2010 Lummi Clam Survey Summary

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LUMMI NATION

TREATY OF 1855

Executive Summary

In 2010 Lummi Natural Resources contracted with Wilbert LeClair to survey clam densities on several important reservation beaches. A total of 2,424 samples were dug, which was equivalent to 12,008 square feet. Legal biomass estimates for Lummi Bay was 792,449 lbs, and for Portage Bay was 103,732 lbs. These results show a large decline in clam abundance since the last stock assessment survey was conducted in 2008. Likely causes for the decline include recent over-harvest, along with suspicions that a winter-kill event occurred in Portage Bay during the winter of the 2008—2009 season.

Recommended harvest levels would provide 159,781 lbs of harvest in the coming season. This compares to last year's harvest of 284,103 lbs for the same beaches. However, these figures do not include any harvest taken from Lummi Shore Road (S4), Inside Portage Bay (S6), or Inside Brant Point (S7A).

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Introduction

General 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).

In the early 1990's (1989-1995) the fishery was primarily based out of Portage Bay and Semiahmoo harvest areas. As harvest areas in Semiahmoo were closed due to fecal coliform contamination, and after commercial quantities of Manila clams were discovered in Lummi Bay, the fishery went through a period of transition from 1995 to 2000. At the beginning of this time, Portage Bay was the primary harvest area. Since the 1999—2000 season, however, the magnitude of the harvest from Lummi Bay has generally exceeded that of Portage Bay by a large amount. The highest recorded commercial harvest was 428,855 lbs in the 2008—2009 season (excludes harvest from the Lummi Seapond facility).

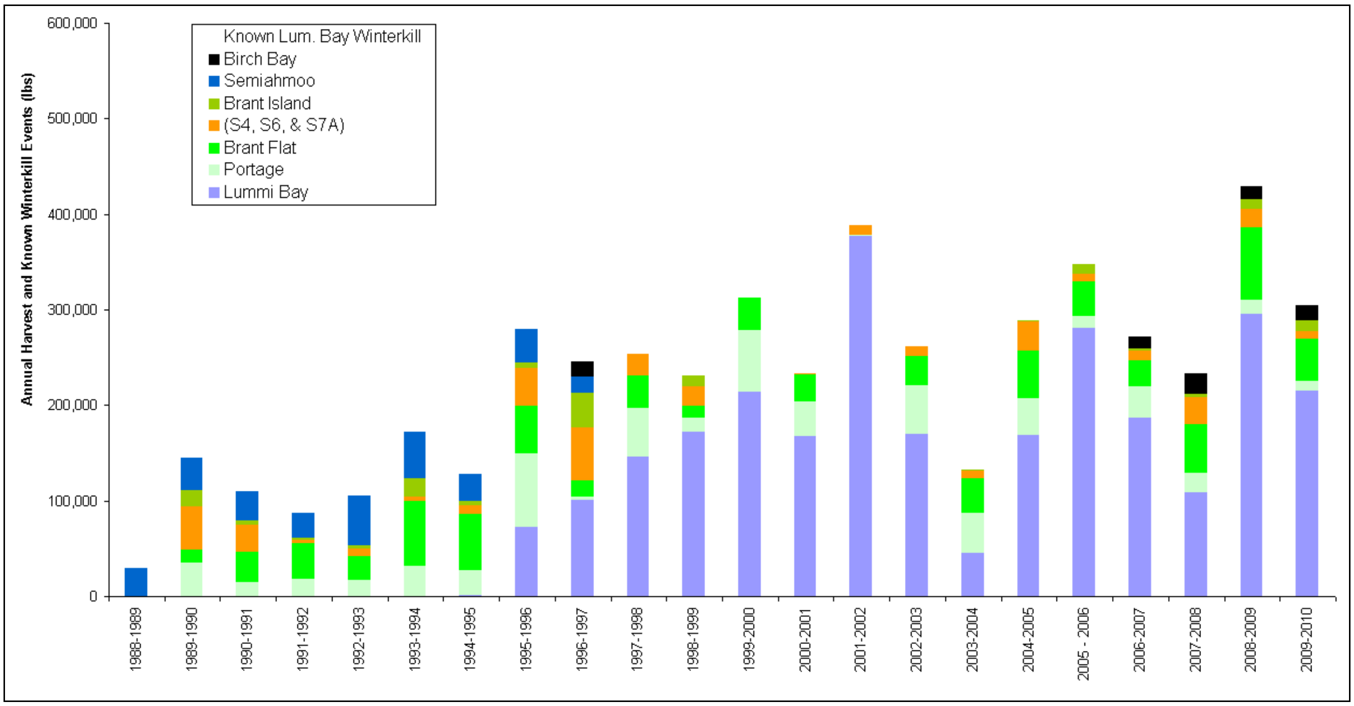

Figure 1. Recorded harvests (and significant known natural mortality events) since 1989 (Portage Beaches) and 1996 (Lummi Bay beaches)

Semiahmoo History

Growing Area Status

Prior to 1995, Semiahmoo/Drayton Harbor was classified as an approved shellfish growing area. However, worsening fecal coliform contamination of the waters in Drayton Harbor led to a partial closure of some Semiahmoo harvest areas in 1995, and then a complete closure in 1999. Subsequently, the area has remained closed to shellfish harvest except for a portion of Drayton Harbor that was reclassified as conditionally approved in 2006 (Figure 2). The conditionally approved portion of Drayton Harbor does not contain areas that are known to be productive for Manila clams.

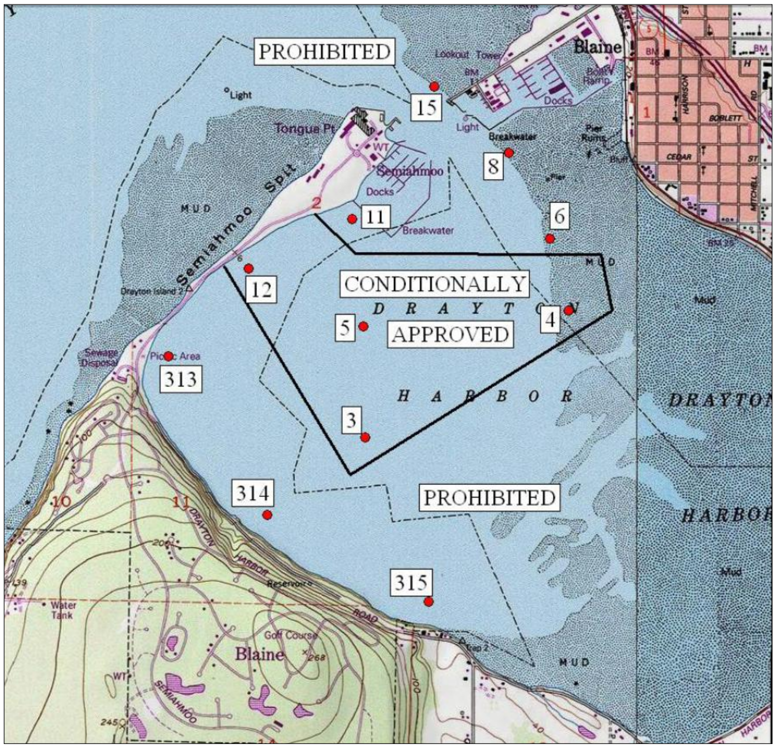

Figure 2. Map of Semiahmoo/Drayton Harbor showing current growing area status and water quality monitoring stations (WADOH 2009a)

Landings History

Total landings from Semiahmoo averaged approximately 33,000 lbs from 1988 – 1997 (Figure 3). The highest annual harvest from Semiahmoo was 51,288 lbs that were landed during the 1992—1993 season. However, the last productive portions of Drayton Harbor were closed to commercial harvest in 1997 due to fecal coliform contamination. No tribal harvest of Manila clams from Semiahmoo/Drayton Harbor has occurred since the closure in 1997, although there is still interest in harvesting the area.

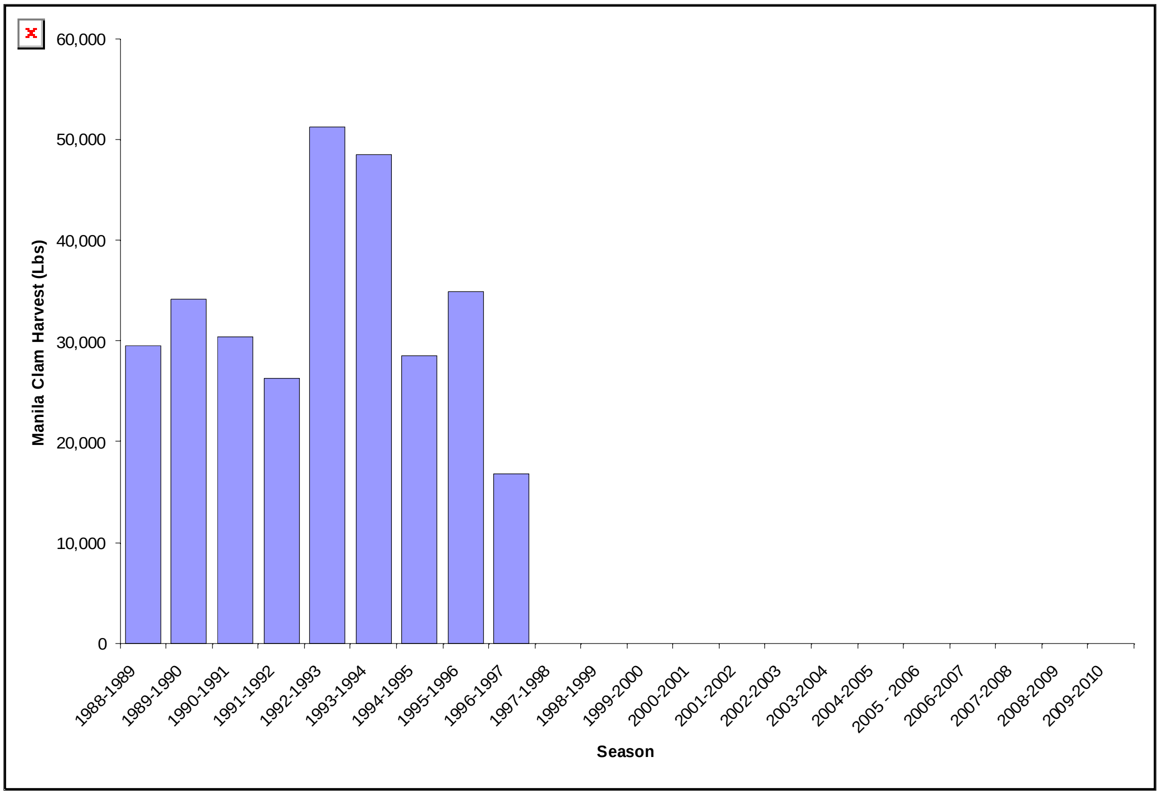

Figure 3. Recorded landings from Semiahmoo since 1988

Birch Bay State Park History

Growing Area Status

Birch Bay State Park is located within an approved growing area (Figure 4).

