An analysis of 2002 inter-tidal manila clam surveys on reservation beaches

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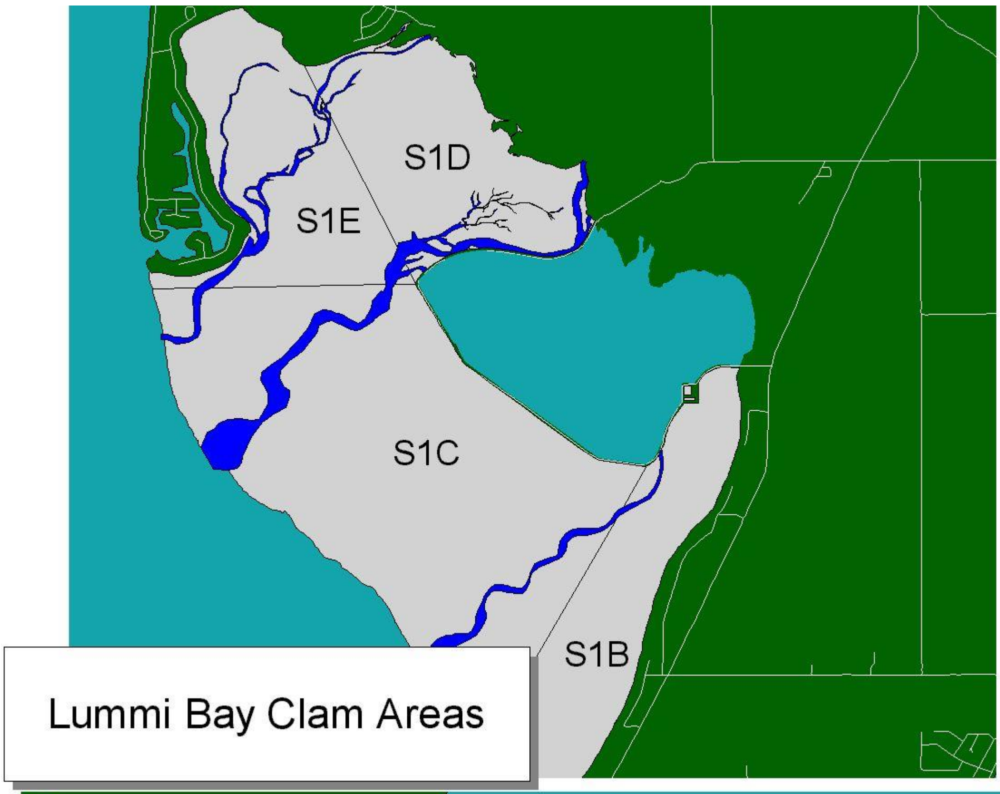

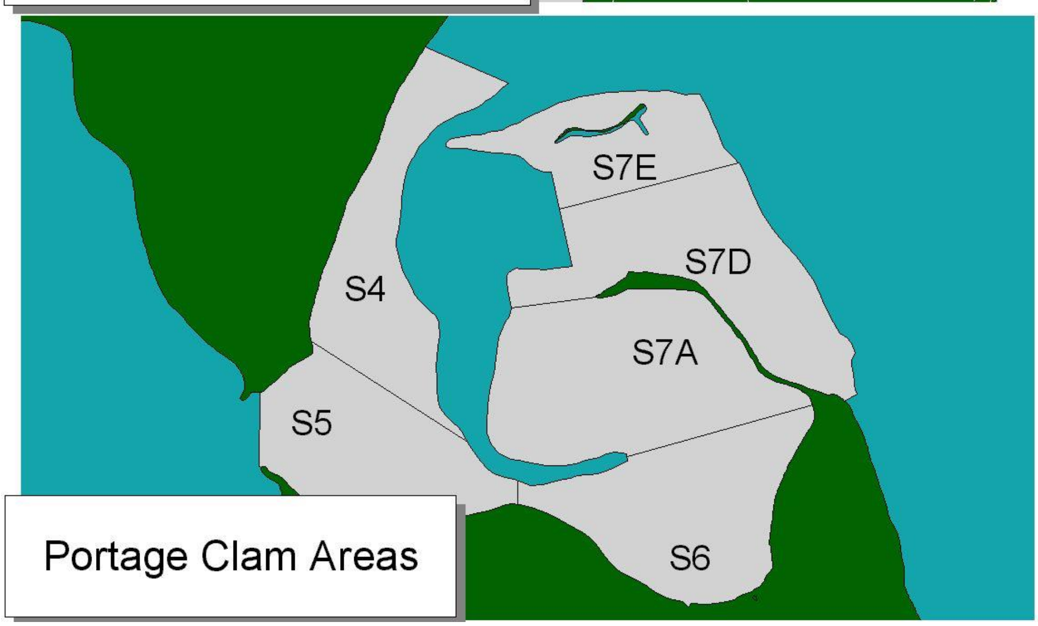

Executive Summary

- 1,372 sample stations (6,536 ft^2) across 2,021 acres of tidelands were used to determine Manila clam densities, distributions, and annual production rates for several on-reservation beaches

- On average, Portage bay beaches had 3 ¼ times the clam density found at Lummi Bay beaches, but the clams tend to be smaller in size and are often more difficult to dig because cobbles and rocks are more common in Portage. Clam densities were highest at Portage Spit (S5) and Brandt Flat (S7D).

- Portage beaches have productivity rates varying between 24% and 52%, this compares to a range of 12% – 17% for Lummi Bay beaches. The differences may be due to water currents and food availability.

- Portage spit has the highest productivity (52%) of any surveyed beach on the reservation, being 21% higher than the next-most productive beach. This unusually high productivity is probably due to extra larvae arriving from clam populations Brandt Flats and Brandt Island.

- Harvest target recommendations for the surveyed, approved areas in Portage Bay total a maximum of **81,348** lbs for the coming year (not including S6 and S7A). This is broken down as 50,274 lbs from Portage Spit (S5 & S5A), 30,611 lbs from the open portion of Brandt Flats (S7D), and 413 lbs from the open portion of the senior's beach (S4). This does not include harvest from S6 or S7A. Harvest recommendations for Lummi Bay total a maximum of **169,968** lbs, which is broken down into 33,777 lbs from S1B, 36,179 lbs from S1C, and 100,012 lbs from S1D&S1E combined.

- S1C has been over-harvested, and fewer than the possible 36,179 lbs should be harvested if recovery of clam densities in S1C is desired.

- Lost harvest opportunity in the coming year for areas closed by the Department of Health (Brandt Island, portions of Brandt Flat, and along Lummi Shore Road) is estimated to be 39,342 lbs. (= **$59,013** @ $1.50 per pound).

Introduction

Harvest History

Tribal fishermen have commercially harvested reservation tidelands since at least 1985, but harvest data is only available from 1989 onwards for Portage Bay beaches and 1996 for Lummi Bay beaches (Figure 1).

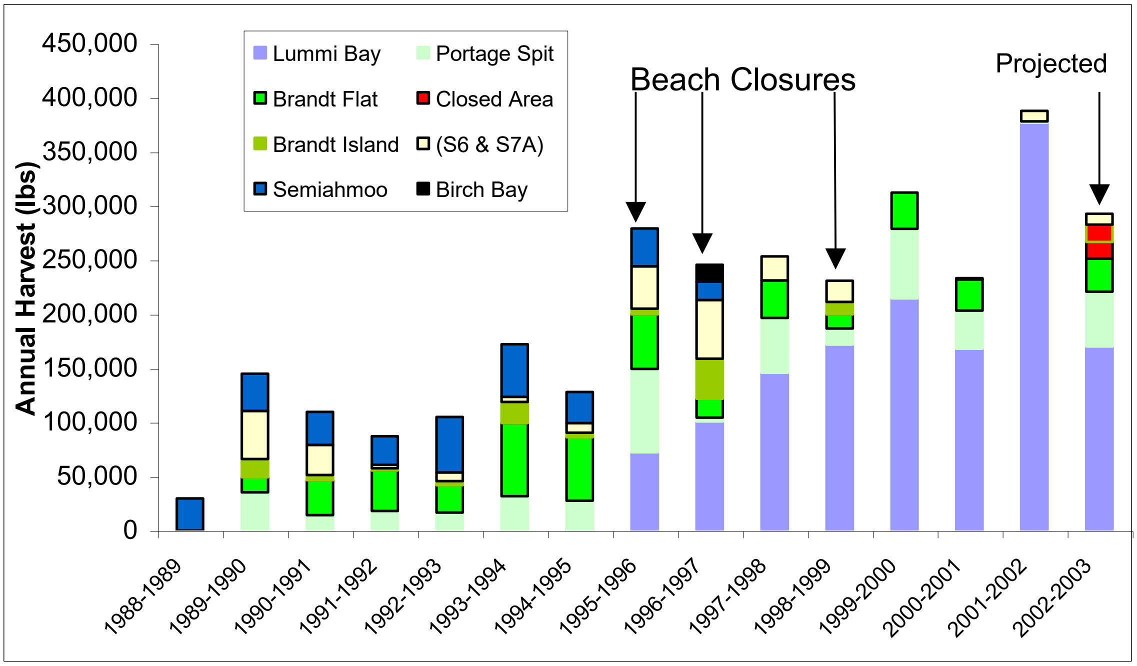

Figure 1. Recorded harvests since 1989.

