Lummi Intertidal Baseline Inventory

Appendix A: Intertidal Biota Survey

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Collecting Intertidal Biota Survey samples during the LIBI.

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Executive Summary

The Intertidal Biota Survey documented the presence, relative abundance, and preferred habitats of benthic infauna that are present on the Lummi Reservation tidelands. 366 sites were characterized and sampled across the Lummi Reservation tidelands, and the biota present were identified and counted.

Approximately 150 taxa were identified in the samples, with some taxonomic labels including more than one species. Overall, polychaete worms in the Family Oweniidae were the most abundant animal taxon present across the Reservation tidelands, followed by caprellid amphipods (*Caprella* sp.), and then horn shells (*Batillaria attramentaria*).

The most abundant clam species was the recently arrived purple varnish clam (*Nuttallia obscurata*), which also had the largest total biomass (19.9 million pounds) of any clam species. Butter clam (*Saxidomus gigantea*), cockle (*Clinocardium nuttali*), Manila clam (*Venerupis phillipinarum*), and Pacific littleneck clam (*Leukoma staminea*) populations had 6.7, 2.7, 2.9, and 2.1 million pounds of biomass, respectively. Horse clam (*Tresus* sp.) and softshell clam (*Mya arenaria*) populations were also present but estimates of biomass indicate lower overall biomass for these species (1.6 and 1.2 million pounds, respectively). Other populous clam species included large populations of bentnose clams (*Macoma nasuta*), pointed macoma clams (*Macoma inquinata*), Baltic macoma clams (*Macoma balthica*), and California softshell clams (*Cryptomya californica*).

The distribution and habitat preferences of selected species, along with a comparison of habitat factors present in different geographical areas, are presented and discussed in this appendix. A community-level ecological analysis is presented separately in Appendix I.

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1.0 Introduction

The Lummi Reservation tidelands include a range of habitats that directly support at least three species of commercial importance (Manila clams, Pacific oysters, and Dungeness crabs) as well as several species that are important for ceremonial and subsistence purposes. Most efforts to assess distribution and abundance of organisms within the Reservation tidelands have focused on Manila clam abundance; data for other ecologically and culturally important species were either very limited or not available at all previous to this study.

1.1 Existing Information

The distribution and abundance of Manila clams (*Venerupis philippinarum*) on Reservation tidelands are well documented and the population is specifically managed to ensure sustainable harvest (Cochrane 1990; Dolphin 2002; Dolphin 2008; Dolphin unpublished). Intertidal clam surveys for Manila clams have been performed annually since 2002 in order to determine reliable abundance estimates for harvestable biomass and to set sustainable catch targets for the fishery. Estimates of legal-sized Manila clam biomass in surveyed portions of the Lummi Reservation tidelands have ranged from 1.3 to 1.7 million pounds (lbs) between 2002 and 2008.

Pacific oyster (*Crassostrea gigas*) distribution and abundance data were collected coincidentally during some of the Manila clam surveys, although no size information was recorded. The Manila clam survey data have only limited utility for Pacific oysters because the spatial distribution of oysters is not the same as Manila clams and it is likely that there are areas with Pacific oysters that were not included in the Manila clam surveys.

Dungeness crab larvae (*Cancer magister*) are known to settle and rear for up to two years in intertidal areas of the Reservation (Dinnel *et al*. 1986). Even though Dungeness crab settlement timing, recruitment, and adult abundance have been documented in Lummi Bay (Dinnel *et al*. 1986; McMillan 1991), knowledge of recruitment patterns across intertidal areas on the Reservation is limited. Dinnel *et al*. (1986) described the process of settlement of megalops larvae at upper intertidal areas through the summer, and their subsequent seaward migration as they increased in size. Dungeness crab densities were measured at a few locations in Lummi Bay and these results were used to extrapolate overall crab abundance across Lummi Bay. Juvenile Dungeness crab densities were low in Lummi Bay compared to other areas; however, because of limited sampling these estimates may not be accurate (Dinnel *et al*. 1986; McMillan 1991). Dungeness crabs settle in a variety of intertidal habitats across the Reservation (McMillan 1991; Dolphin and LeMoine personal observation), but distribution information about Dungeness crab settlement and residency is also limited. Rocky intertidal areas and eelgrass meadows have yet to be fully surveyed for Dungeness crabs on the Reservation, and comparisons between Portage Bay and Lummi Bay cannot be made at this point.

During the annual Manila clam surveys, the presence of several other clam species was noted, but no size information for species other than Manila clams was recorded. Also, the depths excavated were usually too shallow to reliably document the presence of many other species. Some species that have occasionally been encountered include bentnose clams (*Macoma nasuta*), purple varnish clams (*Nuttallia obscurata*), eastern softshell clams (*Mya arenaria*), Pacific littleneck clams (*Leukoma stamina*), cockles (*Clinocardium nuttalli*), butter clams (*Saxidomus giganteus*), bay mussels (*Mytilus trossulus*), Pacific oysters (*Crassostrea gigas*), and european flat oysters (*Ostrea edulis*). Horse clams (*Tresus nuttalli* and *Tresus capax*), and geoduck clams (*Panopea abrupta*) have never been encountered during the regular Manila clam surveys, which is not surprising given their much lower distribution on the shore and the greater depth in the substrate. The only exception to this was a 2002 clam survey of Brant Island and Brant Flats that excavated smaller quadrats to greater depths, and which provided data on the distribution and abundance of several clam species, including horse clams, within a comparatively small survey area (Dolphin 2002).

The Nooksack River Estuary Report (Brown *et al*. 2004) summarized the work of Ross and Weispfenning (2004) and Spikes *et al*. (2003), who described species richness and biomass of benthic macroinvertebrates at 23 sites in the Nooksack River estuary, Lummi Bay, and Portage Bay. Lummi Bay and Portage Bay had the highest species diversity and the highest biomass of all of the sites sampled (Spikes *et al*. 2003)

Martin (1973) investigated differences in intertidal benthic populations between Lummi Bay and Portage Bay, and suggested that the freshwater influence of the Nooksack River impacts the composition of benthic communities that are present in Portage Bay.

Within Lummi Bay, the intertidal benthic fauna of the Lummi Bay Aquaculture Pond (Seapond) was found to be similar inside and outside of the Seapond structure (U.S. Army Corp of Engineers 1988). More recently, clam populations in the Seapond were surveyed in 2002 and again in 2005 using a venturi suction method, and starry flounders and Dungeness crabs that were visible from the surface were counted using an ad-hoc visual transect method (Dolphin unpublished). Large populations of Manila and bentnose clams were present in the Seapond, along with smaller populations of Pacific oysters, european flat oysters, and pointed macomas (*Macoma inquinata*). The Seapond also had populations of adult starry flounder (*Platichthys stellatus*), staghorn sculpins (*Leptocottus armatus*), Dungeness crabs (*Cancer magister*). The area of the Seapond adjacent to the northern tidegates often has large assemblages of juvenile finfishes present during the spring and summer months: including Pacific cod (*Gadus macrocephalus*), greenlings (*Hexagrammos* sp.), Pacific herring (*Clupea pallasii*), sandlance (*Ammodytes hexapterus*), pink salmon (*Oncorhynchus gorbuscha*), sticklebacks (*Gasterosteus aculeatus*), and others (Dolphin, personal observation). The Seapond is also the site of release and recapture for coho salmon (*Oncorhynchus kisutch*) associated with the Lummi Bay Salmon Hatchery, which is operated by the Lummi Natural Resources Department.

Near the Reservation, benthic fauna abundances have been investigated to document effects resulting from industrial effluent in the Whatcom waterway (Shea *et al*. 1981; Broad *et al*. 1984; Becker *et al*. 1989).

In summary, with the exception of Manila clams, the distribution and abundance of benthic biota is not well described on the Reservation tidelands. The abundance and distribution of species such as Pacific littleneck clams, cockles, butter clams, geoduck clams, and horse clams is documented only for a small portion of the Reservation tidelands, even though they are important to subsistence harvests and distributed widely. Documentation is also lacking for juvenile Dungeness crabs, as their abundance across the Reservation and over time has not yet been adequately studied.

1.2 Goals and Objectives

The Lummi Intertidal Baseline Inventory (LIBI) final work plan (LeMoine *et al*. 2009) identified the need to obtain a comprehensive dataset that could be used to document the presence, distribution, and abundance of benthic organisms that are present on the Lummi Reservation tidelands. To fill this data gap, a reservation-wide survey of benthic biota was conducted.

The Intertidal Biota Survey was designed to sample all intertidal benthic organisms with a specific focus on species of direct importance to Lummi harvests, including: Manila clams, Pacific littleneck clams, purple varnish clams, cockles, eastern softshell clams, geoduck clams, horse clams, butter clams, Pacific oysters, and juvenile Dungeness crabs. Using these results, the LIBI could document, map, and enumerate intertidal populations of these species, and describe community assemblages across the Lummi Reservation tidelands. In addition, the LIBI was designed to document the relationships between benthic biota and the physical environment in which they live.

Despite the considerable effort expended in conducting the dig survey described in this appendix, confidence in the results for horse clams and geoduck clams is low because of the very large depths at which these species live. To address this weakness, a supplemental survey was conducted that used a different methodology to better describe the distribution and abundance of these species (Appendix B).

2.0 Methods

The intertidal biota inventory was conducted by sampling a number of systematically distributed locations throughout the Lummi tidelands and by describing the physical and biological characteristics of each location.

The LIBI literature review indicated that methods for assessing diverse intertidal areas similar to those on the Reservation tidelands were not well defined. Based on this literature review, LNR staff identified the most appropriate methods for characterizing intertidal biota and habitats (Beach Watchers 2003; Defeo and Rueda 2002; Elliot 1977; Fyfe 2002; Griffin 1995). Through field testing of methods during the summer of 2008, LIBI project team members developed a protocol for intertidal surveys that was consistent over diverse habitats, efficient for collecting many samples over a short period of time, and applicable to geostatistical analysis. The specific steps of characterizing and sampling sites are described below. Example data collection forms are shown as a reference for each stage in the process. The data forms were used to develop the customer database that is described in Appendix J and that was used to manage and analyze the survey data.

2.1 Sampling Methods

Based on timed field trials conducted during 2008, the LIBI goal was to sample a minimum of 300 specific locations distributed throughout the study area (Figure A.1). Additional sites were prepared in case progress was better than expected.

The specific site locations were chosen using a combination of approaches. For very large areas like the Nooksack Delta and Lummi Bay, sites were chosen systematically using the point-grid generating tool that is part of the Hawth's Analysis Tools Version 3.17 extension to the ArcGIS software. The original grid spacing for these large expanses was approximately 0.33 mile by 0.33 mile. However, because progress was better than anticipated, more sites were sampled in Lummi Bay that than were originally planned. These additional sites were located mid-way between the original site locations.

For smaller areas, the spacing of sites was reduced to 0.1 mile by 0.1 mile in order to achieve a higher sample density in areas of particular diversity and importance like Portage Spit and Brant Flats.

For steep, relatively narrow beach areas, like those along the Sandy Point peninsula and portions of Portage Island, a series of regularly-spaced transects perpendicular to the shore was created. Along each transect, four sites were selected for sampling. To determine the height of the topmost sampling site within the upper quarter of the surveyed range random numbers were used. The three remaining sites were located along each transect at equal vertical intervals thereafter (Figure A.2A). The latitude-longitude of each site was determined by using the digital elevation model derived in Appendix H ensuring that each sample location was located at the correct beach elevation along the transect. Because intertidal organisms tend to be strongly affected by vertical zonation, this approach ensured that a representative range of organisms would be collected from the beach along each transect regardless of the vertical profile of the beach. The alternative method, to equally space the sites along the horizontal range of the transect (Figure A.2B), would be less likely to sample as wide a diversity of organisms on beaches that feature a rapidly sloping section with a more gradual slope at the lower extent of the beach.

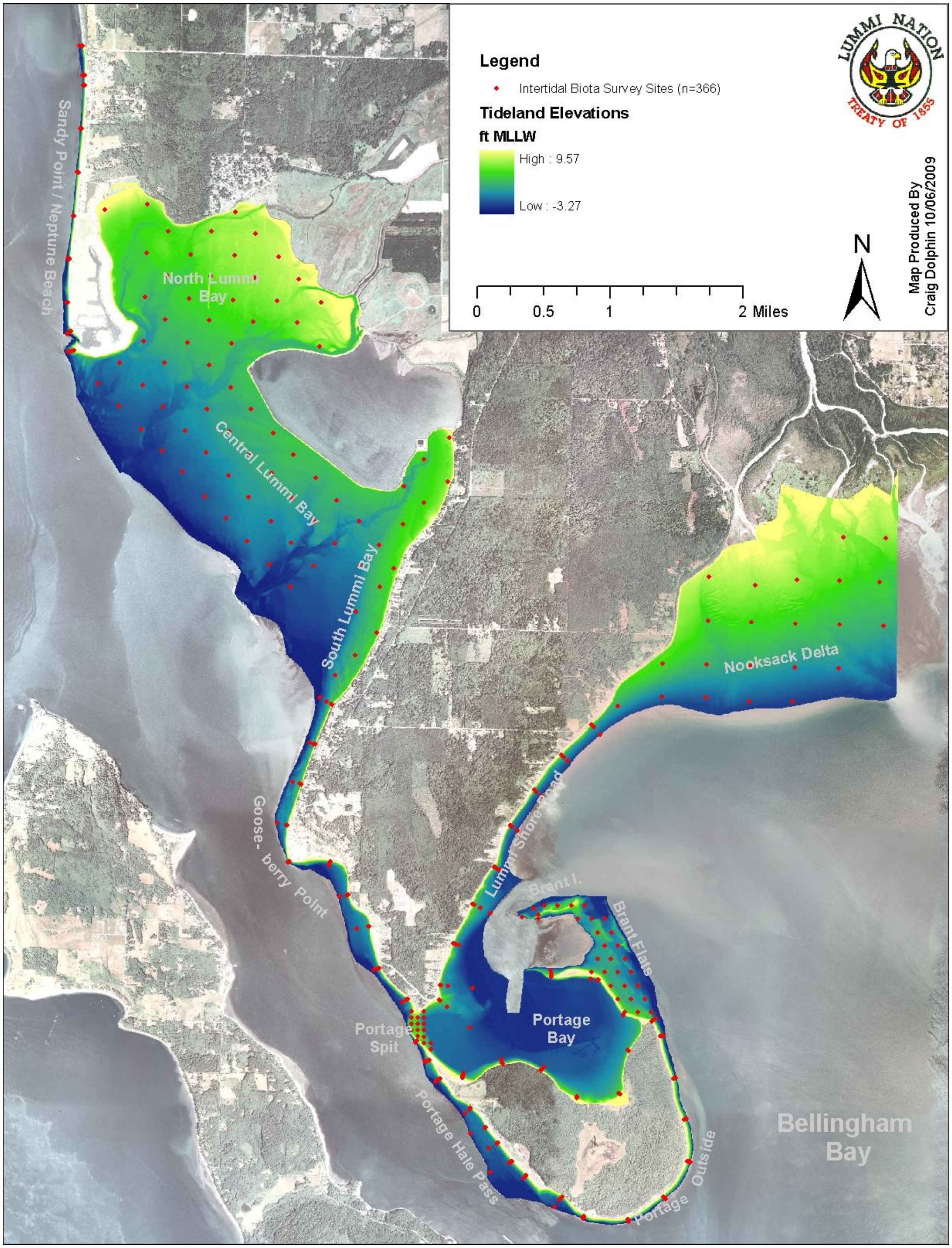


Figure A.1. Intertidal Benthic Inventory Sample Locations (n = 366)

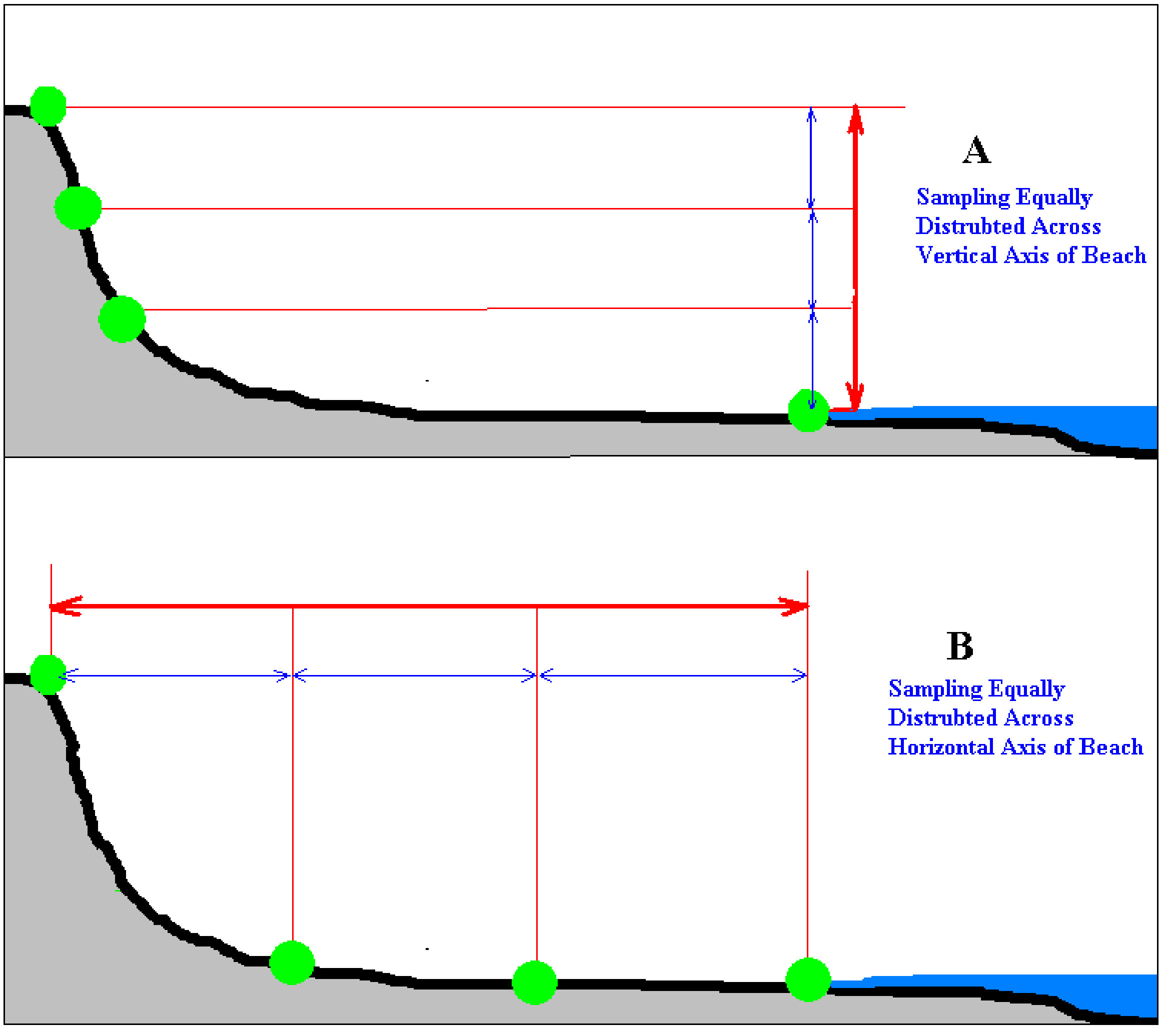


Figure A.2. Two Alternative Approaches to Systematically Sampling Organisms Found on Beaches. The Intertidal Biota Survey Adopted Option A for Sampling Beaches

2.2 Site Evaluation

Hand-held GPS receivers (Garmin Etrex Venture; Garmin Etrex Legend) with a maximum horizontal resolution of ± 10 ft were used to spatially locate each site in the field. Pre-printed forms and visual assessment were used to describe the physical location and characteristics of the site at a variety of spatial scales (Figure A.3). Substrates at each location were subjectively categorized based on standard methods (e.g., Diether 1990). A photograph was taken of the specific site to be excavated and four photographs of the surrounding areas. A handheld compass was used to determine the bearing of each photograph. At sites on noticeably sloping beaches, the orientation of the four photographs was generally up the shore towards land, down the shore towards the water, and then left and right parallel to the shore. At sites in the middle of bays where the beach slope was difficult to judge, the directions of the four photographs were based on the four ordinal compass bearings instead.

After the site was photographed and categorized, the physical habitat characteristics of the site were assessed. The depth of any standing water on the site was measured to the nearest centimeter. A visual assessment of three types of surface coverages was also conducted for the site prior to disturbance. These surface coverages were broken down into vegetation (vascular plants and macroalgae), epibenthic animals, and substrates (Fig. A.4). All surface coverage percentages were subjectively estimated prior to disturbance within the area to be excavated by the field crew.

Given the available resources, it was not logistically feasible to transport large amounts of rock by foot across several miles of tidelands for later sorting and enumeration. This meant that sessile organisms attached to big rocks may not have been retained after the sediment at the site had been excavated and sieved, and after the heavy rocks were removed from the sample. In an effort to document the presence and relative abundance of these organisms when rocks were present on the surface, up to five of the larger rocks at each site were randomly selected and the encrusting organisms were identified in the field and tallied (Figure A.5). The field identification keys used by the field crews were based on the identification keys used by Island County Beach Watchers (Adams and Holmes 2007; Adams and Holmes 2009).

LIBI Field Form A

Page# 1

Site Evaluation Section **Site ID** 131 **Waypoint** 131

Time

Sky Clear Part Cloudy Overcast (circle)

Crew Initials

Precipitation None Light Heavy (circle)

Site Descriptions:

Large Scale *(100's - 1000's of feet surrounding sampled area)*

Energy Category (circle one)

Exposed	Semi-Protected
Partially Exposed	Protected

Geomorphic Type (circle one)

Cove	Headland
Flat	Beach

Medium Scale *(10's of feet surrounding sampled area)*

Dethier Substrate Descriptor (circle one)

	> 75% one type	Mixed substrates	Other
Coarse	Bedrock Boulder Cobble Gravel	Mixed Coarse *(coarse combined > 75%)* Fines with Gravel (<55 % coarse)	Artificial
Fines	Sand Mud Hardpan	Mixed Fines *(< 15% coarse, <6% cob/boulder)*	

Habitat Forming Organisms (circle one)

Green Algae	Mussel Mats
Red Algae	Oyster Reefs
Brown Algae	Burr. Shrimp
Mixed Algae	
Eelgrass	
Saltmarsh	None

Anthropogenic Influences (circle all that apply)

Garbage/Debris Pilings/Docks Rip-Rap Cement Tires Boat Launch

Other:

Sample Scale *(sampled area)*

Geospatial Information

	Target deg.min	**Actual** deg.min	**On Target? If not, why not.**
Latitude 48°N	42.563		☐Y
Longitude 122°W	47.294		☐Y

Photos Taken

Camera:

	Photo#	**Compass Bearing**
1 (Upslope or North)		
2 (Downslope or South)		
3 (Left or West)		
4 (Right or East)		
5 (Down on sample spot)		0

1 - 360 = compass degrees

Checked By: Date:

Figure A.3. First Page of the Site Characterization Field Form

LIBI Field Form B

Page # 2

Surficial Water

Channel? Yes No

Standing Water? Yes No

Depth ______ cm

Obvious Burrow Counts

______ (Burrows greater than 1 cm diameter)

Surface Coverage Section

% Coverage Category

Check each row that applies

		1 - 5 %	5 - 25%	25	25 - 50%	50	50 - 75%	75	75 - 100%	100
Macro-algae	Green									
	Brown									
	Red									
Vascular Plants	*Z. marina*									
	Z. japonica									
	Saltmarsh									
	Other									
Reef Forming Animals	Mussels									
	Oysters									
	Other									
Other Epifauna	Barnacles									
Substrates	Hardpan									
	Mud									
	Sand									
	Shell									
	Gravel									
	Cobble									
	Boulders									
	Bedrock									
	Wood									
	Other									

Site ID 131

Figure A.4. Second Page of the Site Characterization Field Form

LIBI Field Form C

Page # 3

Sessile Epibenthic Diversity Section

Attached Species Present on 5 Rocks after Rinsing

- ☐ Anemones
- ☐ SeaSquirts
- ☐ Seastars
- ☐ Limpets
- ☐ Chitons
- ☐ Mussels
- ☐ Barnacles
- ☐ Tube Worms - Calcareous
- ☐ Tube Worms - Horny

Other Species Present (write in)

Sampling Unit Section

Sample Dimensions

Sample Diameter: 1.32 ft 1.91 ft (circle one)

Sampled Depth: ______ inches

Smallest Mesh Size: 4 2 mm

Oyster Census

Maximum Dimension (mm)

Free-Swimming Organisms

Water Netted For Free Swimming organisms? Yes No (circle one)

Substrate Volume Evaluation

Substrate	Clay	Mud	Sand	Shell	Gravel	Cobble
Percent						

Site ID 131

Figure A.5. Third Page of the Site Characterization Field Form

LIBI Field Form D

Page # 4

Final Checklist

- [ ] Tags in bag(s)?
- [ ] Bag(s) tied off?
- [ ] Hole back-filled

Comments/Additional Information

Site ID
131

Tag 1	Tag 2	Tag 3
Site ID #	Site ID #	Site ID #
131	131	131
LIBI	LIBI	LIBI

Figure A.6. Final Page of the Site Characterization Field Form

2.3 Site Excavation

To collect benthic invertebrates from substrates, the field crew placed a cylindrical, sampling tube made of heavy-duty plastic on the site. It was embedded into the sediment to a maximum depth of 1 ft using a heavy mallet and wood to drive the edge into the substrate. This prevented slumping of the surrounding substrates into the hole during excavation and ensured that the area sampled at each site could be correctly quantified even in very soft sediments. Wherever possible, rocks and other obstacles were removed by hand as necessary while the cylinder was forced into the ground. In the event that hardpan clay or boulders prevented the cylinder from being inserted to the correct depth, the final depth of the hole was noted.