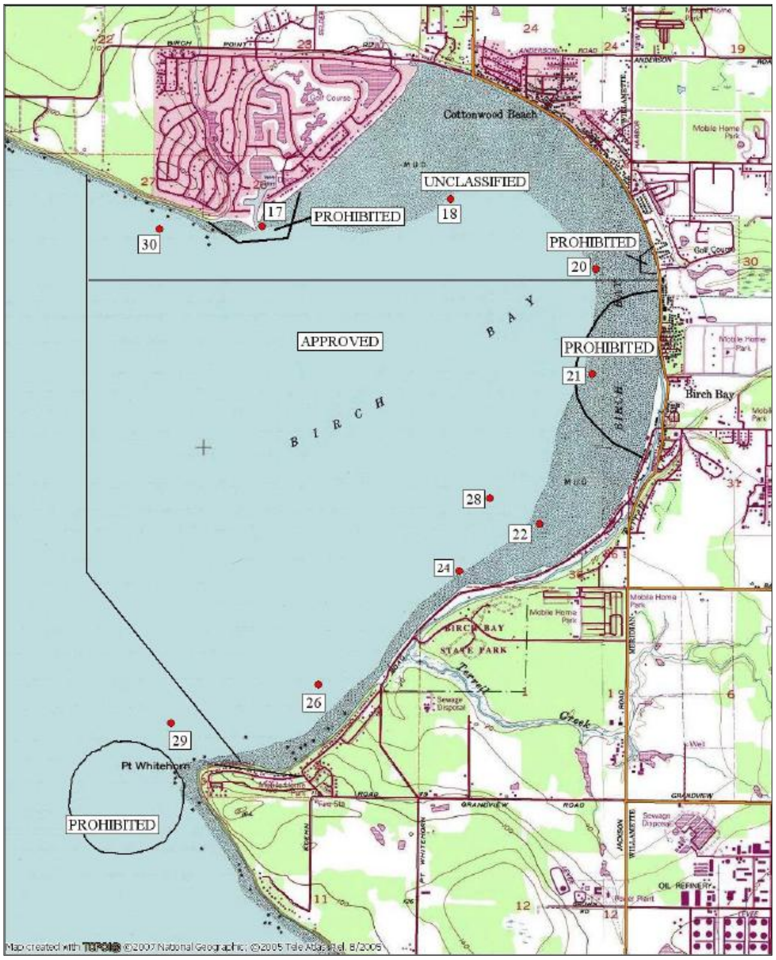

Figure 4. Map of Birch Bay showing current growing area status and water quality monitoring stations (WADOH 2009b)

Landings History

Birch Bay State Park (BBSP) has only sporadically been harvested by Lummi clam diggers (Figure 5). In years where harvest has occurred, the average harvest has been approximately 15,000 lbs. However, digger dissatisfaction with the clam densities encountered at BBSP in 1997, along with the closure of many Semiahmoo beaches, led to tribal diggers focusing their effort on the reservation clam beaches. Regular harvests of Manila clams from BBSP were resumed in the 2006—2007 season.

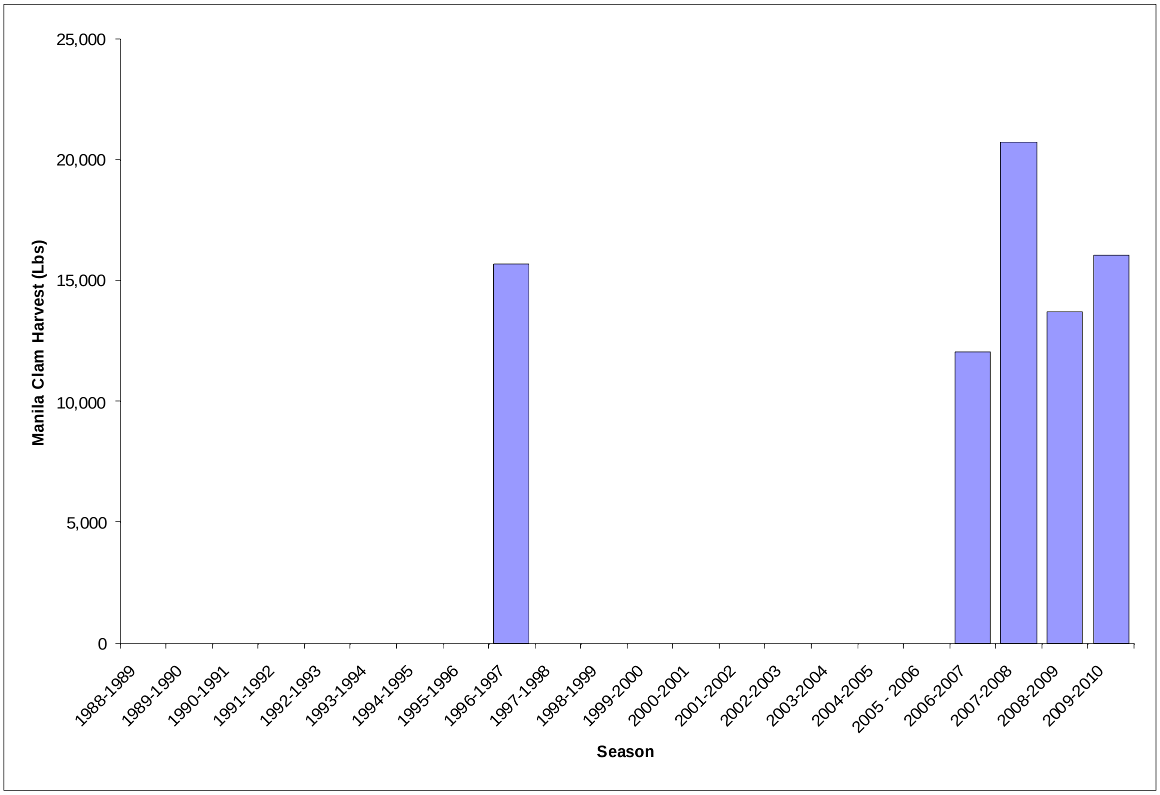

Figure 5. Recorded landings from Birch Bay State Park since 1988

Portage Bay History

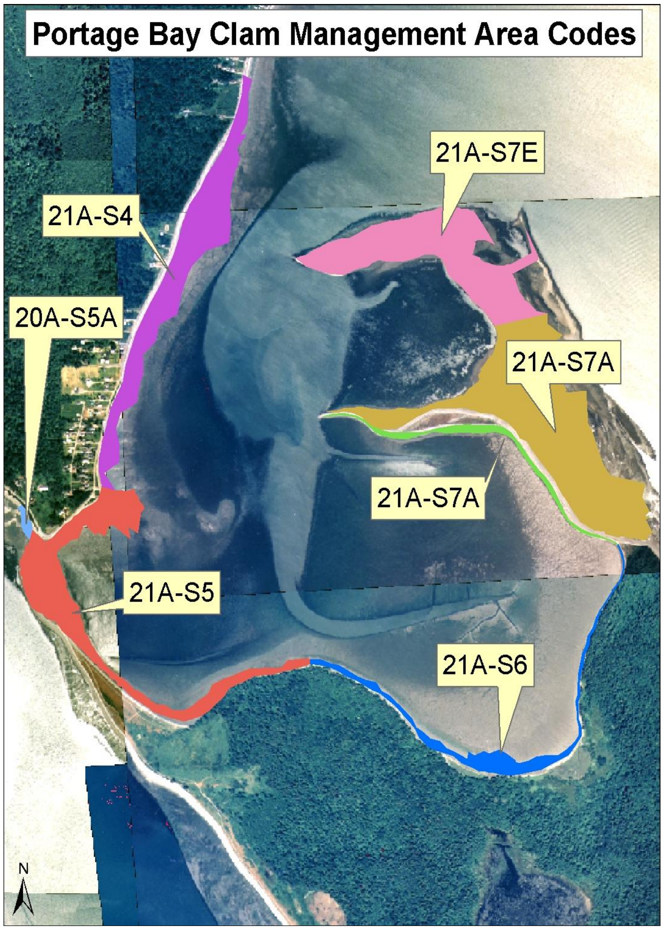

Figure 6. Portage Bay clam management area codes

Growing Area Status

Prior to 1997, Portage Bay was an approved growing area. However, worsening fecal coliform contamination led to Brant Island (21A-S7E) and much of the Senior's Beach (21A-S4) being closed to harvest in 1997. Subsequently, the southern half of Brant Flats (21A-S7D) was also closed in 1999.

Following stepped-up enforcement of agricultural waste management regulations, improving water quality indicators led to the restricted portion of Brant Flats being re-opened in 2003, and Brant Island and the northern portion of Senior's Beach was re-approved for harvest in June 2006.

In 2009, a 20-Acre portion of Portage Bay (21A-S6) was closed to harvest due to elevated fecal coliform counts from a small stream discharging from Portage Island into Portage Bay (Figure 7). The fecal coliform counts are likely the result of contamination by a semi-wild herd of cattle living on Portage Island. Efforts to remove the cattle are currently underway.

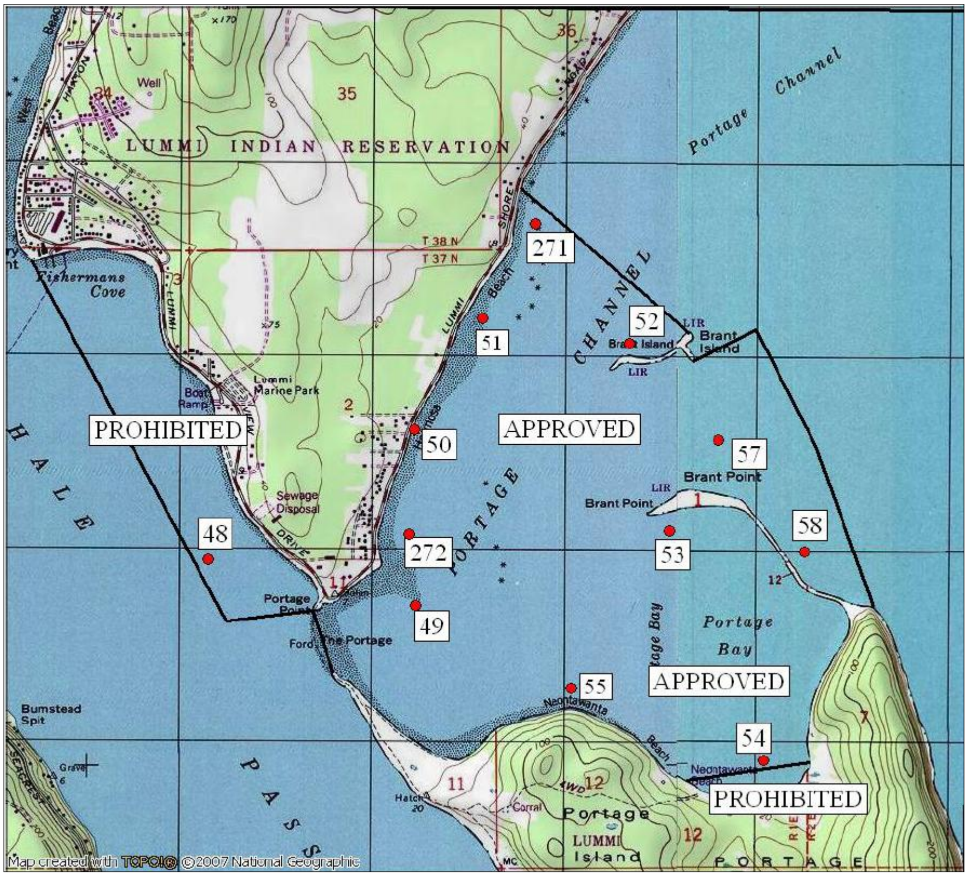

Figure 7. Map of Portage Bay and Hale Passage showing current growing area status and water quality monitoring stations (WADOH 2009c)

Landings History

Although clam harvests occurred in Portage Bay prior to 1989, no harvest records have been kept from that time period. Since 1989, the total harvest from Portage Bay beaches has ranged from a low of approximately 26,000 lbs to a high of approximately 172,000 lbs (Figure 8). Overall, the average harvest during this time period has been approximately 93,000 lbs per year. During the period when the fecal coliform closures were at their largest extent, the average harvest from Portage Bay was 63,000 lbs, which compares to the average harvest of approximately 101,000 lbs when no closures were in effect. However, this difference is compounded by an anomalous season in 2001—2002 where wholesale buyers preferred the larger clams available from Lummi Bay resulting in a shift in digger effort to Lummi Bay.