In the early 1990's (1989-1995) the fishery was primarily based out of Portage Bay beaches. Total landings from Portage beaches averaged approximately 80,000 lbs, with another c. 33,000 lbs harvested from Semiahmoo.

From 1995 to 1999, fishing pressure in Portage Bay increased with average landings reaching approximately 113,000 lbs per year. During this time, some clam beaches in Semiahmoo were closed during 1995, and the remainder closed in 1999. Similarly, portions of Portage Bay were closed in 1997 and another portion in 1999. Since the closure of Brandt Island and Brandt Flat in 1999, Portage beaches have yielded an average harvest of 58,000 lbs per year although this is primarily due to a relocation of effort to Lummi Bay beaches.

Harvest records for Lummi Bay beaches only go back as far as 1994-1995, when 780 lbs were reportedly harvested. The following season, 1995-1996, resulted in over 70,000 lbs being harvested. Annual harvests from Lummi Bay increased by approximately 30,000 to 40,000 lbs per year to reach over 214,000 lbs during the 1999-2000 season. The 2000-2001 season saw the first reduction in harvest when 165,000 lbs were taken. However, these harvests were overshadowed during the 2001-2002 season when a massive 376,000 lbs of clams were harvested from Lummi Bay.

Management of the resource has been primarily by use of ‘openings’ and individual daily limits for diggers in an attempt to spread the harvest effort throughout the year. The current management area designations for reservation beaches are provided in Figure 1.

The bulk of the harvest in Portage is derived from two primary areas: Portage Spit (S5) and Brandt Flats (S7D) which have typically averaged ~31,000 and 34,000 pounds respectively. Next in importance is Brandt Point (S7A; 15,000 lbs per year) and then Brandt Island (S7E; 12,000 lbs per year). Portage (S6) usually provides only a small amount (~5,000 lbs) and S5A and S4 have seldom been commercially targeted. S4 is designated as an area only able to be dug by tribal seniors.

In Lummi Bay, the lion’s share of the harvest has come from S1C and, intermittently, from S1D.

Previous Survey Work

Table I shows the results of tribal clam surveys, where information is available, for all tribally harvested clam beaches between 1989 and 2001. The majority of survey effort has been focused on some Portage beaches and at Semiahmoo, as well as some later work at Birch Bay. Moreover, it is apparent that the survey results for Lummi Bay could not reflect the actual biomass in the area since harvests from Lummi Bay were much larger than the surveyed biomass for that year. To a lesser degree, this is also true of surveys in Portage.

Table I. *Summary of tribal clam survey results between 1989 and 2001.*

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Portage Beaches													
Brandt Flats (S7D)	22,585	37,550	-	-	-	54,448	60,868	29,971	25,794	-	-	-	-
Brandt Island (S7E)	-	-	-	-	-	-	-	-	40,375	27,884	-	-	-
Brandt Point (S7A?)	29,343	13,682	-	-	-	5,421	12,200	4,609	11,611	5,625	-	-	-
S6 (Portage)	-	-	-	-	-	-	-	-	-	-	-	-	-
Hale Passage/Spit (S5A)	-	-	-	-	-	-	-	-	-	-	-	-	-
Portage Spit (S5)	26,343	22,070	-	-	-	45,542	48,101	37,939	29,802	33,982	-	-	-
Senior's Beach (S4)	-	-	-	-	-	-	-	-	-	-	-	-	-
Lummi Bay Beaches													
S1B	-	-	-	-	-	-	-	-	61,012	89,010	-	-	-
S1C	-	-	-	-	-	-	-	-	-	-	-	-	-
S1D	-	-	-	-	-	-	-	48,405	67,447	-	-	-	-
S1E	-	-	-	-	-	-	-	-	-	43,147	-	-	-
Birch Bay													
	-	-	-	-	-	-	-	-	42,626	26,107	28,940	-	-
Semiahmoo													
Combined	-	-	-	-	-	31,037	35,589	32,121	34,167	27,626	18,053	-	-

Unfortunately, none of these surveys were properly documented so it is very difficult to determine what was done and whether anything can be salvaged from the data. In particular, it is difficult to ascertain exactly what part of the indicated area was covered by the survey. What is readily apparent, however, is that none of the surveys covered the majority of the management area in question. For example, Portage Spit surveys between 1994 and 1998 reportedly covered 450,000 ft^2 (10 Acres), but the boundaries of the management area encompass over 1,500,000 ft^2 (~35 Acres) of tidelands, so how much biomass was undetected in the 25 Acres outside of the surveyed area?

Moreover, the number of samples taken within the surveyed area often varied between years. For example, 45 1ft^2 samples were collected in Portage Spit in 1997, but only 25 were taken in 1996. I do not even know if the samples were spread systematically across the surveyed area or not. So even if the sampling intensity were ‘adequate’, it is possible that sample placement may have more to do with the final results than real changes in biomass, especially with so few samples being taken.

Consequently, the survey results in Table I are impossible to compare meaningfully to contemporary surveys or harvest data, and should be treated with caution. Additionally, conclusions that were based on the potentially misleading survey data, such as harvest rates near 80% being sustainable, should be considered highly suspect.

Until now, management of the clam resource has been mostly reactive and guided primarily by feedback from clammers. However, given the increasing pressure on the resource, and the increasingly restricted area in which harvesting remains possible, it has become necessary to obtain accurate information regarding the biological productivity of the harvested beaches, so that we know how much we can safely harvest without collapsing the fishery.

To address this critical need, a series of clam surveys was undertaken in the summer of 2002 across several beaches on the Lummi reservation. The primary aims of the survey program were to answer the following questions:

1. How many pounds of legal sized Manila clams are present in each management area?

2. Where are the major Manila clam populations on reservation beaches?

3. How much can we expect to harvest in each area without reducing clam densities? (i.e., not make the situation worse)

This report summarizes the findings of the 2002 survey program.

Methods

Field Protocols

Due to the size of the area to be covered, and limitations in staff availability, it was not possible to use Department of Fisheries and Wildlife clam surveying protocols to survey the reservation beaches. Because the principle investigator had no previous experience in the distribution of Manila clams on the reservation, and no information about the spatial extent of the clam populations was available, it was not possible to pre-stratify the survey area. Consequently, a grid-like systematic coverage of the survey area was initially attempted at Brandt Island. However, the time needed to establish sample station locations using this method, and the depth of excavation used (12”), led to fewer samples being processed than required. Consequently, an alternate survey method, using parallel transect lines perpendicular to beach orientation was used in other locations.

The orientation of each transect line was maintained by using distant visual reference points such as mountain ranges, etc. The spacing between transect lines was determined using a pre-set number of paces along the beach, and varied depending on factors such as staff availability, and the amount of area to be covered in the time available. Typically, transect lines were between 50 to 90 paces apart in the Portage area surveys, and 250 to 350 paces apart in the Lummi Bay surveys. Along each transect line a predetermined number of paces separated each sample station. The number of paces between stations in each transect line varied according to the beach slope and the overall length of the transect line. Distances between samples typically ranged from 10 - 50 paces, depending on the area. Smaller intervals than 10 – 15 paces between samples along transect lines were not possible due to limitations on the precision of the GPS unit.

At each sample station, a quadrat was established, using either a 1ft^2 PVC quadrat, or 2 $^1/_4$ ft^2 plots measured out with yardsticks and marked by surveyor flags in the corners. The size of the quadrat being used was noted at the top of each data sheet. The position of each station was determined using a hand-held Garmin GPS unit (Model 12XL), set to display decimal degrees (NAD 83), and recorded on a data sheet. The Garmin 12XL has an accuracy of $\pm$15 ft.

The top 4 - 6 inches of the substrate was excavated using various implements, such as specially sharpened, cut-down rakes. All Manila clams found in the quadrat were removed, to the best ability of each digger, as the ground was excavated and piled on a plastic bag to ensure none re-buried while the rest of the quadrat was being excavated. The longest dimension of the shells of the manila clams were then measured, to the nearest 1mm, with a pair of plastic calipers with 1mm graduations. The dimensions of each clam were recorded on a data sheet beside the GPS coordinates for that quadrat. The number of native littleneck clams (*Protothaca staminea*) and cockles (*Clinocardium nuttalli*) were also recorded for all areas except northern Lummi

Bay, but no size measurements were taken. Other clams such as Mahogany clams (*Nuttalia obscurata*), Softshell clams (*Mya arenaria*), and butter clams (*Saxidomus giganteus*) were also encountered occasionally but not recorded (except for the Brandt Island survey). This was because these clams typically live deeper in the substrate than manila clams, and more could have been present in the quadrat but not dug up.