Two sizes of sampling cylinder were used in the intertidal biotic inventory (Figure A.7). The larger size cylinder of 1.9 ft in diameter (area of 2.86 ft^2) was used preferentially. In rocky substrates where inserting the larger cylinder was difficult and hand sorting the substrates within became too time intensive, the smaller sampling cylinder of 1.31 ft in diameter (area 1.37 ft^2) was used instead.

Figure A.7. Photograph of the Two Sizes of Sampling Cylinder

Once the cylinder was inserted into the ground, all sediment within it was carefully excavated using a small shovel and placed into a bucket with coarse 4-mm mesh on the bottom. This coarse-meshed sieve was nested within another bucket that had a finer 2-mm square mesh bottom that would retain much smaller organisms, including Dungeness crab megalops and small seed clams. Both were lowered into a normal bucket that was filled with seawater, and vertically agitated to wash away any mud and sand from the sample (Figure A.8).

Rocks and other large particles were hand-washed inside the mesh-screened buckets to dislodge any loosely attached organisms and then discarded from the samples. Eelgrass shoots and blades were retained to obtain shoot counts during sample sorting. Dense mats of epibenthic mussels were also generally excluded from the samples when present due to sample volume and weight considerations, except for some representative subsamples. However, where practicable, all other organisms within the mussel matrix were retained in the sample. Any other organisms and sediments retained by the mesh were double-bagged, and a pre-printed identification tag was placed with each sample bag (see Figure A.6). The samples were retained for later sorting and identification in the lab, and were kept in a freezer until that time.

Figure A.8. View Down into the Top Sieve-Bucket During Sample Collection

2.4 Sample Sorting

Samples were removed from the freezer and thawed before sorting. Small amounts of the thawed sediment were transferred to a shallow sorting tray and washed with small amounts of fresh water. A very fine mesh net was used to filter any excess water after rinsing the sample to prevent the loss of any organisms. The tray contents were examined under a lighted swing-arm 10x-magnifying lens, and any organisms found were extracted with forceps and kept for identification. Eelgrass shoots were identified to species, counted, and documented, but not retained.

LNR staff identified samples to the lowest taxonomic resolution that could reasonably be attempted given the expertise of staff, the time required to make the identifications, and the objectives of the project (See Appendix E for details). Dr. Eugene Kozloff, a regional expert in intertidal biota, also provided advice on some difficult identifications for a subset of specimens. Carapace width was measured for crabs; carapace length was measured for shrimp; total lengths were measured for fish; and shell lengths were measured for bivalves. Clam weights were also measured for a representative range of individuals so that length-weight relationships could be ascertained, and biomass estimates could be extrapolated from the length data.

After all contents had been examined and organisms removed, the site tag and the specimens were placed in a glass bottle and preserved with 80% ethanol. Samples and a specimen voucher collection are stored at the Northwest Indian College to allow for future educational opportunities.

2.5 Data Analysis

The data recorded on the field forms (Figure A.3 through A.6) were entered into the custom Access database developed for the Intertidal Biota Survey (see Appendix J). Spatial distributions of biota were analyzed using the ArcMap 9.3 Geographic Information System (GIS). Point data layers were created for each benthic species collected.

In order to document the distribution of established clam populations, seed clams were excluded from the results whenever possible. For Manila clams, the metric stored in the data layer was the surveyed biomass per unit area of clams that exceeded the minimum legal size for harvest, at each site. For other clam species (Pacific littlenecks, butter clams, cockles, purple varnish clams, and softshell clams) the minimum size used in the spatial analysis was determined by identifying and removing the young-of-the-year (YOY) using the size-frequency histogram for each species to determine the threshold size.

For all other species, the metric stored in the data layer was individuals per unit area without a size restriction.

An additional data layer was created that summarizes total taxonomic richness found at each site, as well as total biotic abundance found at each site.

Estimating total species abundance from sample densities required sophisticated analysis procedures. Benthic densities are highly interdependent and variable across intertidal environmental conditions. Because of this interdependence and variability, which can result in contraction and expansion of the across-shore distribution of macroinfauna, simple averages of combined density can result in significant biases of across-shore abundance (Brazeiro and Defeo 1996). Due to this interdependency and variability, simple parametric statistics are unreliable, and extreme outliers can potentially bias assessments. Spatial interpolation methods use the spatial proximity of sites to determine the values at locations that fall between point measurements, and thus account for the interdependence of the sample measures. Examples of such methods include linear interpolation, kriging, and Thiessen (Voronoi) polygons (Voronoi 1907).

The Thiessen polygon analysis method was preferred because confidence limits can be calculated for estimates derived using this method, unlike linear interpolation, and it appears to be a relatively unbiased estimator compared to kriging (Dolphin 2004a).

Figure A.9 shows a hypothetical distribution of sample sites (blue dots) and the Thiessen polygons that would be generated based on the location of those sites. The shading of the polygons indicates the quantity of clams found. Values from larger polygons are weighted more heavily than values from smaller polygons when calculating the mean and variance of the results.

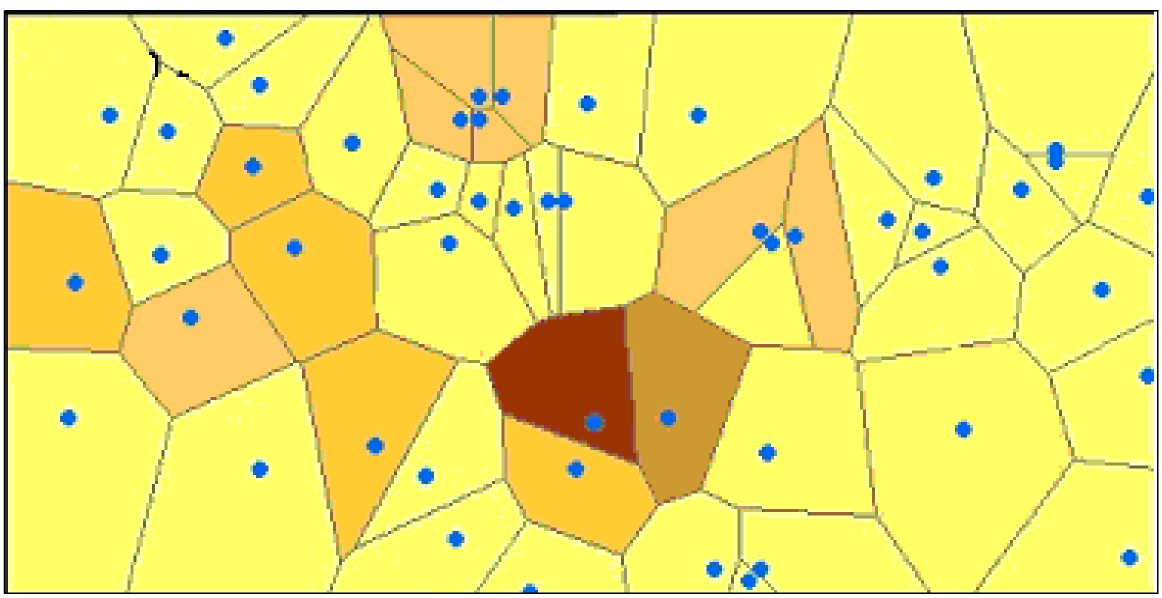


Figure A.9. Example of Thiessen Polygons Generated from Sample Sites on a Randomly Sampled Hypothetical Beach

Thiessen polygons were used to analyze the Intertidal Biota Survey results to obtain spatially weighted population estimates for species of interest in order to remove any potential spatial bias introduced by the survey design and for mapping purposes.

The vertical distributions of benthic biota are also important in analyzing the distribution of species across the Reservation tidelands. Accordingly, the vertical distribution of selected species was plotted to determine the upper and lower vertical limits, which contain 90% of the population. In addition, a Kendall’s tau correlation (Kendall 1938) was conducted to determine significant relationships between selected species of interest and intertidal habitat measures.

3.0 Results

3.1 Benthic Communities

Taxonomic richness varied across the Reservation tidelands. The sites with the highest taxonomic richness were located at Lummi Bay and Brant Flats (Figure A.10). The areas of Lummi Bay with high taxonomic richness are closely associated with eelgrass meadows, and Brant Flats has a wide diversity of habitat types that range from cobble barrens to sandy flats. Each provides complex habitats for benthic biota. The two sites in Lummi Bay with a recorded diversity of 0 taxonomic richness are both primarily coarse sand substrates. However, Japanese eelgrass (*Zostera japonica*) is visible in the photographs of both sites even though no shoots were recorded. It is possible that the shoot counts for these two sites were mistakenly not recorded during sorting. The Nooksack River Delta had the lowest taxonomic richness observed on the Reservation tidelands. Trends in taxonomic richness at Sandy Point diverge across tidal elevation. Upper elevations are nearly devoid of biota, but lower portions exhibit moderate taxonomic richness. Field notes and photographs show that the upper tidal elevations of Sandy Point are primarily clean gravel and cobble substrates, whereas the lower tidal elevations have muddy embedded cobble substrates with attached macroalgae.

The determination of taxonomic richness depends heavily on the taxonomic resolution of the study, and the taxonomic resolution depends, in turn, on the taxonomic expertise of the investigators. The LIBI project staff determined the lowest reliable identification that could be attained based on their level of expertise and the resources available (Appendix E). Since taxonomic richness is so dependent on methodology, LNR staff had to compare the relative frequencies of the richness scores to qualify ‘high’ taxonomic richness scores compared to ‘low’ taxonomic richness scores (Figure A.11). In this study, taxonomic richness scores from 30 to 40 are considered ‘high’ and taxonomic richness scores from 0 to 5 are considered ‘low’.

Taxonomic richness was generally similar across the range of tidal elevations surveyed in this study, however, most of the sites that were taxonomically rich were found between 4 ft MLLW and –2 ft MLLW (Figure A.11).

Taxonomic richness had weak significant correlations with beach slope and with Japanese eelgrass (*Zostera japonica*) shoot density, $p\text{-value} < 0.05$ (Table A.1). However, this type of analysis cannot account for changes in community structure if different taxa replace each other in different habitat conditions. A much more comprehensive analysis of the response of community structure to differences in environmental gradients is provided in Appendix I.

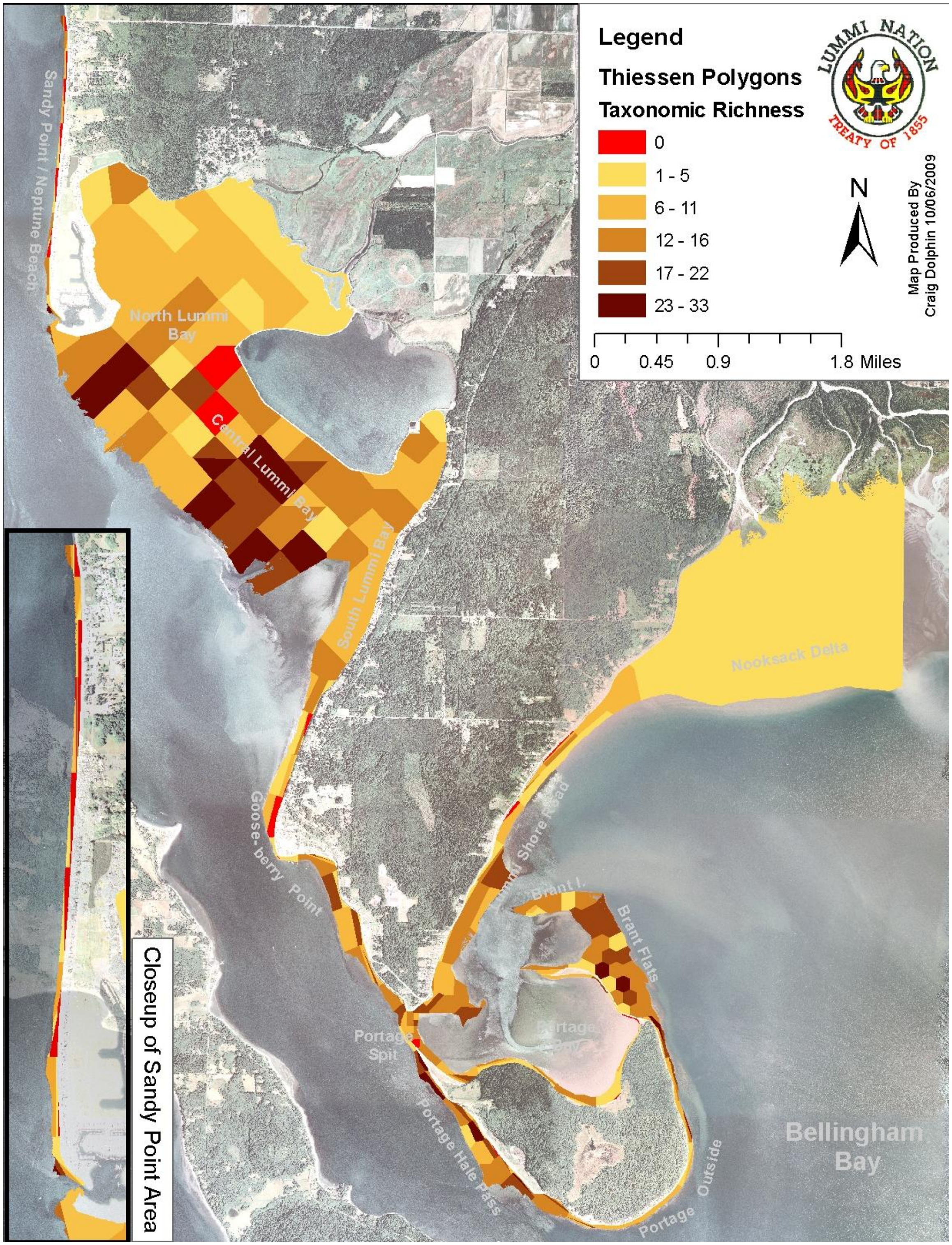
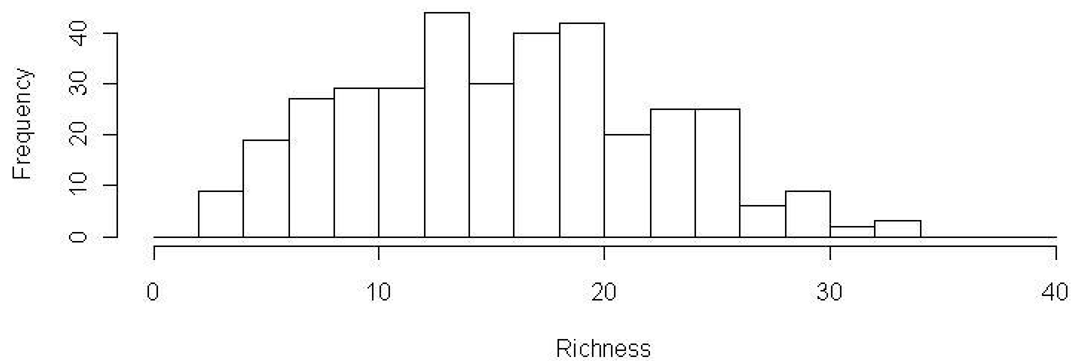


Figure A.10. Map of Thiessen Polygons Showing Taxonomic Richness



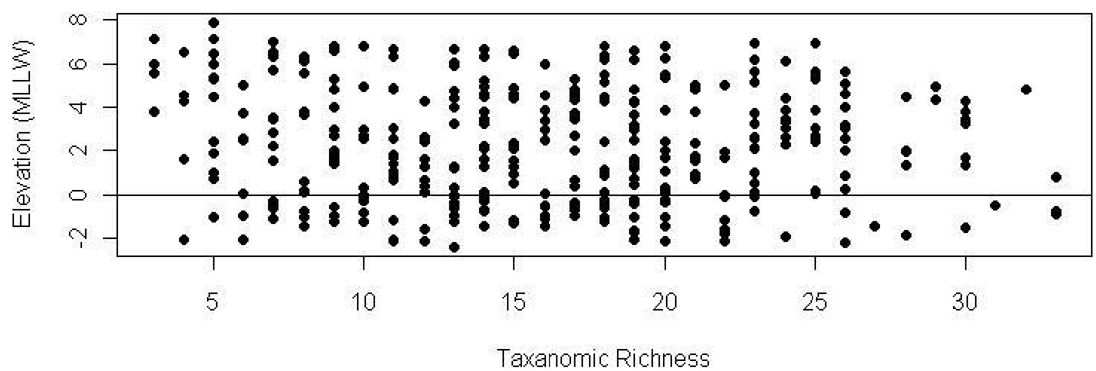


Figure A.11. Taxonomic Richness Frequency and Taxonomic Richness Scores Across Tidal Elevations

Table A.1. Kendall's Tau Correlation of Taxonomic Richness with Habitat Values

	Taxonomic Richness	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.2620	-0.04
Slope (%)	0.0001	0.14
Fetch (ft)	0.8060	-0.01
Salinity (ppt)	0.3800	0.03
SCI.Score	0.1540	0.05
Japanese Eelgrass (shoots/sq.ft.)	0.0221	0.10
Pacific Eelgrass (shoots/sq.ft.)	0.8940	-0.01

3.2 Species of interest

Lummi Natural Resources Department staff identified several benthic species that have particular importance to the Lummi Nation fisheries and the ecology of the Reservation tidelands (Table A.2). Those that were encountered during the survey are described individually in the following sections.

This list does not constitute a complete list of benthic species harvested by the Lummi people. For example, geoduck clams (*Panopea abrupta*) and red rock crabs (*Cancer productus*) are important species to the Lummi people but neither species was encountered during the dig survey.

Table A.2. LIBI benthic species of interest

Butter Clams *(Saxidomus giganteus*)
Cockles (*Clinocardium nuttalli*)
Horse Clams (*Tresus* sp.)
Purple Varnish Clams (*Nuttalia obscurata*)
Manila Clam (*Venerupis phillipinarum*)
Pacific Littleneck Clams (*Leukoma staminea*)
Eastern Softshell Clams (*Mya arenaria*)
Japanese Eelgrass (*Zostera japonica*)
Pacific Eelgrass (*Zostera marina*)
Dungeness Crabs (*Cancer magister*)

3.2.1 Butter Clams

Butter clams have a limited distribution across the Reservation tidelands (Figure A.12). The densest populations of butter clams were observed in the Hale Passage and Brant Flats areas with localized populations near the mouth of the Sandy Point marina. Butter clams are also found in parts of Lummi Bay, but the densities in these areas are relatively low compared to the previously described areas. From a visual assessment of the horizontal distributions, butter clams prefer areas with wave action and higher currents. Vertical distributions of butter clams ranged from –2.2 to +4.1 ft MLLW with 90% of the population found between –1.7 and +2.1 ft MLLW (Figure A.13).

Densities of butter clams were significantly correlated with tidal elevation and the substrate coarseness index, p-value < 0.05, however both relationships were weak (Table A.3).

Based on the size frequency data for butter clams (Fig. A.14), young-of-the-year (YOY) butter clams were assumed to have a maximum shell length of 12 mm. Excluding YOY, the spatially weighted population estimate calculated for butter clams was 42,990,467 individuals with an estimated total biomass of 6,666,028 pounds (lbs). The 95% confidence intervals for these estimates have a statistical precision of 200% and 183% respectively. Approximately 29.6 million YOY butter clams were estimated to be present during sampling.

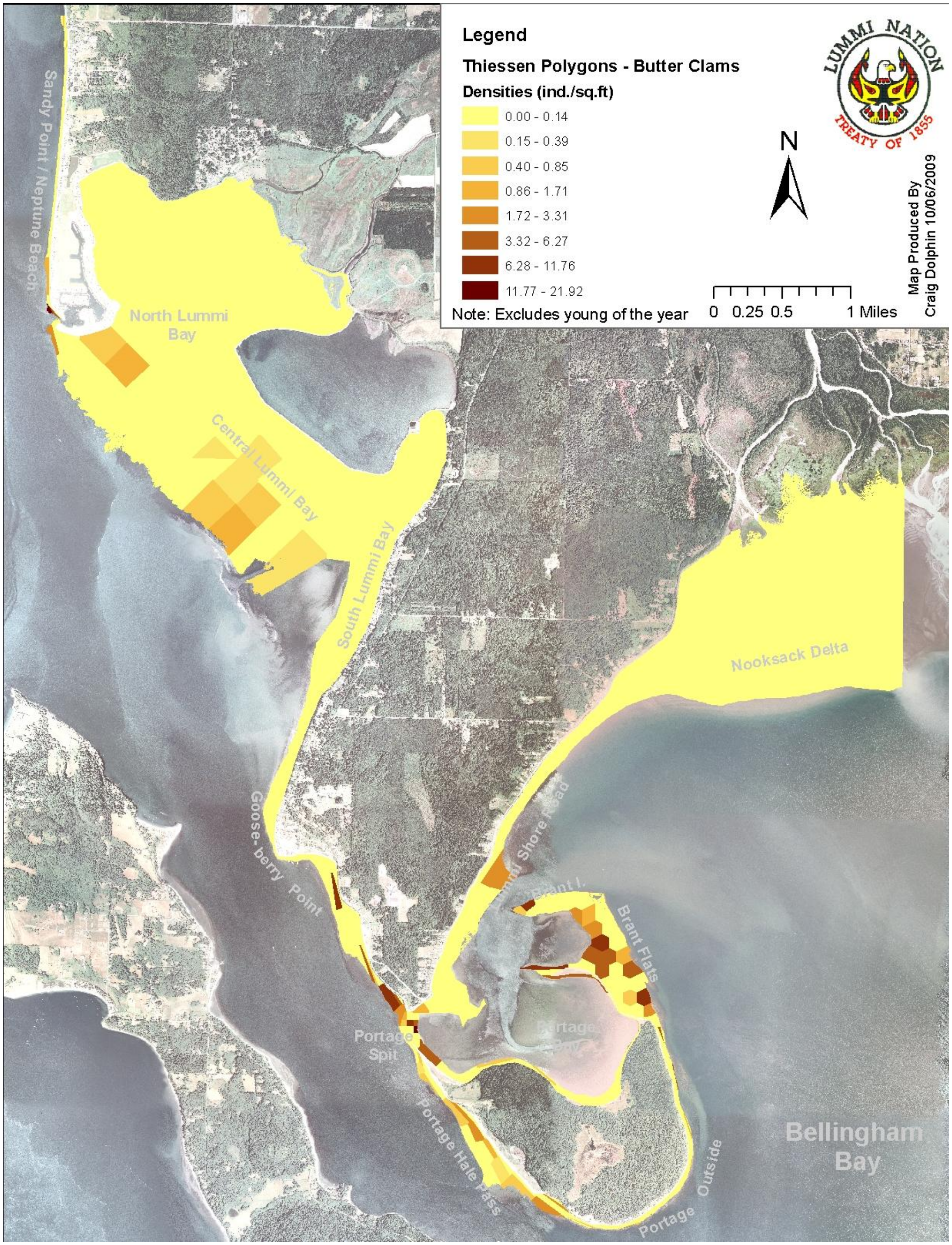


Figure A.12. Thiessen Polygons of Butter Clam Individuals Per Square Foot Across the Reservation Tidelands