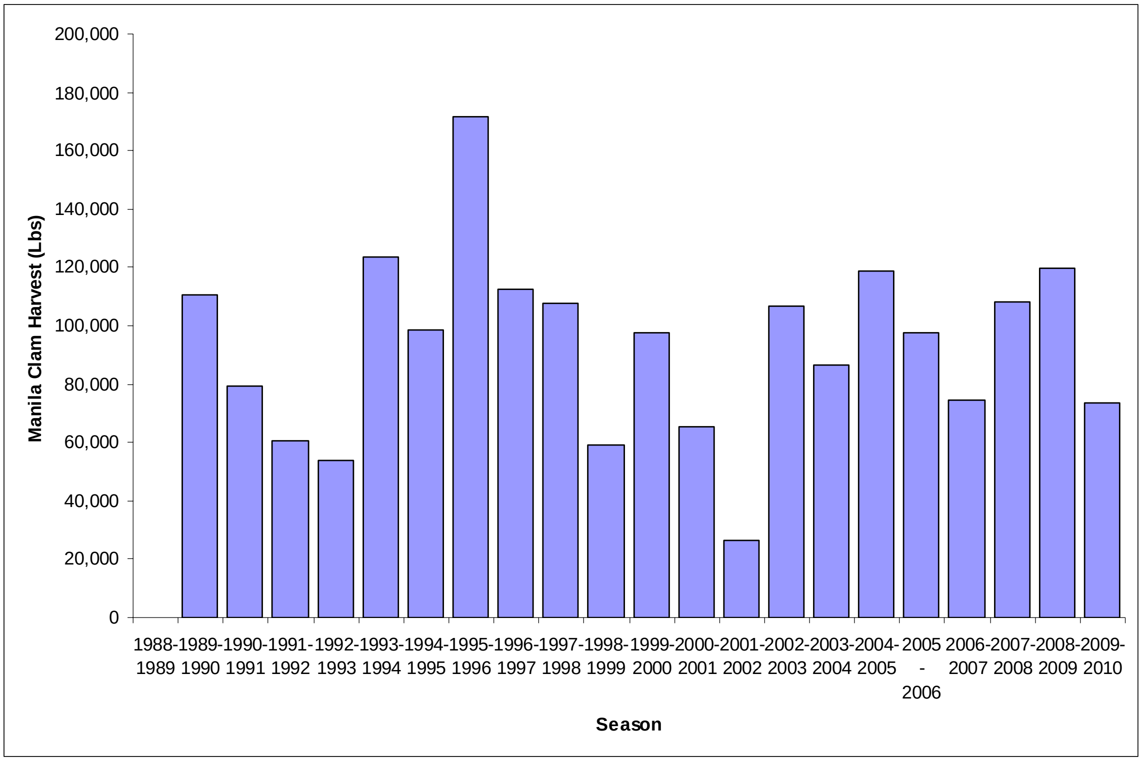

Figure 8. Recorded landings from Portage Bay clam management areas since 1989

In the 2000 – 2001 season almost no harvest was taken from Portage Bay. This reduction in effort was primarily the result of strong buyer preferences in that year for the larger Lummi Bay clams. Generally, however, buyer preferences tend to favor the smaller clams from Portage Bay over the comparatively larger Lummi Bay clams.

The bulk of the harvest in Portage is derived from two areas: Portage Spit (S5) and Brant Flats (S7D), which typically produce approximately 31,000 lbs and 38,000 lbs respectively. Next in importance is Brant Point (S7A; 15,000 lbs per year) and then Brant Island (S7E; 12,000 lbs per year). Portage Bay (S6) usually provides only a small amount (~5,000 lbs). S4 is designated as an area to be dug by tribal seniors only.

Lummi Bay History

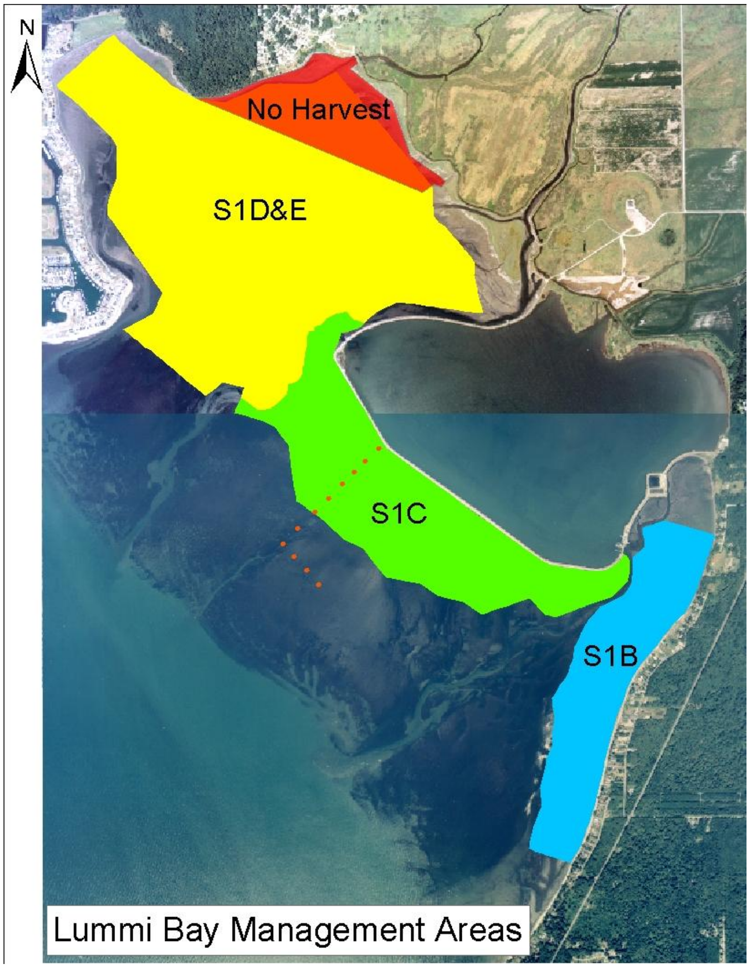

Figure 9. Lummi Bay clam management area codes

Growing Area Status

Lummi Bay has been an approved shellfish growing area (Figure 10) during the whole period of record.

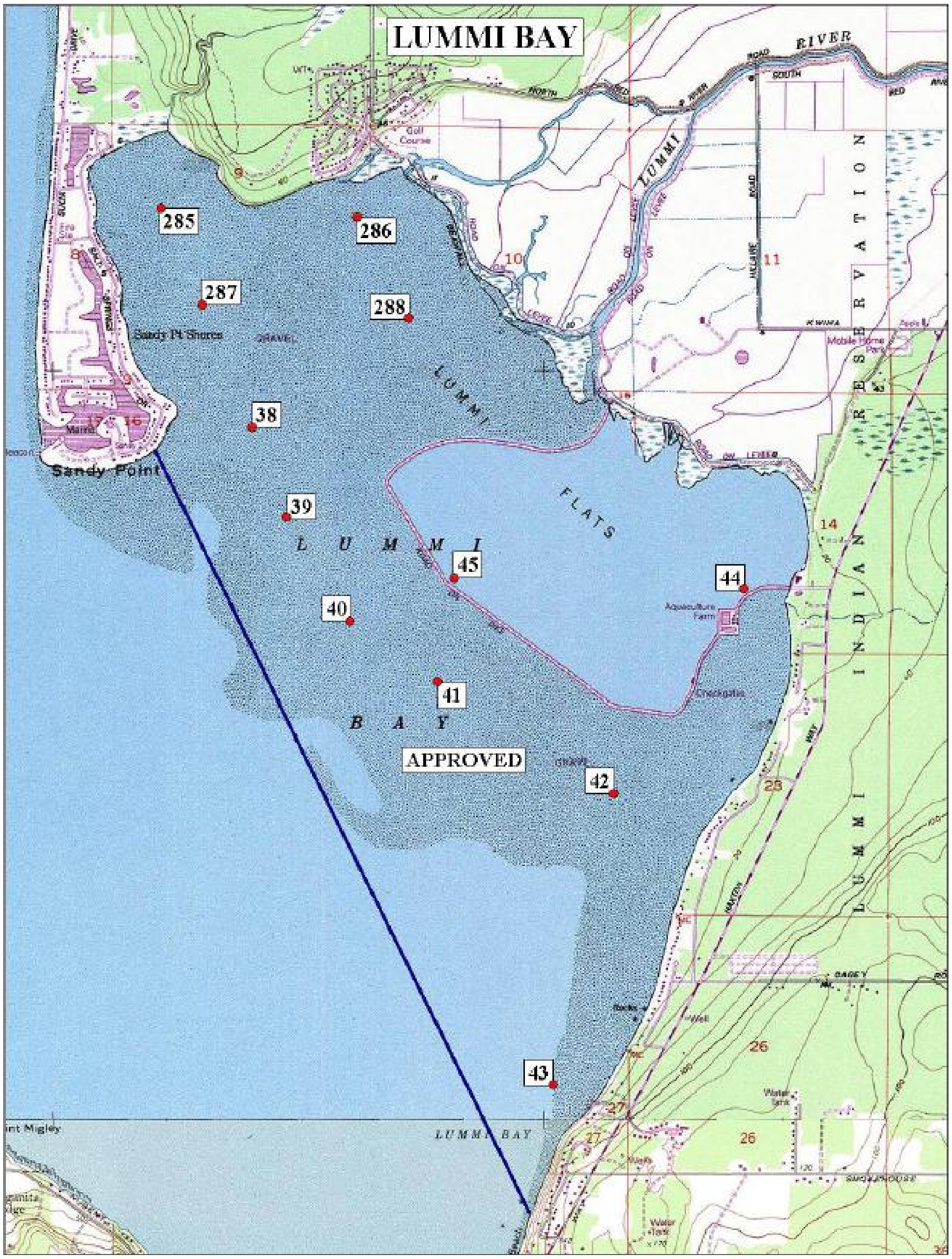

Figure 10. Map of Lummi Bay showing current growing area status and water quality monitoring stations (WADOH 2009d)

Landings History

Prior to the 1994 season, no Manila clams were harvested from Lummi Bay. In 1994, 780 lbs were harvested and the Lummi Bay Manila clam population was discovered. Subsequently, digger effort quickly ramped up in Lummi Bay and eventually this area became the dominant fishery for Manila clams, peaking in the 2001—2002 season at 377,000 lbs (Figure 11). Since 2000, total landings from Lummi Bay management areas have averaged 201,000 lbs per year.

The lowest harvest during this period was 45,000 lbs recorded for the 2003—2004 season. The minimal harvest in that season resulted from a reduction in effort caused solely by a reluctance by wholesale buyers for clams from Lummi

Bay that were deemed to be less marketable that year due to their larger size and thicker shells.

The 2005—2006 season was impacted by a significant winter-kill event that took place in Lummi Bay. This event was estimated to kill approximately 185,000 lbs of legal-sized clams. It also impacted sub-legal clams that would otherwise have matured in the subsequent three years. Because sublegal clams tend to live closer to the surface they are more vulnerable to winter-time freeze events than adults. As a consequence, it is likely that seed clams that settled in 2005 were the most bast badly effected year-class. Clams from that year-class would have reached legal size in the 2008—2009 season. The 2005 winterkill was almost equivalent to losing an entire year's harvest as well as disrupting recruitment for the following three years.

The other notable year of reduced landings was the 2007—2008 season where 108,000 lbs were landed from Lummi Bay. This reduction was primarily due to reduced harvest targets based on the 2007 stock assessment survey results.

The 2008—2009 season landing of 295,00 lbs was the second highest on record and exceeded the recommended harvest targets arising from the 2008 survey. No stock assessment survey was conducted in 2009 due to logistical constraints arising from the Lummi Intertidal Baseline Inventory project being undertaken at the same time. As a result, harvest targets could not be set using up-to-date empirical data and the management policy decision was taken to carry over the previous year's targets.

