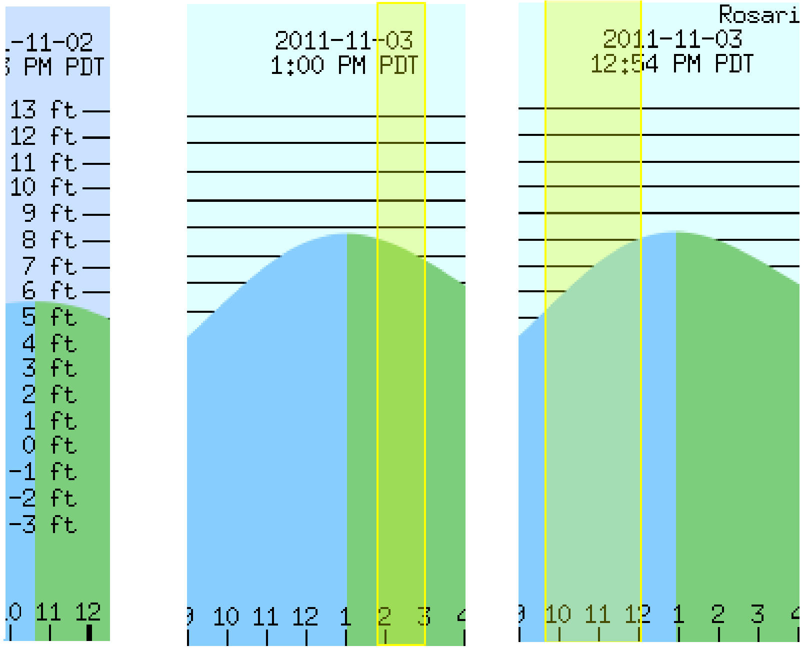
## Results

### *Atmospheric Conditions and tidal currents*

Atmospheric conditions were reported from the weather station maintained at Eastsound Airport. Conditions were stable for the six hour duration of sampling. Temperature rose from 7 to $9^{o}$ C, barometric pressure was unchanged, with a light wind of 8-16 km/hr out of the southeast.

Tidal gauges are no longer maintained on Orcas Island so predictions from the National Oceanographic and Atmospheric Administration website are reported here. Sampling in East Sound occurred during a flood tidal cycle and sampling in West Sound occurred near the end of slack tide (Figure U). Tidal flux was likely less than 1m during sampling. On board measurements from the Acoustic Doppler Current Profiler confirmed that currents were low, nearing zero in West Sounds, and sampling in both sounds likely occurred near slack tide.

**Figure 6**



Scale A) West Sound B) East Sound

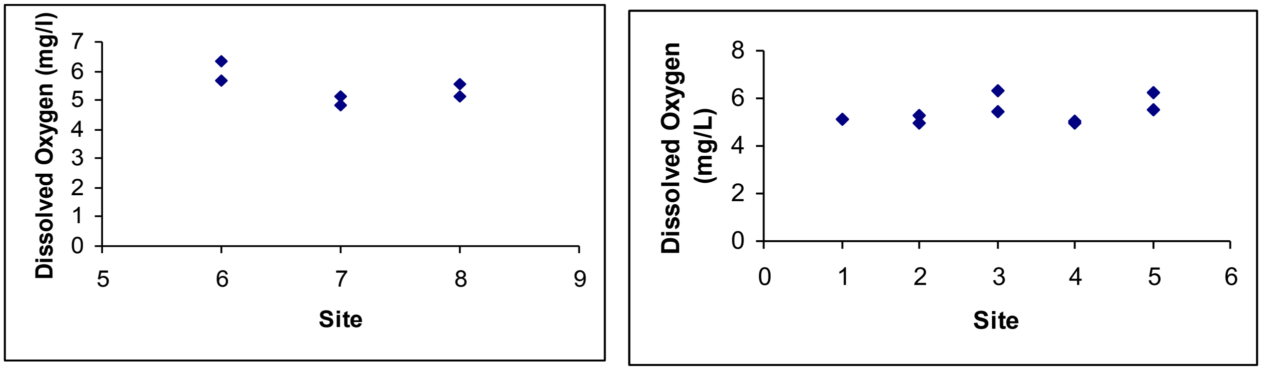
Figure 6. A) West Sound tidal prediction places sampling at the end of slack from 1355–1453 hrs local time, B) East Sound tidal prediction places sampling during flood tide from 0945–1205 hrs local time.

