

2011 Lummi Clam Survey Summary



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Executive Summary

In 2011 Lummi Natural Resources contracted with Wilbert LeClair to survey clam densities on several important reservation beaches. A total of 1,923 samples were dug, which was equivalent to 9,612 square feet.

Legal biomass estimates were 1,056,460 lbs for Lummi Bay and 214,282 lbs for Portage Bay (excluding S4, S7A, and S7E). These results show a moderate recovery in clam abundance has occurred on several beaches since the 2010 survey was conducted. Likely causes for the improvement were a higher than usual recruitment of juvenile clams reaching legal size, as well as a reduction in harvest intensity during the 2010 – 2011 season. However, little recovery was observed in the central portion of Lummi Bay (S1C) and too little data was collected at Brant Island to determine whether any recovery has occurred on that beach.

Recommended harvest levels for the 2011-2012 season would provide 232,532 lbs of on-reservation harvest in the coming season. This compares to last year's harvest of 140,680 lbs for the same beaches. These figures do not include any harvest taken from Lummi Shore Road (S4), Inside Portage Bay (S6), Inside Brant Point (S7A), or from off-reservation beaches (Birch Bay State Park, Drayton Harbor).

A separate survey by WDFW with participation by Lummi of Birch Bay State Park resulted in a calculated tribal quota of 24,972 lbs for the upcoming season.

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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 from 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 (Note: data for all seasons excludes harvest from the Lummi Seapond facility).