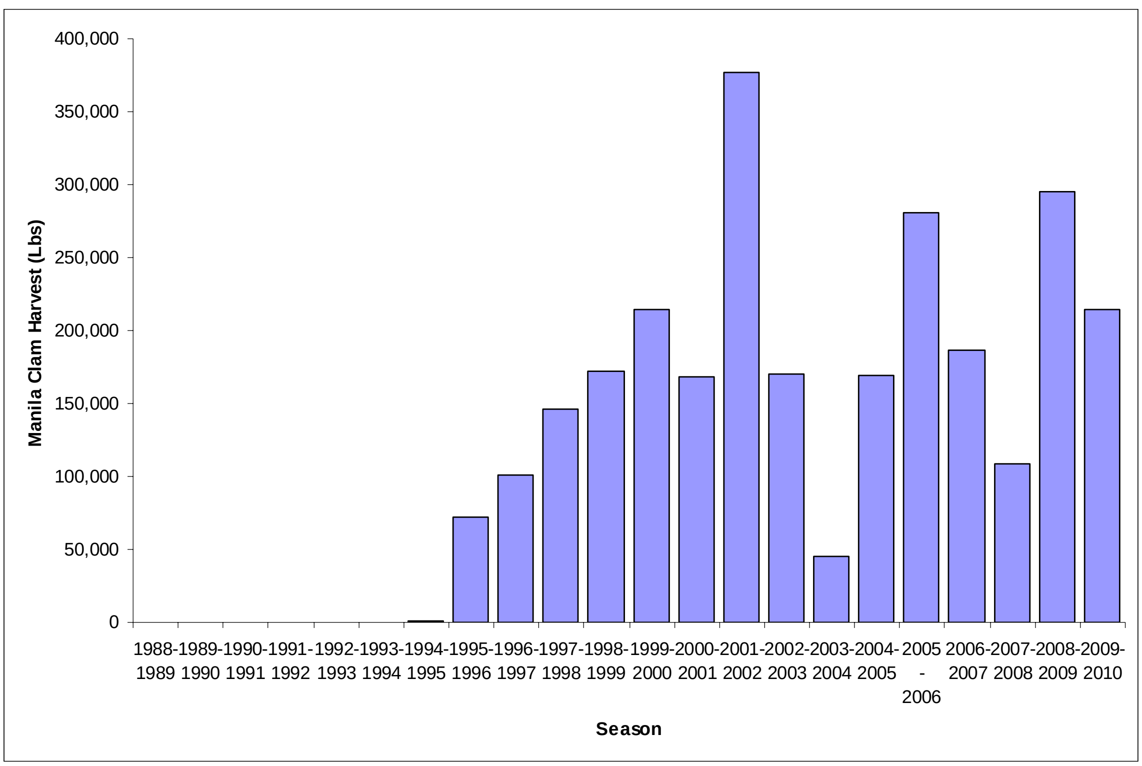

Figure 11. Recorded landings from Lummi Bay clam management areas since 1989

Harvest records indicate that the majority of the Lummi Bay harvest came from S1C during the initial years of the Lummi Bay fishery, but subsequently the digger effort switched to the S1D and S1E management areas.

Following the first wide-scale survey of clam distributions in Lummi Bay (Dolphin, 2002) it was clear that there was no meaningful break in the population between areas S1D and S1E and, consequently, both of these areas are now managed as one area. Moreover, the clam biomass in S1C was revealed to be approximately one-third of the biomass in the S1D/S1E area. As a consequence, of declining biomass in S1C, harvest effort in S1C has been limited since 2005 to 'senior' diggers, or diggers with medical issues to provide an opportunity for the population in S1C to recover. However, little recovery has been detected to date, and the population was further setback by the 2005 winterkill event.

Harvest effort in S1B (Robertson Road) has been sporadic over the years as survey data suggests that population in this area is more sensitive to harvest activities than fish ticket data would suggest should be the case. It is possible that unreported, illegal harvesters may be targeting this area in particular due to ease of access.

General Harvest Strategy

Openings during the year have sometimes been limited in an attempt to spread the harvest effort throughout the year, and daily limits for diggers have also periodically been used to try to extend the duration of the season. Generally speaking, diggers collectively choose where and when to focus harvest efforts temporally and spatially until the harvest targets have been met. However, clam digger attendance and participation at scheduled meetings remains low. Recently, lack of compliance with the harvest recommendations in the 2008—2009 season, along with the lack of followup stock assessment data in 2009 to generate harvest targets for the 2009—2010 season has meant that the harvest rates of the past two seasons are probably not sustainable.

2009 – 2010 Season Landings by Area

Table 1. 2009—2010 Season Landings by Management Area

On-Reservation				Off-Reservation			
Lummi Bay		Portage Bay		Birch Bay State Park		Semiahmoo/Drayton Harbor	
20A-S1B	23,091	21A-S4	8,209	20A-060	16,046	20A-001	0
20A-S1C	8,780	21A-S5	10,273				
20A-S1D&E	183,600	21A-S6	0				
		21A-S7A	0				
		21A-S7D	44,259				
		21A-S7E	10,546				
Total	215,471	Total	73,287	Total	16,046	Total	0

Landings from Reservation beaches during the 2009—2010 season totaled 284,103 lbs of Manila clams (Table 1). This harvest was approximately 80,000 lbs higher than average, and is the 6th-highest annual harvest during the 15 year period of record. It also followed directly after the highest-ever harvest of 415,166 lbs in 2008—2009. Approximately one quarter of the On-Reservation harvest was taken from Portage Bay, and the remaining three-quarters was harvested from Lummi Bay during the 2009—2010 season.

Lummi tribal diggers also harvested an additional 16,046 lbs of Manila clams off-reservation at Birch Bay State Park in the 2009—2010 season (Table 1).

Survey Aims

No Manila clam survey was conducted in 2009 due to the competing demands of the Lummi Intertidal Baseline Inventory project (LNR 2010). The purpose of the 2010 Manila clam survey program was to provide critical data for management purposes such as quantifying the harvestable biomass remaining on the beaches, and to make sustainable harvest recommendations for the 2010—2011 season.

Methods

The routine aspects of the clam survey were once again contracted out to a private contractor (Wilbert Hillaire), who also successfully conducted the survey field efforts in 2006, 2007, and 2008.

Field Protocols

Due to the size of the area to be covered at most beaches, and limitations in staff availability, it was not possible to use Department of Fisheries and Wildlife clam surveying protocols to survey beaches. Instead, the Lummi survey method uses a series of parallel transects that extend across the beach. Along each transect, a series of samples are taken at a predetermined number of steps apart.

The orientation of each transect line was maintained by using distant visual reference points, such as mountain peaks, houses etc, and walking directly toward that reference point after each sampling station was excavated. The spacing between the transect lines was similarly 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 spaced at 50 steps apart in the Portage area surveys, and 200 steps in Lummi Bay. 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 15 - 70 paces, depending on the area. Intervals between samples smaller than 10 steps were not possible due to limitations on the precision of the handheld GPS units used to spatially locate each station.

At each sample station, a quadrat was established, using either a 2.25 ft^2 (Portage Bay) or a 9 ft^2 (Lummi Bay) PVC quadrat. The size of the quadrat being used was noted at the bottom of each data sheet. The position of each station was determined using a hand-held WAAS enabled Garmin GPS unit (“Etrex legend”), set to display decimal degrees (NAD 83), and recorded on a data sheet. The Etrex has a theoretical accuracy of $\pm$9 ft with WAAS enabled, but typical operating accuracies varied between 10 and 25 feet.

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 shells of the manila clams were then measured, to the nearest 1mm, with a pair of plastic calipers with 1mm graduations. The dimension chosen for measurement this year was shell width. This was because comparative data on shell width and shell length measurements indicated that; overall, shell width is a marginally better predictor of actual clam weight than shell length (Unpublished data, Dolphin 2005). The dimensions of each clam were recorded on a data sheet beside the GPS coordinates for that quadrat. The number of native littleneck clams (*Leukoma staminea*), Mahogany clams (*Nuttalia obscurata*), and cockles (*Clinocardium nuttalli*) were also counted, but no size measurements were taken for these non-target species. Other clams such as Softshell clams (*Mya arenaria*), Macoma clams (*Macoma* spp.), and butter clams (*Saxidomus giganteus*) were also encountered occasionally but not recorded. However, counts of all species, except Manila Clams and Cockles, are probably incomplete because they typically live deeper in the substrate than Manila clams and could have been missed by the digger.

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 widths were entered into a Microsoft Access database. In the past, Length-weight data from a WDFW Manila clam survey in Birch Bay were used to convert individual clam lengths into individual clam weights. However, in 2005 Lummi collected size-weight data for freshly caught, unfrozen Manila clams taken from Lummi Bay, Portage Bay, and Birch Bay State Park All weights were measured using an Acculab AL 203 electronic scale. Beach-specific shell-width-weight relationships were derived from this data and are used to estimate individual clam weights based on the shell-width data that is collected in the field.

Since the calipers we use in the field can only measure clams to the nearest 1mm increment, it is assumed that half of the clams that were measured to be equal to the legal size threshold were actually marginally sublegal, and half were legal. Unfortunately, it is not possible to determine which of these threshold-sized individuals were sublegal. Including these sublegal threshold clams would artificially inflate the final biomass estimate, and excluding all threshold clams would needlessly underestimate the final biomass estimate. Consequently, the approach used in this analysis was to include all threshold individuals as if they were legal-sized, but assign each of these threshold-sized clams half of their probable weight.

The threshold shell width (equivalent to a shell length of 38mm) was estimated to be 20mm at both Birch and Portage Bays, while the more globular-shaped clams at Lummi Bay had a threshold shell width was 21mm.

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. Legal clam densities for each quadrat were determined by dividing the summed weight of the legal-sized clams found in the quadrat by the area of the quadrat used.

The clam survey Access database was used to export a table with the following columns: latitude, longitude, and legal pounds per square foot. This table was imported into ESRI ArcMap 9.3 G.I.S. software and displayed using the GPS coordinates to determine the spatial 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 and transcription/transposition errors in the coordinates. 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 or if a transcription error may have occurred. 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 for the data analysis.

Data Analysis

Because the placement of quadrats is not randomly determined, and because the sample density varies between and within management areas, 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 potential spatial bias in the survey layout.

To get the best estimate of clam density…

To remove spatial bias introduced by unequal sample densities, the point data in the survey shapefile was analyzed using Thiessen polygons (Dolphin, 2004a). The software used was ArcMap 9.3 (ESRI) with a specialty extension named ‘CreateThiessenPoly (Terrace GIS).

Firstly, polygon shapefiles were created within ArcMap that connected up all the end points of the transect lines on each beach and formed polygons enclosing the entire surveyed area for each beach. These survey area polygons were used to set the boundary extents for the Thiessen polygon analysis. Boundary polygons for the analysis were created for entire beaches or bays where survey effort was contiguous, even where this extent included more than one management area. The ‘snapping’ feature of the shapefile editor was used to get the best possible accuracy. The survey boundary polygon was then buffered by a distance of 1 meter to ensure that all survey points were included in the analysis.

Separate polygon shapefiles were also created using the survey area shapefile as a basis, but with the entire polygon area broken into separate management area polygons.

The survey data point shapefile was then used to create to generate Thiessen polygons that were bounded by the buffered survey area shapefile. The point-polygon link ID field used was the density of legal sized clams found in the survey.

The result of this process was a new polygon shapefile with one polygon surrounding the area represented by each of the survey points. The attribute table for this shapefile contained fields called ‘ThPolyID’, ‘Area’, and ‘Percent’. The ‘ThPolyID’ field contained the surveyed legal clam densities (lbs/ft^2). The Area field contained the area covered by each polygon (ft^2). The Percent field contained the approximate percentage of the total area of the survey that was represented by each polygon rounded to 2 decimal places. This shapefile was used as the basis for estimating biomass in the total surveyed area, and was also subsequently clipped into separate management areas, using the management area polygons derived earlier, to derive individual biomass estimates for each management area. Because the management area boundaries within surveyed beach areas did not fall along the boundaries of the polygons generated by the Thiessen Polygon analysis this meant that some polygons were split into two during the clipping process. Consequently, the summed number of polygons for each management area sometimes exceeded the total number of polygons generated for the total survey area.

To calculate the area covered by the survey…

The Xtools extension in ArcMap was used to calculate the dimension of each Thiessen Polygon in acres, and also in square feet.

Further operations necessary for further analysis

Although the Thiessen Polygon analysis provided three fields of attribute data, the percentage field was rounded to two decimal places and when there are over a thousand samples, and some represent an area less than 0.01% of the total area, then this can lead to error in the final calculation. Therefore it was necessary to import the attribute table into a spreadsheet (Microsoft Excel) to perform further mathematical operations.