The identification of Manila clams was primarily based on external morphology. In particular, this was accomplished using the presence of a 'scooped out' hollow found immediately posterior to the dorsal hinge. The same area in native littleneck shells usually has a small ridge extending up to the hinge and looks less 'scooped out'. Any clams that were difficult to identify using overall shell shape, and the 'scooped out hollow' characteristics, were opened up and internal shell characteristics were used (such as the purple suffusion found inside manila shells but absent in littlenecks, or the tiny ridges on the inside 'lips' of native littlenecks shells, but not manilas). All other clams were returned to the excavated holes and given the opportunity to rebury themselves.

Data Processing

GPS co-ordinates, quadrat size, and individual shell lengths were entered into a Microsoft Excel spreadsheet. Length-weight data from a WDFW Manila clam survey in Birch Bay were used to convert individual clam lengths into individual clam weights. The weights of all clams in each sample, and also legal-sized clams (≥ 38mm SL) only, were obtained. Sub-legal clam weights in each quadrat were determined by subtracting the legal clam weight for each quadrat, from the total clam weight for each quadrat. Summary information such as the number of legal clams, sublegal clams, smallest clam size, largest clam size, and average clam size, were also calculated for each quadrat. Legal clam densities for each quadrat were determined by dividing the summed weight of the legal clams in each quadrat by the area of the quadrat used.

The Excel spreadsheet was then converted into a dbf file with the following columns: latitude, longtitude, quadrat number, legal clams found, sublegal clams found, total clams found, minimum size, maximum size, average size, legal pounds per square foot, and sublegal pounds per square foot. This dbf file was imported into ESRI ArcMap 8.2 G.I.S. software and displayed using the GPS coordinates to determine the location of each quadrat. At this point, the data was overlaid with rectified and registered aerial ortho-photographs of the tidelands to check for data entry errors. The positions of any quadrats that were obviously out of their correct place were checked against the original data sheets, and corrected if a data entry error was found. If the GPS coordinate was recorded incorrectly, and data points existed on either side of the wrongly recorded data, a position midway between the two 'good' points was used, and the revised data was imported into the ArcMap GIS software. This process was done iteratively to minimize data errors. From the revised dbf file a final point shapefile was created and used as the basis of the data analysis.

Data Analysis

Because the placement of quadrats was not randomly determined, and sample density varied with area, a simple average of the combined samples could result in significant bias since clam densities also vary spatially. Consequently, spatial analysis of the data was undertaken in order to remove spatial bias in the survey layout.

To get the best estimate of clam density…

To remove spatial bias introduced by varying sample densities, the point data in the final shapefile was interpolated using the Spatial Analyst extension of ArcMap 8.2. The interpolation method used was 'kriging'. Kriging is essentially a method of calculating a 'moving average' for areas that lie between sample points and weights this average by the relative proximity of contributing samples. Therefore, samples that are closest to the location are weighted more heavily than stations that are further away. For this analysis, only the 3 nearest samples were used to predict the values for the cells in the output. The cell size used was chosen arbitrarily to be 4.5m by 4.5m. The output of this kriging interpolation was a rectangular raster grid with predicted values for each 4.5m x 4.5m square across the surveyed area.

Because the interpolation process creates a rectangular area with dimensions equal to the full horizontal and vertical extent of the survey data, there were areas within the grid that were outside of the area that was surveyed. To remove these, it was necessary to create another raster data set (surveyarea) that only had cells within the survey area.

To do this, a polygon shapefile was created within ArcMap that connected up all the end points of the transect lines, and formed a polygon enclosing the surveyed area. The 'snapping' feature of the shapefile editor was used to get the best possible accuracy. Another polygon shapefile was also created that detailed river channel areas based on rectified and registered ortho-photographs. The river channel areas were then erased from the survey area polygon using the Xtools extension. This resulting polygon shapefile was then converted into a raster grid using the spatial analyst 'convert feature to raster' function. The same cell sizes were used as in the kriging raster, and all cells were assigned a zero value.

When the raster calculator function in spatial analyst is used to add the kriging grid to the survey area grid, only the cells common to both raster grids are retained. Thus, the kriging raster was trimmed down to include only the cells within the boundaries of the survey, and since the values of the survey area grid were zero, the values of the cells in the final grid were those of the kriging raster only.

Once the kriging raster had been trimmed down, the individual cells could be thought of as a grid of separate 4.5m x 4.5m quadrats covering the entire survey area with associated clam density estimates for each. Consequently, the average value of all the cells throughout the survey area represents a spatially *unbiased* estimate of the true population density. By creating several raster grids to represent the extent of each management area, and also for the open or closed harvest areas, it was possible to subdivide the overall kriged raster into different sub-areas, and obtain separate estimates for each area of interest.

To calculate the area covered by the survey…

The polygon shapefiles created to generate the raster grids of the survey areas were retained, and the Xtools extension in ArcMap was used to calculate the dimension of each polygon in acres, and also in square feet.

To calculate the final legal clam biomass…

The final legal clam biomass in each area was determined by simply multiplying the average kriged estimate of clam density (lbs/ft^2) by the square feet of that area (ft^2).

Precision of the estimate

Although I understand that it is possible to calculate an estimate of precision for kriging, I do not have the expertise, or access to the necessary software, to undertake this process. Consequently, I can offer no meaningful estimate of precision for the biomass estimates. However, I can still calculate the statistical precision of each estimate using the sample variance of the quadrats within each area, as with any normal sample estimate. The relevance of the resulting precision estimates to the kriged estimate of average clam density is unknown, but they are presented along with the results for whatever they are worth.

In addition, I should note that, despite that larger quadrat size used in many of the areas (2 ¼ ft^2, 9 ft^2, etc), none of the precision estimates have 25% or fewer 'zero' values in the data that produced them. This is one of the fundamental assumptions that underpin the validity of this statistic. Consequently, the estimates of precision in this survey have no theoretical 'validity' even when applied to the sample estimate of average clam density. This is not an unusual circumstance for clam surveys, however. I can say with some certainty that none of my predecessor's precision estimates for any of his surveys met with this requirement, and I would be surprised if it is met in any of the state surveys since they use 1ft^2 sample stations in their surveys. This raises the question whether or not the WDFW 'precision' target of $\pm$30% for survey data really means anything at all.

Determining Production Rates

Size frequency data for the clams from each management area were compiled and assumed to represent an unbiased size-frequency 'snapshot' of the population in each area. The individual weights of clams in each 1mm size increment were put in a column beside the size-frequency data, and the collective weight of all individuals within that size increment was calculated in the next column. The cumulative weight of individuals 38mm or larger was divided by the total area sampled in that management area to provide a sample estimate of legal clam density. This sample estimate was corrected for spatial bias by dividing the sample estimate of clam density by the kriged estimate of clam density for that area.

Because some clams die from natural mortality, and the surviving clams will each grow in size during the following year, the 'population' represented by each size-frequency distribution was 'grown out' using the spreadsheet. To do this it was necessary to make some predictions about growth rates and natural mortality rates.

I used annual survivorship rates of 64% for all sublegal clams (i.e., 32 - 37 mm) and 84% for all legal clams (i.e. 38 mm or larger). The estimate of natural survivorship for legal clams is a WDFW estimate; the lower 64% value is an arbitrary one that my predecessor used, since he felt that sublegal clam survival would be somewhat lower than the 84% rate. Since only clams 32mm or larger are likely to reach legal size, the 64% value may be somewhat conservative as used to predict recruitment of sublegal clams into the fishery.

Annual growth rates used are described by the following equation:

$$\text{Size Increase (mm)} = -6.0433 * \ln(\text{Current Size (mm)}) + 26.921$$

This equation is derived from a subjective interpretation of cohorts in size-frequency data from the 2002 survey of Lummi Bay. Each cohort was assumed to represent a year class. The resulting growth rate is shown in Figure 2 where it is presented compared to Manila clam growth rates derived from the available literature. Clearly, the growth rates used in the spreadsheet are well within the range of rates published in scientific journals. It is to be expected that the Lummi rates are lower than those for Hartstene Island since south Puget Sound growth rates are typically higher than north Puget Sound growth rates.

By predicting the growth of clams in each size increment, and the reduced frequency of clams after natural mortality, it is possible to recalculate the collective weight of clams in each size increment for the following year. The cumulative weight of all size increments that had reached 38mm or above, rounded to the nearest mm, was divided by the sampled area to predict the legal sample density for next year. The predicted sample estimate was corrected for spatial bias by factoring in the kriged estimate of clam density divided by the original sample estimate. This assumes that population distribution patterns are persistent from year to year. Next year's legal biomass could then be predicted by multiplying next year's calculated clam density by the survey area. The difference between the predicted legal clam biomass for next year and the estimate for this year is the total amount of new biomass produced. It was also possible to break this total down into new biomass from recruitment to legal size, and to biomass resulting from the growth of existing legal clams, by using the cumulative sums of the relevant size increments.