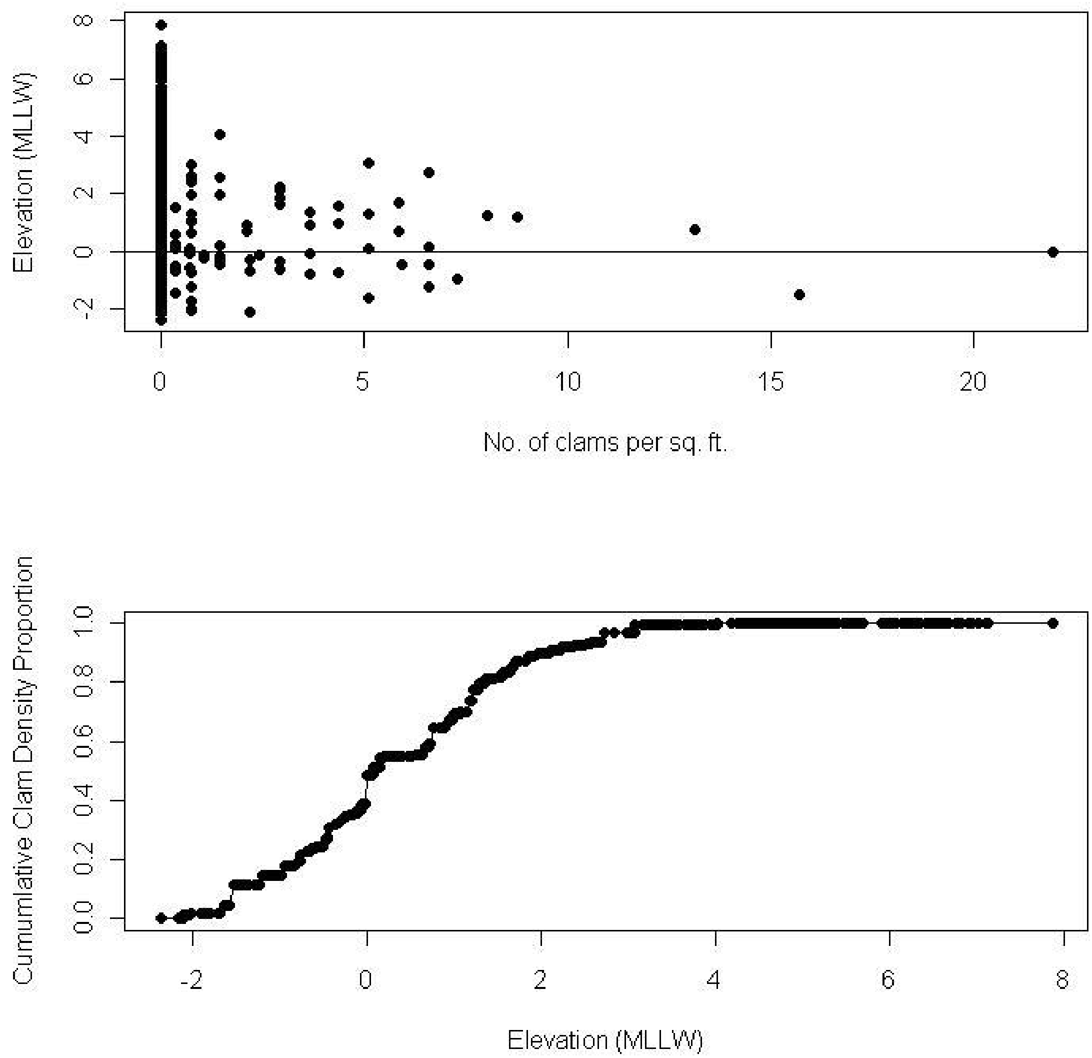


Figure A.13. Vertical Distribution of Butter Clams on the Reservation Tidelands

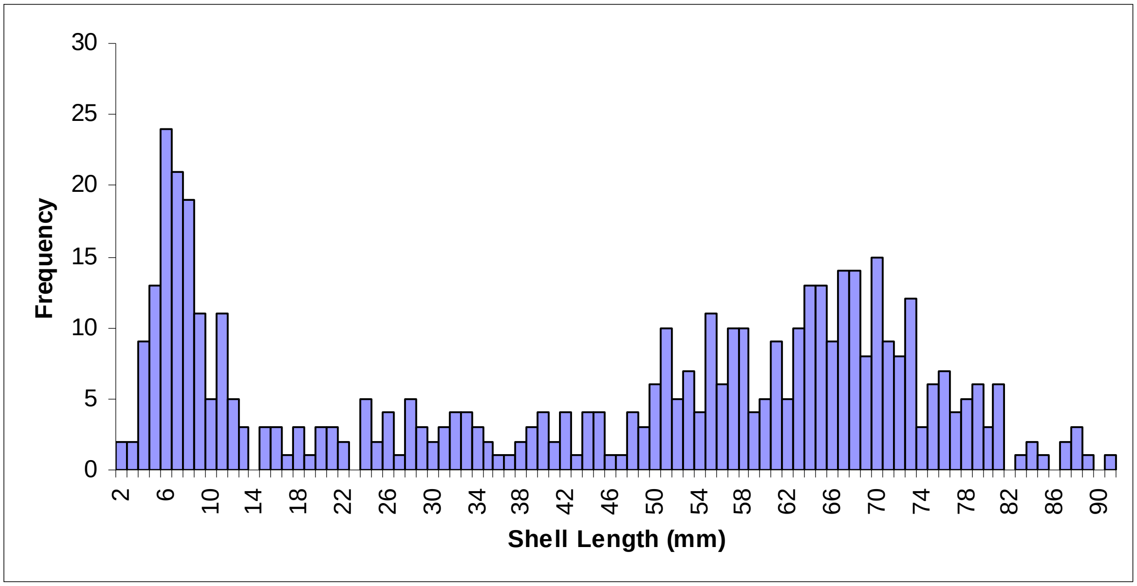


Figure A.14. Size-Frequency Distribution of Butter Clams (n=485)

Table A.3. Kendall's Tau Correlation of Butter Clam Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0000	-0.26
Slope (%)	0.2510	-0.05
Fetch (ft)	0.5670	-0.02
Salinity (ppt)	0.1810	-0.05
SCI.Score	0.0004	0.15
Japanese Eelgrass (shoots/sq.ft.)	0.1370	-0.07
Pacific Eelgrass (shoots/sq.ft.)	0.2810	0.05

3.2.2 Cockles

Cockles have a similar distribution to butter clams across the Reservation tidelands (Figure A.15). Cockle densities were highest in the Hale Passage and Brant flats areas with localized populations near the mouth of the Sandy Point marina. Low-elevation parts of Lummi Bay also had high densities of cockles. From a visual assessment of the horizontal distributions, cockles prefer areas with wave action and higher currents. The highest densities of cockle populations were generally associated with eelgrass. The vertical distribution of cockles ranged from –1.7 to +4.0 ft MLLW, with 90% of the population found between –1.6 and +2.1 ft MLLW (Figure A.16).

Cockle densities were significantly correlated with tidal elevation and slope (p-value < 0.05), however both relationships were statistically weak (Table A.4).

Based on the size frequency data for cockles (Fig. A.17), young-of-the-year (YOY) cockles were assumed to have a maximum shell length of 13 mm. Excluding YOY, the spatially weighted population estimate calculated for cockles was 26,875,537 individuals with an estimated biomass of 2,666,129 lbs. The 95% confidence intervals for these estimates have a statistical precision of 74% and 78.6% respectively. Approximately 14.2 million YOY cockles were estimated to be present during sampling.

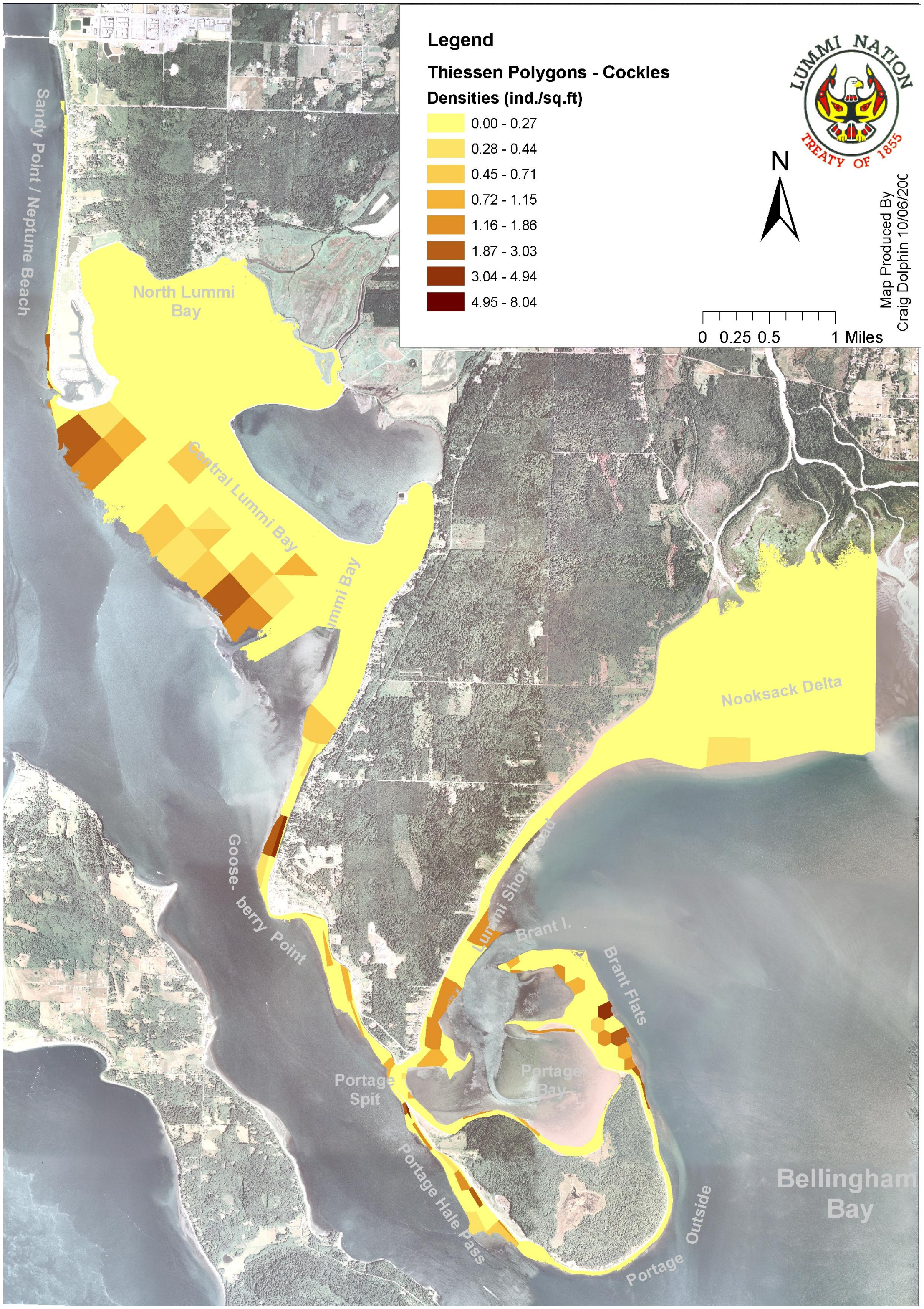


Figure A.15. Thiessen Polygons Showing Cockle Individuals Per Square Foot Across the Reservation Tidelands

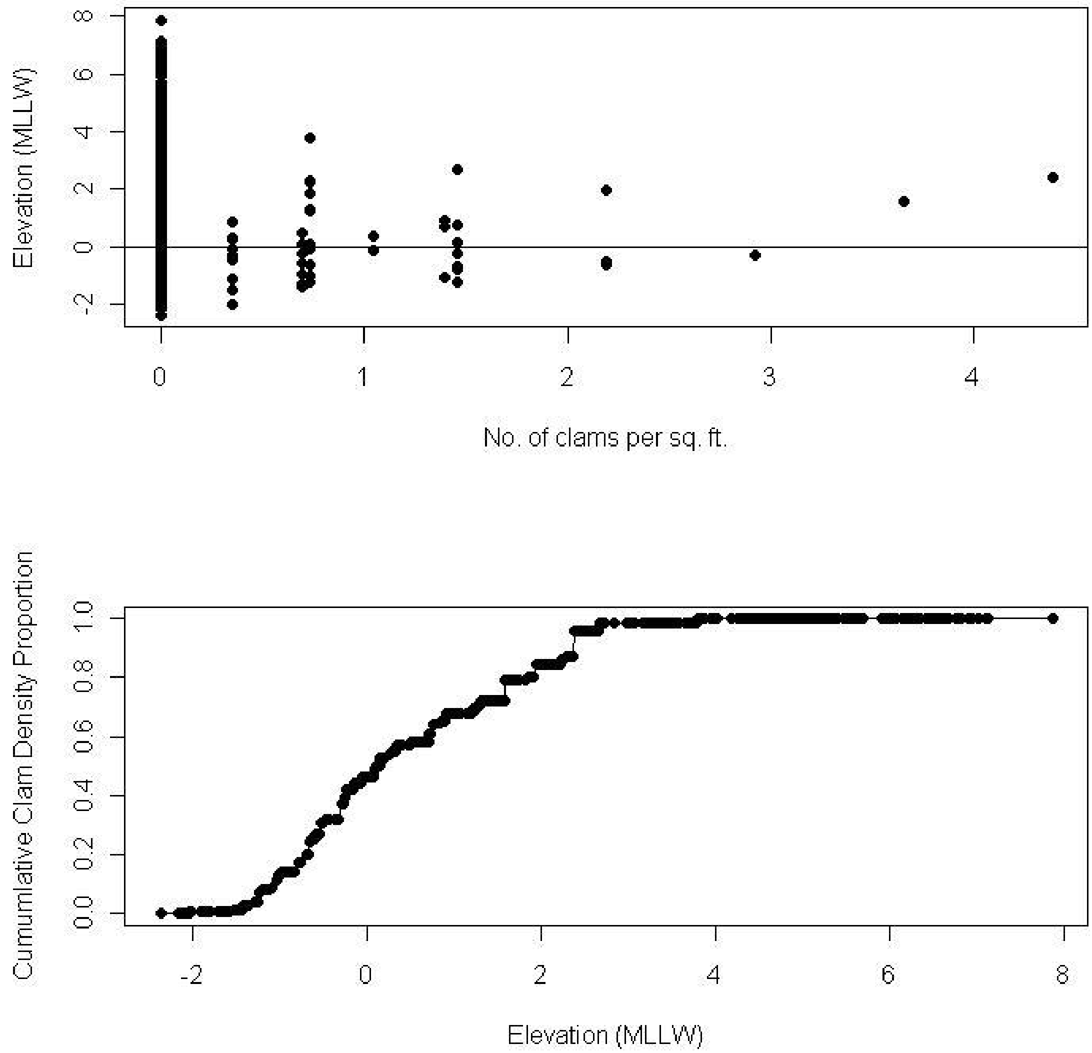


Figure A.16. Vertical Distribution of Cockles on the Reservation Tidelands

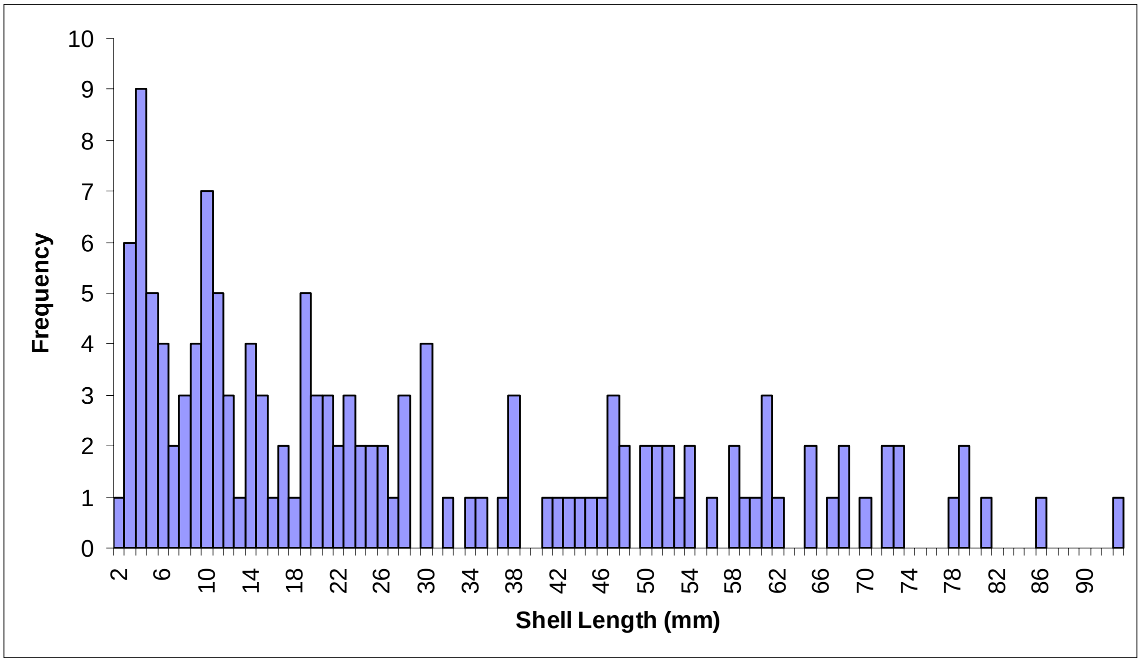


Figure A.17. Size-Frequency Distribution of Cockles (n=143)

Table A.4. Kendall's Tau Correlation of Cockle Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0000	-0.24
Slope (%)	0.0081	-0.11
Fetch (ft)	0.7720	0.01
Salinity (ppt)	0.3770	0.04
SCI.Score	0.3300	-0.04
Japanese Eelgrass (shoots/sq.ft.)	0.9330	0.00
Pacific Eelgrass (shoots/sq.ft.)	0.4920	-0.03

3.2.3 Horse Clams

Horse clams were not commonly observed in the Intertidal Biota Inventory samples (Figure A.18). Horse clam densities were highest in the Hale Passage area, and near the western tip of Brant Island, and with localized populations near the mouth of the Sandy Point marina channel. A moderate density horse clam population was also present in low elevation areas of Lummi Bay. From a visual assessment of the horizontal distributions, horse clams appear to prefer lower elevation areas with wave action and high currents. The vertical range of horse clam populations extends beyond the scope of this work into the subtidal. Accordingly, no lower elevation limit was determined for this species. The highest elevation at which a horse clam was found was +2.2 ft MLLW (Figure A.19).

Horse clams were significantly correlated with tidal elevation and Pacific eelgrass (*Zostera marina*) (p-value < 0.05), however both relationships were statistically weak (Table A.5).

Based on the limited size frequency data for horse clams (Fig. A.20), no size threshold for young of the year horse clams could be determined. Accordingly, the spatially weighted population estimate calculated for all horse clams from the dig survey was 5,103,103 individuals with an estimated biomass of 1,207,124 lbs. The 95% confidence intervals for these estimates have a statistical precision of 220% and 409% respectively.

Horse clam population results from the large bivalve survey are described and contrasted with the dig survey results in Appendix B.

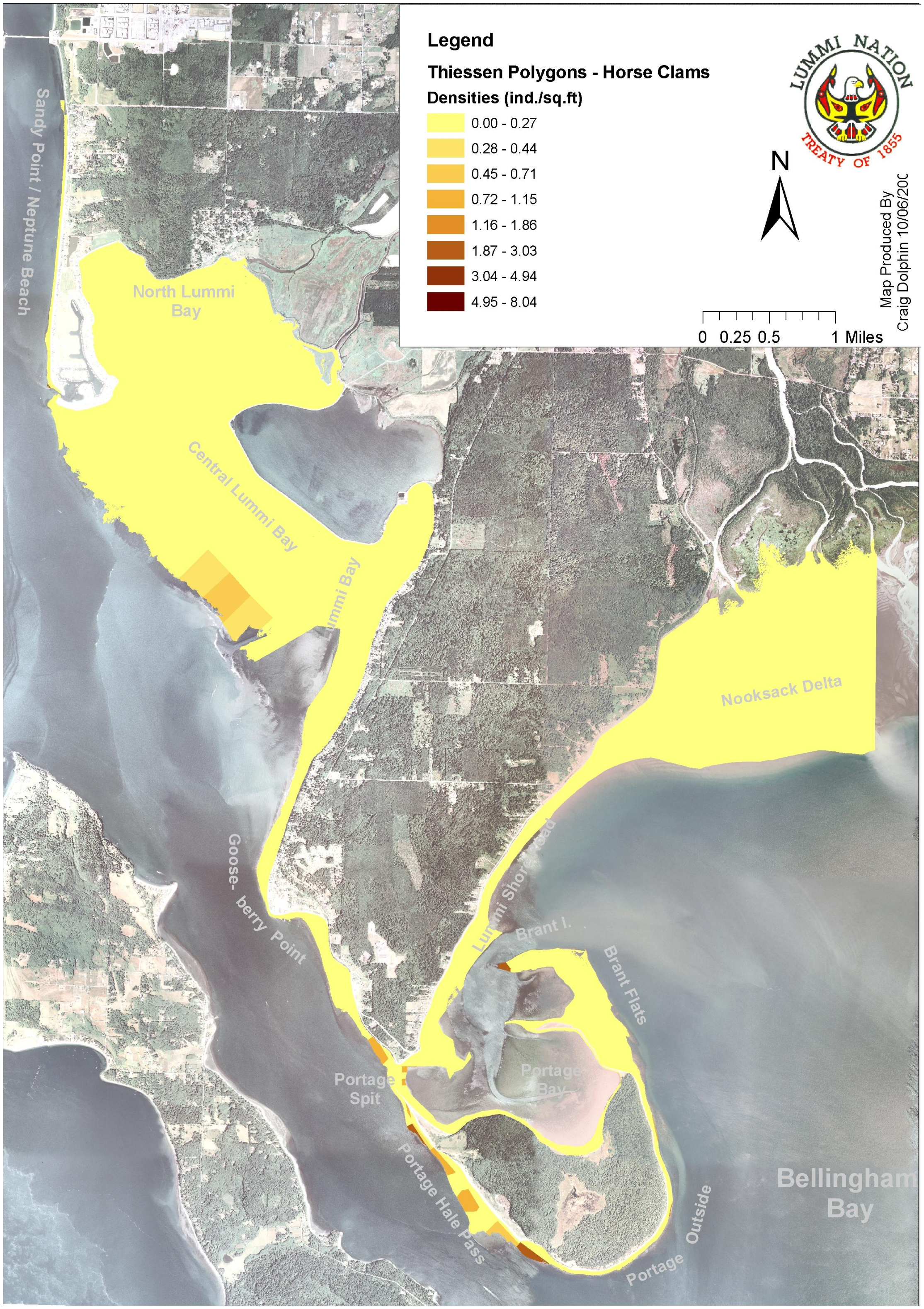


Figure A.18. Thiessen Polygons Showing Horse Clam Individuals Per Square Foot Across the Reservation Tidelands