*Water Chemistry*

Near bottom niskin sampling

## ***Oxygen***

Dissolved oxygen levels remained consistent along the transects in each sound, however, levels in East Sound were lower at all sites than in West Sound.

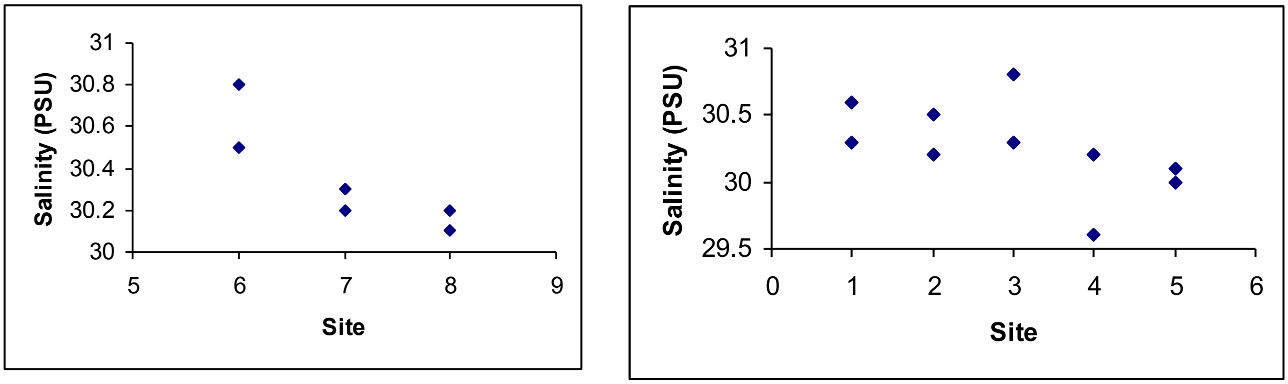

A) West Sound

B) East Sound

Figure 7. Dissolved oxygen values for niskin bottle drops. Levels in East Sound are lower than those in West Sound.

## ***Salinity***

Salinity was slightly lower near the heads of both sounds. Field probe results in the field yielded large differences in salinity at each site, but reanalysis in the lab showed salinity to change little between sites.

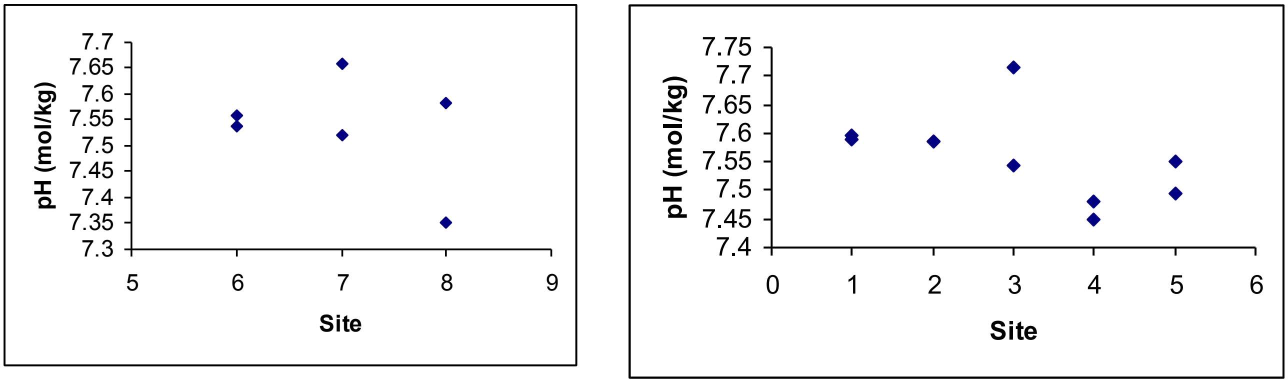

A) West Sound

B) East Sound

Figure 8. Salinity lowered up sound in both fjords.

## ***pH***

In both sounds, pH varied less than 0.4 mol/kg. Discrepancies between replicates at each site may be the result of microbial activity after collection and before poisoning of the sample. East Sound exhibited lowest pH at site 4.