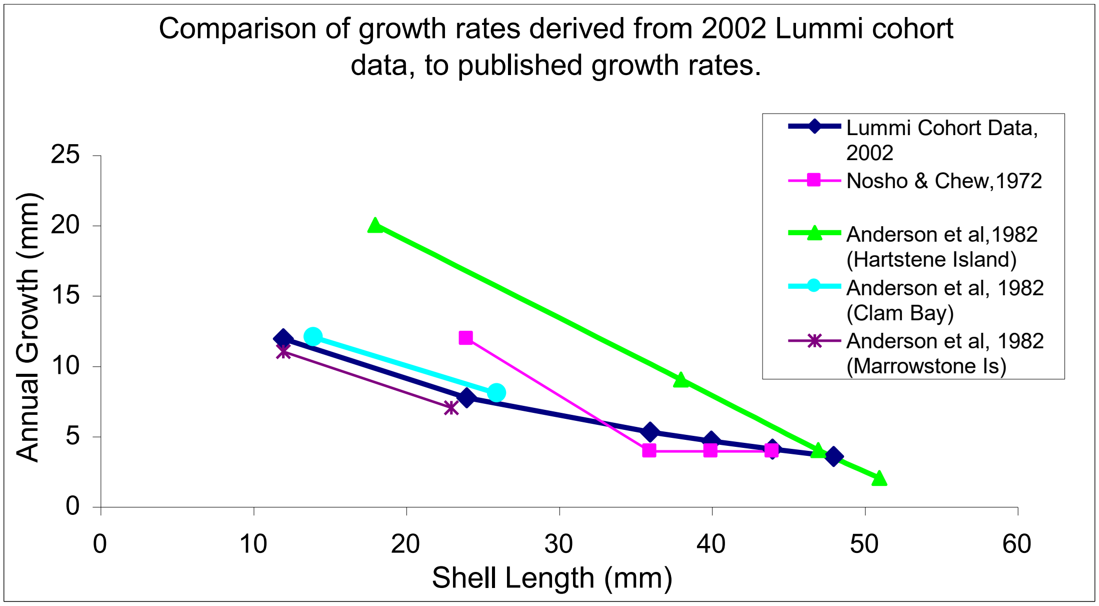

Figure 2. Comparison of the Lummi growth rates, used to predict the future growth of clams, to growth rates available in the scientific literature.

Results

789 survey stations across an area of 171 Acres were sampled between May and September in Portage Bay. 583 survey stations were sampled between June and August in Lummi Bay. Portage survey stations used either 1ft^2 or 2 ¼ ft^2 quadrat sizes. Lummi Bay survey stations used 9 ft^2 quadrats only. Table II summarizes the details of the survey, by management area and status, and Figure 3 shows the location of each station.

Table II. Summary of 2002 survey results, broken down by management area.

Portage Bay								
Area Description	**Survey Stations**	**Individual Station Areas (ft^2)**	**Acres surveyed**	**lbs/ft^2**	**statistical precision* of estimate**	**lower 95% biomass estimate***	**mean biomass estimate**	**upper 95% biomass estimate***
S5	**176**	**2.25**	32.88	0.0669	27.8%	69,146	**95,818**	122,490
S5A	**28**	**2.25**	1.77	0.0293	104.5%	0	**2,259**	4,620
S4 (open)	**31**	**2.25**	5.2	0.0059	113.9%	0	**1,336**	2,858
S4 (closed)	**165**	**2.25**	32.64	0.0181	38.7%	15,774	**25,735**	35,695
S7E (closed)	**152**	**1**	41.23	0.0300	33.3%	35,938	**53,880****	71,821
S7D (closed)	**70**	**1**	13.6	0.0674	40.3%	23,820	**39,929****	56,038
S7D (open)	**167**	**1**	44.1	0.0562	35.3%	69,830	**107,960**	146,091
Open Areas Pooled	**402**	**-**	83.95	0.0561	26.94%	149,889	**205,151**	260,412
Closed Areas Pooled	**387**	**-**	87.47	0.0314	22.35%	92,898	**119,641****	146,383
All Combined	**789**	**1,289**	171.42	0.0436	15.95%	273,636	**325,565**	377,493
Lummi Bay								
Area Description	**Survey Stations**	**Individual Station Areas (ft^2)**	**Acres surveyed**	**lbs/ft^2**	**statistical precision* of estimate**	**lower 95% biomass estimate***	**mean biomass estimate**	**upper 95% biomass estimate***
S1B	**141**	**9**	314.7	0.0144	23.3%	151,407	**197,401**	243,395
S1C	**190**	**9**	557.75	0.0119	18%	237,075	**289,116**	341,157
S1D & S1E	**252**	**9**	977.49	0.0140	19.7%	478,680	**596,115**	713,550
All Combined	**583**	**5,247**	1849.94	0.0134	11.9%	953,799	**1,082,632**	1,211,465

* Precision estimates used are those calculated for the spatially ‘biased’ sample estimates from the stations within the indicated area, not for the spatially unbiased kriged estimate of clam density within that area. See methods for fuller discussion of this parameter.
**biomass estimates presented here for the closed portions of S7D and S7E do not include any clam biomass from unsurveyed portions of those areas. See Table IV for projections for unsurveyed portions of the two areas.

Figure 4 shows the kriged estimate of legal clam density throughout the surveyed areas for Portage beaches and Figure 5 shows the kriged estimate of legal clam density for Lummi Bay. Areas that are colored dark red-brown represent the highest clam densities, and progressively lighter shadings of yellow show progressively lower densities. Areas without any shading within the survey boundaries have negligible clam densities (<0.0035 lbs/ft^2). The color shadings used in Figures 4 & 5 are not directly comparable because the range of densities differs in the two areas (see legends for comparison of ranges used). For a direct comparison of densities in the two areas, on the same color and spatial scales, I have included a figure (A1) in the appendices that uses a lower resolution grid (due to computational limitations).

Expected clam densities were as high as c 0.4 lbs/ft^2 at some Portage beaches (S7D (Brandt Flats) and Portage Spit (S5)) but only 0.09 lbs/ft2 in the best parts of Lummi Bay. Likewise, the average density was 0.0436 lbs/ft^2 for the combined Portage beaches, compared with only 0.0134 lbs/ft^2 for Lummi Bay. In general, clam densities in Lummi Bay are approximately one third of those in Portage Bay.

Average clam densities were highest in Portage Spit (S5; 0.0669lbs/ft^2) and Brandt Flats (S7D; 0.0588 lbs/ft^2), followed by Brandt Island (S7E; 0.0300 lbs/ft^2), S5A (0.0293 lbs/ft^2), S4 (Lummi Shore Road; 0.0164 lbs/ft^2), S1B (0.0144 lbs/ft^2), S1D&E (0.0140 lbs/ft^2), and finally S1C (0.0119 lbs/ft^2).

Clam densities were typically higher in the closed portions of S7D (0.0674lbs/ft^2) than the open portion (0.0562lbs/ft^2), and likewise for the closed portion of S4 (0.0181 lbs/ft^2) compared to the open portion of S4 (0.0059 lbs/ft^2). Despite this, the overall clam densities in all closed areas combined (0.0314 lbs/ft^2) was lower than the open areas combined (0.0561 lbs/ft^2), in part due to the very small portion of S4 that remains open.

Biomass estimates for each surveyed area, broken down by open/closed status, are provided in Table II. In terms of the amount of legal biomass, the most significant areas, in descending order of importance, are S1D&E, S1C, S1B, S7D, S5, S7E, S4, and lastly S5A. The large amount of biomass in the low-density, Lummi Bay beaches is due to the very large area of the tidelands in Lummi Bay.