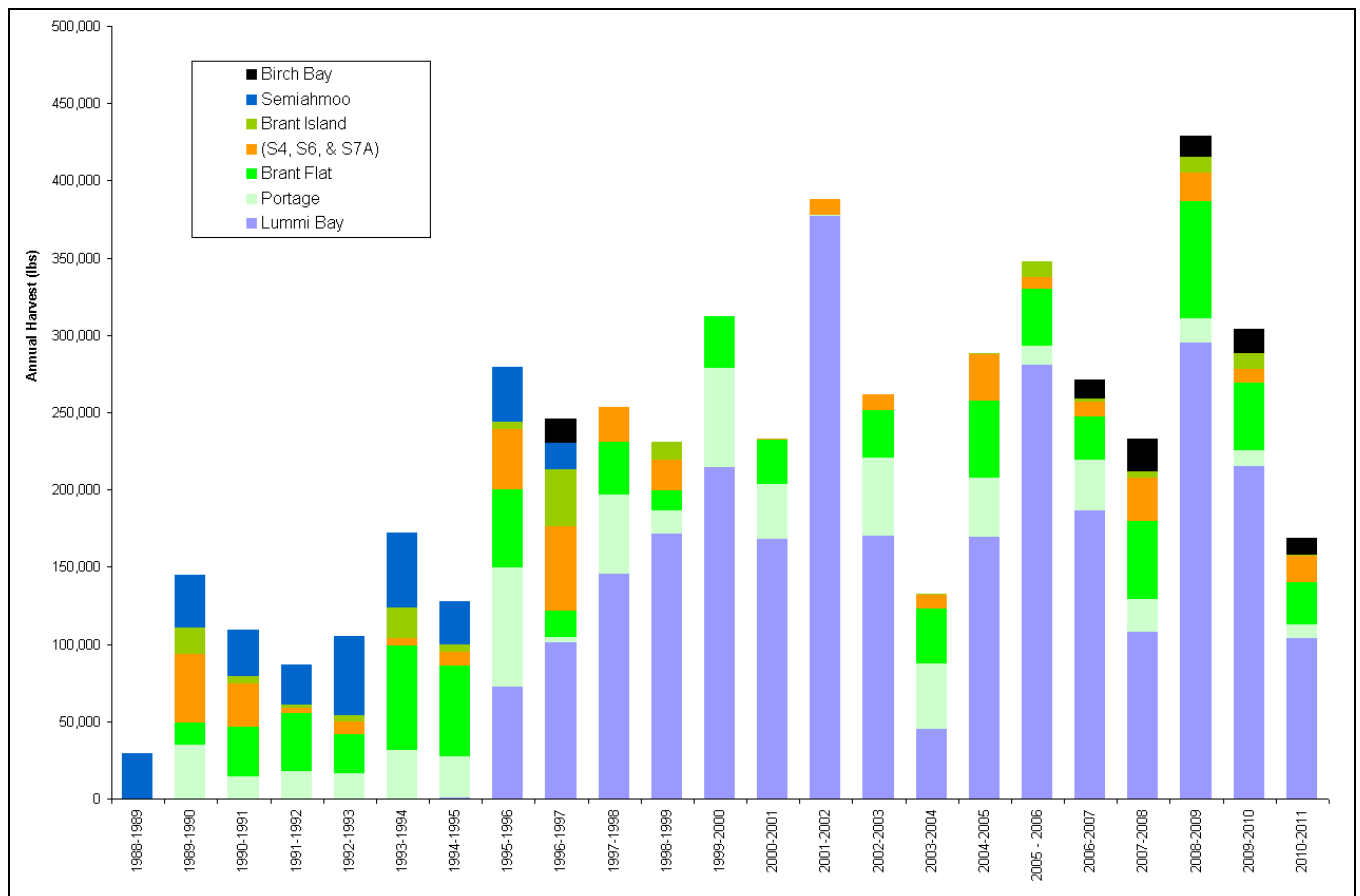


Figure 1. Recorded harvests (and significant known natural mortality events) since 1989 (Portage Beaches) and 1996 (Lummi Bay beaches)

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, and which was expanded again in December 2010 (Figure 2). Until the 2010 review, the conditionally approved portion of Drayton Harbor did not contain areas that were known to be productive enough to sustain a tribal harvest. However, the conditionally approved area now encompasses the portion of shoreline adjacent to the bluffs on the western part of the harbor. This area does contain a narrow ribbon featuring good densities of Manila clams and could now be considered as a viable option for springtime harvest. The conditionally approved area is unavailable for harvest from December Through February, and likewise for 6 days following any rainfall event larger than 0.75 inches in 24-hours.

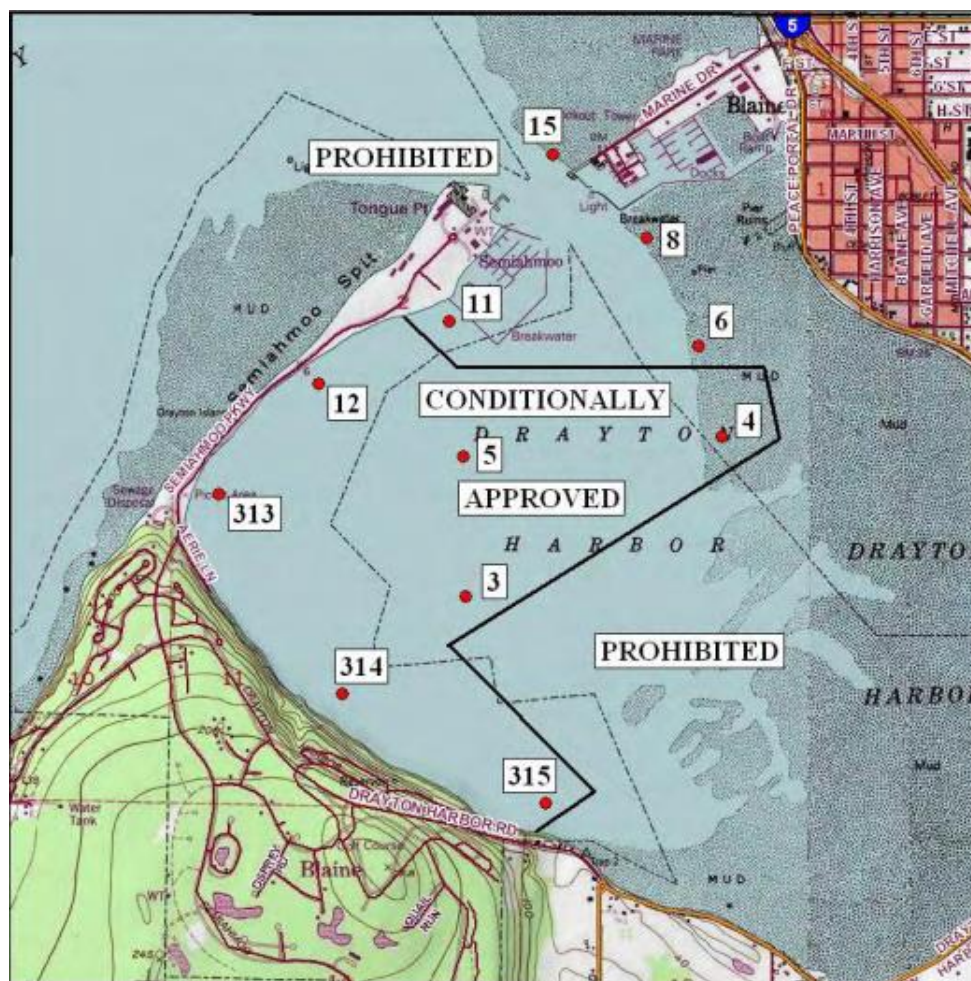


Figure 2. Map of Semiahmoo/Drayton Harbor showing current growing area status and water quality monitoring stations (WADOH 2010a)

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.