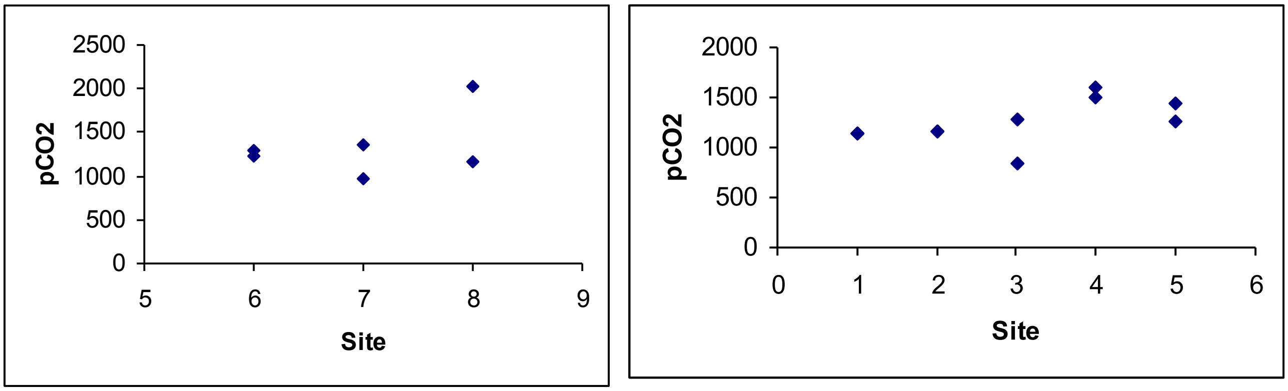

A) West Sound

B) East Sound

Figure 9. PH decreased near the heads of both fjords, East Sound exhibited lowest pH at site 4 at 7.448 mol/kg.

### ***pCO2***

pCO2 values are higher than expected but not unusual for the Salish Sea and increase up sound in both fjords (Connie Sullivan, personal communication, 2011).



A) West Sound

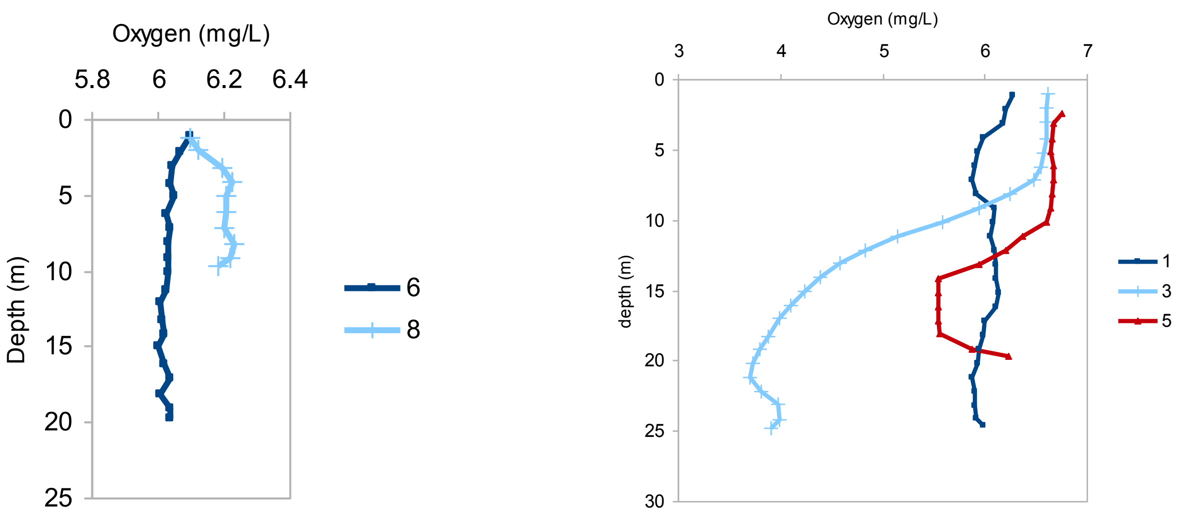
B) East Sound

Figure 10. pCO2 values are high, but not unusual for the area.

CTD profile

## ***Oxygen***

Oxygen levels varied with depth at Site 8 in West Sound and at Sites 3 and 5 in East Sound (Figure 11). In West Sound levels were consistent at depth with levels in upper West sound being slightly higher.  East Sound indicated an oxycline at Site 3 and at Site 5.