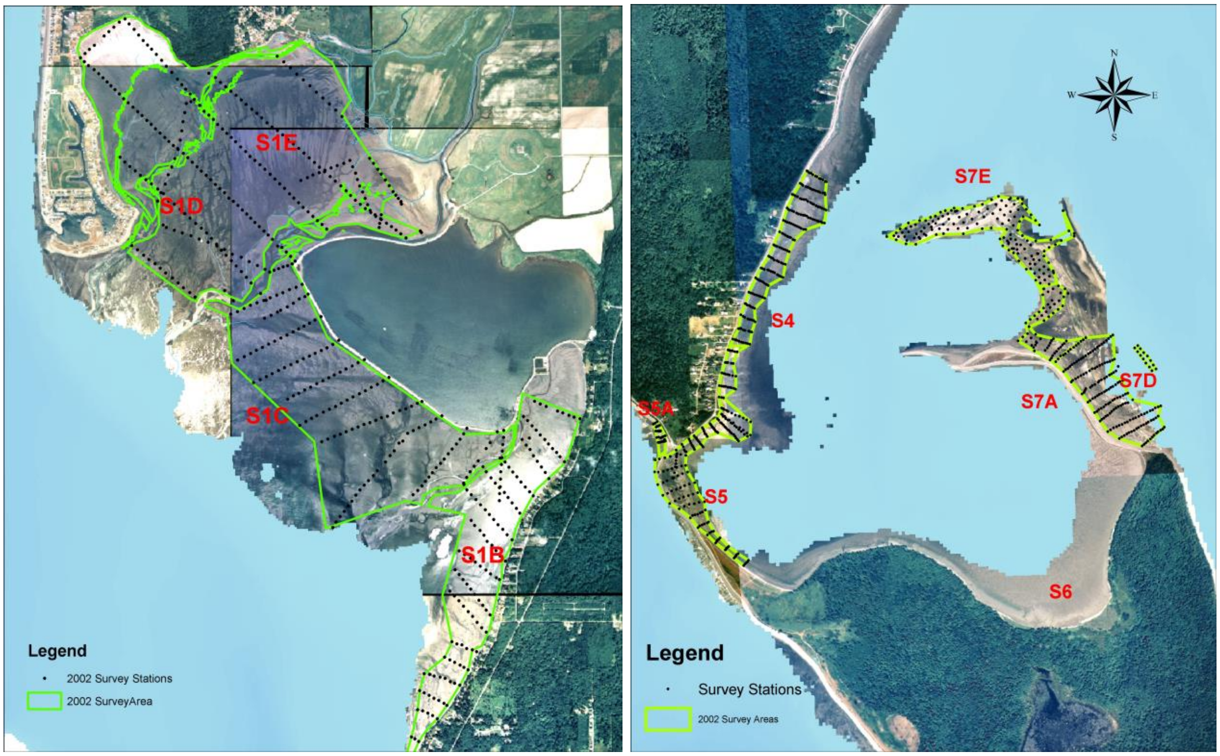

Figure 3. Location of 583 sample stations in Lummi Bay, and 789 sample stations in Portage Bay the 2002 Manila clam survey.

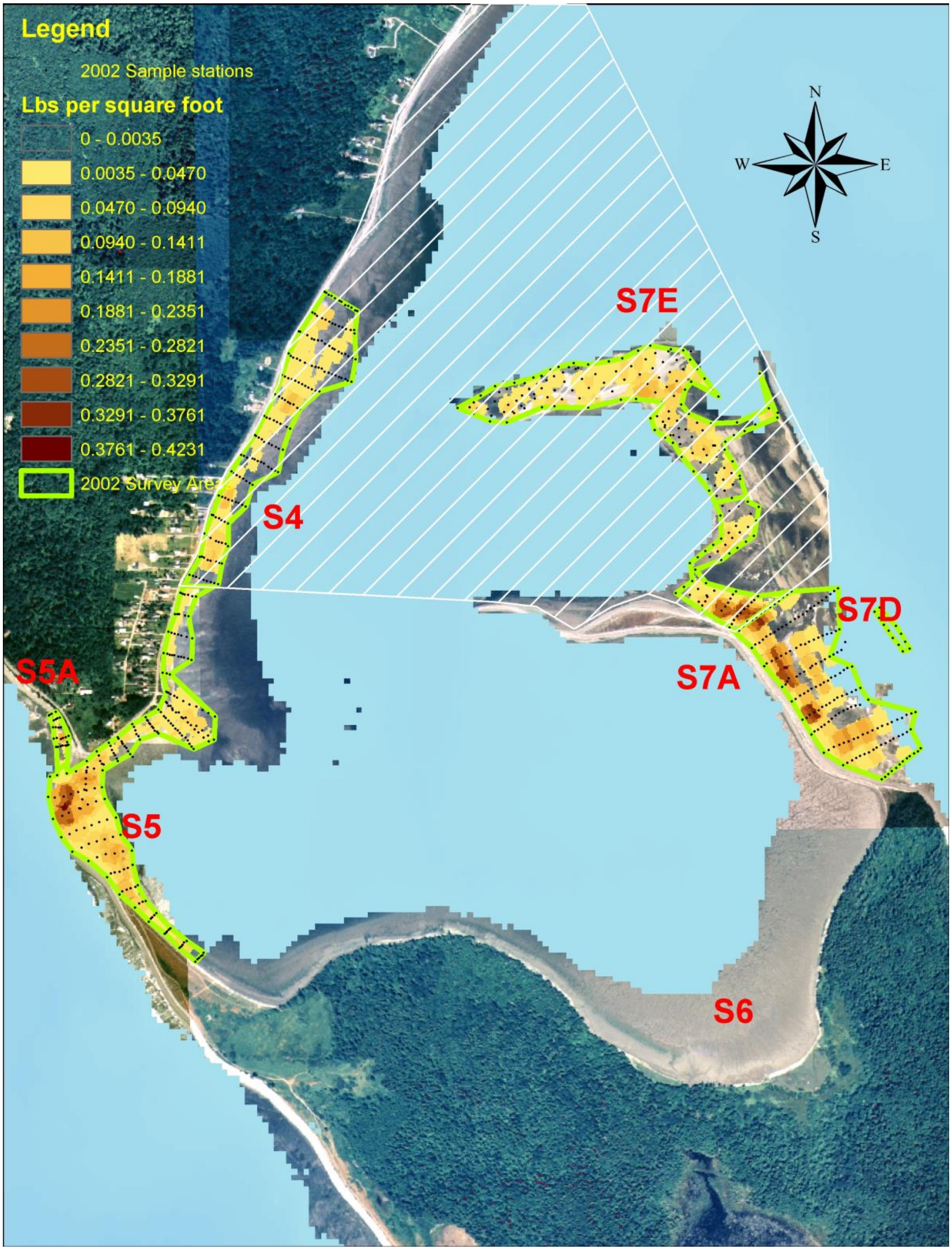

Figure 4. Kriging estimate of legal pound density in Portage area (white shaded area shows the areas closed due to excessive fecal coliforms)

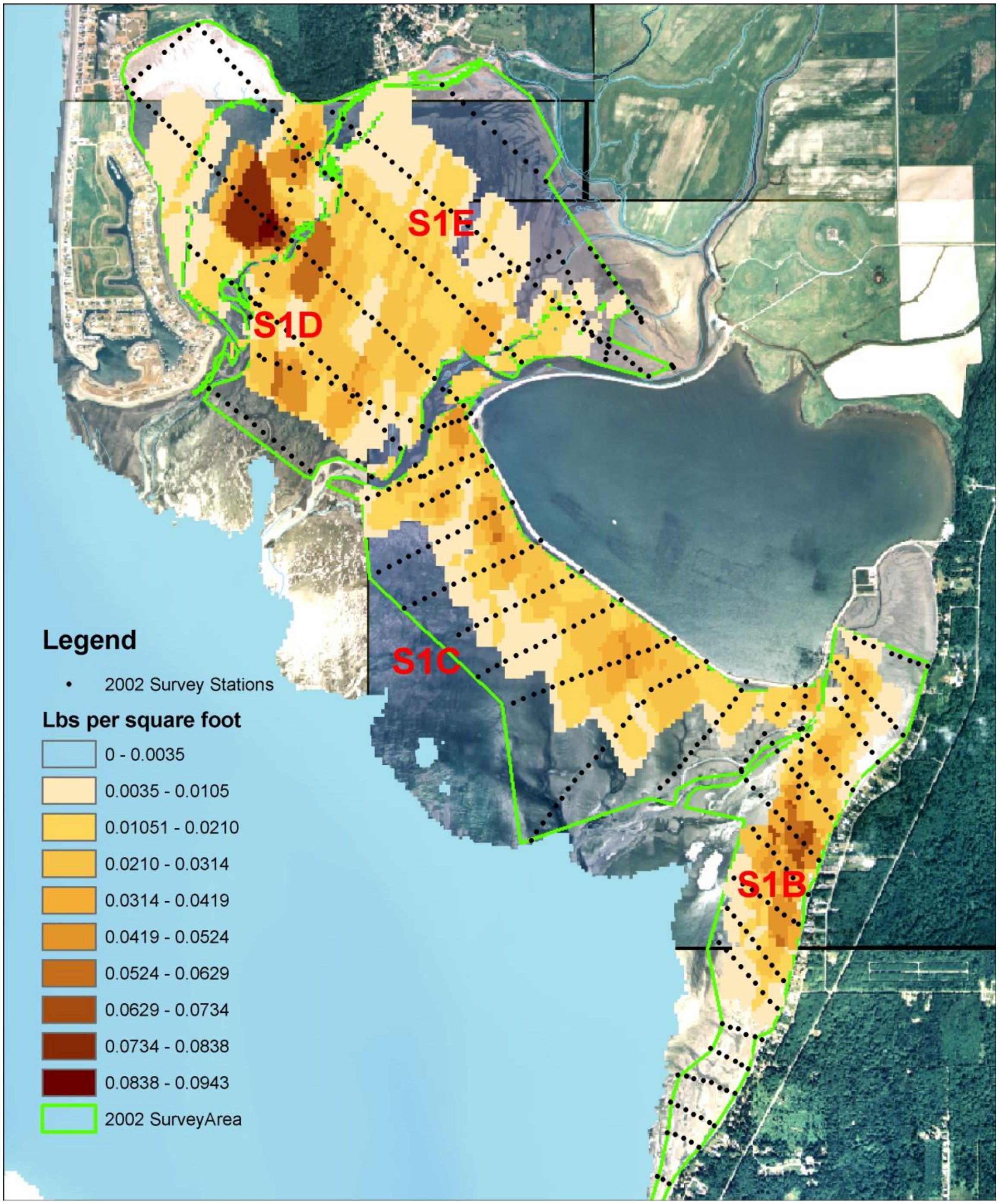

Figure 5. Kriging estimate of legal pound density in Lummi Bay.