Firstly, the area column was summed to derive a grand total for the area surveyed. Then the 'Percent' column was renamed 'Proportion' and the values recalculated by dividing each polygon's area by the grand total of the surveyed area, and values were rounded to 5 decimal places. The summed values in the 'Proportion' column equal 1.

A new column was then created named 'Proportion Squared'. This column contained values calculated by squaring the values in the 'Proportion' column.

The final column to be added to the spreadsheet was named 'Biomass' and the values in this column were calculated by multiplying the value in the 'Proportion' column by the corresponding value in the 'ThPolyID' column.

To calculate the spatially weighted average clam density

The spatially weighted average clam density can be represented by the equation:

$$X_i = \sum_{i=1}^{n} w_i * x_i \quad \text{…Equation 1}$$

Where X_i represented the spatially weighted average clam density, w_i represents the proportion of the total area represented by each Thiessen polygon, and x_i represents the clam density found in each Thiessen polygon. In terms of the spreadsheet discussed above, this means that the spatially-weighted average clam density could be determined by summing all values in the biomass column.

Precision of the estimate

Precision is a comparison of 95% confidence intervals relative to the value being estimated and is expressed as a percentage. The lower the precision the more accurate the estimate is thought to be.

95% Confidence Intervals are calculated by the following equation:

$$\mathbf{95\%\ C.I. = 1.96 * Std.Error} \quad \text{… Equation 2}$$

And the Standard Error is calculated using the equation:

$$\mathbf{Std.Error} = \frac{\mathbf{s}}{\sqrt{\mathbf{n}}} \quad \text{… Equation 3}$$

…Where s equals the standard deviation and n equals the number of observations/samples.

However, because we are estimating the precision of a spatially-weighted average clam density, we cannot use the standard deviation of the observations in Equation 3. Instead, we need to calculate the spatially-weighted standard deviation of the spatially weighted average.

The spatially weighted Variance (Var_w) can be calculated using the following formula:

$$Var_w = s^2 . \left(\sum_{i=1}^{n} w_i^2\right) \quad \text{…Equation 4}$$

…where s^2 is the spatially unweighted variance of the observations, and w_i is the proportion of the total area represented by each Thiessen Polygon.

In terms of the spreadsheet above, s^2 is calculated using the spreadsheet function VAR on the values in the ThPolyID column. The value within the brackets is calculated by summing all the values in the 'Proportion Squared' column. The weighted variance is the product of these two values.

We can then calculate the weighted standard deviation (s_w) by calculating the square root of the weighted variance.

Once we have the weighted standard deviation, we calculate the spatially weighted standard error of the weighted mean using equation 3, and then calculate the half-width of the spatially weighted 95% confidence interval using Equation 2.

Finally, the precision of the survey is determined by dividing the half-width of the 95% confidence interval (calculated in Equation 2) by the average clam density (obtained from Equation 1), and then multiplying the result by 100%.

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 that were estimated to have a shell-length of 38mm or larger was divided by the total area sampled in that management area to provide a spatially biased sample estimate of legal clam density. This sample estimate was corrected for spatial bias by dividing the sample estimate of clam density by the spatially weighted estimate of clam density for that area.

Because some clams die from natural mortality, and the surviving clams will each grow 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.

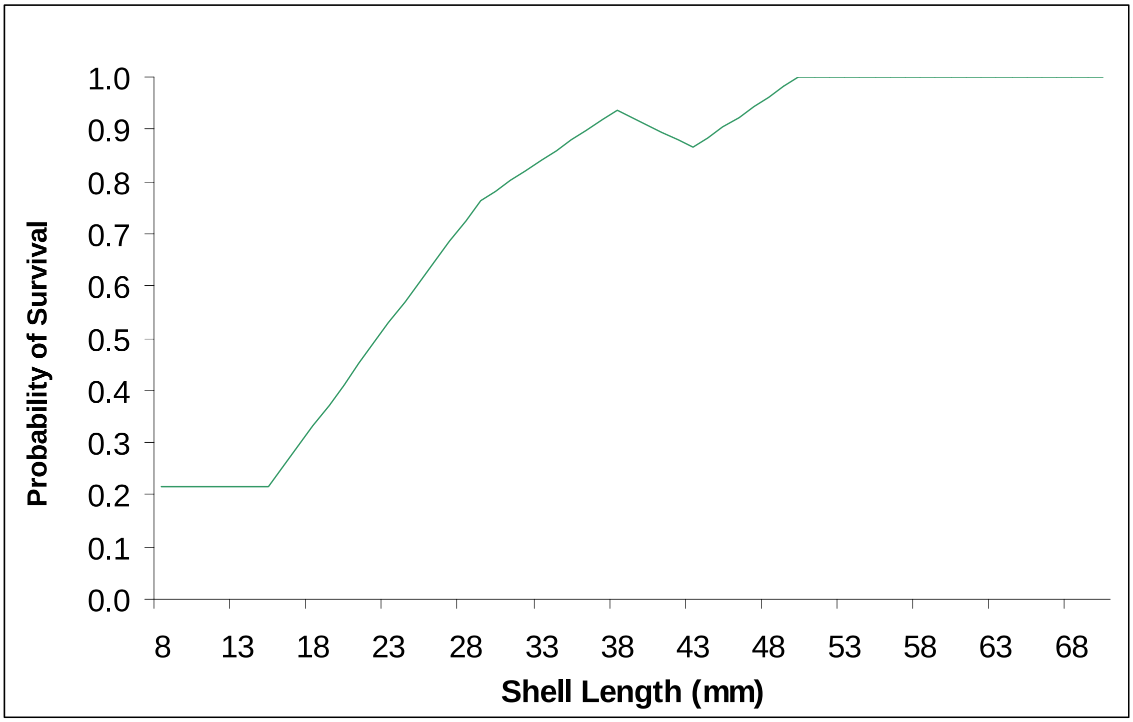

Figure 12. Survival rates used in calculating Production Estimates (from Dolphin, 2004b)

Clam survival and growth rates were obtained from a 2004 grow-out experiment in Lummi Bay (Dolphin 2004b), and these have incorporated into the production rate calculations. Figure 12 shows the size-specific survival rates. However, it should be noted that this survival rate data is extremely limited and much more work is needed to better understand this critical parameter.

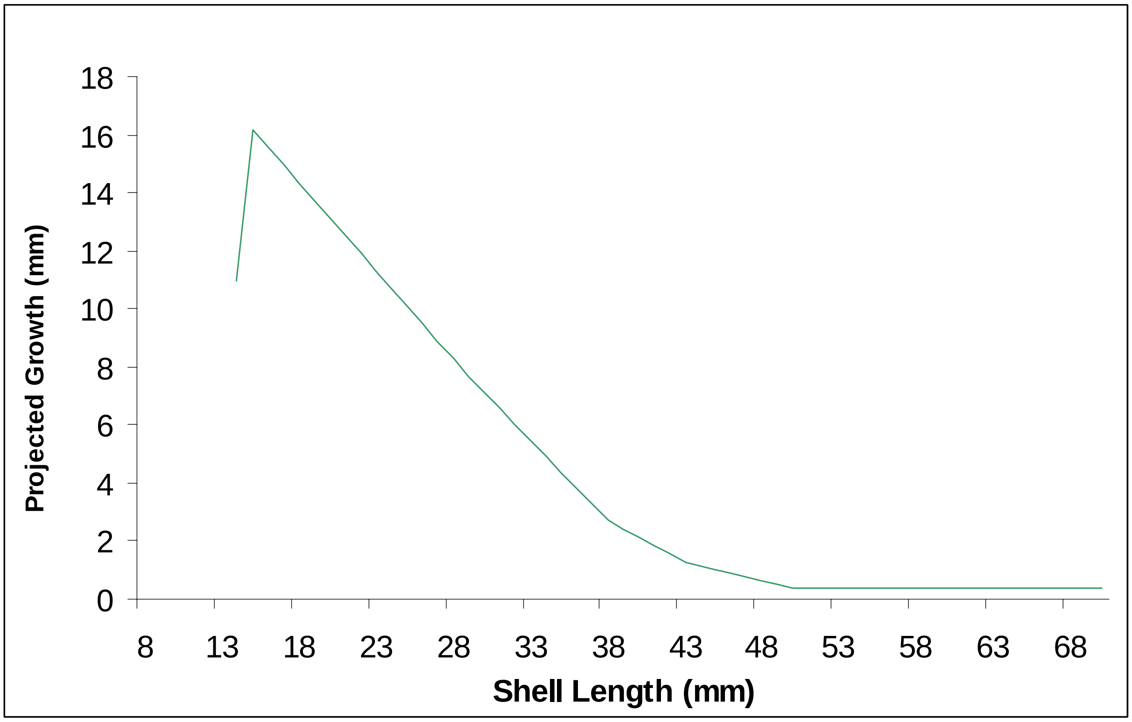

Figure 13. Annual size-specific growth rates used in calculating production estimates

Annual growth rates used to 'grow-out' the observed size-frequency distribution by one year are shown in Figure 13. The relationships in Figure 12 and Figure 13 were converted to equivalent shell lengths for use in the production rate model.

By predicting the growth of clams in each size increment, and estimating the reduced frequency of clams after natural mortality occurs, 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 the legal threshold (or above) after one hypothetical year was then divided by the sampled area to predict the legal sample density for next year. The predicted sample estimate was again corrected for spatial bias by factoring in the spatially weighted 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 that is expected.

Data Validation

To audit the accuracy of the survey data being received from the contractor, a n independent resurvey of a section of Lummi Bay was conducted by the LNR Shellfish Biologist using the same protocol provided to the contractor. Because the estimates of mean clam density from the contractor and the independent survey were not statistically different, the data from the independent survey was combined with the data from the contractor prior to the final analysis.

Results

Survey activities began on June 12 and continued through almost all of the available daylight tides until July 26. Clam populations were surveyed in Lummi Bay and in the most important of Portage Bay beaches (Portage Spit, Brant Flat, Brant Island). Survey results are presented in Table 2. Clam density maps for Lummi Bay, Portage Spit, and the Brant area are presented in Figure 14, Figure 15, and Figure 16 respectively.

Table 2. Summary of 2010 Survey Results.

Portage Bay								
Area Description	**Thiessen Polygons**	**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***
S4	Not Surveyed							
S5	**479**	**2.25**	31.19	0.017930	14.83%	20,748	**24,360**	27,972
S6	Not Surveyed							
S7A	Not Surveyed							
S7D	**635**	**2.25**	56.41	0.027490	16.09%	56,676	**67,548**	78,419
S7E	**337**	**2.25**	34.64	0.007835	24.96%	8,873	**11,824**	14,774
All Combined	**1451**		122.24			86,297	**103,732**	121,165

Lummi Bay								
Area Description	**Thiessen Polygons**	**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	**264**	**9**	175.3	0.018337	18.86%	113,617	140,030	166,442
S1C	**320**	**9**	300.7	0.009055	40.16%	70,975	118,601	166,228
S1D & S1E	**479**	**9**	922.1	0.013289	17.45%	440,670	533,818	626,966
All Combined	**1,063**		1,398.1			625,262	**792,449**	959,636

* Precision estimates used here are spatially weighted estimates derived from the Thiessen Polygon Analysis. See methods for fuller discussion of this parameter.