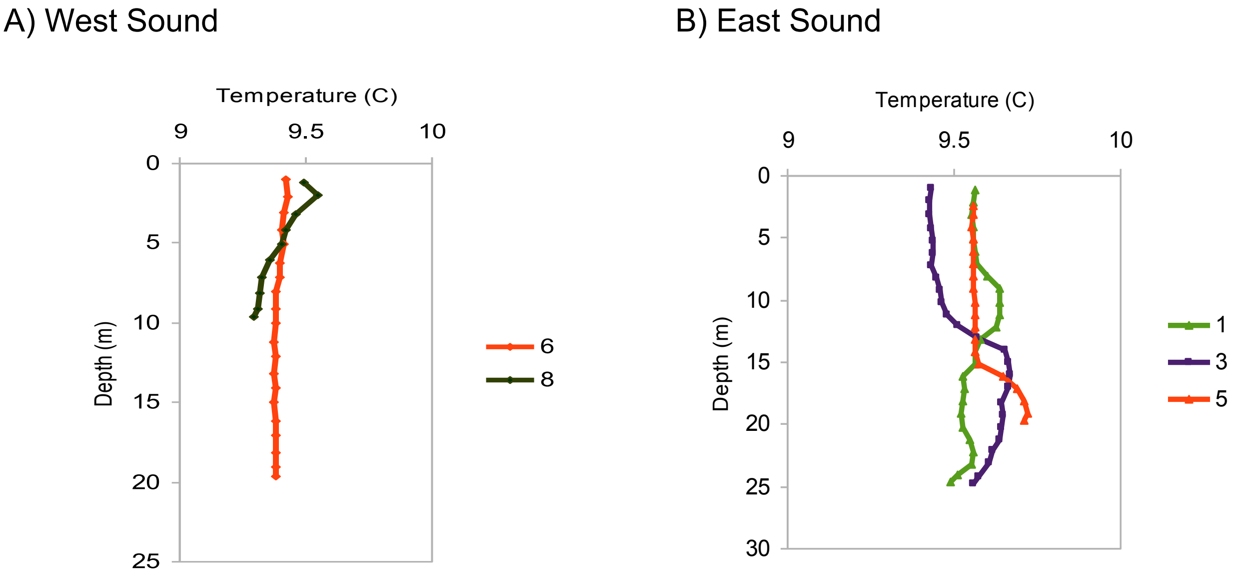

A) West Sound

B) East Sound

Figure 11. CTD profile of Oxygen levels in A) West Sound and B) East Sound, by site.  Note difference in scale between West and East Sound.  East Sound exhibited the greatest changes with depth at Site 3 and 5.

## ***Temperature***

Temperature remained stable with depth, changing less than 1 $^{o}$C in each sound.

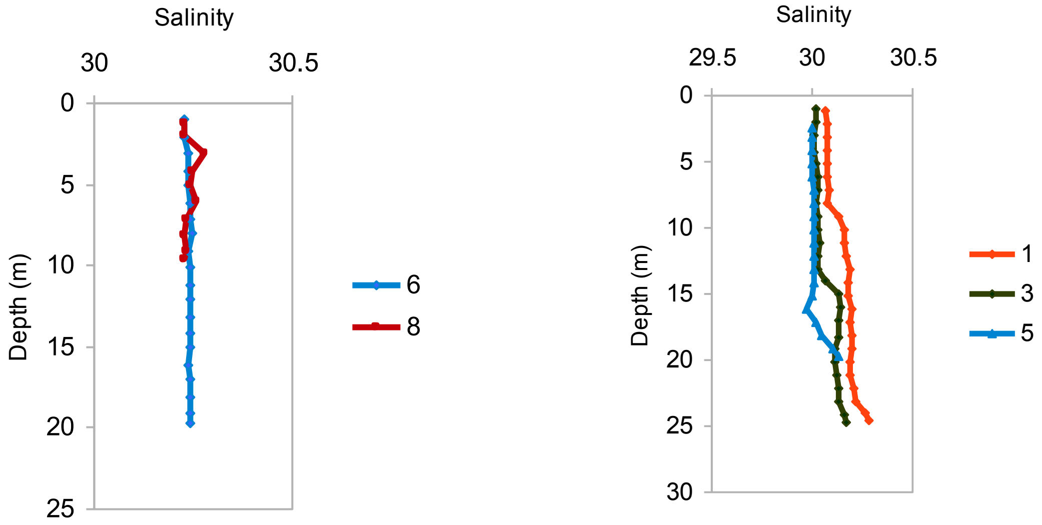

A) West Sound

B) East Sound

Figure 12. CTD temperature profile with depth for A) West Sound and B) East Sound

### ***Salinity***

Salinity remained stable with depth varying less than 1 PSU in each sound.