Productivity Estimates

Table III summarizes the expected biomass production in each management area. The highest production rate is predicted to occur at Portage Spit (S5) where annual production of new, legal biomass is expected to be 51% of the starting legal biomass. In comparison, production rates in S4, S5A, S7D, and S7E range between 24 and 30%, and Lummi Bay beaches have estimated production rates of only 12.5 to 17%.

For the closed portions of S4, S7D, and all of S7E, the average production rates are 30.9%, 28.4%, and 24.1% respectively. There is c.119,641 legal lbs in the surveyed portion of the closed area (Table II), and a further 26,798 legal lbs is projected to occur in 9.7 unsurveyed acres of S7E, and 6.4 unsurveyed acres of S7D. (Obtained by extrapolating the average densities of the closed portions of S7D and S7E to the unsurveyed portions of those areas, see Table IV). Assuming that the areas were to be harvested at the same rate as new biomass is produced, we could expect to harvest 39,342 lbs from the prohibited area in the coming season. At $1.50 per pound, this would have a value of $59,013.00.

Table III. *Estimated production from management areas in Portage and Lummi Bay.*

Area	2002 Biomass (lbs)	New Legal Clams in 2003 (lbs)	Growth of Existing Legal Clams (lbs)	Total New Biomass Produced (lbs)	New Biomass relative to 2002 Biomass	Recruitment :Growth ratio
Portage Bay						
21A-S4	**27,071**	6,953	1,418	**8,371**	30.9%	4.9
21A-S5	**95,818**	43,169	6,531	**49,701**	51.9%	6.6
20A-S5A	**2,259**	471	73	**544**	24.1%	6.5
21A-S7D*	**147,890***	34,997*	7,004*	**42,001***	28.4%	5.0
21A-S7E*	**53,880***	10,631*	2,365*	**12,996***	24.1%	4.5
Total	324,555	95,625	17,272	113,613*	34.8%	5.5
Lummi Bay						
20A-S1B*	**197,401***	26,306*	7,471*	**33,777***	17.1%	3.5
20A-S1C	**289,116**	34,276	1,903	**36,179**	12.5%	18.0
20A-S1D&E	**596,115**	82,755	17,257	**100,012**	16.8%	4.8
Total	1,082,632	143,337	26,631	169,968*	15.7%	5.4

* Estimates exclude any biomass in unsurveyed areas. See Table V for projections for unsurveyed portions of S7D & S7E.

Table IV. *Breakdown of proposed harvest amounts for Portage beaches, including projections for unsurveyed portions of S7D and S7E.*

Area Description	Biomass	Production Rate	Harvest Amount
S4 (open)	1,336	30.9%	413
S4 (closed)	25,735	30.9%	7,952
S5 (open)	95,818	51.9%	49,730
S5A (open)	2,259	24.1%	544
S7D (surveyed, closed)	39,929	28.4%	11,340
S7D (projected, closed)	14,122	28.4%	4,011
S7D (open)	107,960	28.4%	30,661
S7E (surveyed, closed)	53,880	24.1%	12,985
S7E (projected, closed)	12,676	24.1%	3,055
		Open Areas Total	**81,348**
		Closed Areas Total	**39,342**
		Overall	**120,690**

Recruitment Patterns

Figures 6 and 7 shows the distribution of sublegal clam densities and sublegal pounds for the surveyed beaches. Once again, the color shadings for Figure 6 do not represent the same densities as Figure 7. Darker shades represent higher densities of clams/pounds. Please note that the legend for Figure 7 (Lummi Bay) uses clams/pounds per square *yard* while the legend for Figure 6 uses clams/pounds per square *foot*.

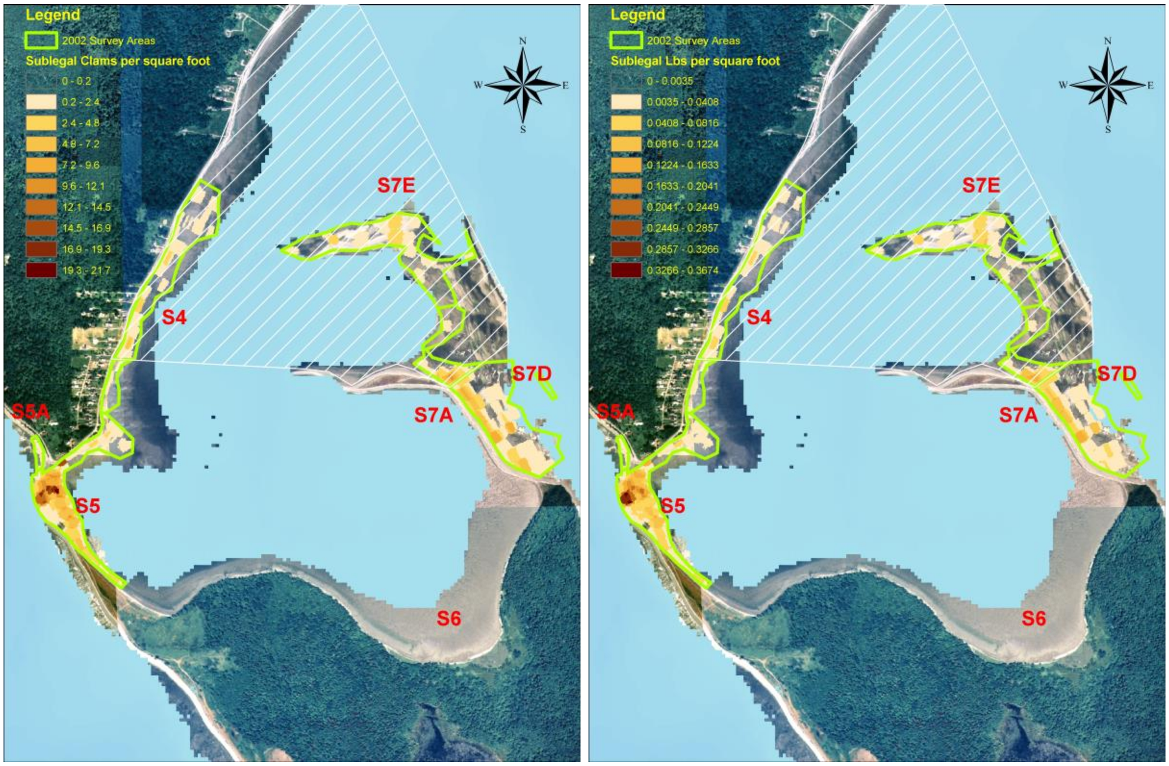

Figure 6. Distribution of *A*. sublegal clams and *B*. sublegal pounds at Portage beaches.

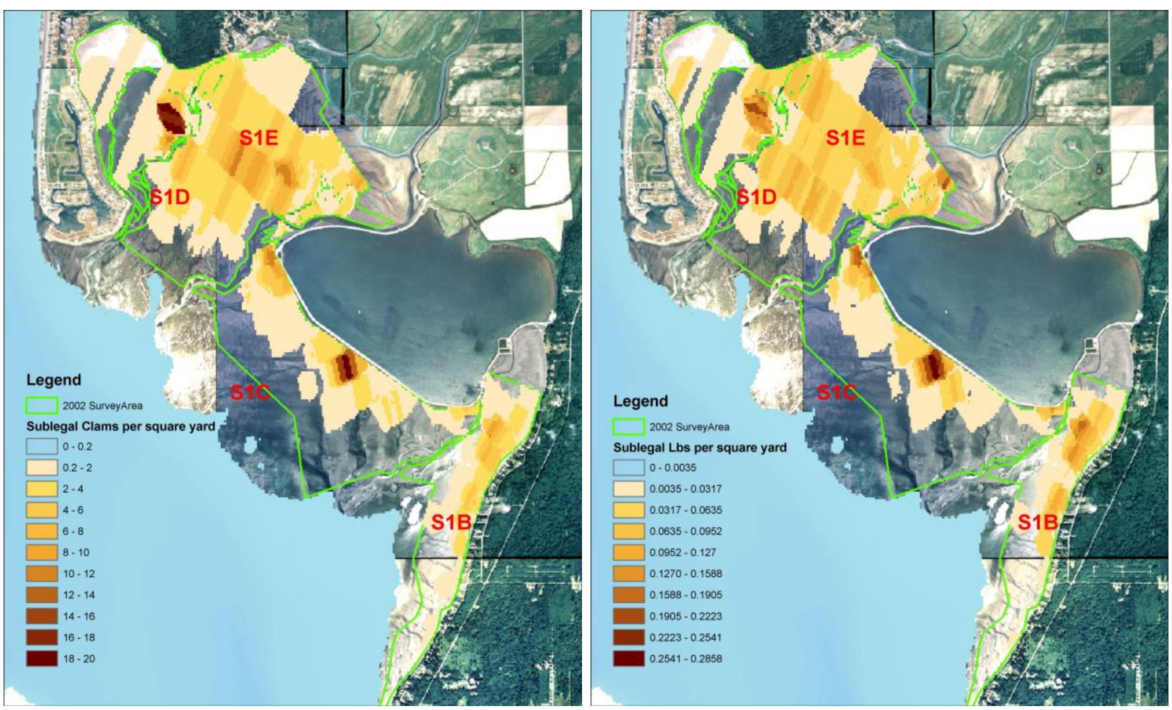

Figure 7. Distribution of *A.* sublegal clams and *B*. sublegal pounds per square yard in Lummi Bay.