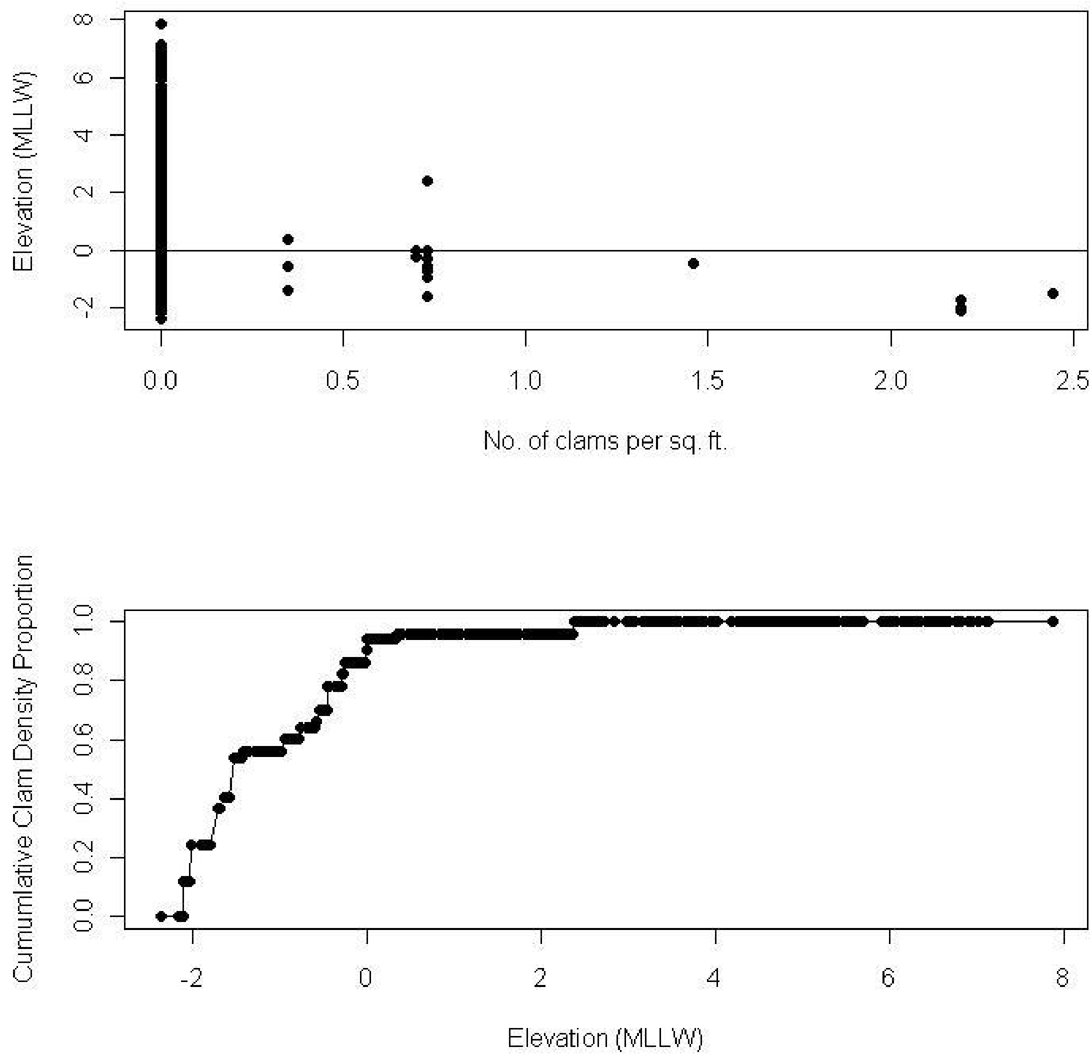


Figure A.19. Vertical Distribution of Horse Clams on the Reservation Tidelands

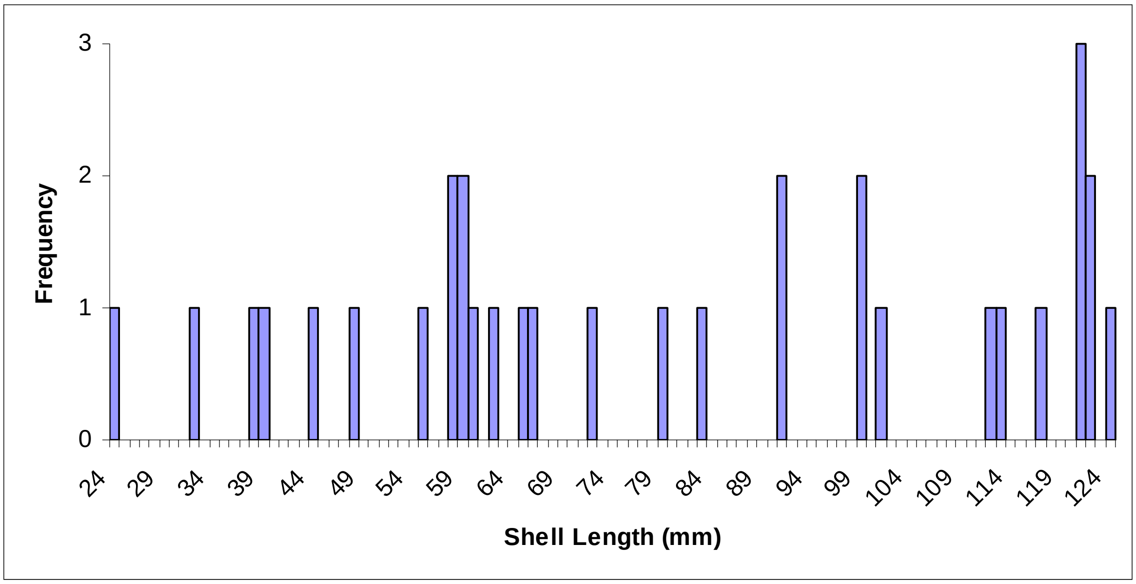


Figure A.20. Size-Frequency Distribution of Horse Clams (n=32)

Table A.5. Kendall's Tau Correlation of Horse Clam Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0000	-0.21
Slope (%)	0.1480	-0.06
Fetch (ft)	0.6630	0.02
Salinity (ppt)	0.8830	0.01
SCI.Score	0.7900	-0.01
Japanese Eelgrass (shoots/sq.ft.)	0.2650	-0.06
Pacific Eelgrass (shoots/sq.ft.)	0.0041	0.14

3.2.4 Purple Varnish/Mahogany Clams

Purple varnish clams were primarily found in upper elevations in Lummi Bay and the Nooksack delta, and usually near freshwater sources (Figure A.21). The vertical distribution of purple varnish clams ranged from –0.2 to +6.2 ft MLLW, with 90% of the population found between +1.3 and +6.0 ft MLLW (Figure A.22).

Purple varnish clam densities were significantly correlated with tidal elevation, salinity, the substrate coarseness index, and both eelgrass species (p-value < 0.05), however these relationships were statistically weak (Table A.6). On the Nooksack River delta especially, purple varnish clams were the most abundant species numbering up to 120 individuals per square foot.

Based on the size frequency data for purple varnish clams (Fig. A.23), young-of-the-year (YOY) purple varnish clams were assumed to have a maximum shell length of 12 mm. Excluding YOY, the spatially weighted population estimate calculated for purple varnish clams was 1,172,143,358 individuals with an estimated biomass of 19.9 million lbs. The 95% confidence intervals for these estimates have a statistical precision of 36% and 46% respectively. Approximately 90.6 million YOY purple varnish clams were estimated to be present during sampling.

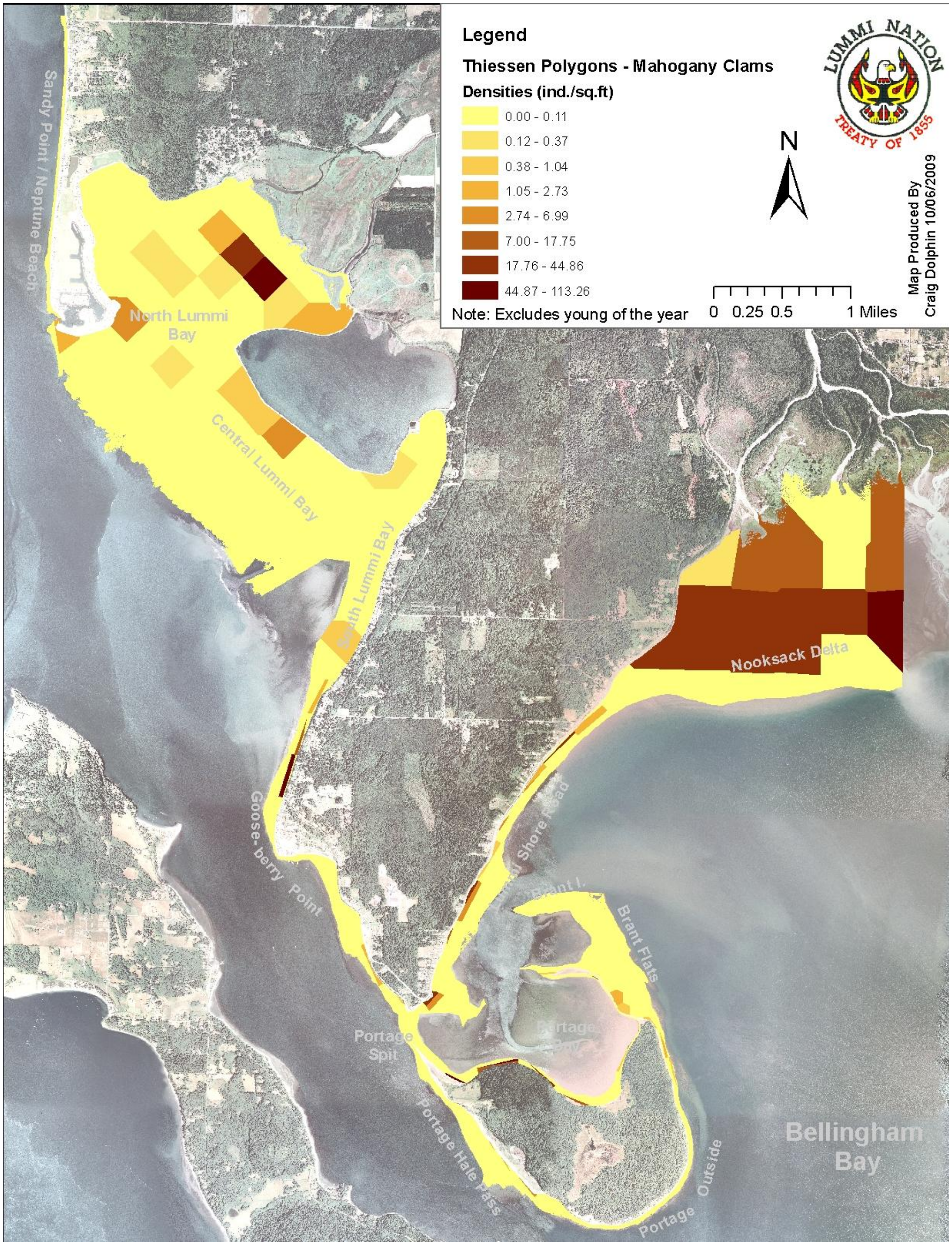
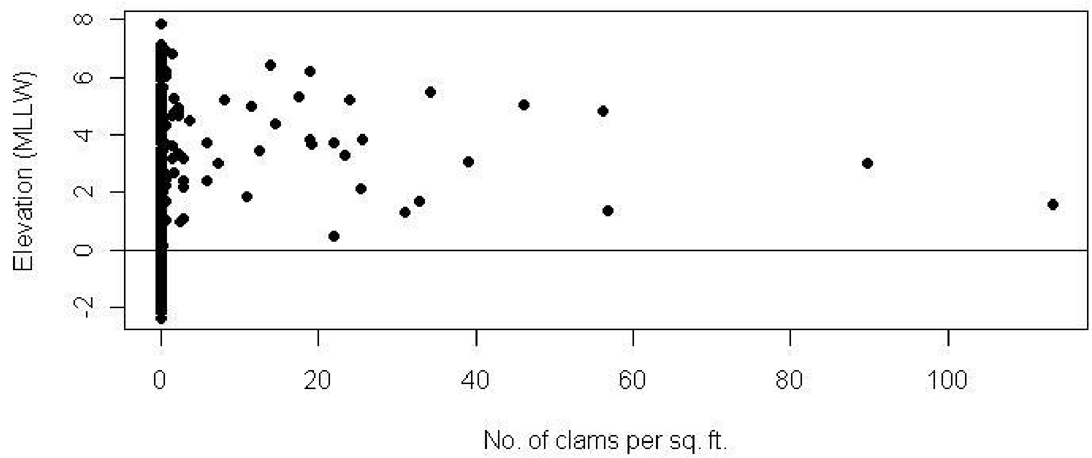


Figure A.21. Thiessen Polygons of Purple Varnish Clam Individuals Per Square Foot Across the Reservation Tidelands



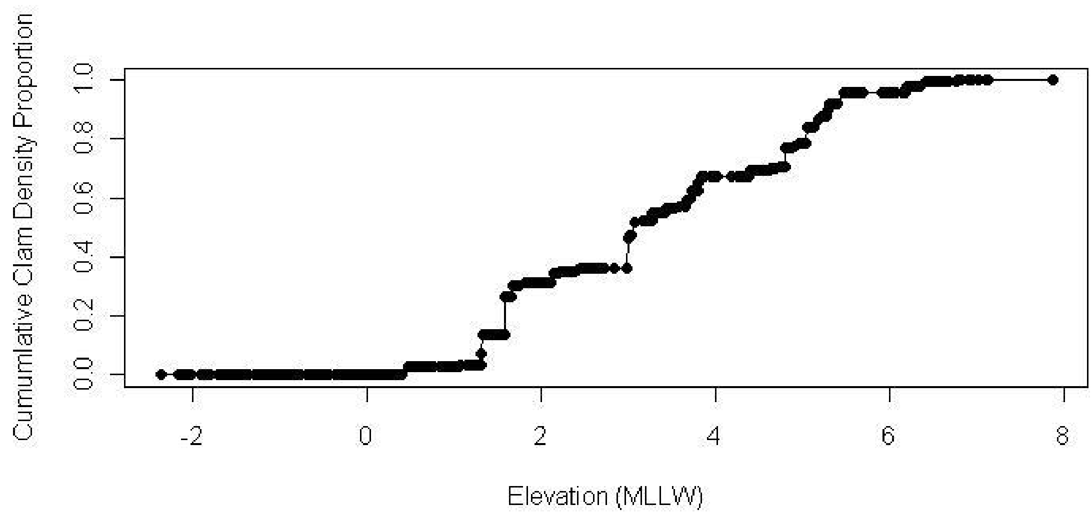


Figure A. 22. Vertical Distribution of Purple Varnish Clams on the Reservation Tidelands

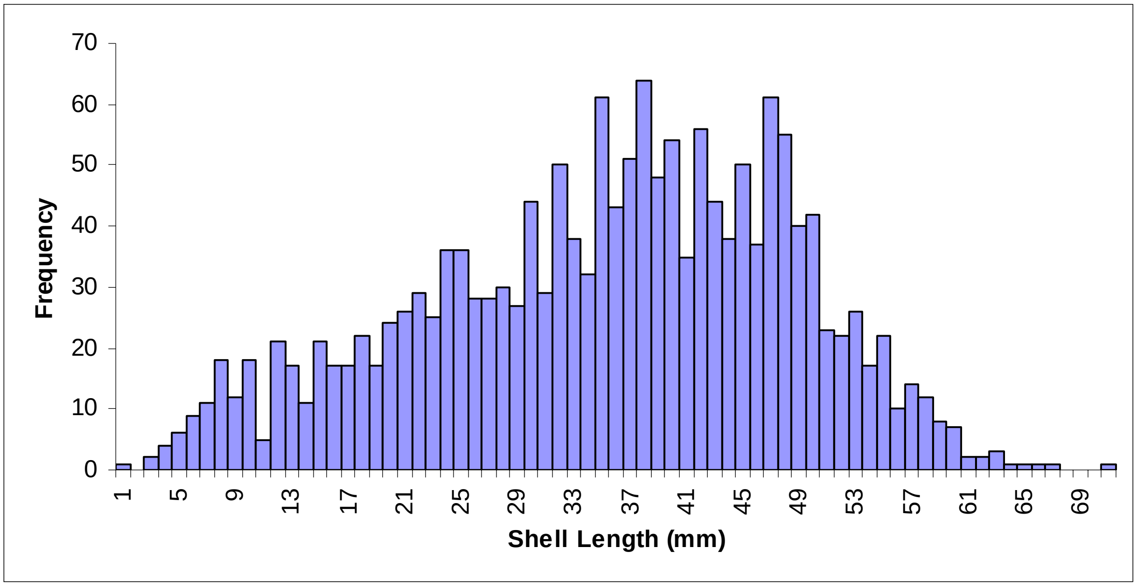


Figure A.23. Size-Frequency Distribution of Purple Varnish Clams (n=1,663)

Table A.6. Kendall's Tau Correlation of Purple Varnish Clams Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0000	0.22
Slope (%)	0.2930	-0.04
Fetch (ft)	0.4870	-0.03
Salinity (ppt)	0.0010	-0.14
SCI.Score	0.0400	-0.09
Japanese Eelgrass (shoots/sq.ft.)	0.0288	0.11
Pacific Eelgrass (shoots/sq.ft.)	0.0384	-0.10

3.2.5 Manila Clams

To map the distribution of Manila clams across Reservation tidelands, the results from the Intertidal Biota Inventory were combined with the results from the annual Manila clam surveys conducted from 2002 to 2008 (Dolphin 2008). Pounds of legal-size Manila clams per square foot were used to ensure that the units of measurement were consistent between the two data sets.

Manila clams are consistently present across the middle elevations in the protected areas of Lummi Bay, Portage Spit and Brant Flats (Figure A.24). Manila clam population densities are up to three times higher at Brant Flats and Portage Spit compared to densities found in Lummi Bay.

The vertical distribution of Manila clams ranged from –1.2 to +6.1 ft MLLW, with 90% of the population present between 0 ft MLLW and +4.0 ft MLLW (Figure A.25).

Manila clam densities were significantly correlated with tidal elevation, slope, and fetch, p-value < 0.05, however all relationships were statistically weak (Table A.7).

Based on the size frequency data for Manila clams surveyed during the LIBI (Fig. A.26), and from previous small-scale growth studies (Dolphin 2004b), young-of-the-year (YOY) Manila clams were assumed to have a maximum shell length of 12 mm. Approximately 34 million YOY Manila clams were estimated to be present during sampling.

Excluding YOY, the spatially weighted population estimate calculated for Manila clams was 67,605,075 individuals with an estimated biomass of 2,878,950 lbs. The 95% confidence intervals for these estimates have a statistical precision of 118% and 75.3% respectively.

The estimated biomass of legal-sized Manila clams (38 mm or larger) was 2.45 million lbs (±64%).

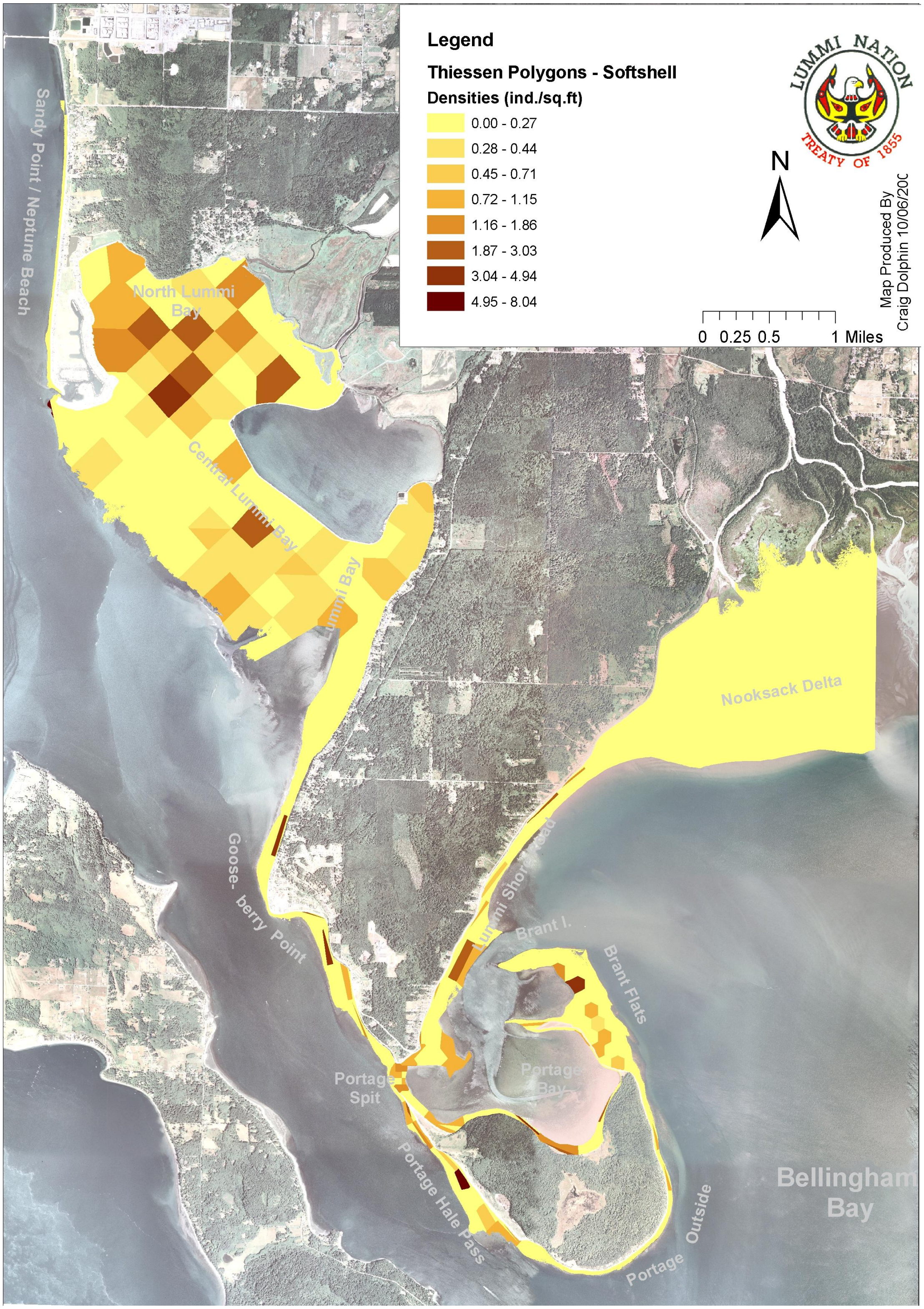


Figure A.24. Thiessen Polygons Showing Manila Clam Densities (Pounds of Legal-Sized Clams per Square Foot) Across the Reservation tidelands

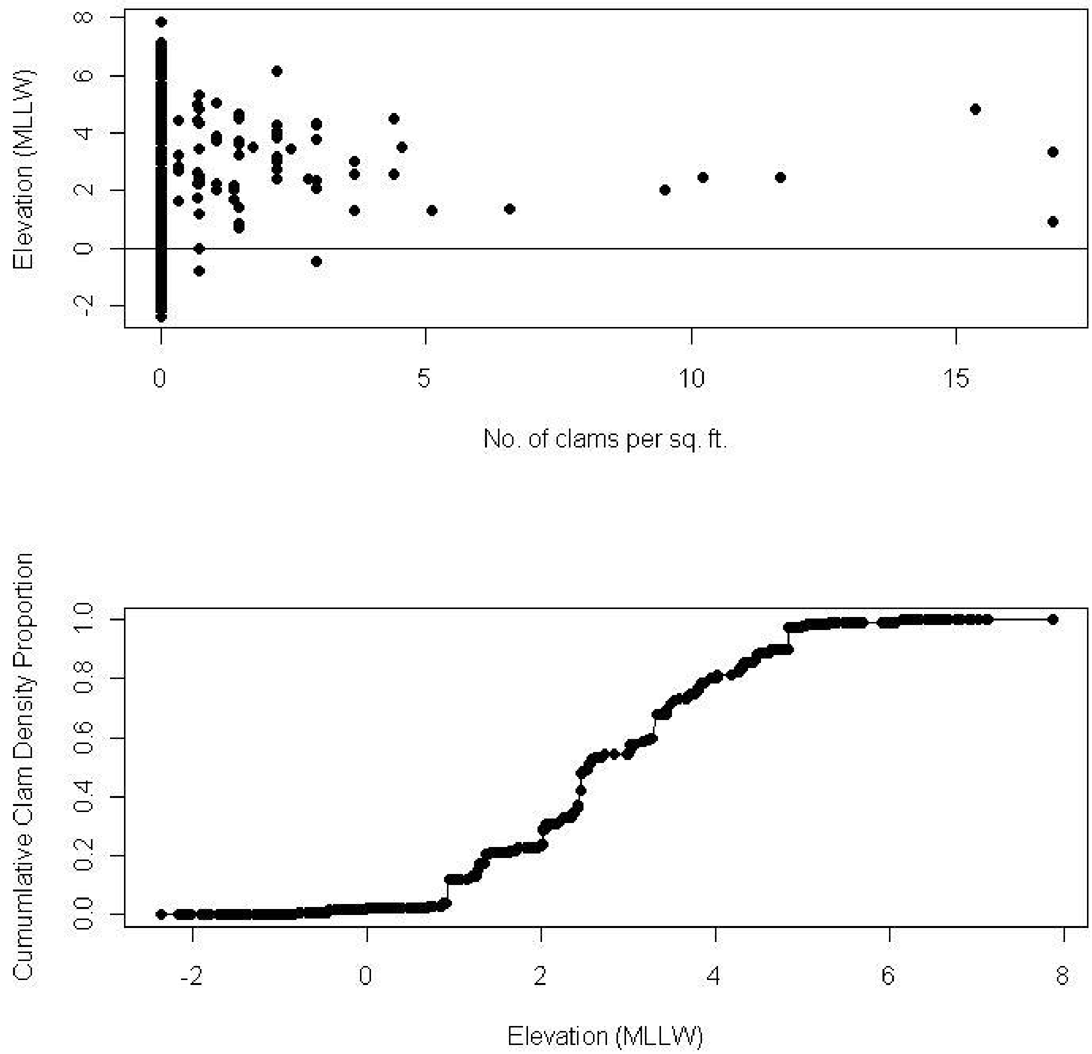


Figure A.25. Vertical Distribution of Manila Clams on the Reservation Tidelands

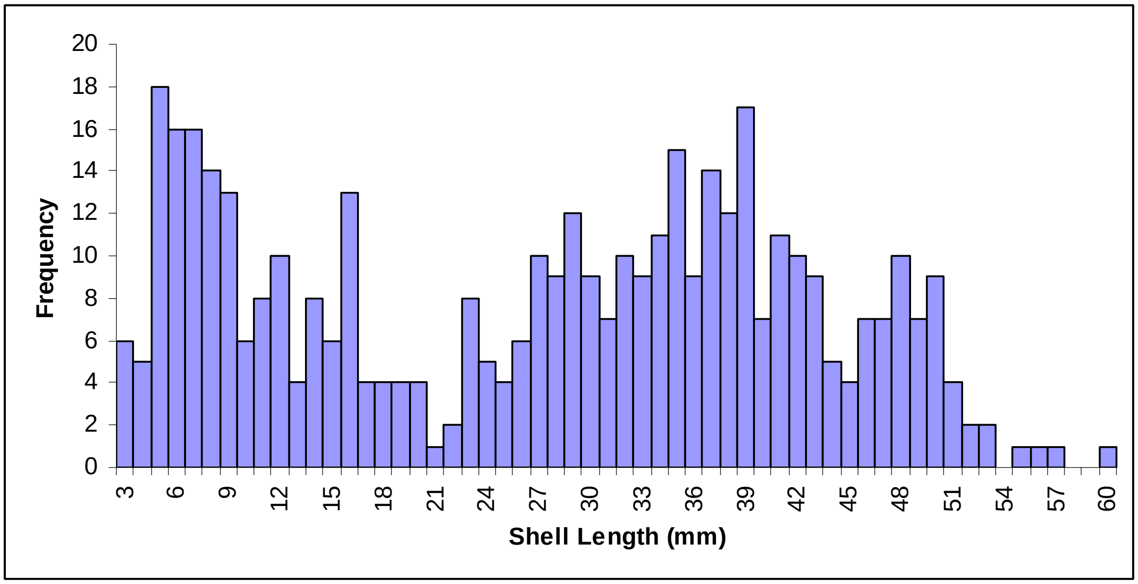


Figure A.26. Size-Frequency Distribution of Manila Clams (n=427)

Table A.7. Kendall's Tau Correlation of Manila Clam Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0037	0.12
Slope (%)	0.0898	-0.07
Fetch (ft)	0.0000	-0.27
Salinity (ppt)	0.5160	-0.03
SCI.Score	0.4160	-0.03
Japanese Eelgrass (shoots/sq.ft.)	0.7470	-0.02
Pacific Eelgrass (shoots/sq.ft.)	0.3150	-0.05

3.2.6 Pacific Littleneck Clams

Pacific littleneck clams are observed across all areas of the Reservation tidelands except the Nooksack River delta. Densities of Pacific littleneck clams were highest in the Brant Flats, Hale Passage, and Gooseberry Point areas (Figure A.27). Pacific littleneck clams are also present in Lummi Bay but usually only at low population densities. Pacific littleneck clams are usually found within the middle tidal elevations. The vertical distribution of Pacific littleneck clams ranged from –2.0 to +4.4 ft MLLW, with 90% of the population between –1.8 and +4.4 ft MLLW (Figure A.28).