A) West Sound

B) East Sound

Figure 13. Salinity for A) West Sound and B) East Sound

### *Sedimentary Analysis*

Sediment grain size in both aggregated and disaggregated sets were predominantly of the silt and mud fraction. However, aggregated samples were composed of a greater percent sand fraction in all samples. Distribution of grain size did change along the transect in both sounds.

**Figure 14**

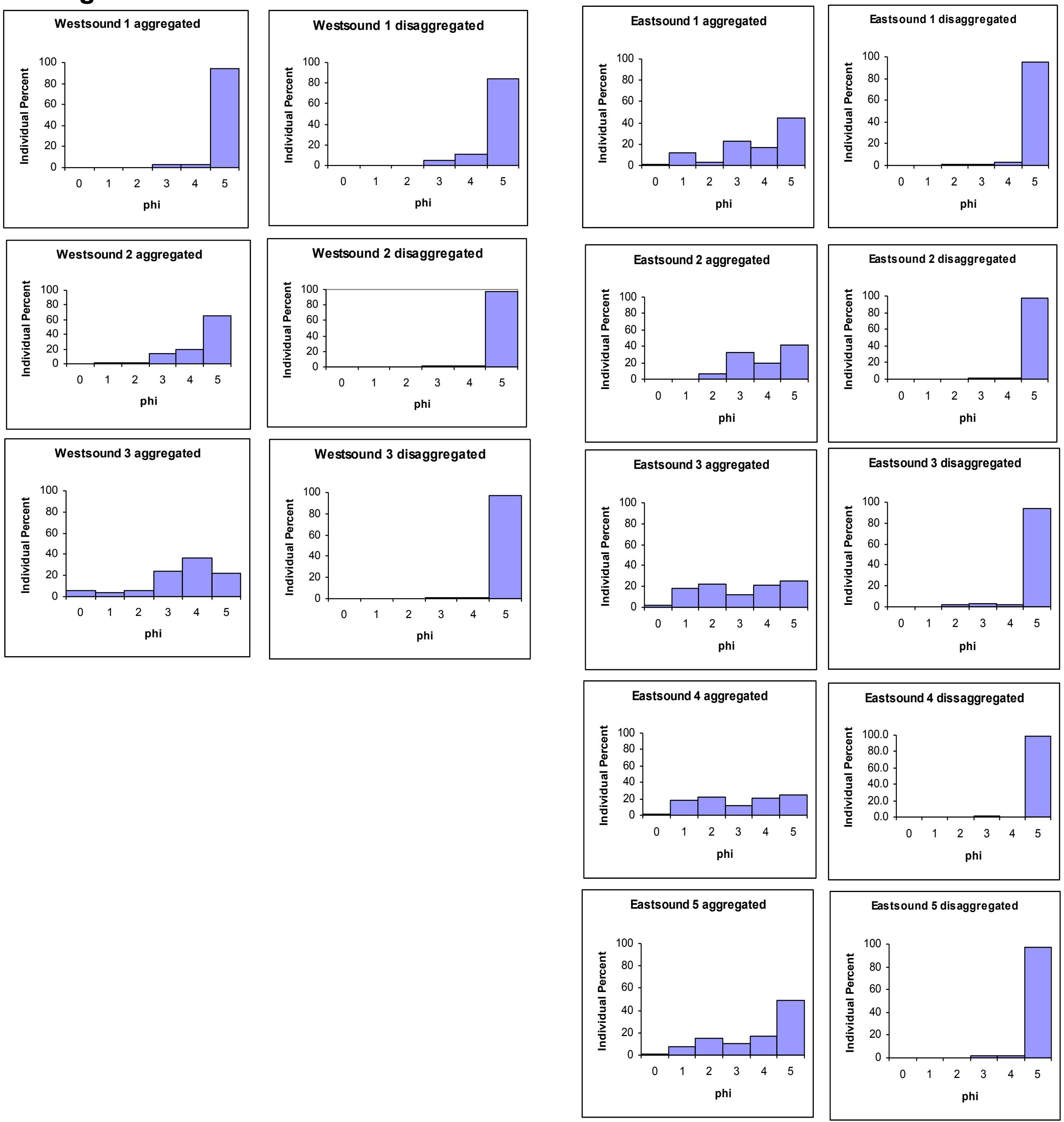


Figure 14: West sound samples on the left, East Sound on the right. Graphs on the left are aggregated and disaggregated on the right. All disaggregated samples were composed of greater than 90% 5phi.