Discussion

Clam Densities

Portage Spit (S5) and Brandt Flats (S7D) have the best densities of legal clams found on any reservation beach this year. The area of very high clam density in Portage Spit coincides with a large area of overlaying mussels and barnacles, which is exposed to good water flow across the spit at high tide. It is possible that the thick matrix of mussels and barnacles etc provide protection from predators such as Dungeness crabs and seagulls. Similarly, an overlying layer of embedded cobbles may also serve as a protective feature across the high-density portion of Brandt Flats.

Outside of these two areas, clam densities are comparatively sparse. On average, however, legal clam densities in Portage are 3 ¼ times the average density of legal clams in Lummi Bay. However, the Lummi Bay tidelands are more than 10 times the area of the Portage beaches and consequently the most significant quantities of clams are present there: albeit at much lower densities.

The spatial distribution of legal size clams (Figs. 4&5) is very similar to that of sublegal clams (Figs. 6&7), suggesting that the population distributions are likely to be persistent for the foreseeable future. The largest difference in the two distributions can be most easily seen in Lummi Bay. Here it appears that sublegal clams are seldom found in quantity in the lower reaches of the intertidal even though there appears to be moderate amounts of legal size clam biomass in those areas. This is the result of the presence of some very old, large clams in the eelgrass beds. If there is no significant larval settlement in the area, then this could suggest that these clams have migrated down the shore over time as their size increased and their risk of predation from crabs decreased. Alternatively, larval recruitment in these areas could simply be more infrequent, and/or less intensive, compared to higher up the shore. If so, then clams in these areas could only sustain low harvest rates compared to areas further up the shore. Regardless of the cause, it is likely that these large, old clams play an important role in production of larvae. Given that these areas will be unable to sustain intense harvest, I would recommend not permitting harvest within the areas of dense eelgrass beds.

It isn’t surprising that many diggers prefer to be harvesting at Portage beaches rather than Lummi Bay since clam densities at Portage are much higher, and they would have to dig up less ground in Portage to obtain the same amount of clams. Offsetting the lower density at Lummi Bay, though, is the somewhat easier digging conditions found there. Digging conditions can be much more difficult in many portions of Portage due to the presence of cobbles, gravel, and sometimes thick overlying matrices of mussels and barnacles.

Production Rates

Overall, Portage bay beaches produce new biomass more rapidly than Lummi Bay beaches (Table III). One reason for this could be that food availability is better in Bellingham Bay, where the Nooksack River has a strong influence. Alternatively, water circulation patterns may be responsible for the higher production by collecting and holding larvae in the Portage area.

Portage Spit, in particular, has an extremely high production rate (51.9%). The information from this survey supports the idea that Portage Spit is acting as a 'sink' for larvae sourced from areas that lie 'upstream'. Dye studies have shown that water tends to move from Portage Bay across the spit, and into Hale Passage during the flood tide (Meriwether, 2001). It is likely that some of the larvae produced in the Brandt Island/Brandt Flat areas are concentrated in Portage Bay during the tidal cycle, and then rapidly settle out on Portage Spit as the water starts spilling across during the flood tide.

Harvesting only as much biomass as will be produced avoids continually reducing clam densities. However, this does not constitute an estimate of maximum sustainable yield. By reducing the number of adult clams there is some thought that more larvae would survive the settlement process, because they are less likely to be filtered out of the water by an adult. Also, turning over the ground is thought by some to help the small clams get settled in. However, larval clams also exhibit an active preference for beaches that have large numbers of adult clams, and recruitment rates for some hardshell clams have been shown to decline with reduced adult densities, and this is thought to have prevented recovery even after fishing operations have been ceased (Peterson, 2002). Consequently, it is difficult to say whether harvesting clams will result in increased, or reduced, recruitment rates without a lot more information than I have available. Unfortunately, stock-recruitment relationships for Manila clams are not known, and even if they were, they would probably depend strongly on local factors such as water currents, substrate type, and the proximity and location of nearby clam populations, etc. Without very specific information to determine likely estimates for maximum sustainable yield I propose that we limit annual harvest rates to no more than the expected production of new biomass, so that we do not reduce stock densities year after year. In some cases, particularly S1C in Lummi Bay I would go further and recommend harvesting less than the estimated production rate in order to restore clam densities to higher levels.

For Portage Beaches, I would recommend we aim to cap the harvest amounts for the upcoming season to those given in Table IV. Unfortunately, we will be unable to harvest the 39,342 lbs. produced in the closed portions of Portage.

Survey Design

Traditionally, sampling bias has been avoided by attempting to either systematically sample (so that each sample represents the same amount of area as any other sample) or randomly sample throughout the area. This survey employed a pseudo-systematic survey design, and relies on spatial analysis to quantify and remove spatial bias in the data.

Random sampling theory relies on the theorem of central tendency to assure that the results are not biased over time. In essence, this says that over infinite random surveys, as long as the variable being estimated doesn't change, the average of the survey results will be the same as that variable being estimated (i.e., average population clam density). However, since there is usually only one survey conducted per year, and clam densities vary from year to year, the theorem of central tendency hardly applies. In any given survey, randomly placed quadrats could very easily create a biased result. Consequently, systematic surveys are generally preferred.

Systematically sampling potentially risks confounding due to unrecognized systematic variation in the measured variable (in this case the variable is clam densities). However, this is usually only a minor concern in practice. Likewise, statistical description of data is based on an assumption that the data was collected randomly. Strictly speaking, parametric estimates of sample 'precision' are not theoretically valid for systematically collected data. However, applied ecologists have found that this theoretical consideration seldom makes any difference, and the use of parametric statistics to analyze systematically collected data is commonplace.

The main problem with truly systematic data collection is that it is logistically difficult to detect changes in population densities on small scales without also massively increasing the number of sample stations required over areas where fewer samples would suffice. For example, clam populations are known to vary with the height of the shore. Beaches with wide, nearly flat topography do not change height very fast compared to narrower, steeply sloping beaches. Steep, narrow beaches are therefore likely to require more samples per unit area to detect the change in clam distribution with shore height. So if you are sampling across a large area, with both broad flat expanses as well as steep narrow beaches, you will need to sample according to the requirements of the steep narrow beaches. In a systematic survey, this means sampling across the broad flat expanses at the same intensity as for the steep beaches, and this will increase the number of samples needed by a very large amount. The tradeoff between sampling intensity and the size of the final surveyed area is a common issue in fishery science. Although it is possible to make a case for both approaches, Hilborn & Walters (1992) stated that they felt it is the lesser of two evils to sample diffusely across a large area rather than sample intensively in a smaller area. Consequently, it is necessary to find some means by which very large beaches can be sampled and to maximize the value of the samples within that area

Ideally, it would be most efficient to vary sampling intensity along with known gradients that affect the parameter of interest, such as when the slope of beaches changes in different parts of a surveyed area. This would allow sampling intensity to increase when the clam distributions is likely to change over a small scale, and to decrease the sampling intensity when shore-height related changes in clam distribution are less likely. Unfortunately, until the advent of spatial analysis, spatial bias that arises when sampling intensity varies spatially could not be removed. However, the recent availability of reliable field positioning systems (GPS) and spatial analysis tools (such as GIS) has removed this impediment.