Pacific littleneck clam densities were significantly correlated with tidal elevation, substrate coarseness index, and Japanese eelgrass (*Z. japonica*) (p-value < 0.05), however these relationships were statistically weak (Table A.8).

Based on the size frequency data for Pacific littleneck clams (Fig. A.29), young-of-the-year (YOY) Pacific littleneck clams were assumed to have a maximum shell length of 12 mm. Approximately 16 million YOY Pacific littleneck clams were estimated to be present during sampling.

Excluding YOY, the spatially weighted population estimate calculated for Pacific littleneck clams was 41,293,258 individuals with an estimated biomass of 2,088,511 lbs. The 95% confidence intervals for these estimates have a statistical precision of 137% and 130% respectively.

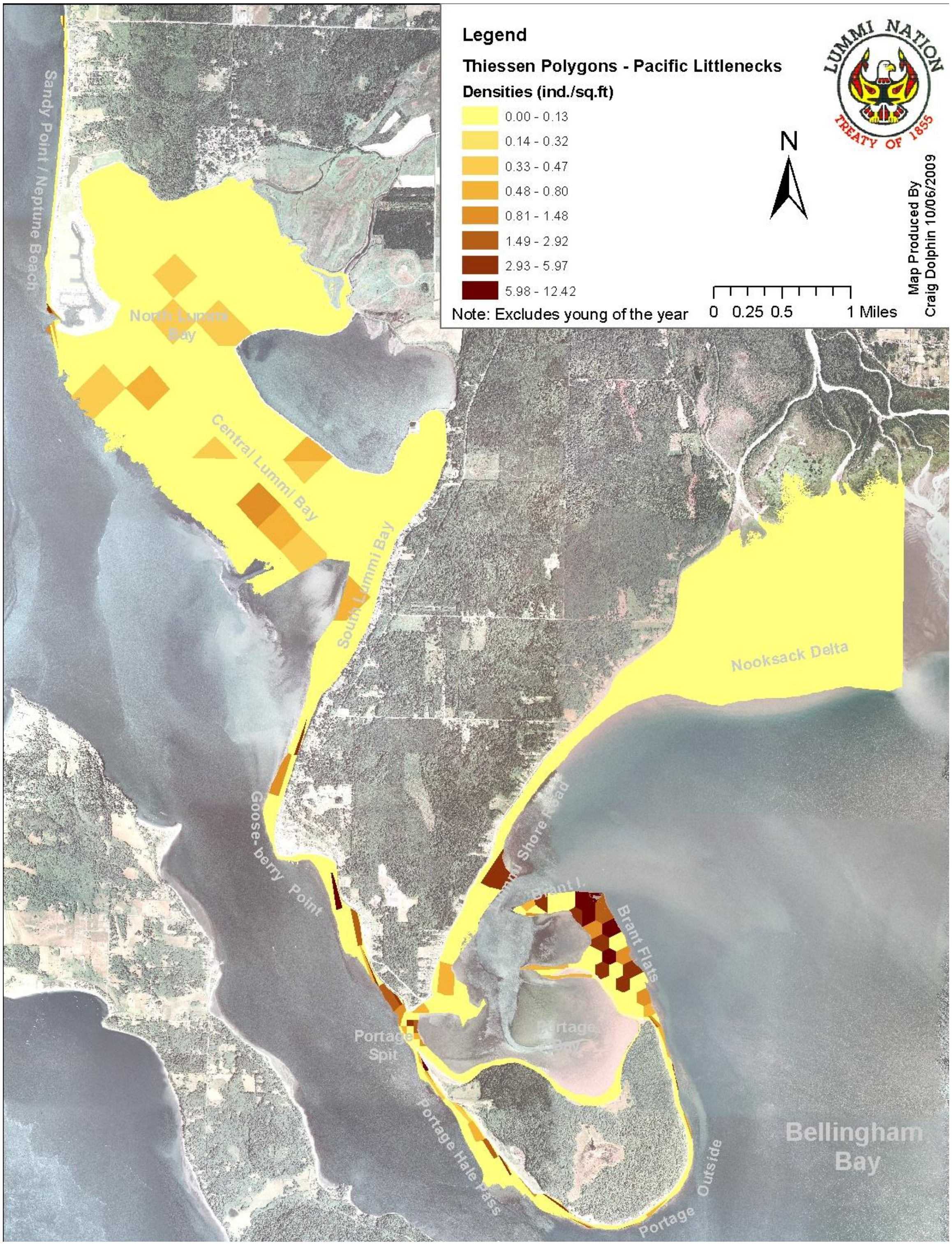


Figure A.27. Thiessen Polygons Showing Pacific Littleneck Clam Individuals Per Square Foot Across the Reservation Tidelands

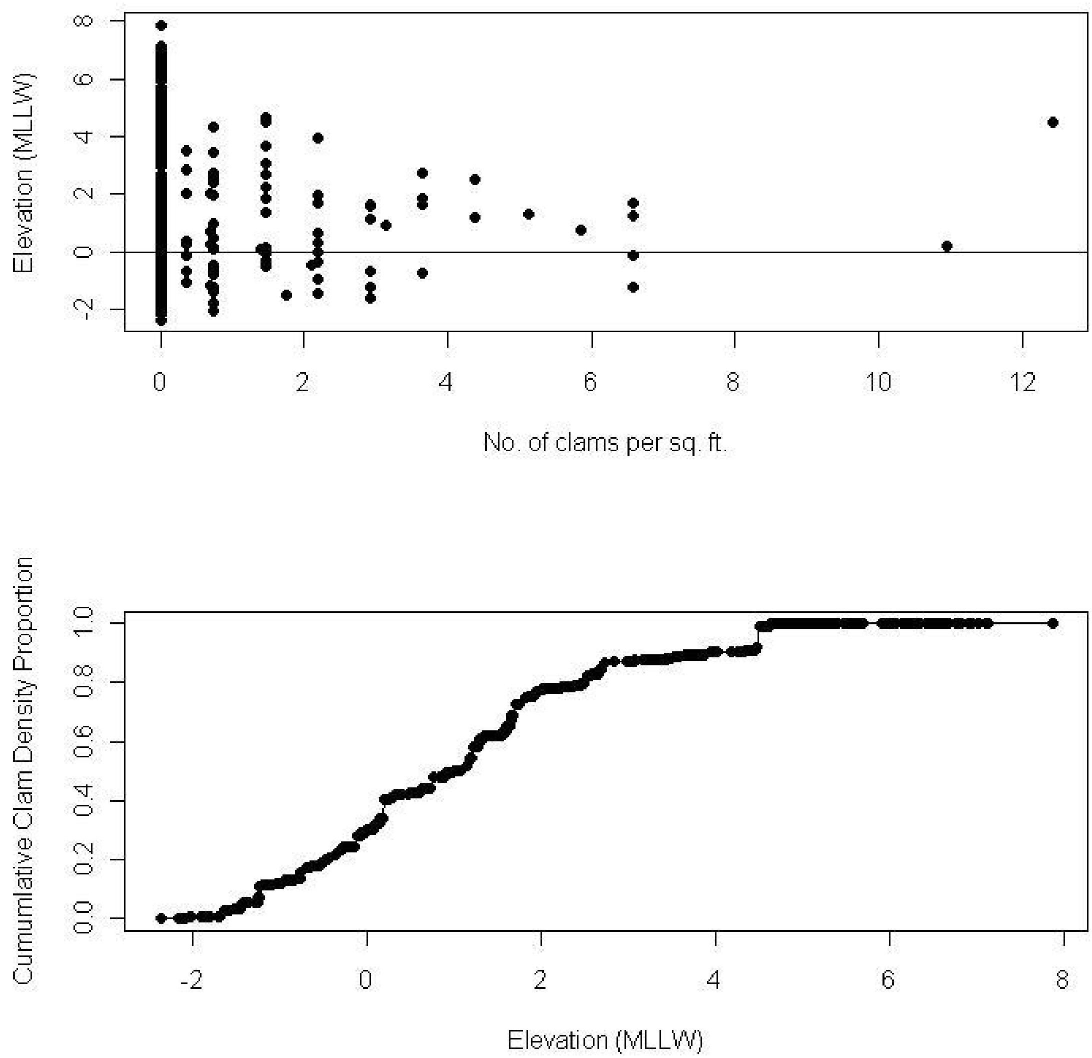


Figure A.28. Vertical Distribution of Pacific Littleneck Clams on the Reservation Tidelands

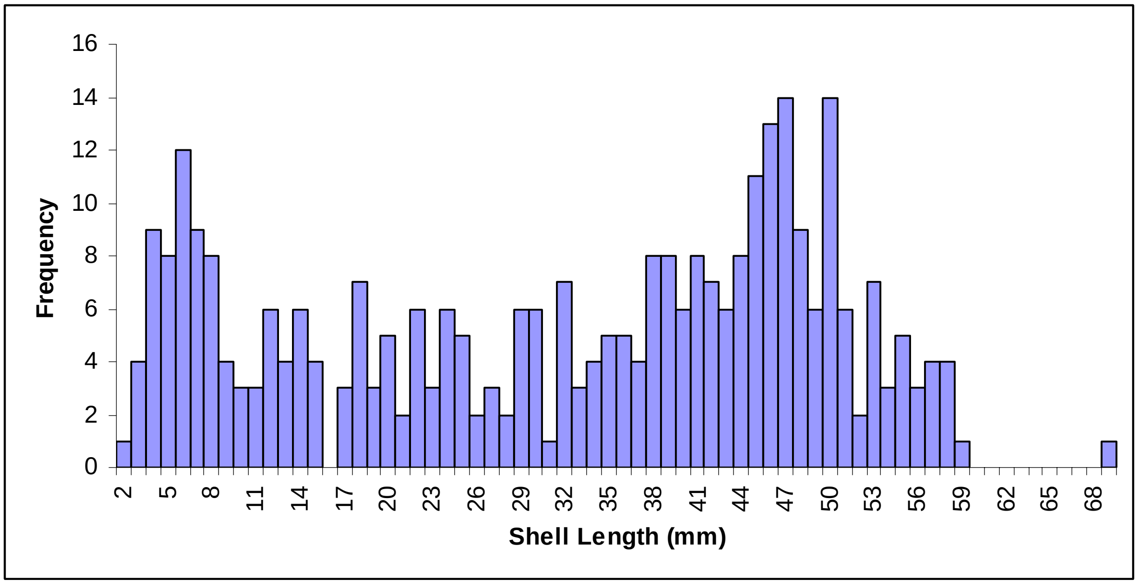


Figure A.29. Size-Frequency Distribution of Pacific Littleneck Clams (n=323)

Table A.8. Kendall's Tau Correlation of Pacific Littleneck Clam Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0000	-0.20
Slope (%)	0.9670	0.00
Fetch (ft)	0.6340	-0.02
Salinity (ppt)	0.0661	-0.08
SCI.Score	0.0000	0.22
Japanese Eelgrass (shoots	0.0076	-0.13
Pacific Eelgrass (shoots/sq	0.9420	0.00

3.2.7 Eastern Softshell Clams

Eastern softshell clams were widely distributed across the Reservation tidelands except for the Nooksack River delta where they were absent (Figure A.30). Generally, eastern softshell clam densities were low compared to other bivalve species, and the population was strongly dominated by very young individuals. The vertical distribution of eastern softshell clams ranged from –1.4 to +6.1 ft MLLW, with 90% of the population being found between –0.7 and +5.0 ft MLLW (Figure A.31).

Eastern softshell clam densities were significantly correlated with slope, fetch, and coarse substrate index (p-value < 0.05), however these relationships were statistically weak (Table A.9).

Based on the size frequency data for eastern softshell clams (Fig. A.32), young-of-the-year (YOY) clams were assumed to have a maximum shell length of 14 mm. Approximately 52 million YOY eastern softshell clams were estimated to be present during sampling.

Excluding YOY, the spatially weighted population estimate for eastern softshell clams was calculated to be 20,517,637 individuals with an estimated biomass of 1,199,412 lbs. The 95% confidence intervals for these estimates have a statistical precision of 36% and 89% respectively.

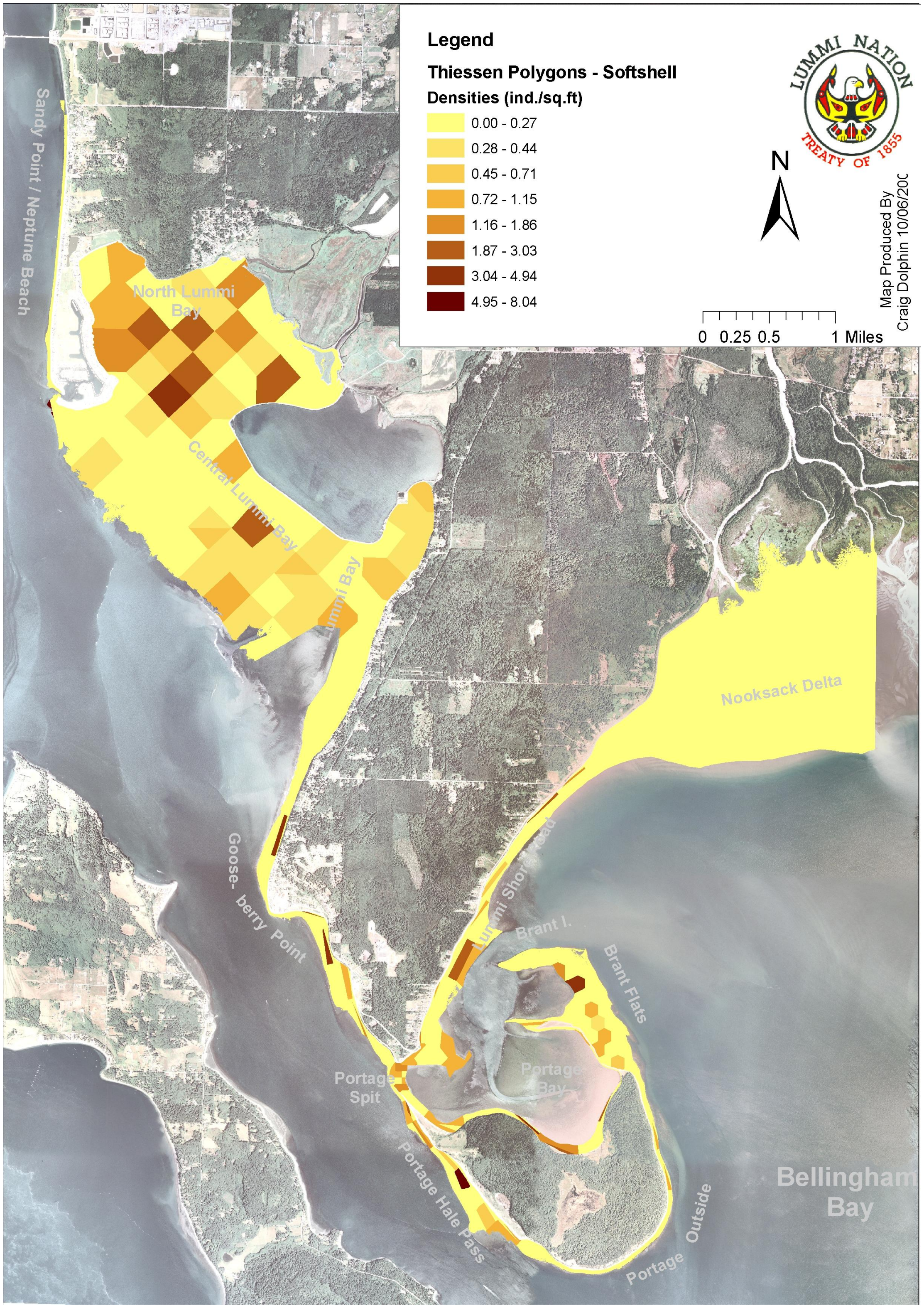
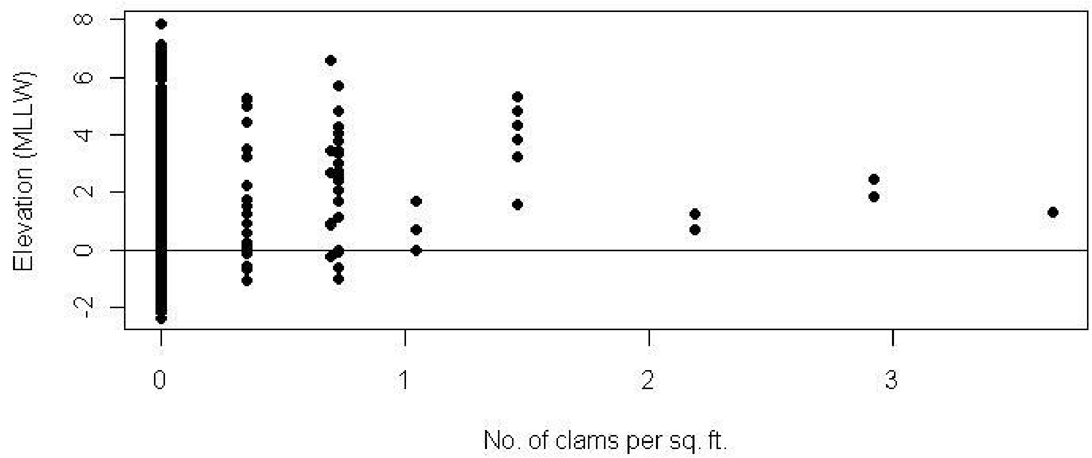


Figure A.30. Thiessen Polygons of Eastern Softshell Clam Individuals Per Square Foot Across the Reservation Tidelands



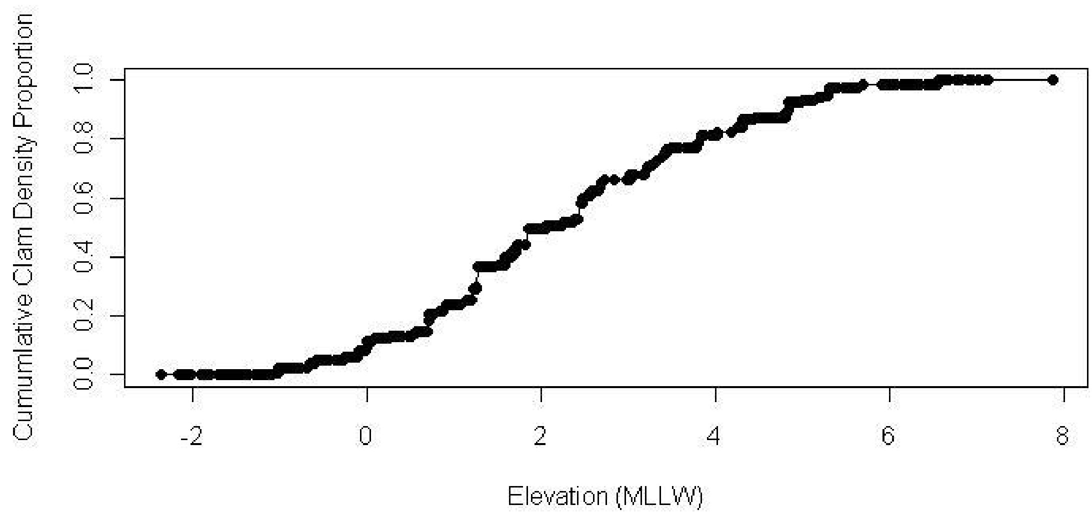


Figure A.31. Vertical Distributions of Eastern Softshell Clams on the Reservation Tidelands

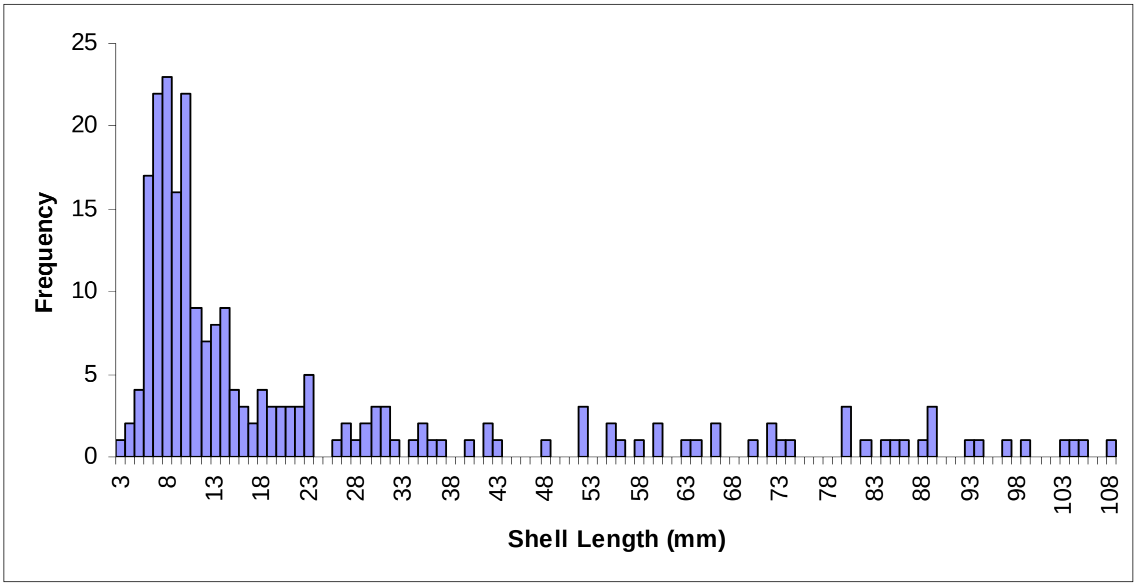


Figure A.32. Size-Frequency Distribution of Eastern Softshell Clams (n=230)

Table A.9. Kendall's Tau Correlation of Eastern Softshell Clam Abundance with Habitat Parameters

	Abundance (No./sq. ft.)	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.6450	0.02
Slope (%)	0.0021	-0.13
Fetch (ft)	0.0001	-0.16
Salinity (ppt)	0.1720	0.06
SCI.Score	0.0032	-0.12
Japanese Eelgrass (shoots/sq.ft.)	0.2010	0.06
Pacific Eelgrass (shoots/sq.ft.)	0.0456	-0.10

3.2.8 Eelgrass

Japanese eelgrass (*Zostera japonica*) is a non-endemic eelgrass species that was commonly present at medium elevations in protected parts of Lummi Bay, and also was present as comparatively isolated patches at Brant Flats, Portage Bay, and Gooseberry Point (Figure A.33 and Figure A.34).