*Infaunal Abundance*

East Sound is less diverse and has reduced abundances compared to West Sound (Table 1). Five phyla were collected in West Sound and three phyla were collected in East Sound. Arthropoda and Cephalorhyncha were only found in West Sound and Annelida was the most diverse group in both Sounds. Cirratulidae is the most abundant family in West Sound and Nephtyidae is the most abundant and only family present at all sites in East Sound. Upper East Sound only yielded Nephtyids.

**Table 1: Faunal Abundance by Site**

| Phylum | Family | West6 | West7 | West8 | East1 | East2 | East3 | East4 | East5 |
|---|---|---|---|---|---|---|---|---|---|
| Annelida | Goniadidae | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| Annelida | Pilargid | 0 | 0 | 1 | 5 | 0 | 0 | 0 | 0 |
| Annelida | Capitellidae | 2 | 1 | 11 | 16 | 6 | 0 | 0 | 0 |
| Annelida | Nephtyidae | 1 | 0 | 0 | 17 | 19 | 8 | 12 | 19 |
| Annelida | Orbiniidae | 5 | 2 | 5 | 15 | 14 | 0 | 0 | 0 |
| Annelida | Spionidae | 6 | 4 | 3 | 3 | 6 | 0 | 0 | 0 |
| Annelida | Cirratulidae | 379 | 238 | 232 | 1 | 1 | 0 | 0 | 0 |
| Annelida | Terebellidae | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 |
| Annelida | Sternapsidae | 9 | 1 | 4 | 0 | 0 | 0 | 0 | 0 |
| Annelida | Scalibreginidae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Annelida | Opheliidae | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Nemertean | Nemertean | 0 | 1 | 3 | 1 | 0 | 0 | 0 | 0 |
| Cephalorhyncha | Priapulidae | 0 | 5 | 9 | 0 | 0 | 0 | 0 | 0 |
| Mollusca | Nuculidae | 67 | 20 | 1 | 4 | 1 | 0 | 0 | 0 |
| Mollusca | Lucinidae | 18 | 9 | 16 | 12 | 4 | 0 | 0 | 0 |
| Mollusca | Veneridae | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mollusca | Tusk | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Arthropoda | Pinnotheridae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Arthropoda | Amphipoda | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 1. Abundance by family and site within East and West Sound showing a distinct difference between the two sounds. Note sites located in upper East Sound are restricted to a single family of polychaetes.

*Statistical Analysis*

Three distinct communities separate in nMDS ordinations when all grabs at all sites were considered (Fig. 15). One-way ANOSIM highlighted significant differences between sites (R=0.777; p=0.001). No significant difference was found with any single physical factor. pH replicates yielded a single value when binned could not be analyzed. Percent mud aggregated did not return significant results (R=0.252; p=0.138), but a general pattern does emerge (Figure 16) and additional replication may bear this out.

**Table 2**

| | ANOSIM *R* | *P* value |
|---|---|---|
| Abundance | 0.777 | 0.001 |
| % mud Aggregated | 0.252 | 0.138 |
| Temperature | 0.268 | 0.032 |
| Dissolved Oxygen | -0.074 | 0.717 |
| Salinity | -0.068 | 0.692 |
| pH | | |
| Data were square root transformed | | |

Table 2: ANOSIM results of nMDS tests of abundance by site with the physical factors measured