Table VI. *Direct comparison of the spatially unbiased kriging estimate versus the spatially biased sample estimate of clam density using unmodified sample station results.*

Portage Bay	(Spatially unbiased) Kriging Estimate (lbs/ft^2)	(Spatially biased) Sample Estimate (lbs/ft^2)	Sample Estimate Bias
S5	0.0669	0.0449	-32.9%
S5A	0.0293	0.0273	-6.8%
S4 (open)	0.0059	0.0055	-6.7%
S4 (closed)	0.0181	0.0152	-15.8%
S7E (closed)	0.0300	0.0269	-10.3%
S7D (closed)	0.0674	0.0652	-3.3%
S7D (open)	0.0562	0.0445	-20.7%
Lummi Bay			
S1B	0.01440	0.01141	-20.8%
S1C	0.01190	0.01201	+0.9%
S1D&E	0.01400	0.01207	-13.8%

Table V shows the difference between the spatially unbiased (kriged) estimates and the raw sample estimates for each area. The raw sample estimate for S5 would have underestimated the overall clam density by 33% because relatively fewer samples per unit area were taken in the densest part of the clam bed compared to the number of samples taken in lower density areas. The least biased sample estimate would have been the sample estimate for S1C in Lummi bay, which would have only overestimated the average clam density by around 1%. Generally speaking, most raw sample estimates would have underestimated the final clam densities by 5-20%. The need to scope out the full geographical extent of the clam population, to define patterns of distribution at varying spatial scales, and logistical limitations in staffing and daylight tides, made spatial bias in the survey design unavoidable. Spatial analysis is indispensable for analyzing data from surveys of sessile organisms where sampling intensity varies spatially.

Kriging has been shown to be preferable to linear interpolation in explaining patterns of clam distribution on sandy beaches (Defeo & Rueda, 2002). Moreover, when model-based (kriging) estimates of clam abundance and distribution have been directly compared with design-based (stratified random sampling), it was found that stratified random designs underestimated abundance compared to model-based estimates (Defeo & Rueda, 2002). This was attributed to imperfect a-priori assumptions about the range and extent of the distribution of the target population. As a consequence, Defeo & Rueda concluded:

> *"1) geostatistics* (kriging) *provides useful additional information about population structure and aids in direct abundance estimation; thus we suggest it is a powerful tool for further applications in the study of sandy beach infauna; … 2) environmentally driven sampling strategies fail to provide conclusive results about population structure and abundance, and should be avoided in studies of sandy beach populations"*

While it is, of course, still preferable to have truly systematic sampling across the whole area, at the intensity required for detecting changes on a small scale, it is not logistically possible to achieve this when sampling across beaches that are several hundred acres. For example, using a sampling intensity of 11 quadrats per Acre, as outlined in the WDFW protocol, would have meant that 22,235 1ft^2 quadrats would have been needed to adequately cover the area. By comparison, only 1,372 samples were taken in this survey with a total area excavated being 6,536 ft^2 (because of larger quadrat sizes). The logistical problems with sampling large beaches are acknowledged in the WDFW protocol that accepts that sampling intensity necessarily declines on beaches larger than 10 Acres.

The ability to vary sampling intensity spatially, without introducing spatial bias, allows sample distribution to be tailored to the geomorphology of the survey area without imposing insurmountable logistical considerations that would otherwise be required to systematically sample at the resolution appropriate for detecting changes at the smallest likely spatial scale.

As with all surveys, those analyzed using kriging and other interpolation techniques, assume that all samples are representative of the surrounding area. However, this assumption takes on added importance for spatial analyses compared to non-spatial analyses (e.g., arithmetic mean of systematic samples). This is because the position of a sample is almost as important as the value of that sample. In other words, a zero sample in an area of actually high abundance will potentially distort the pattern of distribution, as well as reduce the final estimate of average density. In contrast, systematic sampling and random sampling assumes that samples will be taken in direct proportion to the relative frequency at which the sampled microhabitat occurs in the survey area. In this instance, a zero in an area that is typically high density is likely to be remedied by the probability of sampling that niche habitat.

The most obvious remedy to avoid potentially non-representative samples is to increase the size of the sampling unit (thereby integrating more small-scale variability). This also has the advantage of reducing sample error associated with edge effects, such as the sides of holes collapsing and introducing clams from outside the quadrat area into the sample. This was identified as the foremost difficulty with clam surveying in the WDFW clam surveying protocol that uses 1ft^2

sample sizes. Another solution to reducing the impact of non-representative samples is to increase the sampling intensity so that the area represented by each sample is decreased. Of course, on large beaches this is a logistical constraint that is unavoidable.

Undoubtedly the lower sampling intensity used in the Lummi Bay and Portage surveys, compared to the Defeo & Rueda study, will increase the risk of small scale error in the estimated pattern of clam distribution. However, I have used the largest sample size that I considered logistically achievable depending on the nature of the substrate, and the personnel available. All samples in Lummi Bay were 9ft^2, and samples in Portage were either 2.25 ft^2 or 1ft^2. This compares to the 0.672 ft^2 sample size used in Defeo & Rueda (2002). It is assumed that the larger sample unit areas will compensate somewhat for the overall reduction in sampling intensity. Moreover, with the exception of the small open portion of S4, and S5A, the statistical precision obtained for beaches in this survey (Table II) was typically within, or better than, the target range of 20 – 40% that WDFW aims for (Campbell, 1996). However, I reiterate that the precision estimates relate to the spatially biased sample estimate, not the spatially unbiased estimate obtained through kriging. Even so, the results suggest that the survey results are comparable in precision to the WDFW survey protocol despite having to cover a much larger area with far fewer samples per acre. The added ability to produce graphical representations of the clam beds, and to cover much larger areas with relatively less effort, represent significant advances over the WDFW methodology.

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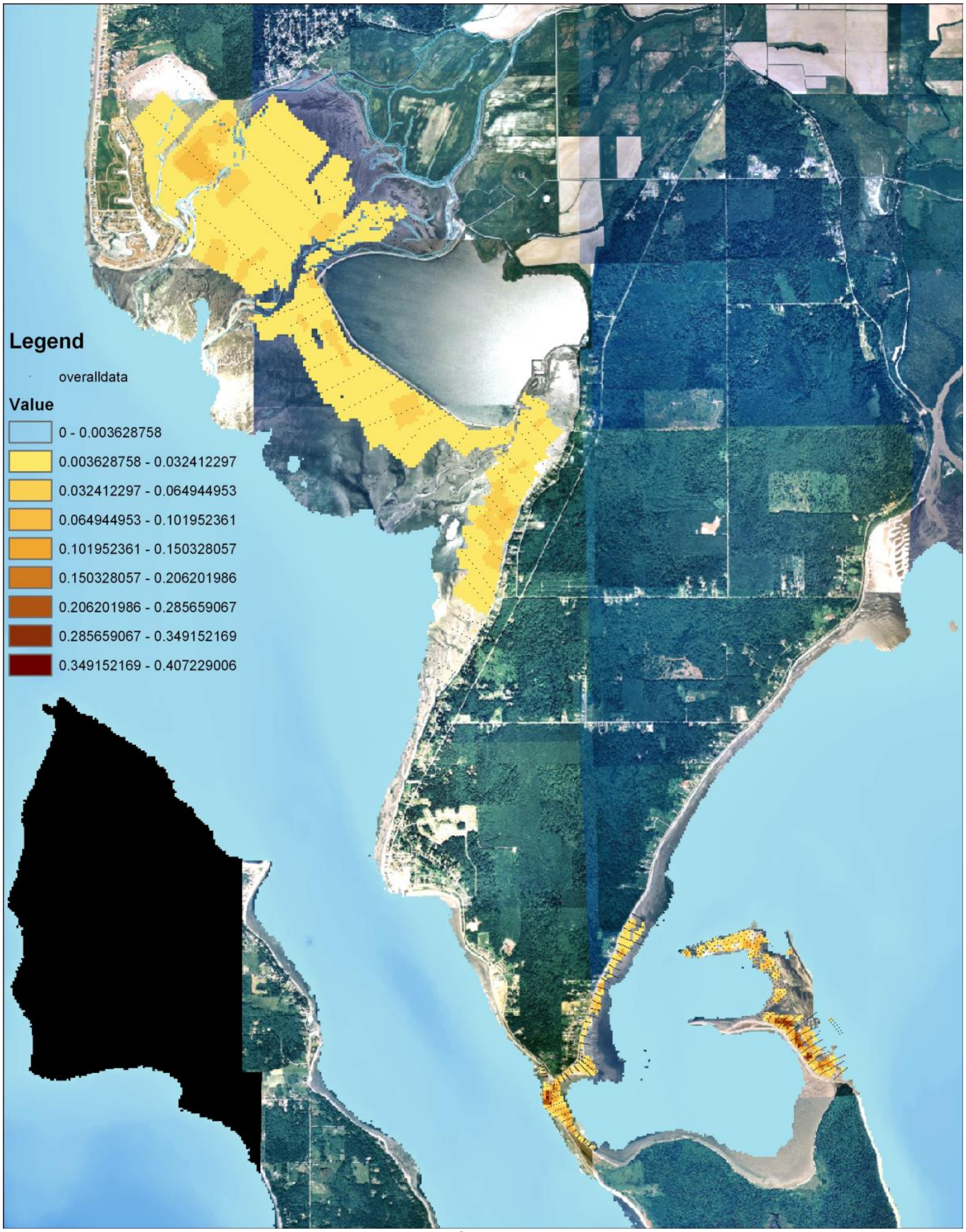

Figure A1. Legal clam densities (lbs/ft^2) in surveyed areas.