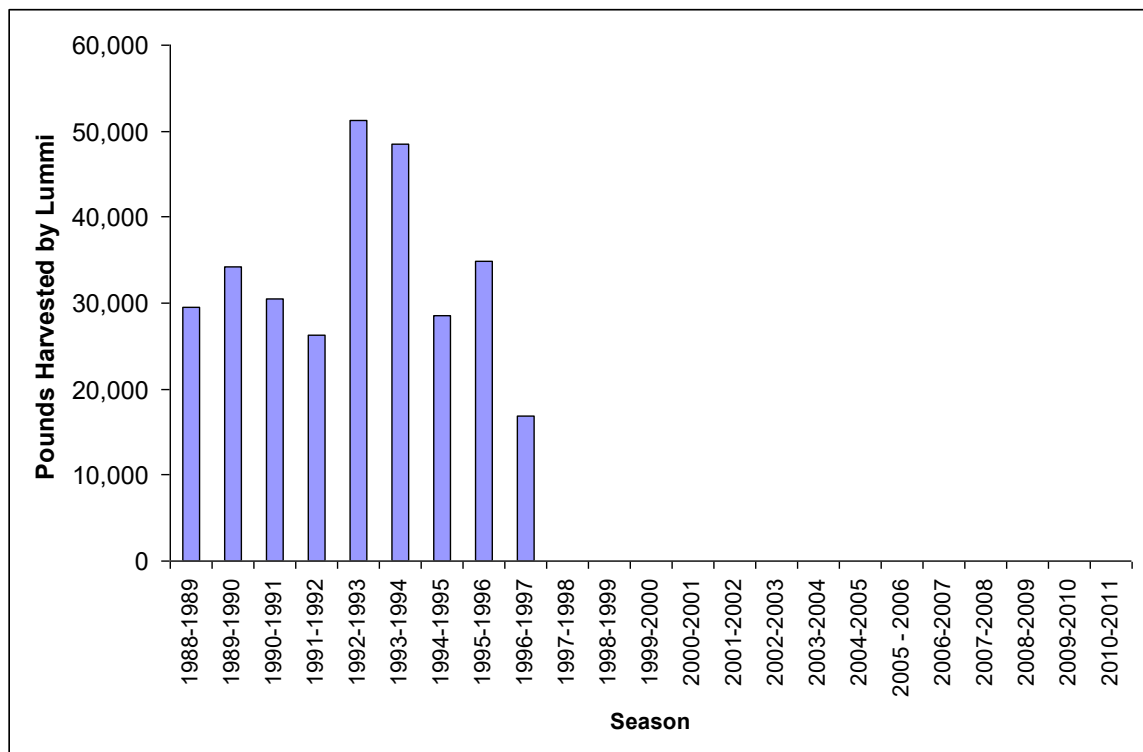


Figure 3. Recorded landings from Semiahmoo since 1988

Survey History

Drayton Harbor was surveyed by LNR in 2003 (Dolphin, 2003). At that time, c. 39 Acres were surveyed along the western portion of Drayton Harbor, and a biomass of 104,567 lbs of legal-sized Manila clams were estimated to be present within the survey boundaries (Figure 4). Based on the size-frequency distribution of the clam population, and using estimates for size-specific growth and natural mortality rates, it was estimated that the surveyed area could support a harvest of 22,667 lbs over the following year. If the 33% rate used in State-Tribal management agreements were used instead, then the TAC would have been set at 34,852 lbs.

Unfortunately, one productive portion of the surveyed area is a rocky reef located adjacent to the marina and which is not located within the conditionally approved harvest area. The conditionally approved area encompasses approximately 2/3 of the total biomass found in the surveyed area. Using this ratio, we would expect that a TAC for the conditionally approved area would probably be in the vicinity of 15,000 – 20,000 lbs. However, we will undoubtedly require more survey data and an update to the Region 1 management agreement if we wish to resume harvesting this beach. It is also possible that there are more Manila clams within the conditionally approved area that were not surveyed in 2003.