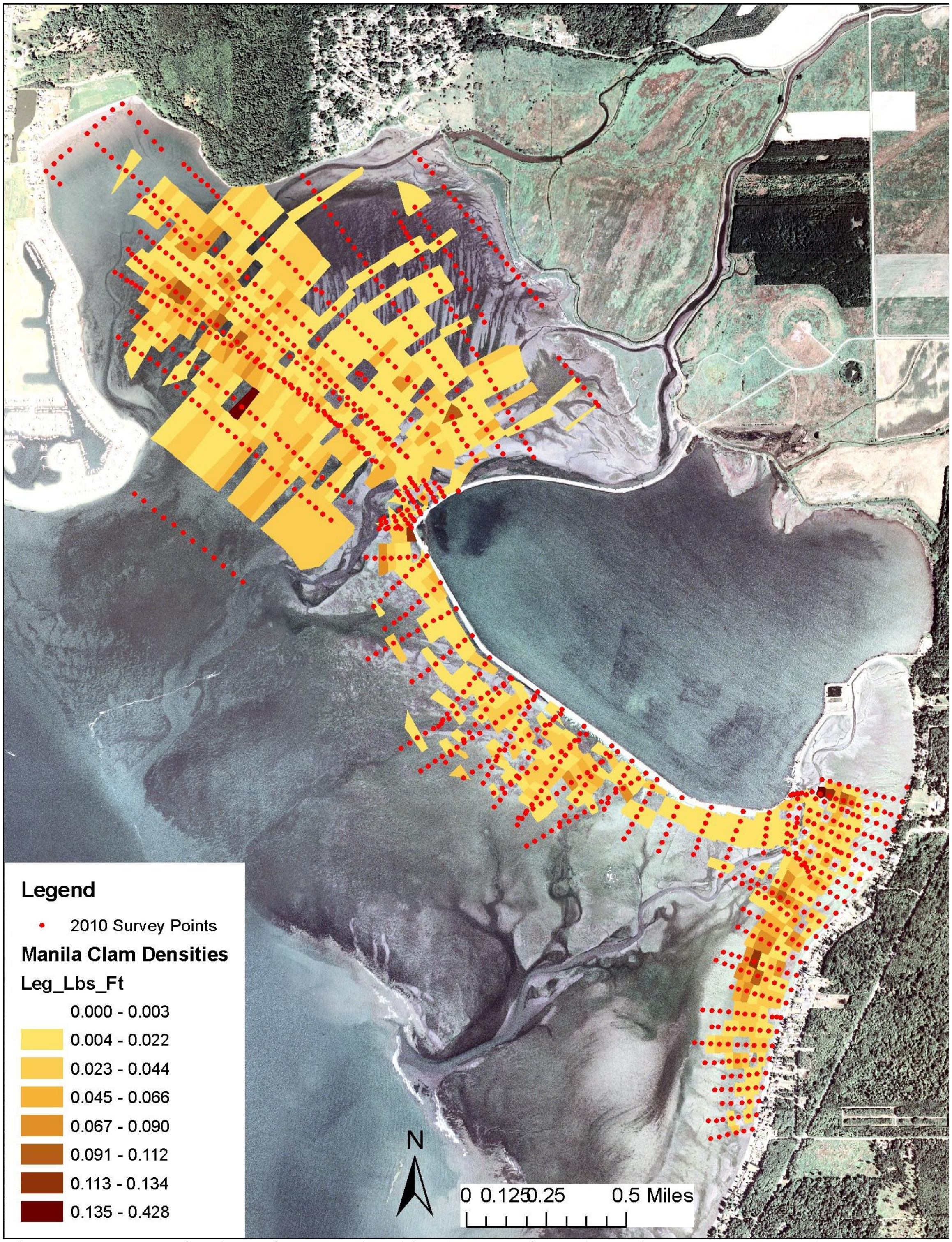

Figure 14. Legal-sized Manila clam densities in Lummi Bay based on 2010 survey data

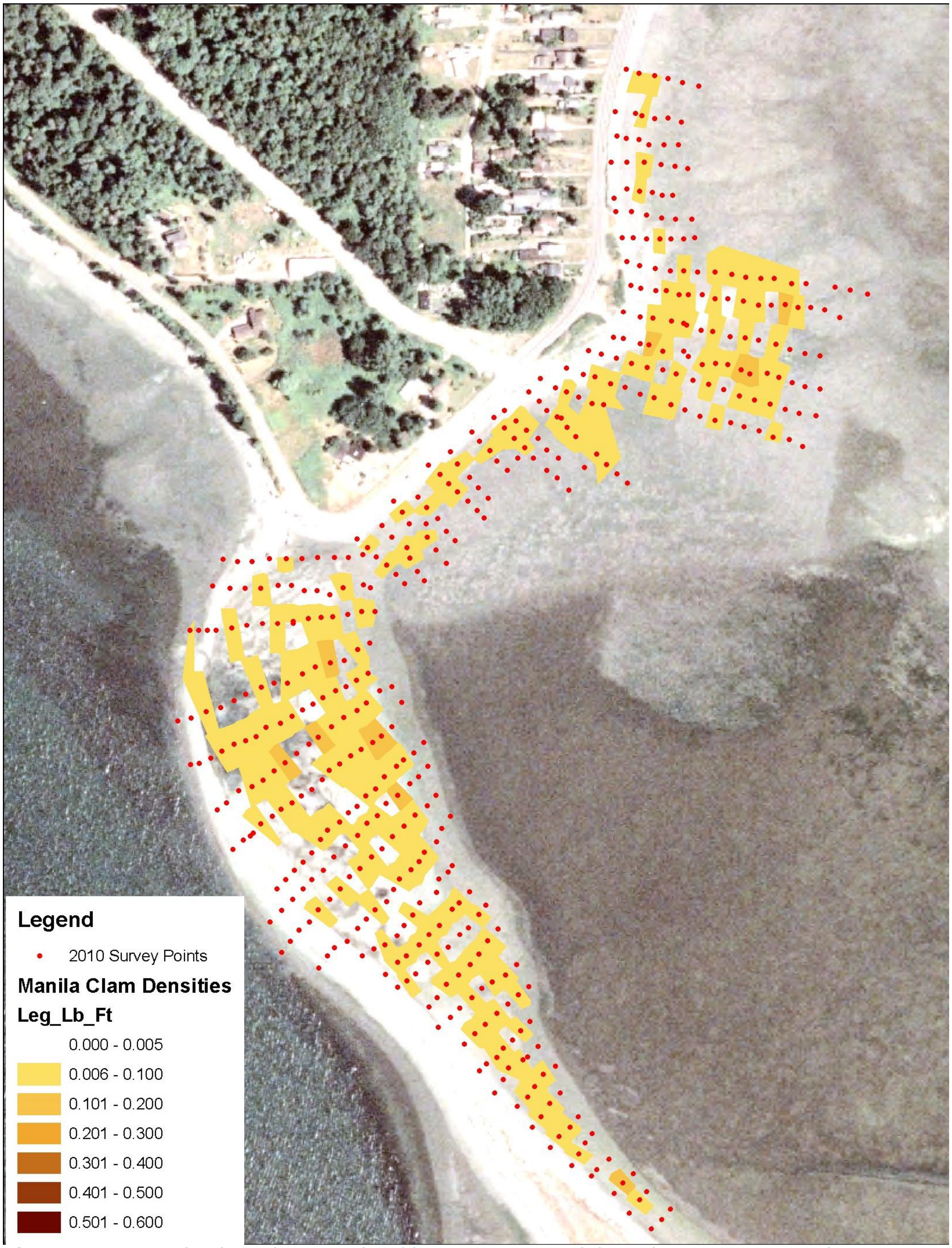

Figure 15. Legal-sized Manila clam densities at Portage Spit based on 2010 survey data.

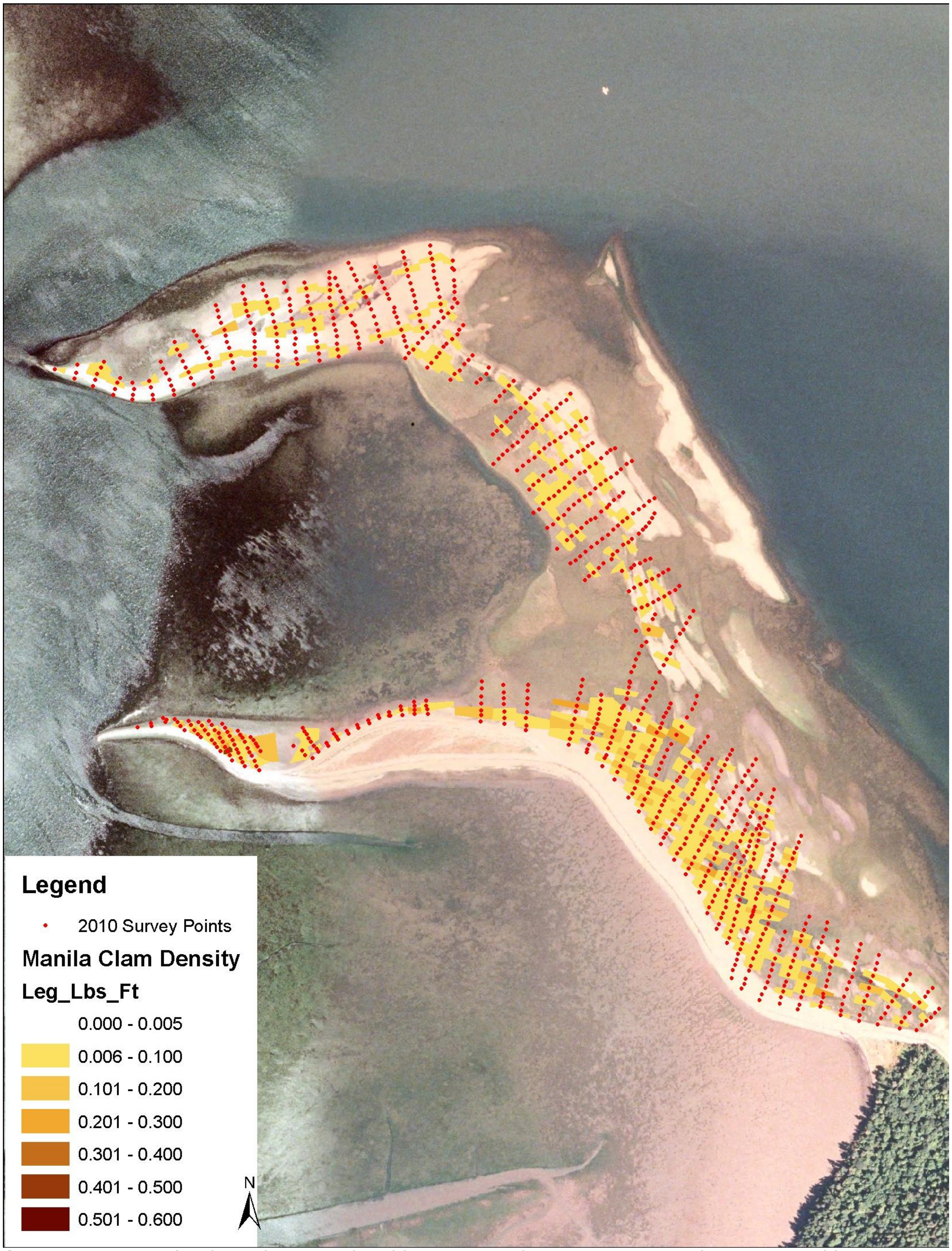

Figure 16. Legal-sized Manila clam densities surveyed at Brant Flats and Brant Island in 2010

Because survey areas have differed between each survey that has been conducted from 2002 to 2010, it is not meaningful to directly compare the different survey results to each other. However, meaningful comparison can be made of clam biomass in the parts of the surveyed areas that was common to more than one survey and this can be used to create an index of clam biomass that approximates the total biomass present each year. Figure 17 shows the relative change in the biomass present in the each management area surveyed in Lummi Bay, and Figure 18 shows relative change in biomass in management areas in Portage Bay.