**Figure 15**

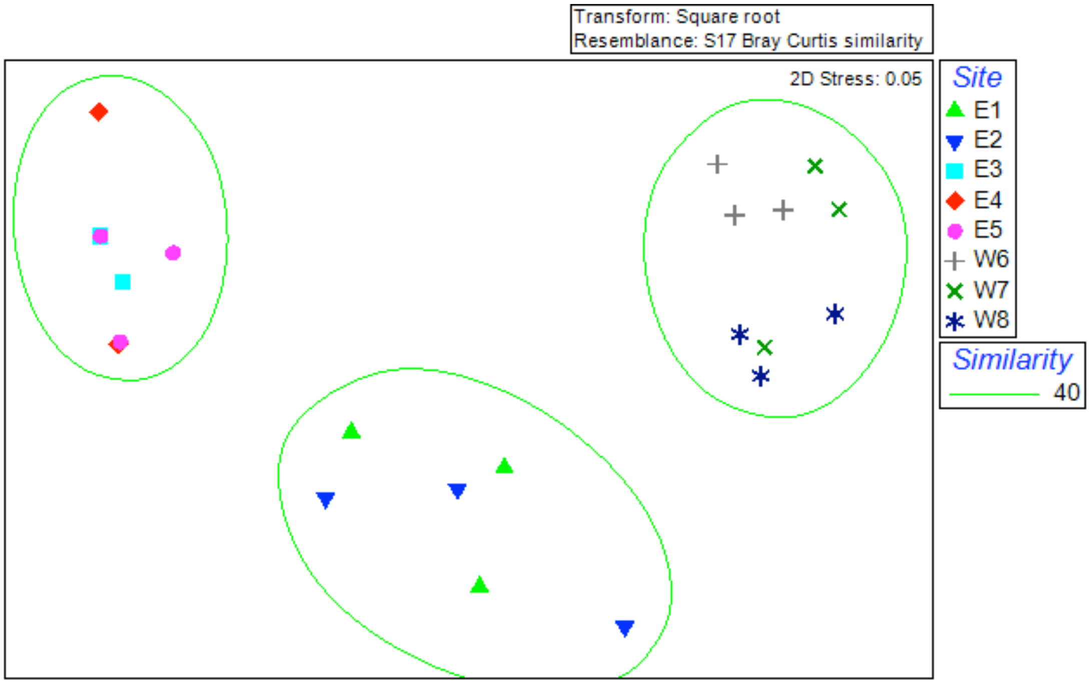


Figure 15. nMDS plot of community structure by abundance at each site at the 40% similarity. East Sound is split into two distinct communities, upper and lower sound. West Sound also exhibits some separation of upper and lower sound.

**Figure 16**

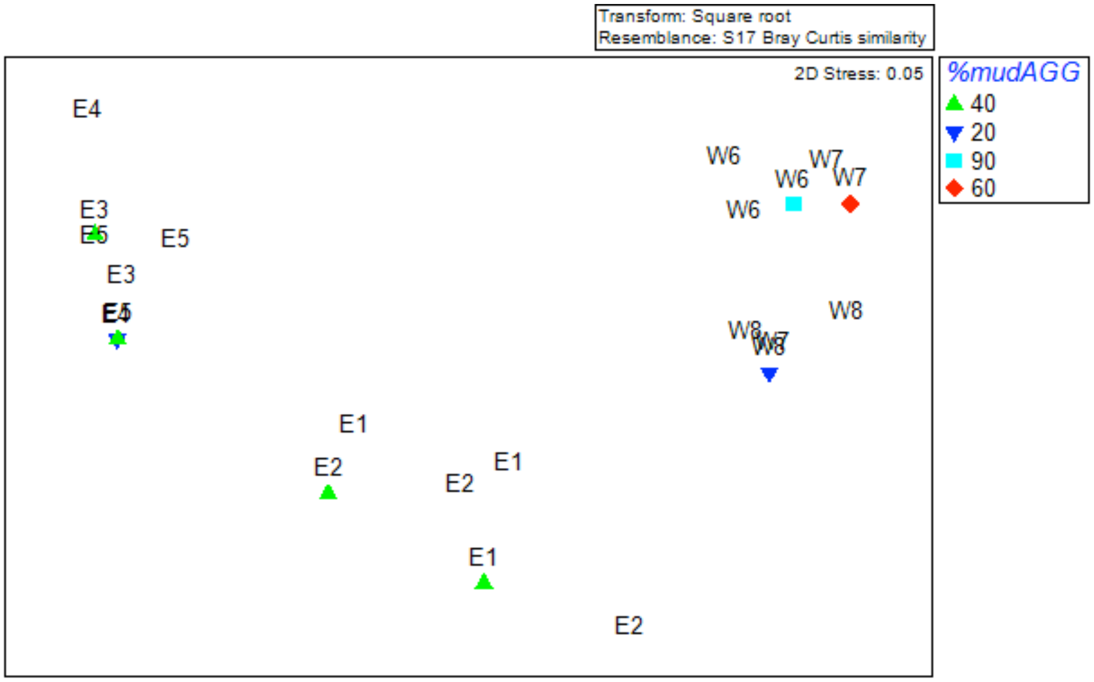


Figure 16. No significant difference was found based on percent mud aggregated, but a general pattern is apparent separating East Sound into a single bin. Further replication may bear a more significant relationship.