Japanese eelgrass shoot densities were significantly correlated with slope, salinity, and the substrate coarseness index (p-value < 0.05), however these relationships were statistically weak (Table A.10).

Thiessen polygon analysis indicates that there were approximately 900,371,186 shoots of Japanese eelgrass across the surveyed portion of the Reservation tidelands. The 95% confidence interval for this estimate has a statistical precision of 76.8%.

Pacific eelgrass was present across large areas, and at high shoot densities, in Lummi Bay, Gooseberry Point, Brant Flats, and along Hale Passage (Figure A.34). It was also present in Portage Bay, but it was unsafe to sample where it occurred there because of very deep and soft sediments. Pacific eelgrass (*Zostera marina*) was generally found in lower-elevation intertidal areas, and sometimes higher on the shore where there were channels or standing water (Figure A.36). The distribution of Pacific eelgrass extends beyond the intertidal elevations surveyed in this study, and into the subtidal zone.

Pacific eelgrass shoot densities were significantly correlated with elevation, slope, fetch, and salinity (p-value < 0.05), however these relationships were statistically weak (Table A.11).

Thiessen polygon analysis indicates that there were approximately 683,313,376 shoots of Pacific eelgrass across the surveyed portion of the Reservation tidelands. The 95% confidence interval for this estimate has a statistical precision of 44.2%. This value excludes shoots that were present in dense subtidal beds, which were particularly evident in Portage Bay.

Although Japanese eelgrass shoots were more abundant than Pacific eelgrass shoots, the individual Japanese eelgrass blades are much narrower and much shorter than the Pacific eelgrass blades. As a result, Pacific eelgrass has a much larger growth form than Japanese eelgrass does and was estimated to cover approximately 6.2% of the intertidal substrate whereas Japanese eelgrass was found to only cover approximately 1.9% of the substrate.

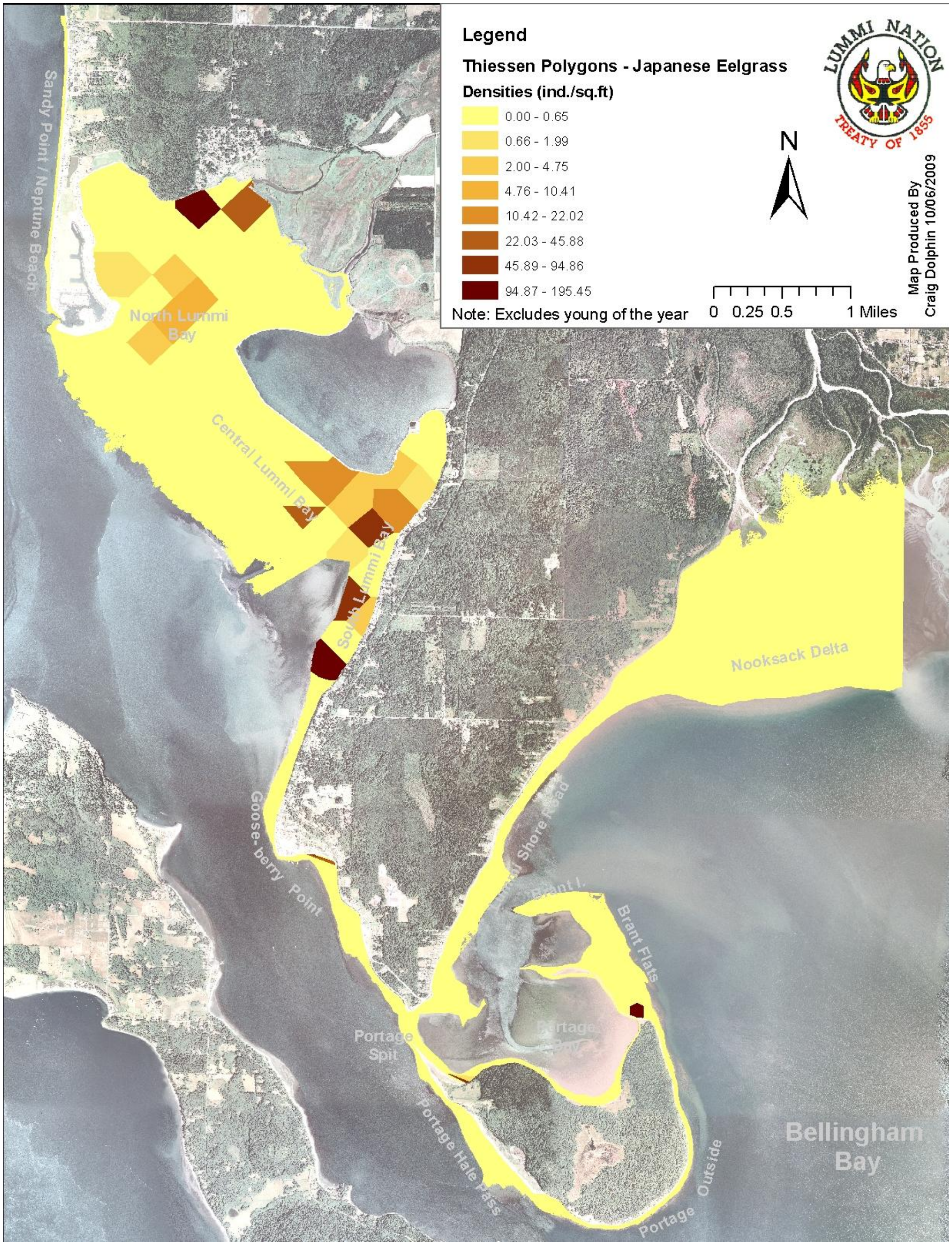
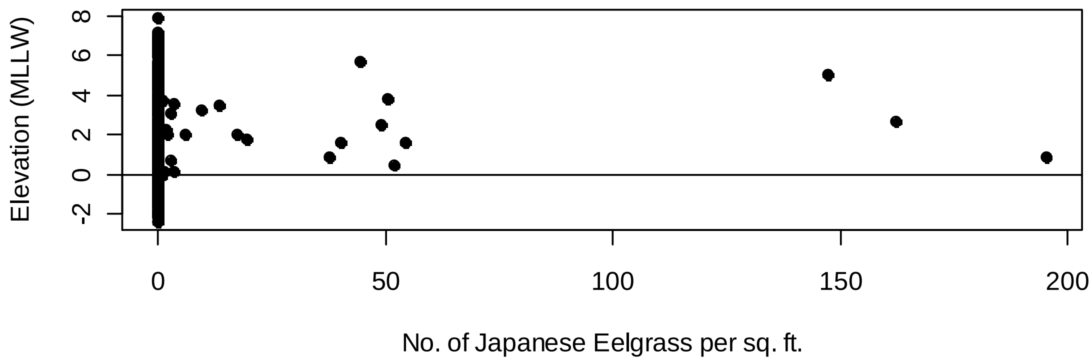


Figure A.33. Thiessen Polygons Showing *Z. japonica* Densities (Shoots per Square foot) across the Reservation Tidelands



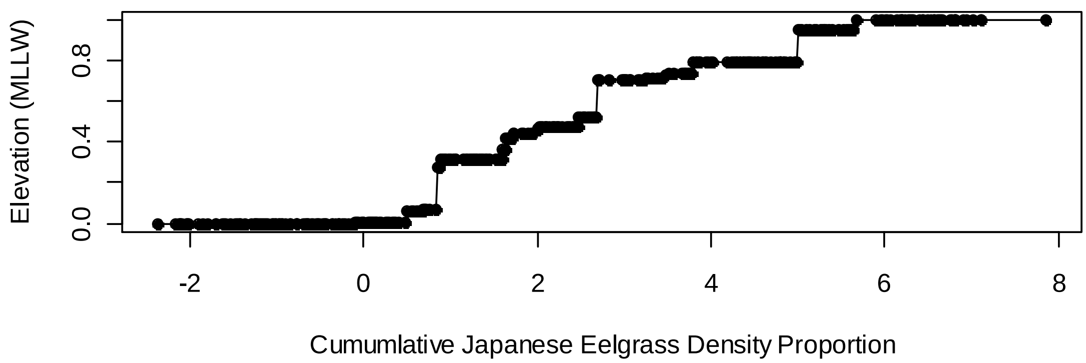


Figure A.34. Vertical Distributions of Japanese eelgrass on the Reservation Tidelands

Table A.10. Kendall's Tau Correlation of Japanese Eelgrass Shoot Density with Habitat Parameters

	Shoot Density	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.7820	0.01
Slope (%)	0.0002	-0.16
Fetch (ft)	0.0793	-0.07
Salinity (ppt)	0.0015	0.13
SCI.Score	0.0034	-0.13

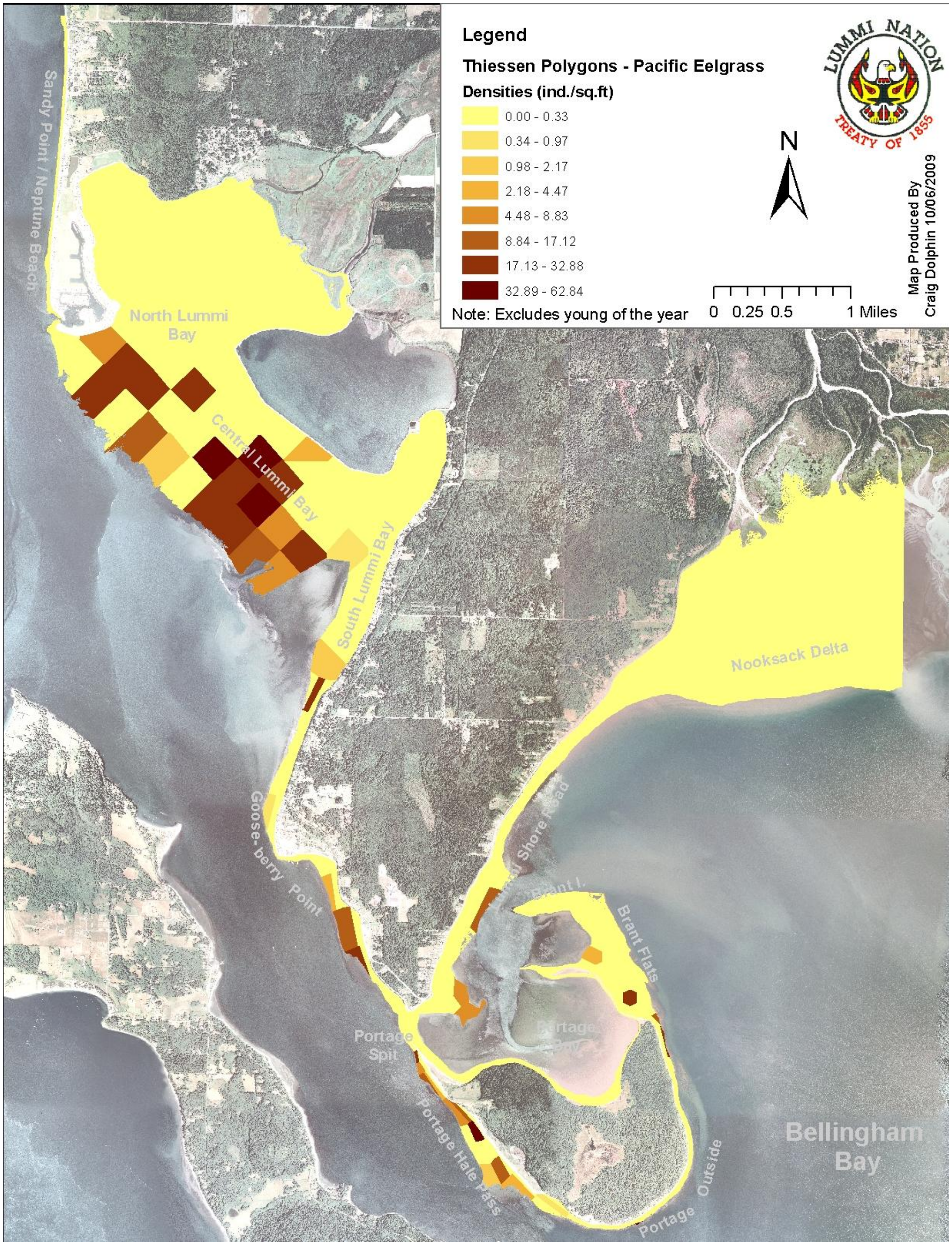
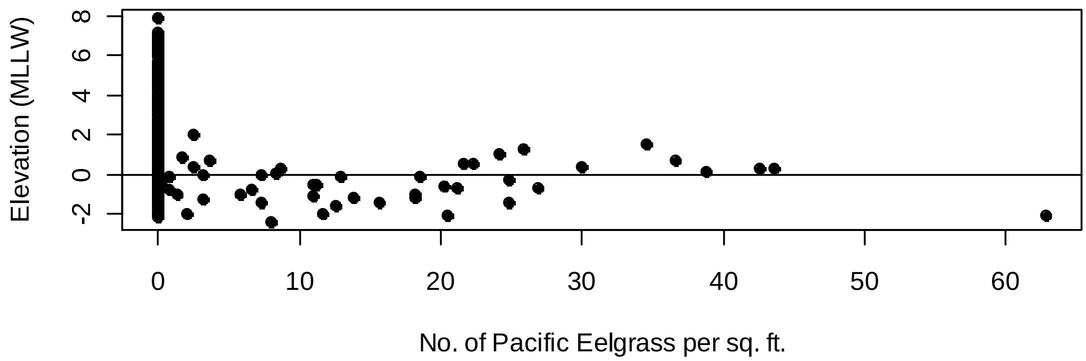


Figure A.35. Thiessen Polygons Showing *Z. marina* Densities (Shoots per Square foot) across the Reservation Tidelands



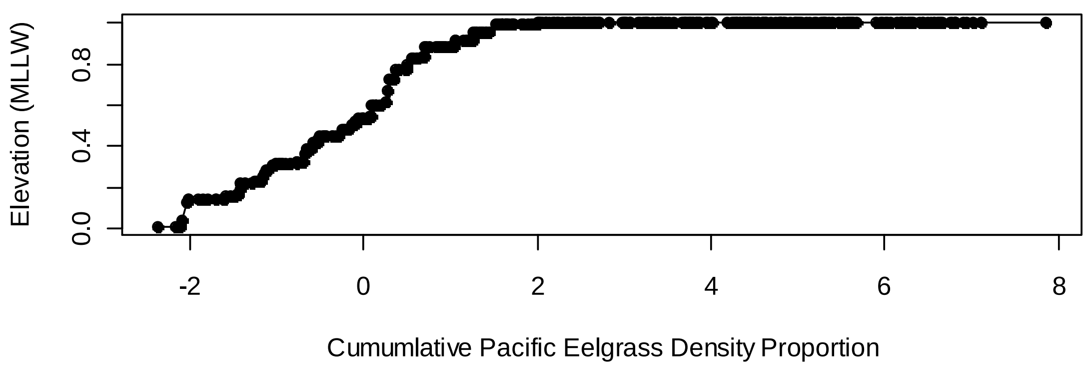


Figure A.36. Vertical Distributions of Pacific eelgrass on the Reservation Tidelands

Table A.11. Kendall's Tau Correlation of Pacific Eelgrass Shoot Density with Habitat Parameters

	Shoot Density	
	p-value	Kendall's tau
Estimated Ele. MLLW (ft)	0.0001	-0.31
Slope (%)	0.0001	-0.26
Fetch (ft)	0.0061	0.11
Salinity (ppt)	0.0012	0.14
SCI.Score	0.4650	-0.03

3.2.9 Dungeness Crab

Dungeness crab juveniles (*Cancer magister*) and *Cancer sp.* megalops larvae (assumed to be *Cancer magister*) were present in all geographic sub-areas except for the Nooksack River Delta.

Dungeness crab juveniles and megalops were not present at sites that were sampled in April and May but were present at sites that were sampled in June and July (Figure A.37 and A.38), which is consistent with the timing of crab settlement reported by Dinnel *et al*. (1986). Because young-of-the-year (YOY) Dungeness crabs and megalops larvae were not present during the first two months of sampling, the abundance of YOY and megalops larvae settling on the tidelands was not estimated.

The vertical distribution of Dungeness crab juveniles and *Cancer sp.* megalops ranged from –2.1 to +6.8 ft MLLW, with 90% of the population being found between –2.1 and +3.8 ft MLLW (Figure A.39).

Based on the size frequency data for Dungeness crab juveniles (Fig. A.37), YOY were assumed to have a maximum carapace width of 15 mm. Table A.12 shows that densities of Dungeness crab YOY were negatively correlated with elevation, and positively associated with eelgrass densities and (weakly) with SCI scores.

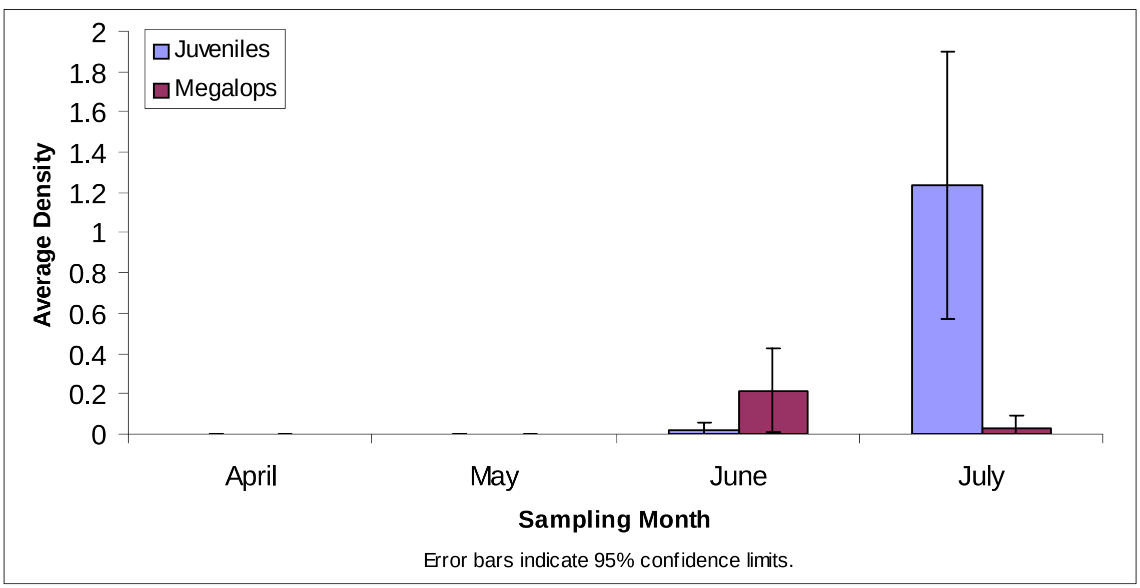


Figure A.37. Comparison of the Average Density of Dungeness Crab Juveniles and *Cancer* sp. Megalops for Low-Elevation Sites Versus Sampling Month

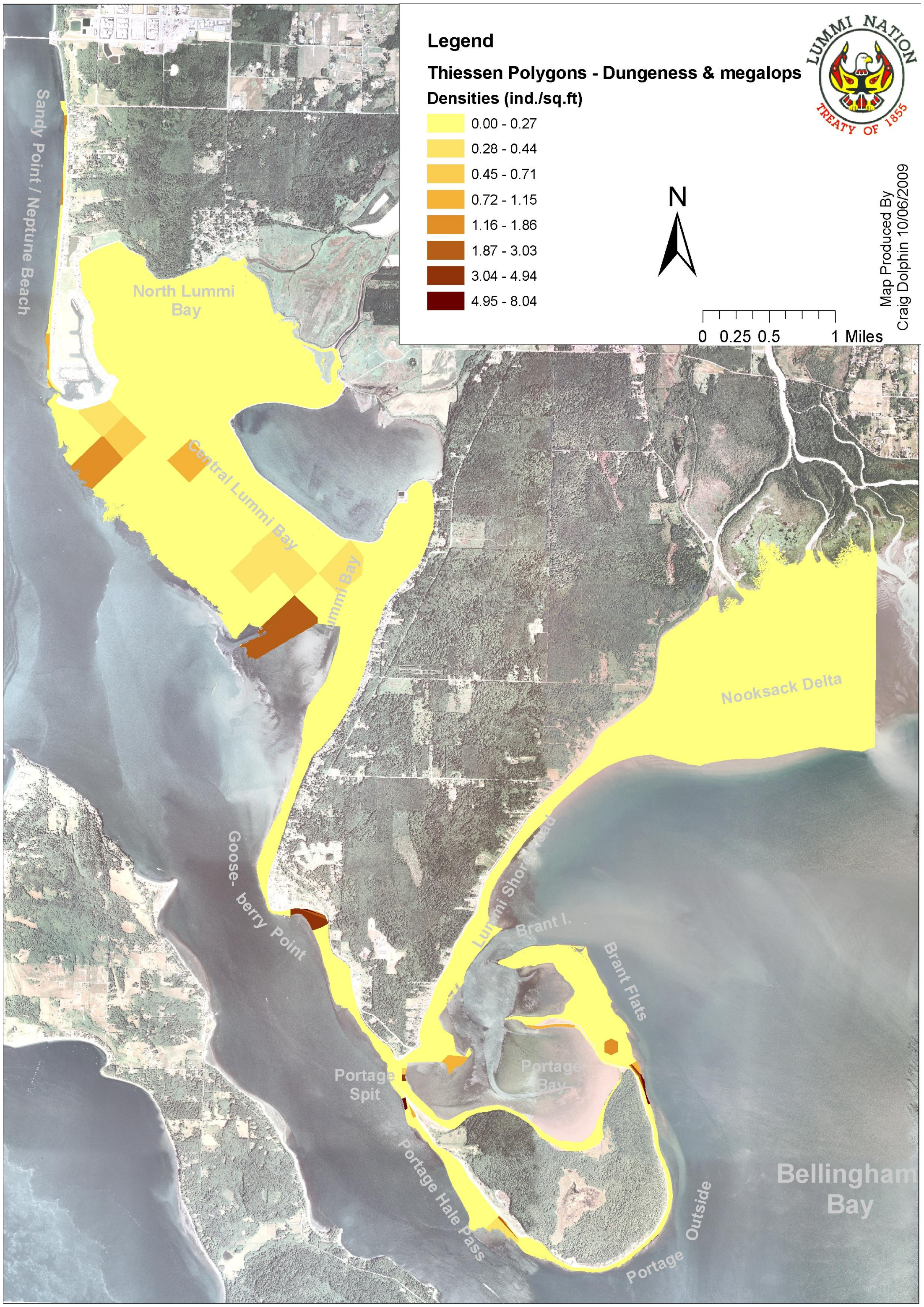
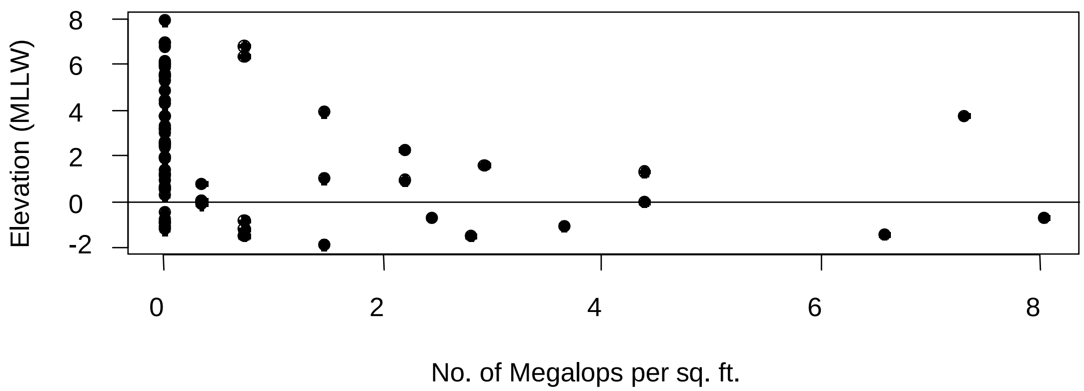


Figure A.38. Thiessen Polygons Showing Combined Densities of Dungeness Crab Juveniles and *Cancer* Megalops Larvae (Individuals per Square Foot)