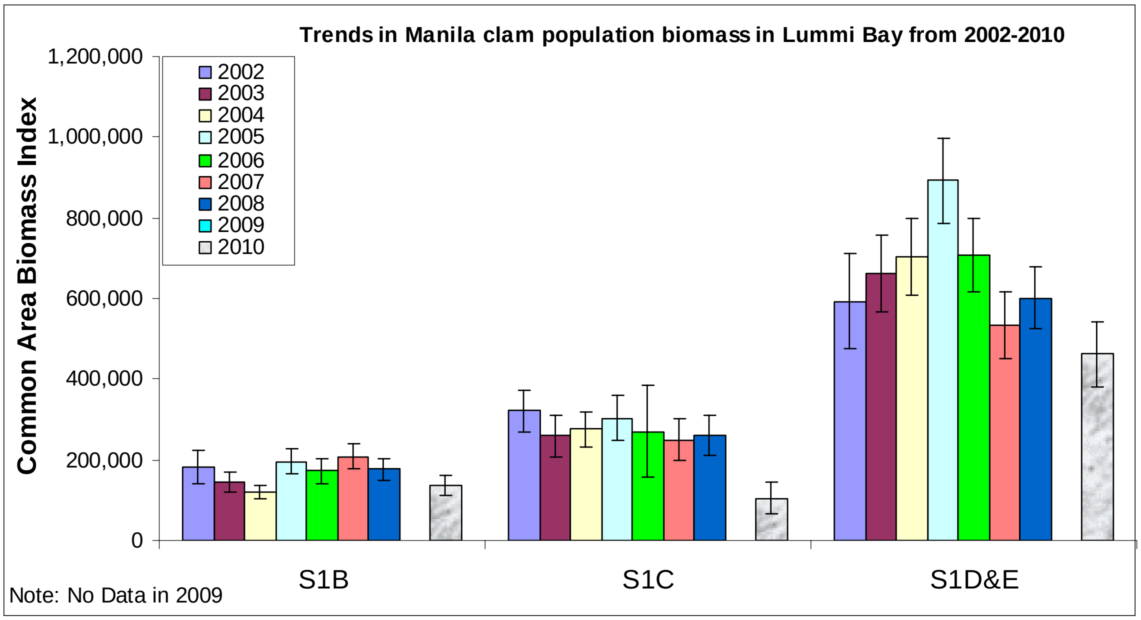

Figure 17. Relative change in legal clam biomass in Lummi Bay management areas from 2002 to 2010 (Error bars indicate 95% Confidence Limits)

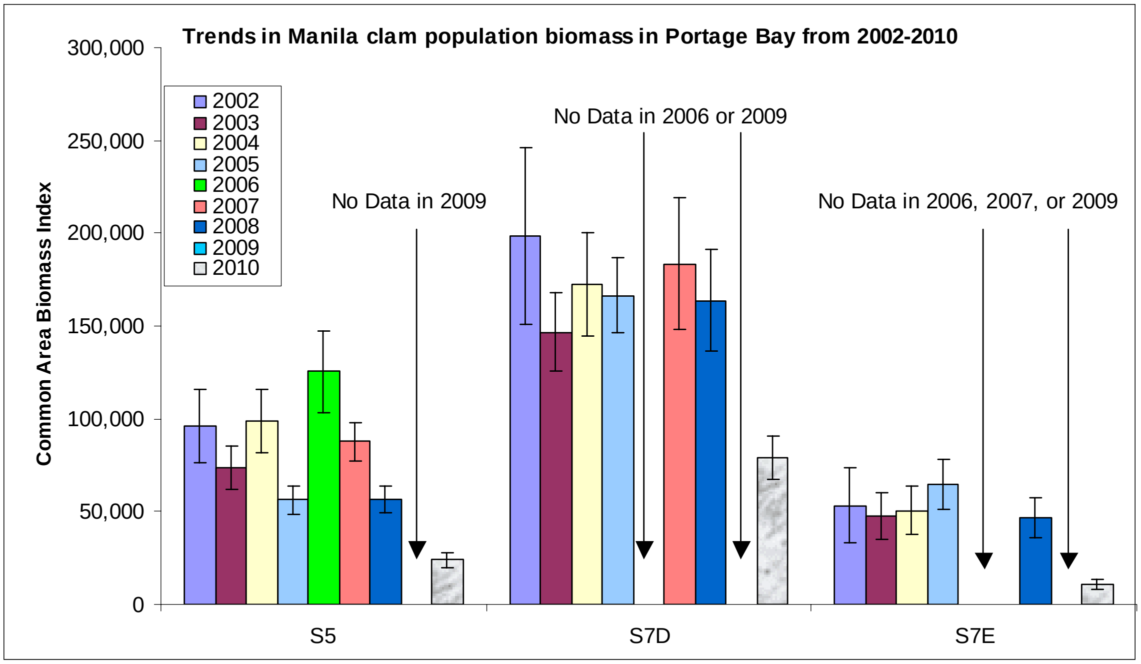

Figure 18. Relative change in legal clam biomass in Portage Bay from 2002 to 2010 (Error bars indicate 95% Confidence Limits)

Table 3. Comparison of Annual Production Estimates based on Lummi Manila clam surveys.

Survey Year (lbs)	Lummi Bay S1B	Lummi Bay S1C	Lummi Bay S1D&E	Portage Bay S5	Portage Bay S7D	Portage Bay S7E	Birch Bay State Park 60
2002	35,254	36,179	100,012	49,701	65,052	16,040	N/A
2003	30,237	29,448	77,488	41,703	63,159	32,371	49,266
2004	28,466	10,349	89,299	34,617	58,458	27,162	61,824
2005	28,490	23,904	109,684	18,249	53,381	31,794	49,013
2006	17,531	41,033	81,210	31,903	N/A	N/A	N/A
2007	19,657	18,529	55,858	29,910	28,236	N/A	N/A
2008	25,251	12,097	61,445	17,685	43,478	14,005	N/A
2009	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	45,692	21,040	81,886	20,294	47,890	12,126	N/A

Production estimates for each beach, based on the 2010 survey data, are presented in Table 3 along with previous estimates that were derived from 2002 – 2008 survey data. (Note that these production estimates are not directly comparable for some Portage Bay beaches because of differences in the surveyed areas between years. In particular, one productive area in S7D was not surveyed in 2002 or 2007).

Because the total biomass on all beaches has declined since 2002, the recommended harvest strategy for 2009 does not directly reflect the anticipated production for the coming year. The recommended harvest amounts for all approved areas that have been surveyed in 2010 are detailed in Table 4 and these values are shown in context with previous harvests in Figure 19.

Table 4. Recommended harvest targets based on 2010 survey data, by beach

Management Area	2011 Recommended Harvest
North Lummi Bay (S1D&E)	**69,089**
Mid Lummi Bay (S1C)	**0**
South-East Lummi Bay (S1B)	**35,692**
Portage Spit (S5)	**10,000**
Brant Flat (S7D)	**40,000**
Brant Flats (S7E*)	**5,000**
Overall Total	**159,781****

****Excludes clams harvested from Birch Bay State Park, S4, S6, or S7A**

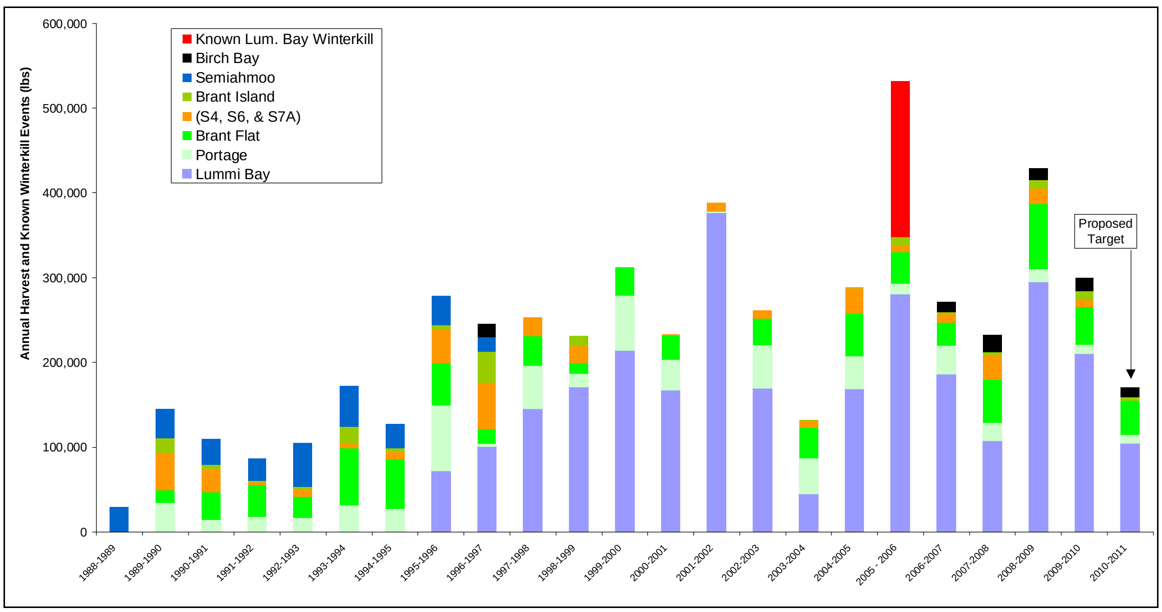

Figure 19. Comparison of proposed harvest targets to past landings (Proposed targets do not include any clams harvested in S4, S6, or S7A)

Discussion

Manila clam populations in Portage Bay and central Lummi Bay have suffered severe declines in biomass since the last stock assessment survey in 2008, and slightly smaller declines have also been noted in northern and southern Lummi Bay. The true cause of these declines is difficult to discern with certainty.

The first question that arises is whether the 2010 survey data was accurate or not?

If the contractor's survey crew were providing data that was biased too low due to insufficient care while excavating the samples, then it is likely that this bias would be strongest for sub-legal/small clams that are comparatively much easier to overlook during the fieldwork compared to larger adult clams.

To test this theory, survey data from four management areas were examined in more detail. The size-frequency distribution of clams from each area showed that the sub-legal clam densities observed in the 2010 survey were approximately the same as, or slightly higher than, the comparable data averaged across the previous three surveys while adult/legal-sized clam densities were generally reduced (Figure 20 A - D).

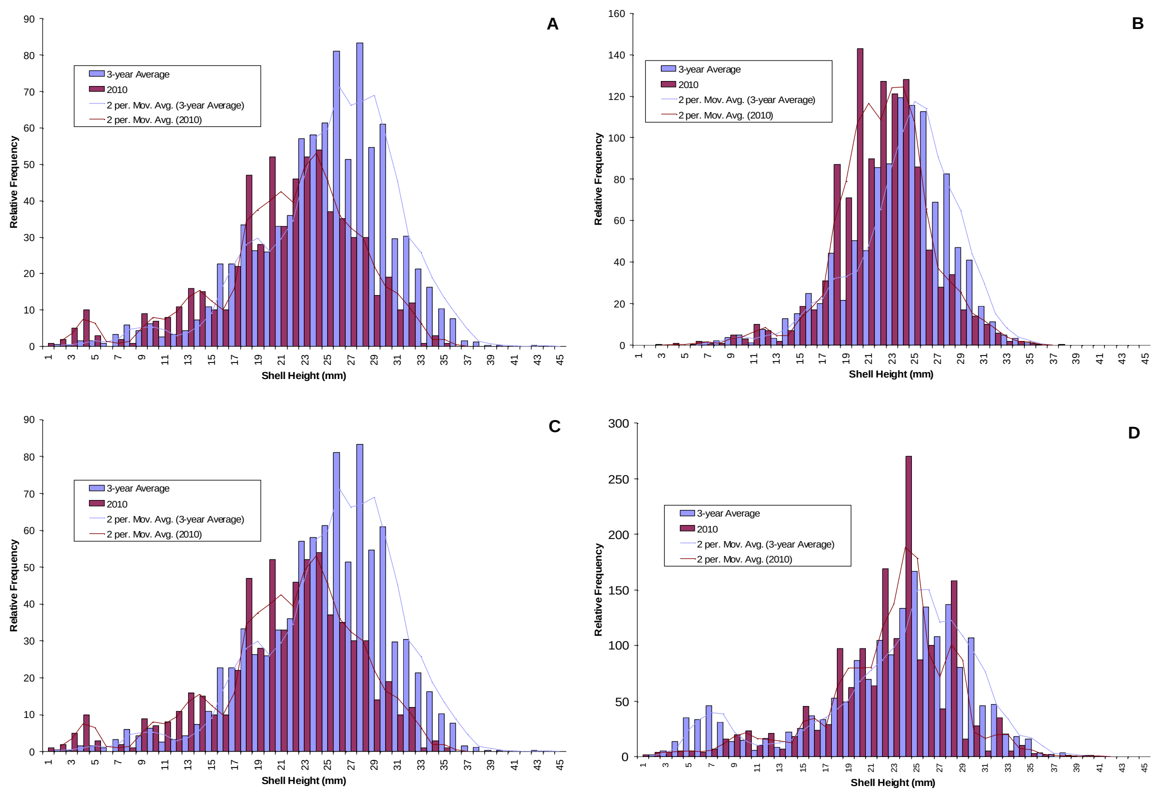

Figure 20. Comparison of 2010 size-frequency distributions from four management areas, to previous results from the same areas (A: 21A-S5; B: 20A-S1B; C: 20A-S1C; D: 20A-S1D&E)

Another possibility for survey error is that the survey crewmembers were not measuring the clams correctly. However, the majority of the personnel had prior experience using this protocol so it is highly unlikely that this was the case.