## Discussion

East and West Sounds, on Orcas Island, have three distinct infaunal macroinvertebrate communities. An attempt was made to discover the underlying mechanisms that may be controlling these soft-sediment communities, but no significant results were returned. However, some general observations can be made from the field and suggestive structures in the nMDS plots that may be pointing to changing conditions in the sediments. Although full chemical analysis was not performed, sediments recovered from upper East Sound exhibited characteristics consistent with sulfate reduction. Samples from Site 3, 4, and 5 in East Sound smelled strongly of rotten eggs, had a high water content, were yellow, had an oily texture, and contained a great deal of detritus. These three sites contained the lowest abundances and lowest diversity, containing a single family of polychaetes, the Nephtyids. This information applied to the subtle difference observed in the backscatter data confirm two separate habitats within East Sound (Figure 17).

These results are similar to studies conducted in Delaware Bay. For two summers Maurer et. al. (1978) conducted a bay-wide survey of benthic invertebrates in Delaware Bay. They found that species richness increased with increasing salinity and grain size and with sharp boundaries between patches. The communities sampled were dominated by infaunal deposit feeders and found to be similar to other estuaries around the world. This study was the first to investigate faunal distributions in relation to environmental factors in the Deleware Bay and has been the foundation for a number of additional studies on the bay (Maurer et. al., 1978).

These results are also consistent with the State of Washington Department of Ecology's Sediment Quality Assessment of 2002-2003. Their samples contained a higher percent sand, which is probably a result of their sites located closer to shore than this study. Their abundances and diversities were consistent with this study.

**Figure 17**

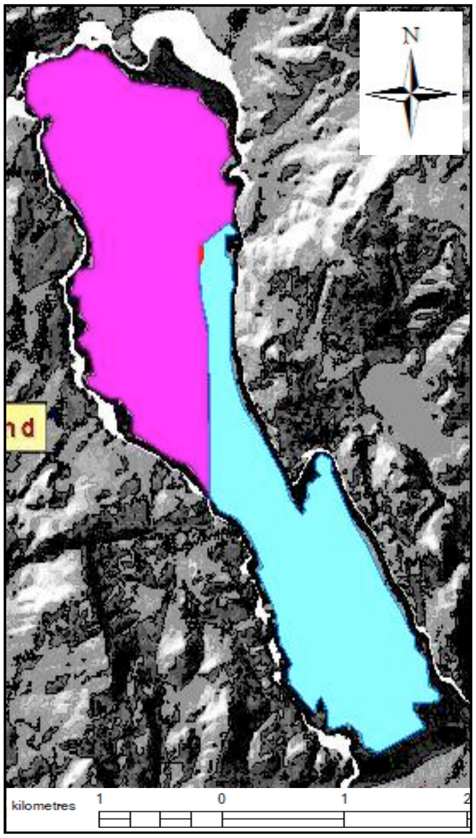


Figure 17. Revised habitat map for East Sound Orcas Island WA including two separate habitats. Lower East Sound in cyan is consolidated mud and Upper

East Sound

## Conclusions

Soft-sediment habitats can vary significantly over a few meters and infauna communities reflect these changes. Multibeam backscatter maps can reveal changes in seafloor composition that may relate to these changes in habitat, but need to be ground-truthed to describe the nature of those changes. In concert, backscatter and in-situ sampling, can generate accurate habitat maps that characterize communities and further the understanding of ecosystem structure. East and West sounds of Orcas Island, Washington state differ in their bathymetry, sedimentology, water chemistry, and infaunal communities. Future sampling of East Sound needs to clarify the relationship between changing bottom conditions and infaunal communities. Bay wide surveys of this sort further our understanding of soft-sediment habitats and the underlying mechanisms that control soft-sediment communities.

## Acknowledgements

I thank the Henry and Holly Wendt Endowment and Linda and Ted Johnson through the Friday Harbor Labs Adopt-A-Student program whose generous support made it possible for me to attend this research apprenticeship. The apprenticeship received additional funds from the Mary Gates Endowment, UW Provost's Fund, the National Science Foundation, and the Northwest Straits Commission. I would also like to thank the numerous students and faculty who made this study possible. The sampling crew who assisted on the cruise: Ryan McLaughlin, Liz Ewings, Alex Witt, Gary Greene, and Mark Anderson. The analysis crew who assisted with water chemistry, statistics, and animal identification: Michelle Herko, Connie Sullivan, Rebecca Guenther, Megan Dethier, Gustav Paulay, Cori Kane, and Tim Dwyer. Ken Sebens, Kevin Turner, Jan Newton, Trish Morse, Dave Duggins, and all the apprentices who helped shape and inform this study.

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