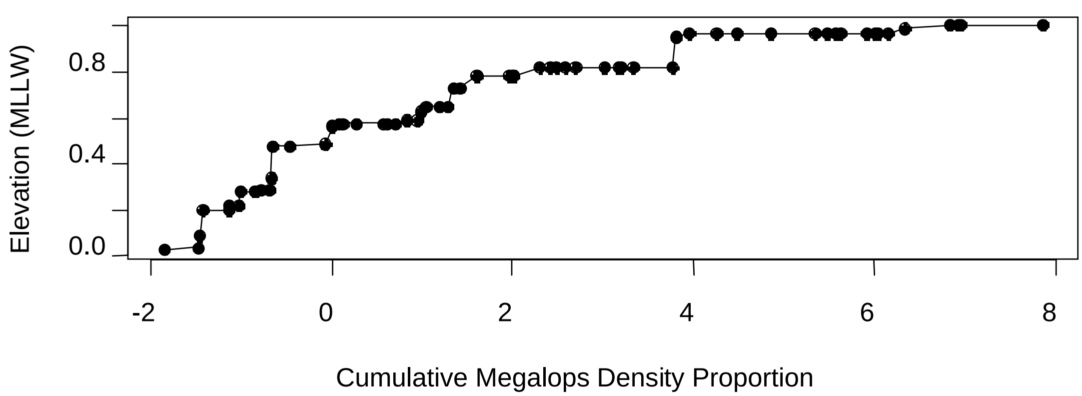


Figure A.39. Vertical Distribution of Dungeness Crab Juveniles Combined with *Cancer* Megalops on the Reservation Tidelands

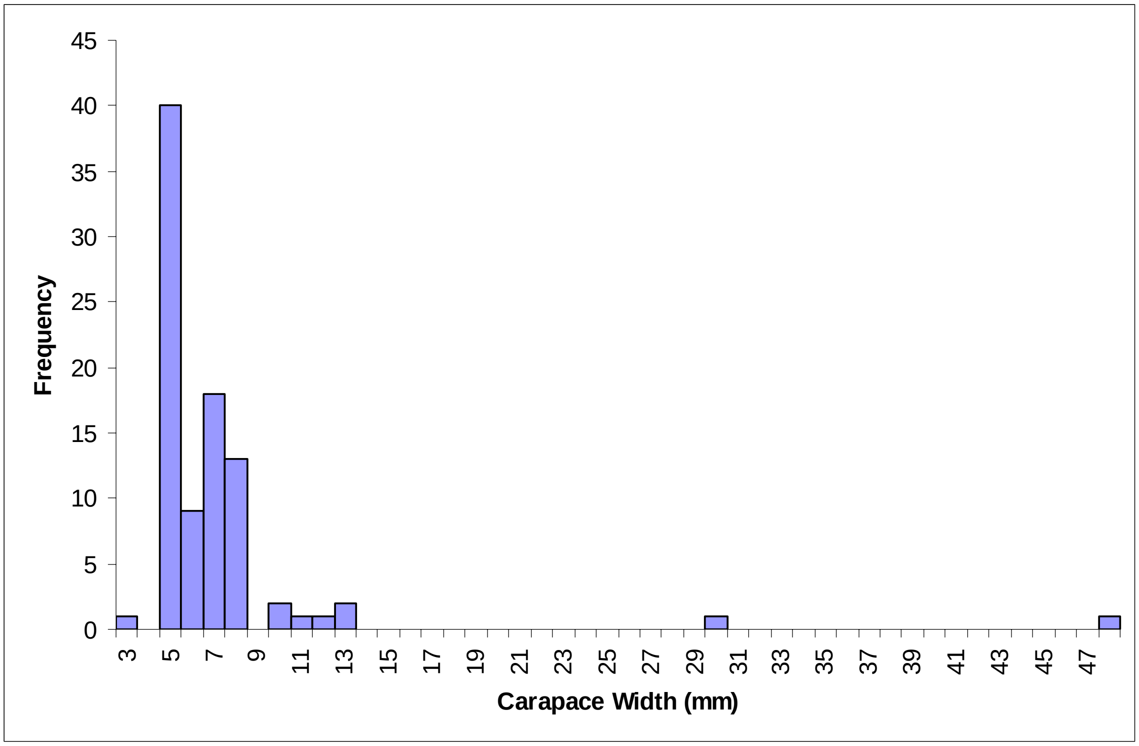


Figure A.40. Size-Frequency Distribution of Dungeness Crab Juveniles (Excludes *Cancer* sp. Megalops)

Table A.12. Kendall's Tau Correlation of Dungeness Crab/Cancer sp. Megalops Biomass and Abundance with Habitat Parameters.

	Abundance (No./sq. ft)	
	p-value	Kendal's tau
Estimated Ele. MLLW (ft)	0.001	-0.313
Slope (%)	0.106	-0.153
Fetch (ft)	0.195	0.122
Salinity (ppt)	0.176	0.129
SCI Score	0.031	0.145
Z.japonica (shoots/sq.ft)	0.002	0.217
Z.marina (shoots/sq.ft)	0.002	0.323

3.3 Surface Characteristics

Lummi Bay and Nooksack River Delta beaches both had relatively flat, homogeneous gradients across the vertical range of the tidelands (<0.3% slope).

Substrates at the Nooksack River Delta were comprised almost exclusively of sand (98%) with traces of mud and woody debris (1% each). No vegetation or epibenthic organisms were present on the delta tideland sites, although some small patches of Pacific eelgrass (*Zostera marina*) were observed near the delta fringe, and saltmarsh dominated by pickleweed (*Salicornia virginica*) was present beyond the upper limit of the surveyed area.

Lummi Bay substrates were dominated by sand (72%) and moderate amounts of mud (26%) with traces of shell (2%). At intermediate and lower elevations, vegetation coverages were dominated by eelgrasses (*Z. japonica* 5%, *Z. marina* 15%) and macroalgae (6% green algae, <1% brown algae). Salt marsh vegetation (pickle weed) was encountered along the upper fringes of the surveyed area (<1%). Large abundances of horn shells (*Batillaria attramentaria*) were also present and provided secondary substrate for acorn barnacles (*Balanus* sp.), although these small organisms covered only 1% of the area.

Portage Spit is characterized by moderate gradients (<2% slope on average), which do not change greatly across the beach profile. Surface substrates are dominated by embedded gravels (41%), shell (21%), sand (29%), mud (7%), and with traces of cobble (2%). Vegetation on Portage spit is limited and almost entirely dominated by macroalgae (13% green algae, 3% red algae, <1% brown algae), with only traces of both eelgrass species present (both < 1%). Epibenthic animals are relatively common on Portage Spit compared to other areas, and these are dominated by extensive mussel mats (10%) and acorn barnacle expanses (11%).

Hale Passage and Gooseberry Point tidelands are typically flat (average 1% slope) expanses at elevations below +1 ft MLLW. Substrates are comprised of sand (72%) and mud (16%) with occasional gravel (11%) and shell (<1%). Vegetation coverage is common and includes Pacific eelgrass (22%) and macroalgae (23% green algae, 4% brown algae). Habitat-forming epibenthic animals were negligible.

At elevations above +1 ft MLLW, the beaches have uniformly steeper gradients (average 4% slope) and the substrates are dominated by embedded cobbles (32%), gravels (37%), and shell (4%), and limited amounts of sand (25%) and mud (1%). Vegetation is much less common at this elevation, and dominated by macroalgae (13% green algae, 3% brown algae, 2% red algae). Trace amounts of Japanese eelgrass are also present (2%). Acorn barnacles are also present on the upper beach (5%).

The exposed beaches on the outside of Portage Island are moderately steep all the way to the edge of the water (~3% slope overall) although the lower part of the beach tends to have a slightly shallower slope than the upper beach. Substrates are dominated by a jumble of cobbles (63%), gravels (18%) and boulders (2%), with some exposed sand patches at the lowest elevations (16% overall) and traces of shell (1%). Vegetation is present along the lower shore, and dominated by a diverse macroalgae community (4% green algae, 2% brown algae, 1% red algae) with occasional patches of Pacific eelgrass (2%) and trace amounts of Japanese eelgrass (<1%). Acorn barnacles are also present across 11% of the beach.

Portage Bay beaches are moderately steep at elevations above +1 foot MLLW (average 3.6% slope) and relatively flatter at lower elevations (average 1.6% slope). However, the substrates at the lowest elevations in Portage Bay are comprised almost entirely of deep, soft mud/clay with traces of sand and shell. For this reason the lowest sites in this area could not be sampled safely except at the very fringes of the mud. The slope of this large muddy flat is less than 0.5%. Vegetation at sites near the fringe of the mud flat included Pacific eelgrass (11%), and a mix of macroalgae (11% green algae, 8% red algae).

At higher elevations, the Portage Bay surface substrates consist of a mix of sand (34%), mud (26%), gravel (21%), and cobble (16%), with traces of shell (2%). Vegetation is less common and dominated by green macroalgae (7%) with traces of Japanese eelgrass and red macroalgae (1% each). Trace amounts of acorn barnacles are also present (2%).

Beaches along Lummi Shore Road exhibited the same pattern: having a steep upper beach (average 2.8% slope) that broadens out to a low-gradient flat expanse at the lower end of the beach (average 0.5% slope). It was also noted that a subsurface layer of hard-packed clay was frequently encountered within the first few inches of depth along this shore.

Surface substrates on the lower beach were dominated by sand (67%) and mud (27%), with minor contributions of shell (3%), gravel (2%), and cobble (1%). Vegetation coverage on the lower beach in this area is dominated by Pacific eelgrass (10%) and macroalgae (6% green algae, 2% brown algae), with negligible traces of Japanese eelgrass. Acorn barnacles and mussels combined cover less than one half of one percent of the area.

By comparison, the upper beach along Lummi Shore Road is dominated by a mix of cobble (33%), gravel (30%), and sand (30%), with occasional boulders (4%) and shell (4%), and trace areas of mud (1%). Vegetation coverage was limited to a mixture of macroalgae (9% green algae, 3% brown algae, <1% red algae), with no eelgrass recorded. However, acorn barnacles (8%), mussels (3%), and Pacific oysters (<1%) were present on the upper beach.

Brant Island and Brant Flats have a heterogeneous mixture of low to moderate gradients defying simplistic assessment. This results from the unusual topography of the area.

Numerous shore-parallel bars of coarse sediments alternate with swales and channels that contain higher amounts of finer-grained sediments. Seaward bars and swales generally have coarser sediments overall, relative to inshore bars and swales that are more protected from wave energy. At the lowest extent of the southeast portion of Brant Flats, large sand flats extend into the subtidal zone. Brant Island is primarily composed of embedded cobbles where wave energy is highest, or of broken shell-gravel mixtures in more protected high-current depositional areas. Overall, the substrates encountered in this complex area were primarily gravel (35%), sand (39%), cobble (13%), shell (8%), and mud (5%). Vegetation coverage is dominated by macroalgae (12% green algae, 5% brown algae) and eelgrasses (5% Pacific eelgrass, 3% Japanese eelgrass). Acorn barnacles (5%), mussels (2%), and Pacific oysters (2%) also contribute to the surface habitat complexity across this area.

3.4 List of Taxa in Samples

During the Intertidal Biota Inventory the LIBI recorded 136 taxonomic groups, with 14 additional higher-level groupings where individual identifications could not be made at the lowest level, were used (Table A.13). (Note: this does not include birds, marine mammals, and finfish that were encountered during other LIBI surveys). The ten most abundant species in the excavated samples are shown in Table A.14.

Table A.13. List of Taxa, by Geographical Subarea

				Lummi Bay									
		SpeciesList	Neptune Beach	Central	North	South	Goose-berry Pt.	Portage Spit	Portage Hale Pass	Portage Outside	Brant Is. / Flats	Portage Bay	Lummi Shore Rd	Nooksack Delta
Annelids	Polychaetes	Bamboo Worms (Family Maldanidae)	+	+	+	+	+	+	+	+	+			+
		Beach Worms (Family Onuphiidae)	+	+									+	
		Blood Worms (Family Glyceridae)	+	+	+	+	+	+	+	+	+	+	+	+
		Bristle Cage Worms (Family Flabelligeridae)				+				+	+			
		Feather Duster Worms (Family Sabellidae)		+	+	+	+	+	+	+	+	+		
		Goddess Worms (Family Nephytidae)	+	+	+		+	+	+	+	+		+	+
		Iridescent Worms (Family Lumbrineridae)	+	+	+	+	+	+	+	+	+	+	+	+
		Lug Worms (Family Arencolidae)	+	+	+	+	+	+	+		+	+	+	+
		Opheliidae (Opheliidae)						+			+			
		Pile Worms (Family Nereidae)	+	+	+	+	+	+	+	+	+	+	+	+
		Polychaete Not Identified **	+	+	+	+	+		+	+	+	+		
		Sand Worms (Family Oweniidae)	+	+	+	+	+	+	+	+	+	+	+	+
		Scale Worms (Halosydna brevisetosa)	+	+				+	+		+	+	+	
		Spaghetti Worms (Family Cirratulidae)		+	+	+	+	+	+	+	+		+	+
		Spaghetti Worms (Family Terebellidae)		+	+		+		+	+		+		
		Three-Section Tube Worms (Family Chaetopteridae)		+	+		+		+	+	+	+	+	
		Tusk Worms (Family Pectinariidae)					+	+	+	+				
Coelenterates	Anemones	Actiniana Anemone (*Actiniana* species)									+			
		Epiactis Not Identified (*Epiactis* species)							+					
		Moonglow Anemone (*Anthopleura artesimia*)	+		+				+	+	+		+	
		Sea Anemone Not Identified (Order Actiniaria)**										+		
		Stubby Rose Anemone (*Urticina coriacea*)				+	+			+				
Crustaceans	Amphipods	Amphipod Not Identified (Order Amphipoda)**			+								+	
		Caprellid Amphipod (*Caprella* species)	+	+	+	+	+	+	+		+			
		Corophiid Amphipod (Family Corophiidae)	+	+	+	+	+	+	+	+	+	+	+	+
		Gammarid Amphipod (Family Gammaridae)	+	+	+	+	+	+	+	+	+	+	+	+
		Sandhopper (*Trasorchestia traskiana*)	+											
		Tanaid Amphipod (Order Tanaidacea		+	+	+								
	Barnacles	Acorn Barnacle (*Balanus glandula*)	+	+	+	+	+	+	+	+	+	+	+	
		Smooth Acorn Barnacle (*Balanus crenatus*)	+		+	+	+	+	+	+	+	+	+	
		Tiny Brown Barnacle (*Chthamatus dalli*)	+					+	+				+	
	Hermit Crabs	Grainy Hermit Crab (*Pagurus granosimanus*)	+	+	+		+	+	+	+	+	+	+	
		Hermit Crab Not Identified (*Pagurus* species)**		+	+			+	+	+	+		+	
		Pagurus hirsutiusculus (*Pagurus hirsutiusculus*)	+	+	+		+	+	+	+	+	+	+	
	Isopods	Eelgrass Isopod (*Idotea resecata*)	+	+	+	+			+	+		+	+	
		Ghost Shrimp Isopod (*Phyllodurus abdominalis*)								+				
		Monterey Idotea (*Idotea montereyensis*)								+				
		Pill Bug Isopod (*Gnorimospaeroma oregonense*)	+	+	+		+	+	+	+	+	+	+	
		Rockweed Isopod (*Idotea wosnesenskii*)							+	+	+			
	Mites	Red Velvet Mite (*Neomolgus littoralis*)											+	

Table A.13. List of Taxa, by Geographical Subarea, continued

				Lummi Bay										
		SpeciesList	Neptune Beach	Central	North	South	Goose-berry Pt.	Portage Spit	Portage Hale Pass	Portage Outside	Brant Is. / Flats	Portage Bay	Lummi Shore Rd	Nooksack Delta
Crustaceans cont'd	Shrimps	Betaus harrimani (*Betaus harrimani*)				+			+				+	
		Blacktail Shrimp (*Crangon nigricauda*)		+						+				+
		Blue Mud Shrimp (*Upogebia pugettensis*)	+			+								
		Broken Backed Shrimp (*Heptacarpus* species)**								+				
		California Bay Shrimp (*Crangon franciscorum*)		+										
		Crangonid Shrimp (Family Crangonidae)	+	+	+		+		+					
		Ghost Shrimp (*Neotrypaena californiensis*)	+		+		+			+			+	
		Herdman Coastal Shrimp (*Heptacarpus herdmani*)		+									+	
		Hippotylid Shrimp (*Eualus biunguis*)		+			+							
		Hippotylid Shrimp (Family Hippolytidae)**		+			+			+				
		Mysid Shrimp (*Neomysis species*)					+							
		Shortscale Eualid (*Eualus suckleyi*)		+										
		Spot Prawn (*Pandalus platyceros*)											+	
		Stout Crangon (*Crangon alba*)		+									+	
	True Crabs	Cancer Megalops (*Cancer* species)**	+	+	+		+			+			+	
		Dungeness Crab (*Cancer magister*)	+	+	+		+	+	+	+	+	+		
		Graceful Decorator Crab (*Oregonia gracilis*)							+					
		Hairy Helmet Crab (*Telmessus cheiragonus*)	+	+	+			+	+		+		+	
		Oregon Shore Crab (*Hemigrapsus oregonensis*)	+	+		+	+	+	+	+	+	+	+	
		Pea Crab (*Pinnixa faba*)	+	+			+	+	+	+	+			
		Purple Shore Crab (*Hemigrapsus nudus*)							+	+			+	
		Pygmy Rock Crab (*Cancer oregonensis*)								+				
		Red Rock Crab (*Cancer productus*)	+											
		Schmitt Pea Crab (*Pinnixa schmitti*)		+					+		+			
		Scleroplax granulata (*Scleroplax granulata*)					+				+		+	
		Tube Dwelling Pea Crab (*Pinnixa tubicola*)	+	+	+	+	+	+	+	+	+			
Echinoderms	Brittle-stars	Brittlestar Long Rayed (*Amphiodia* species)	+	+	+		+		+	+	+		+	
		Brittlestar Not Identified (Order Ophiurida)**						+						
		Red Brittlestar (*Ophiopholis aculeata*)							+					
	Sand Dollars	Sand Dollar (*Dendraster excentricus*)			+				+	+	+			
	Sea-stars	Purple Ochre Seastar (*Pisaster ochraceus*)									+			
		Six Rayed Star (*Leptasterias* species)		+										
Finfish	Teleosts	Arrow Goby (*Clevelandia ios*)				+						+		
		Buffalo Sculpin (*Enophrys bison*)							+					
		Cockscomb Prickleback (*Anoplarchus purpurescens*)								+				
		Crescent Gunnel (*Pholis laeta*)		+									+	
		Larval Fish (Unidentified Teleost)**		+	+									
		Leister Sculpin (*Euophrys lucasi*)							+					
		Pacific Sanddab (*Citharichthys sonididus*)							+					
		Penpoint Gunnel (*Apodichthys flavidus*)			+					+				
		Plainfin Midshipman (*Porichthys notatus*)		+									+	
		Saddleback Gunnel (*Pholis ornata*)		+	+		+			+			+	
		Sculpin Unidentified (Family Cottidae)**		+				+						
		Staghorn Sculpin (*Leptocottus armatus*)		+										
		Three Spine Stickleback (*Gasterosteus aculeatus*)		+									+	

Table A.13. List of Taxa, by Geographical Subarea, continued

		SpeciesList	Neptune Beach	Lummi Bay Central	Lummi Bay North	Lummi Bay South	Goose-berry Pt.	Portage Spit	Portage Hale Pass	Portage Outside	Brant Is. / Flats	Portage Bay	Lummi Shore Rd	Nooksack Delta
Macro Algae	Green	Enteromorpha species (*Enteromorpha* species)	+	+	+	+	+	+	+	+	+	+	+	
		Ulva species (*Ulva* species)	+	+	+	+	+	+	+	+	+	+	+	
Miscellaneous	Miscellaneous Animal	Bryozoan Not Identified (Phylum Bryozoa)						+	+					
		Chironomids (Family Chironomidae)				+								
		Hydrozoan (Class Hydrozoa)		+										
		Peanut Worm (Phylum Sipunculidae)							+	+				
		Sea Spider (Class Pycnogonida)							+					
		Tan Ribbon Worm (*Cerebratulus* species)		+	+		+	+	+	+	+		+	
		White Ribbon Worm (*Amphiphorus* species)	+	+	+		+	+	+	+	+	+	+	+
Mollusks	Bivalves	Bentnose Clam (*Macoma nasuta*)		+	+	+	+	+	+		+	+	+	
		Bivalve Not Identified (Class Bivalvia) **								+				
		Butter Clam (*Saxidomus giganteus*)	+	+	+		+	+	+	+	+	+	+	
		Cockle (*Clinocardium nuttalli*)	+	+	+	+	+	+	+	+	+	+	+	+
		Cryptomya (*Cryptomya californica*)	+		+	+	+	+	+	+	+	+	+	
		Fine Lined Lucine (*Parvalucina tennuisculpta*)		+					+					
		Geoduck Clam (*Panopea abrupta*)*		+	+									
		Horse Clam (*Tresus* species)	+	+			+	+	+	+	+			
		Jack Knife Clam (*Solen sicarius*)							+					
		Macoma balthica (*Macoma balthica*)		+	+	+	+	+		+	+	+	+	+
		Macoma inquinata (*Macoma inquinata*)	+	+	+		+	+	+	+	+	+	+	+
		Macoma Not Identified (*Macoma* species)**	+	+	+	+	+	+	+	+	+	+	+	+
		Macoma secta (*Macoma secta*)		+		+	+		+					
		Purple varnish Clam (*Nuttalia obscurata*)	+	+	+	+	+		+	+	+	+	+	+
		Manila Clam (*Venerupis phillipinarum*)		+	+	+	+	+	+	+	+	+	+	
		Pacific Littleneck (*Leukoma staminea*)	+	+	+	+	+	+	+	+	+	+	+	
		Pacific Blue Mussel (*Mytilus trossulus*)	+	+	+		+	+	+	+	+	+	+	
		Pacific Oyster (*Crassostrea gigas*)									+	+	+	
		Purple Dwarf Venus (*Nutricola tantilla*)		+			+	+	+	+	+			
		Robust mysella (*Rochefortia tumida*)		+		+								
		Softshell Clam (*Mya arenaria*)	+	+	+	+	+	+	+	+	+	+	+	
		Straight Fan HorseMussel (*Modiolus rectus*)*		+										
		Telina Clam (*Tellina* species)		+	+		+	+	+	+	+		+	
		Thin Shelled Littleneck (*Callithaca tenerrima*)		+	+				+		+			
		Western Ringed Lucine (*Lucinoma annulatum*)		+					+	+	+			
		Wrinkled Montacutid (*Nearomya rugifera*)					+							
	Chitons	Coopers Chiton (*Lepidozona cooperi*)	+											
		Woody Mopalia (*Mopalia lignosa*)	+							+	+			
	Limpets	Eelgrass Limpet (*Lottia parallela*)		+	+	+			+				+	
		Limpet Not Identified (Clade Patellogastropoda)	+											
		Mask Limpet (*Tectura persona*)	+	+		+	+	+	+	+	+	+	+	
		Plate Limpet (*Tectura scutum*)	+				+	+	+	+	+			
		Shield Limpet (*Lottia pelta*)	+				+		+	+				
	Seaslugs	Bubble Snail (*Haminoea* species)		+	+				+					
		Dorid Nudibranch (Superfamily Doridoidea								+				

Table A.13. List of Taxa, by Geographical Subarea, continued

				Lummi Bay										
		SpeciesList	Neptune Beach	Central	North	South	Goose-berry Pt.	Portage Spit	Portage Hale Pass	Portage Outside	Brant Is. / Flats	Portage Bay	Lummi Shore Rd	Nooksack Delta
Molluscs cont'd	Snails	Black Turban (*Tegula funebralis*)						+						
		Checkered Periwinkle (*Littorina scutulata*)	+		+		+	+	+	+	+	+	+	
		Chink Shells (*Lacuna species*)	+	+	+	+	+	+	+	+			+	
		Horn Shell (*Batillaria attramentaria*)		+	+	+	+	+	+	+	+	+	+	
		Lewis' Moon Snail (*Polinices lewisii*) *	+											
		Odostomia (*Odostomia* species)		+	+			+	+	+	+			
		Orobitella (*Orobitella rugifera*)								+				
		Puppet Margarites (*Margarites pupillus*)					+		+					
		Sitka Periwinkle (*Littorina sitkana*)	+				+	+	+	+	+	+	+	
		Trochid Snail (Family Trochidae)							+					
		Turbonilla Snail (*Turbonilla* species)									+			
		Turridae (*Ophiodermella inermis*)							+					
	Whelks	Amphissa columbiana (*Amphissa columbiana*)			+	+	+		+		+		+	
		Channelled DogWinkle (*Nucella canaliculata*)								+				
		Dire Whelk (*Lirabuccinum dirum*)	+					+	+		+		+	
		Frilled Dogwinkle (*Nucella lamellosa*)	+		+	+	+		+	+	+	+		
		Japanese Nassa (*Nassarius fraterculus*)		+		+			+		+	+		
		Ribbed Dogwinkle (*Nucella emarignata*)							+					
		Western Lean Nassa (*Nassarius mendicus*)		+	+	+		+		+	+	+	+	
Porifera	Sponges	Sponge Not Identified (Phylum Porifera)							+					
Vascular Plants	Eelgrass	Zostera japonica (*Zostera japonica*)		+	+	+	+	+		+	+	+	+	
		Zostera marina (*Zostera marina*)		+	+	+	+	+	+	+	+	+	+	
	Salt-marsh	Pickleweed (*Salicornia virginica*)			+									
		SaltMarsh Dodder (*Cuscuta salina*)			+									

* Observed during fieldwork but not detected in quantitative assessments.
**Some individuals were not identified to the lowest taxonomic level and these individuals are only reported at higher taxonomic levels, indicated in red.