Nonetheless, to verify the accuracy of the survey data, a portion of one management area was independently re-surveyed by the LNR Shellfish biologist approximately one month after the contractor's crew had surveyed that same area. For the portion of the area that was re-surveyed, the estimate of average density had a calculated precision of ~ 31% for each survey. Although the re-survey showed a somewhat higher density compared to the original survey, the limited precision of each survey meant that there was no statistical difference between the two surveys in 2010 ($p > 0.05$). However, both of these survey estimates were statistically different than the 2008 survey (Figure 21; $p < 0.05$).

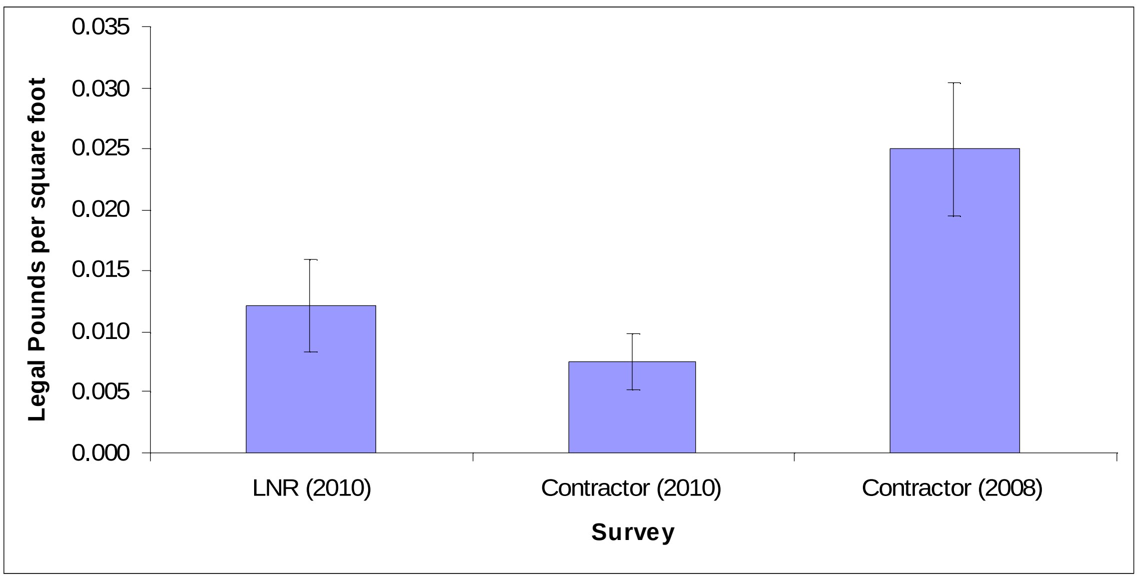

Figure 21. Comparison of repeated survey estimates for a portion of 21A-S1C. (Error bars indicate 95% confidence intervals for each estimate)

Thus, the contractor's survey and the re-survey both showed that clam densities had fallen dramatically since the 2008 survey, which suggests that the decline in clam densities is not the result of an inaccurate survey in 2010.

A more likely explanation for the apparent declines in clam biomass, particularly in Portage Bay, likely includes a combination of recent over-harvest along with one or more natural mortality events, possibly including an undocumented winter-kill in the winter of 2008—2009, and possibly some lingering effects from the 2005 winter-kill also.

Evidence that a winter-kill may have occurred during the winter of the 2008—2009 season is somewhat speculative, and arises from a comparison of size-frequency data from the 2008 & 2010 stock-assessment surveys with size-frequency data obtained during the 2009 LIBI project, along with an examination of air-temperature records.

Although methodological differences exist between the annual stock assessment surveys and the LIBI project, a comparison of the size-frequency distribution can be made by converting shell-lengths to shell widths from an established relationship between these metrics (Dolphin, unpublished data). As expected, the LIBI data clearly shows that very small seed clams (<16 mm SL) are under-reported by the stock assessment methodology compared to methods that sieve the sediment. However, densities of clams above this height appear to be a similar order of magnitude when corrected for the area excavated (Figure 22).

From the three size-frequency distributions in Figure 22, it seems likely that a large-scale event significantly reduced the densities of clams that were > 16mm shell length in 2008 between the 2008 survey and the 2009 LIBI survey. By 2010, the number of clams between 16 and 38 mm SL (sublegal clams) appears to have recovered, likely due to a good recruitment of seed clams in 2009 that would have reached that size range by 2010. By contrast, the number of legal-sized clams remains low in 2010 since sublegal clams that would have reached legal size by 2010 were killed, and more recent seed clams have not yet had time to reach legal size.

Supporting the idea that a winter-kill might be responsible for the observed reduction in clam densities, long term air temperature data from Vancouver International Airport (Figure 23) showed that the winter of 2008—2009 had the most unusually cold minimum temperature since about 1997—1998.

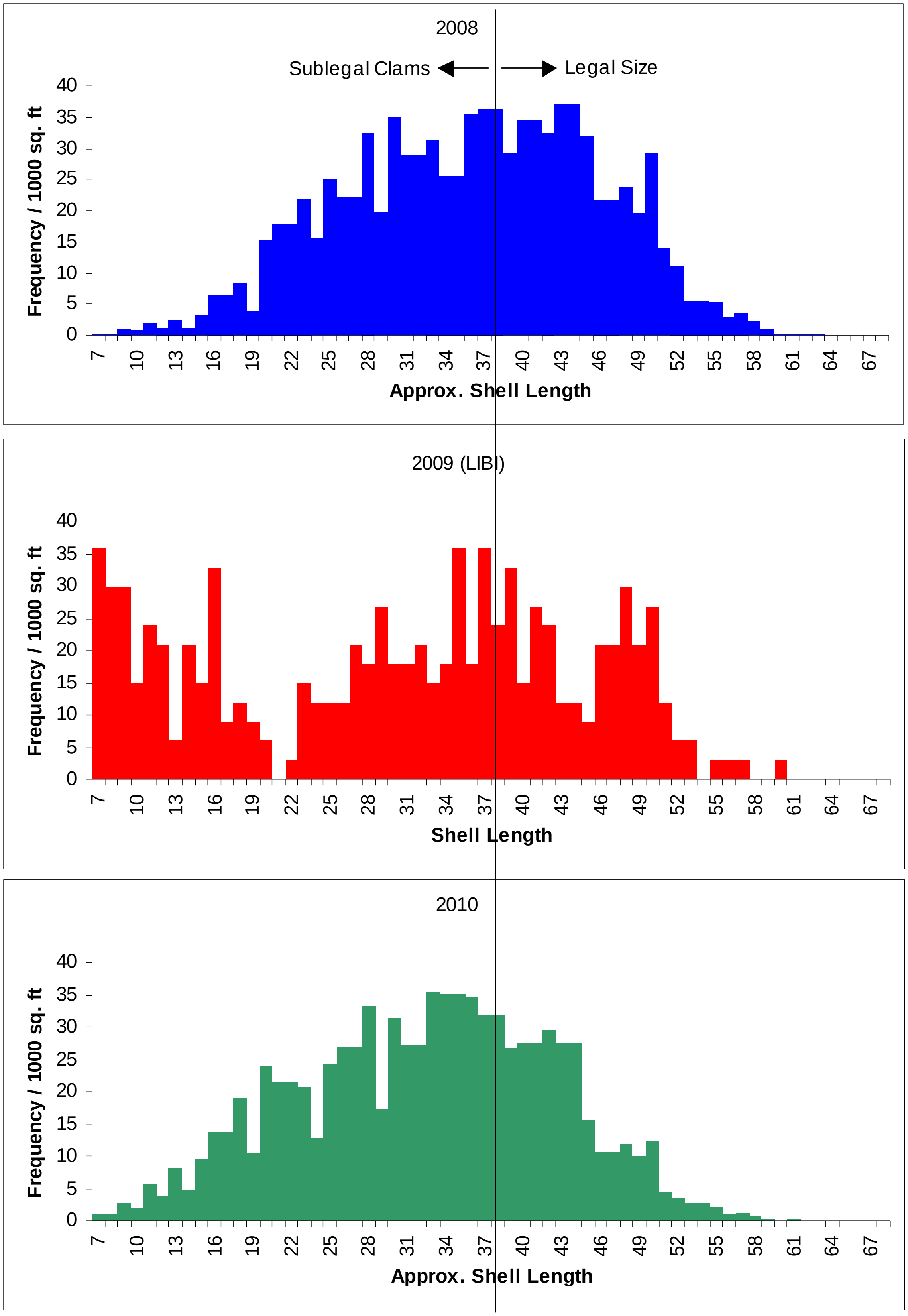

Figure 22. Comparison of Manila clam size-frequency distributions from 2008, 2009, & 2010

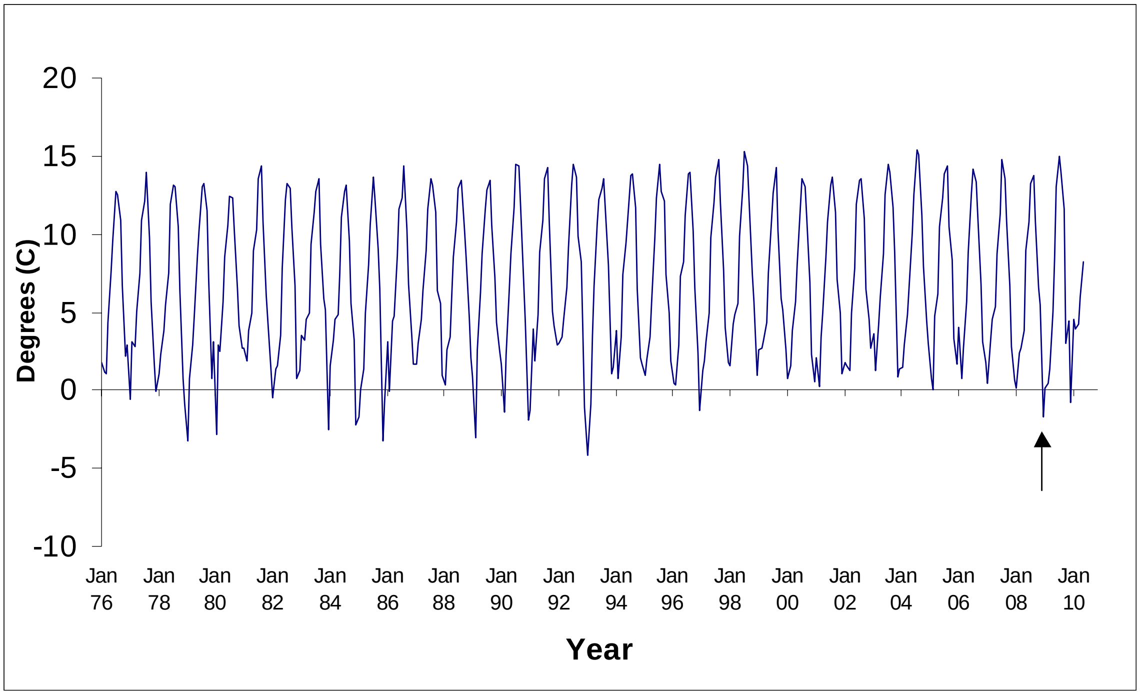

Figure 23. Comparison of monthly mean minimum air temperatures at Vancouver International Airport

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