Table A.14. List of the 10 most abundant Taxa in the LIBI Samples

Rank	Common Name	Taxonomic Reference	Individuals
1	Sand Worms	Family Oweniidae	7,774
2	Caprellid Amphipod	*Caprella* sp.	4,231
3	Japanese Eelgrass	*Zostera japonica*	2,276
4	Horn Shell	*Batillaria attramentaria*	2,149
5	Purple Varnish Clam	*Nuttalia obscurata*	1,893
6	Pacific Eelgrass	*Zostera marina*	1,810
7	Gammarid Amphipod	Family Gammaridae	1,744
8	Macoma (Not Identified)	*Macoma* sp.	1,441
9	Acorn Barnacle	*Balanus glandula*	1,363
10	Pacific Blue Mussel	*Mytilus trossulus*	1,146

4.0 Discussion

4.1 Field Equipment and Methods

The LIBI work plan called for the sampling of approximately 300 sites across the Reservation tidelands. In practice, this goal was exceeded with a total of 366 sites being sampled including 4 sites that were re-sampled in 2009 after being sampled during field-testing of the sampling protocol in 2008.

During the 2008 field-testing of the sampling protocol, it quickly became apparent that transportation of the field crews and their equipment to the sites was likely to be a limiting factor. To resolve this issue, four carts were constructed. The carts functioned like wheelbarrows and enabled weights up to 100 lbs to be readily transported over long distances (Figure A.41).

Figure A.41. Three of the Carts Used to Transport Equipment to Sites

The handles of the carts were hinged to allow the carts to be loaded into the back of the vehicle used to transport the crews to the beach access points. The plastic tub containing the equipment could easily be removed for loading and unloading of gear. The most critical design consideration was the size of the wheel used. The single-wheel design had the advantage of being able to navigate through rocky obstructions more easily than a dual wheel design, but this also concentrates the entire weight of the cart onto one small area. In order to minimize the potential for the cart to become stuck in soft sediments, the carts used wide wheels that were obtained from the rear of two lawn tractors. These wheels had a width of approximately 9.5 inches and an outside diameter of 16 inches.

Overall, the carts proved to be reasonably durable and were used successfully over a wide range of intertidal substrates, although they became significantly more difficult to use when traversing very soft mud sediments. Over time, however, the metal in the hinges warped and undermined the stability of the platform while traveling across uneven ground. This was remedied by using c-clamps to hold the handles tight against the plywood platform when the carts were in use.

The plastic sampling cylinders were made from industrial plastic barrels and successfully prevented the sliding of adjacent soft sediments into the holes during excavation. However, over time their circular shape began to deform and they became more ellipsoid in section. Also, repeated banging along the top edge caused the tops of the cylinders to curve inward making it harder to force the cylinder down into the substrate. Replacement sampling cylinders were used as needed during the field season. A less malleable plastic material with a solid upper edge would make for a more robust design.

The general approach of using sieve buckets to remove fine sediments while still in the field was successful at reducing the weight of samples to manageable levels, and also retained most of the biota. The biggest drawback to this method was that it proved to be destructive to soft-bodied organisms such as polychaete worms, particularly tube worms, and made identifying and counting the broken fragments of these organisms very challenging in the laboratory.

The availability of water for washing the samples at the sites also varied across the tidelands. Having two ordinary square-section buckets allowed very shallow pools of water to be used as a water source by first digging a temporary depression, and then scooping water with the straight edge of one bucket to gradually fill the other bucket.

4.2 Abundance and Population Estimates

The most numerically abundant taxon in the LIBI samples were polychaete worms in the family Oweniidae (Sand Worms), followed by Caprellid amphipods. Other highly abundant organisms that were encountered include both species of eelgrass, horn shell snails, amphipods, and barnacles (Table A.14).

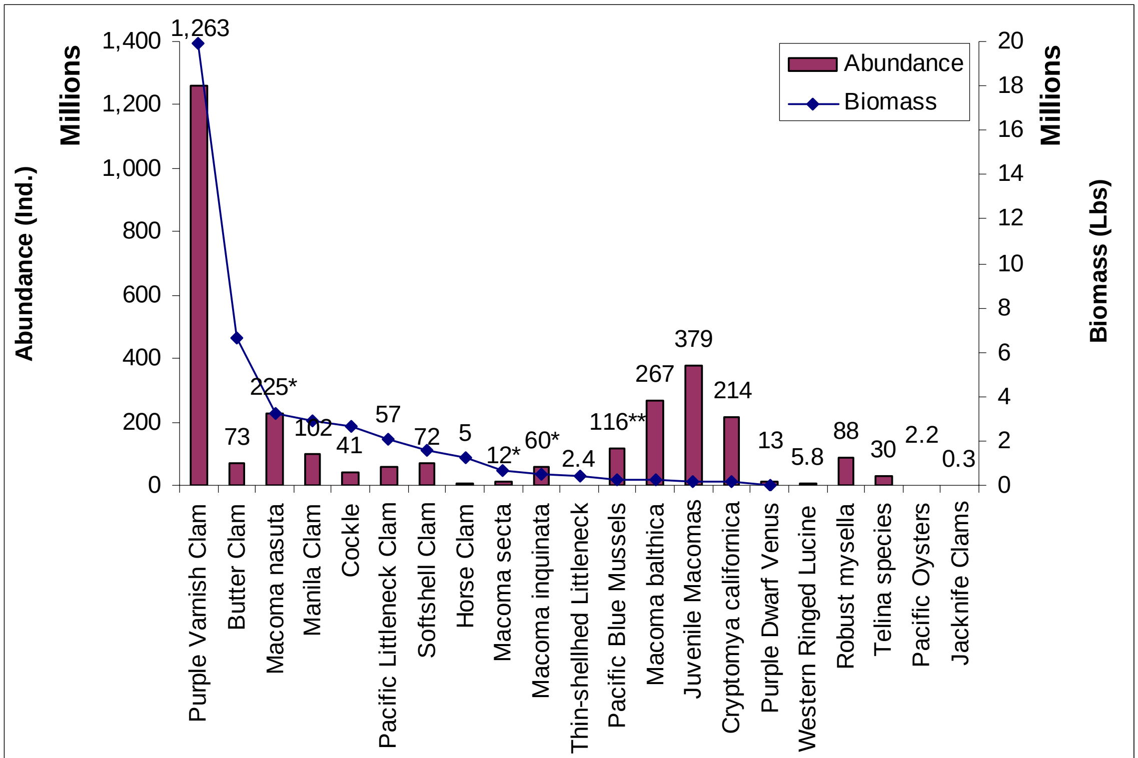
Surprisingly, the most abundant clam species on Reservation tidelands was the recently arrived purple varnish/mahogany clam (*Nuttalia obscurata*). This species was first documented in North America in the early 1990's near Vancouver, British Columbia and likely arrived as larvae in ballast water (Mills 1999). This species was the most abundant clam species in the unadjusted sample counts, and had the highest numerical abundance estimate (1.17 billion individuals), and also the highest total biomass estimate (19.9 million lbs).

The four next most numerically abundant clam taxa were all in the *Macoma* genus, including *M. nasuta*, *M. inquinata*, *M. balthica*, and many juvenile *Macoma* sp. clams that had a shell length less than 20-mm and that were too small to identify with confidence. *Macoma secta* was much less common in the samples. For individuals that could be positively identified, the abundance estimates for the four Macoma species were: *M. balthica* (267 million individuals, 0.2 million lbs); *M. nasuta* (225 million individuals, 3.2 million lbs); *M. inquinata* (60 million individuals, 0.53 million lbs); and *M. secta* (12.1 million individuals, 0.63 million lbs).

Pacific blue mussels (*Mytilus trossulus*) were ranked the 10th most common taxon in the samples although this ranking is artificially low due to the intentional removal of mussel mats from the samples to save on bulk/weight. The vast majority of mussels in the samples were very small (the median size was only 16-mm shell length).

Of the clam species with recognized commercial and subsistence importance, butter clams (*Saxidomus gigantea*) had the highest total biomass (Figure A.42), followed by Manila clams (*Venerupis phillipinarum*), cockles (*Clinocardium nuttali*), Pacific littleneck clams (*Leukoma staminea*), eastern softshell clams (*Mya arenaria*), and horse clams (*Tresus* sp.).

The order of these rankings differs if numerical abundance is considered instead of biomass. Based on the final abundance estimates, for the species with recognized commercial and subsistence importance, Manila clams are the most abundant, followed by butter clams, softshell clams, Pacific littleneck clams, cockles, and lastly horse clams.



These results exclude biomass or abundance from the Lummi Bay Seapond. Numbers indicate the numerical abundance (millions of individuals) of species.
* Individuals <20-mm shell length are considered separately.
** Not all mussels were retained in samples. See methods in Appendix A

Figure A.42. Comparison of Abundance and Biomass Estimates for Bivalves on the Lummi Reservation Tidelands

Although the total biomass of butter clams (6.7 million lbs) was the highest of any of the native clam species, and was twice the biomass of the next-most abundant clam species, the biomass of butter clams was only one third of the biomass of purple varnish/mahogany clams (19.9 million lbs). This clearly illustrates how rapidly the population of purple varnish clams has grown since they were first documented in the region in 1991. It is unclear from this one-time survey whether the population of this species is still growing rapidly, or whether the population has already reached equilibrium with their environment.

Manila clams were inadvertently introduced to the area over a century ago when people introduced Pacific oysters from Japan. Manila clams are the only clam species that is currently harvested commercially on the Reservation tidelands. Manila clams are numerically more abundant than other commercial/subsistence species, but the total biomass of the Manila clam population (2.9 million lbs) is less than half that of the butter clam population. Similarly, the cockle population is only 40% as abundant compared to Manila clams, but overall the biomass of cockles (2.7 million lbs) was almost as high as the biomass of Manila clams. This is due to the heavier weight and larger sizes of individual cockles and butter clams compared to Manila clams.

Pacific littleneck clams were less abundant than Manila clams, butter clams, and softshell clams, but more abundant than cockles and horse clams. Overall, the total biomass of Pacific littleneck clams (2.1 million lbs) was less than the biomass of butter clams, Manila clams, and cockles. Pacific littleneck clams were 11 times more abundant than horse clams and accordingly the biomass of Pacific littleneck clams was larger than the total biomass of horse clams (1.2 million lbs) despite the much larger size of individual horse clams. The abundance of softshell clams was higher than the abundance of Pacific littleneck clams, and the size and weight of large adult softshell clams can exceed that of Pacific littleneck clams, so it is interesting to note that the biomass of Pacific littleneck clams exceeds that of softshell clams (1.6 million lbs). The reason for this apparent contradiction is that the softshell clam population appears to be strongly dominated by young-of-the-year clams, with comparatively few adult clams present the population. This either indicates that a atypically large recruitment of softshell clams occurred at the time of the survey or that post-settlement survival rates are particularly low for this species.

The abundance of horse clams was 14 times lower than that of softshell clams, but the larger size of adult horse clams, and the more balanced size-distribution of the horse clam population meant that the total biomass of horse clams (1.2 million lbs) was only slightly lower compared to the biomass of softshell clams

Dungeness crab results were compromised by the fact that the time of settlement occurred too late in the sampling season to generate useful estimates of total abundance. A survey specifically focused on Dungeness crab is required to better document the use of Reservation tidelands by this important species.

The only existing data that can be used to compare against the abundance estimates generated from the LIBI are the results from the annual Lummi Natural Resources Department (LNR) Manila clam surveys that have been conducted from 2002 to 2008. The LNR surveys calculated results for the total harvestable biomass of legal-sized individuals only (i.e., shell length is 38 mm or larger). Therefore, the Manila clam results in section 3.2.5 of this appendix cannot be directly compared to the results of the LNR surveys because the LIBI results calculate the biomass for all sizes of Manila clams.

The estimate of total legal-size Manila clam abundance across all Reservation tidelands from the LIBI data is 2,453,343 lbs (±63%), which compares to an average biomass of 1,483,874 (±16.5%) from the existing LNR data. Although these two estimates differ by 40%, the low precision of the LIBI estimate means that a difference of this size is not statistically significant (Figure A.43). It should also be noted that the annual biomass estimates for the LNR surveys have fluctuated over time and the highest annual biomass estimate during that time interval was approximately 1.7 million lbs.

Additionally, some areas were included in the LIBI that have never been surveyed previously. Generally, most of these areas were found not to contain Manila clams, but there were two small, low-density occurrences of Manila clams along Lummi Shore Road and on the western side of Portage Island that had not been previously surveyed. If these areas had been included in previous work, the absolute difference between the two estimates would likely have been slightly smaller.

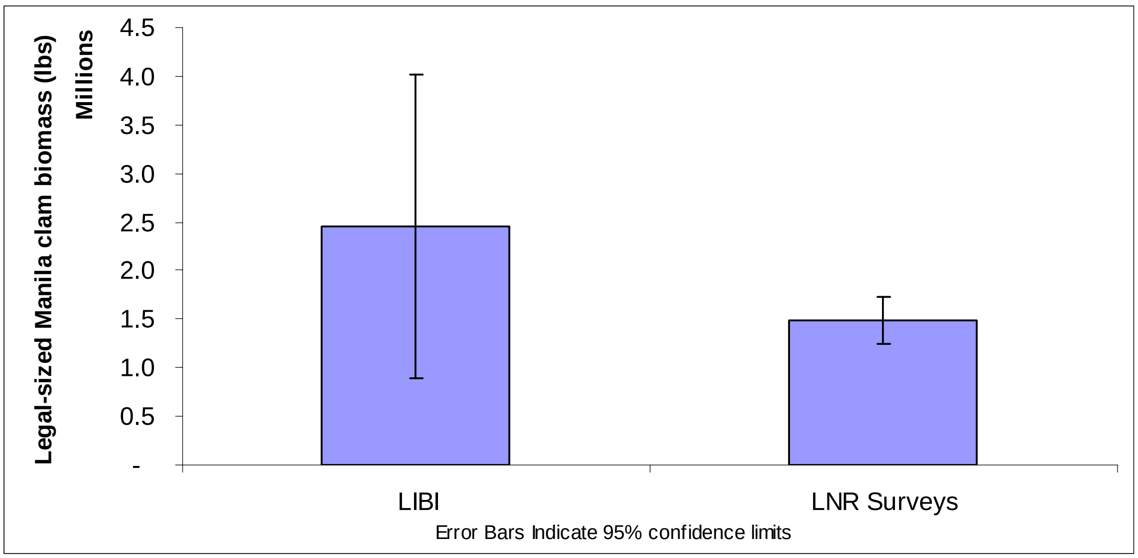


Figure A.43. Comparison of Estimates for Reservation-Wide Biomass of legal-sized Manila Clams from Previous LNR Manila Clam Surveys Versus the LIBI

The relatively low number of samples taken in the LIBI means that the population estimates derived from the LIBI have much wider confidence intervals than has ordinarily been achieved in the annual Manila clams surveys. For comparison, the LIBI sampled 366 locations across the entire reservation whereas the annual Manila clam survey usually achieves 2,000 to 3,000 samples each year across a more narrowly targeted subset of the tideland area. The precision of the LIBI estimate was approximately 63% for Manila clams, whereas the LNR surveys typically achieve precisions ranging from 11 - 25%. For reference, the Washington Department of Fish and Wildlife clam survey protocols aim to achieve a precision of ±30% or lower (Campbell *et al.* 1996).

This comparison illustrates that the abundance estimates from the LIBI are likely to be too imprecise to detect changes in populations over time, particularly if those populations are analyzed at smaller spatial scales. Additional surveys, with greatly reduced spatial and target-species scopes, are likely to be required to obtain estimates with sufficient precision to demonstrate changes in abundance or biomass. This issue is likely to be exacerbated for species that have relatively lower abundances or more variable distributions.

Despite these limitations, the LIBI represents the only dataset that can be used to obtain objective population estimates for almost all of the resident intertidal biota across the Reservation tidelands.

4.3 Spatial Trends

As expected, the pattern of distribution and abundance for different species varied across the tidelands according to the adaptations of each species. For example, Figure A.44 shows that different clam species exhibited different, albeit overlapping vertical ranges.

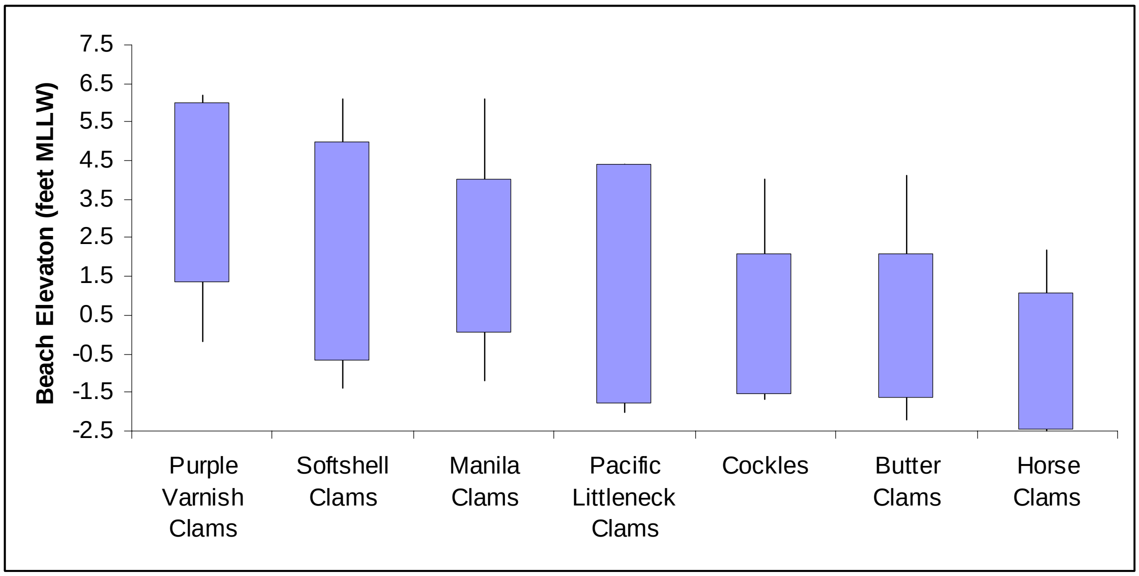


Figure A.44. Comparison of Vertical Elevation Ranges for Seven Clam Species

Purple varnish/mahogany clams were particularly abundant on the Nooksack River Delta, the upper portions of Lummi Bay, and along the gravelly upper beach in Portage Bay. All these areas have freshwater influences. Butter clams, by contrast, were typically found low on the beach and were most abundant at Brant Flats, Hale Passage, Portage Spit, and adjacent to the mouth of the Sandy Point marina channel. Lower density populations of butter clams were also found along the outer portion of Lummi Bay.

Several general patterns were observed when describing the slope and substrate characteristics of the geographical sub-areas used in the study.

Lummi Bay and the Nooksack River Delta are both low-gradient expanses with fine sediments. Lummi Bay has a wider range of wind fetch distances, and hence wave energy, a higher percentage of mud mixed with the sand, and has consistently high salinities. The delta is more uniformly composed of coarse sand, completely exposed to the prevailing winds, and is directly effected by freshwater and sediment deposition impacts from the Nooksack River. Accordingly, Lummi Bay offers a much wider diversity of organisms compared to the Nooksack River Delta. On the other hand, the biomass of purple varnish clams on the delta was very high showing that organisms that can tolerate those conditions can be highly productive in that environment.

A number of beaches around the Reservation were found to share the same general pattern: a steep upper beach composed of embedded coarse substrates, which then flattens out into a broad expanse of fine sediments further down the shore. Such areas include the beaches around Gooseberry Point, Lummi Shore Road, and the Hale Passage side of Portage Island. Beach slope was found to be a significant predictor of taxonomic richness overall. Substrate coarseness, elevation, and occasionally wind fetch, were often found to be significant predictors of abundance for individual clam species. It is likely that beaches with variable profiles like these have quite different communities present on the lower beach versus the upper beach as well as high taxonomic diversity.

The outside of Portage Island had very different characteristics compared to all other beaches on the Reservation. This area has a relatively steep uniform slope for most of the vertical range of the beach, and only begins to flatten out at about –2 ft MLLW. It is dominated by a complex assortment of cobbles and boulders that provide structural complexity for a wide range of organisms. At the lowest levels, the beach becomes a mixture of embedded cobbles and boulders alternating with open patches of coarse sand and shell. A rich diversity of macroalgae blankets the margins of the lower beach.

Neptune Beach along the outside of the Sandy Point peninsula represents another unique area. Most of the beach is composed of highly mobile sand and fine gravel, and these areas are almost entirely devoid of biota, except for sand hoppers along the drift line. On the other hand, the lowest part of the beach tends to have large embedded cobbles that are often covered with a diverse array of macroalgae near the subtidal fringe. This zone has a relatively rich community of echinoderms, clams, worms, and crustaceans living within it. The productive zone varies in size along the shoreline. The rocky shore surrounding the mouth of the Sandy Point marina is relatively broad, but rapidly narrows and eventually gives way to a subtidal sand flat about one third of the way between the marina channel and the northernmost boundary of the Reservation. A narrow band of productive ground reappears near the northernmost boundary of the Reservation, and begins to broaden substantially at the boundary itself.

Portage Spit and Brant Island/Brant Flats present a more challenging situation. Portage Spit is a tombolo, and Brant Flat and Brant Island contain a large number of alternating bars and swales between the high and low waterlines. Community structure in these areas is much more difficult to generalize because the shore does not follow a simple gradient from land to water, and also because a number of shoreline features have the potential to mitigate the actual wave/current energy experienced at a particular location. Instead, each area contains a patchwork of different habitats that change radically over small spatial scales.

4.4 Seasonal Effects

The LIBI fieldwork was conducted from April to July 2009 and, as the larvae of many species settle onto tidelands only during the spring and summer months, the analysis of the results was complicated. To avoid biasing the spatial distribution of species all YOY individuals were removed from the results before creating the distribution maps.

An attempt was made to sample some sites from each of the subareas in each month of the field effort. However, this was not possible for sites along the outside of Portage Island, or on the Nooksack River Delta where boat access was required. Most of the sites in these two areas were sampled within the same day.

Dividing the results for sites by the month sampled could be used to examine settlement timing of various species. However, due to resource constraints, this study was not designed to answer temporal questions. Such an analysis has the risk of confounding temporal effects with spatial effects because different sites were sampled in each month. Nonetheless, the results of this analysis for Dungeness crab settlement timing were consistent with previous work by Dinnel *et al*. (1986). A more rigorously controlled study would be required to definitively examine the question of settlement timing of organisms on the Reservation tidelands.

4.5 Future Work

Many of the lowest-level taxonomic labels used to identify the sampled organisms were not at a species level. For example: polychaete worms were only identified to family level. The total number of species listed would have been considerably higher if all organisms had been identified to species level. The majority of samples are preserved in 80% ethanol, and these are archived at the Northwest Indian College. If identification of the organisms to species level is desired, the samples could be re-examined by specialists if sufficient funding became available.

The LIBI provides an important first step in documenting the presence of many species on the Reservation tidelands. For example, the LIBI identified a spot shrimp juvenile along Lummi Shore Road, which is the first documented instance of this commercially important species on the Lummi Reservation tidelands. On the other hand, at least three species that can be found within Lummi tidelands were not formally sampled in this work. For example, straight fan horse mussels (*Modiolus rectus*) and geoduck clams (*Panopea abrupta*) were observed at several locations along the exposed face of Lummi Bay while field crews were conducting fieldwork but these species were not sampled. Likewise, a moon snail (*Polinices lewisii*) was noted adjacent to a sample location on Neptune Beach, near the Sandy Point marina channel. It is likely that additional species utilize Lummi tidelands beyond those listed in the LIBI final report, and additional work would be required to document these.

The abundance estimates derived from the LIBI data are the only objective abundance estimate for most of the species encountered in this survey. However, these estimates are limited in their usefulness for detecting changes in populations resulting from specific disturbances, such as oil spills. More precise estimates will likely only be obtained from surveys that are more tightly focused on a particular species and geographical area. Future work in this area would need a more limited scope than the LIBI, with much higher sampling densities in order to get estimates with a 30% or better precision.

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