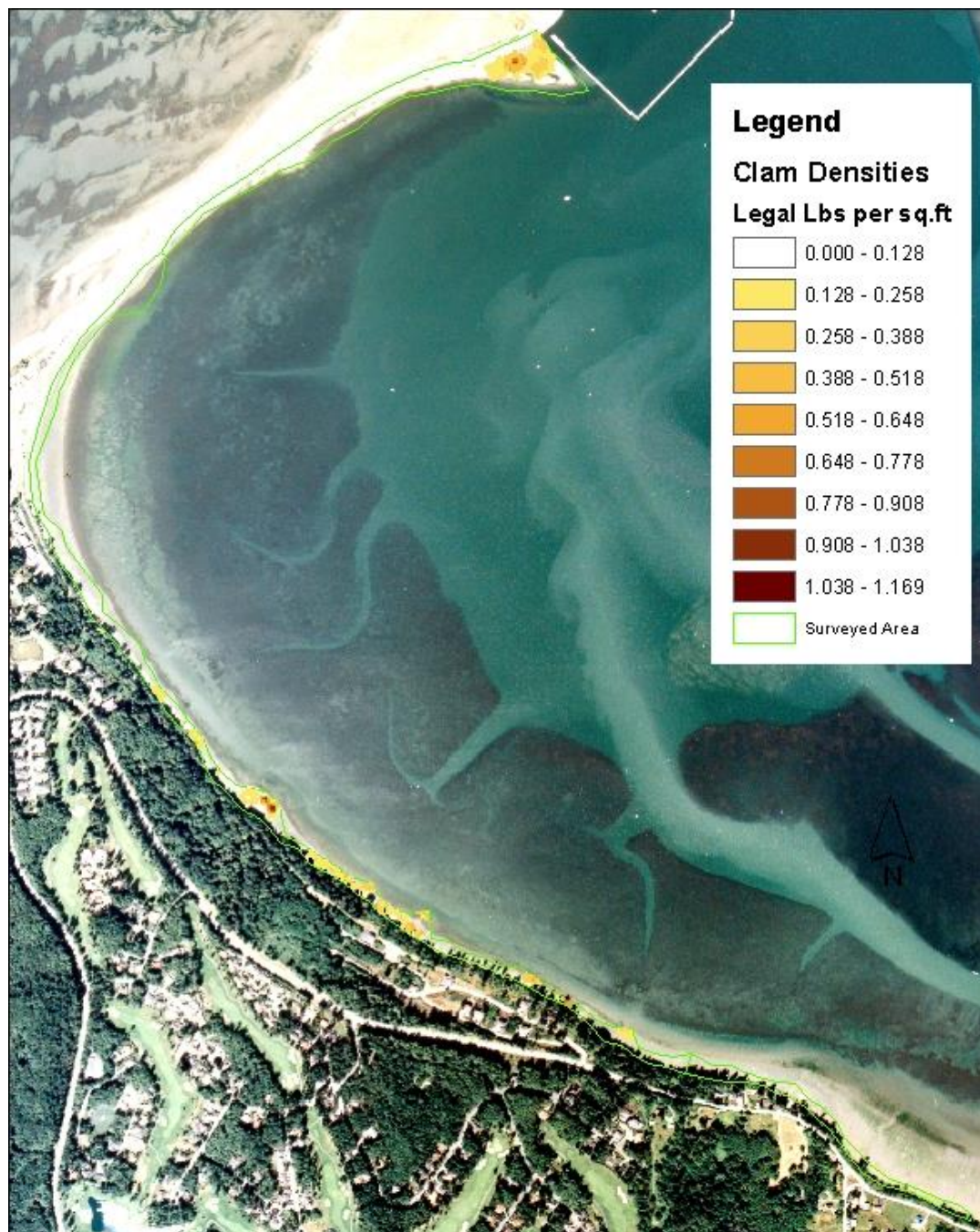


Figure 4. Clam densities in western Drayton Harbor based on 2003 LNR Survey Data

The only other survey conducted in the area was done by the Whatcom County Parks Department (Peterschmidt, 1990), which surveyed the outside of Semiahmoo Spit, and the portion of the inside of Semiahmoo Spit/Drayton Harbor near the marina. On the Drayton Harbor side of the Semiahmoo Spit, Peterschmidt estimated there was a biomass of c. 76,000 lbs present in the portion of beach surveyed, which is roughly 70% higher than was found in the same area in 2003. A further 40,000 lbs of Manila clams were estimated to be present on the outside of Semiahmoo Spit. LNR did not survey that part of Semiahmoo Spit in 2003.

Landings History

Prior to 2006, Birch Bay State Park (BBSP) was harvested only once during the period of record by Lummi clam diggers (Figure 6). Prior to 1997, tribal diggers were more interested in harvesting at Drayton Harbor than at Birch Bay. Partial closure of Drayton Harbor in the early 1990's led to tribal diggers experimenting with conducting a harvest at Birch Bay in 1997 to replace some of the lost opportunity at Drayton Harbor. However, digger dissatisfaction with the clam densities encountered there, together with travel costs, reduced enthusiasm for harvesting at BBSP. In more recent years, the growing number of tribal members participating in the clam harvest has increased pressure on the Manila clam population and led to greater interest in resuming off-Reservation harvest activities. Accordingly, clam harvests at BBSP resumed in 2006. The amount of clams harvested at BBSP has averaged approximately 15,000 lbs.

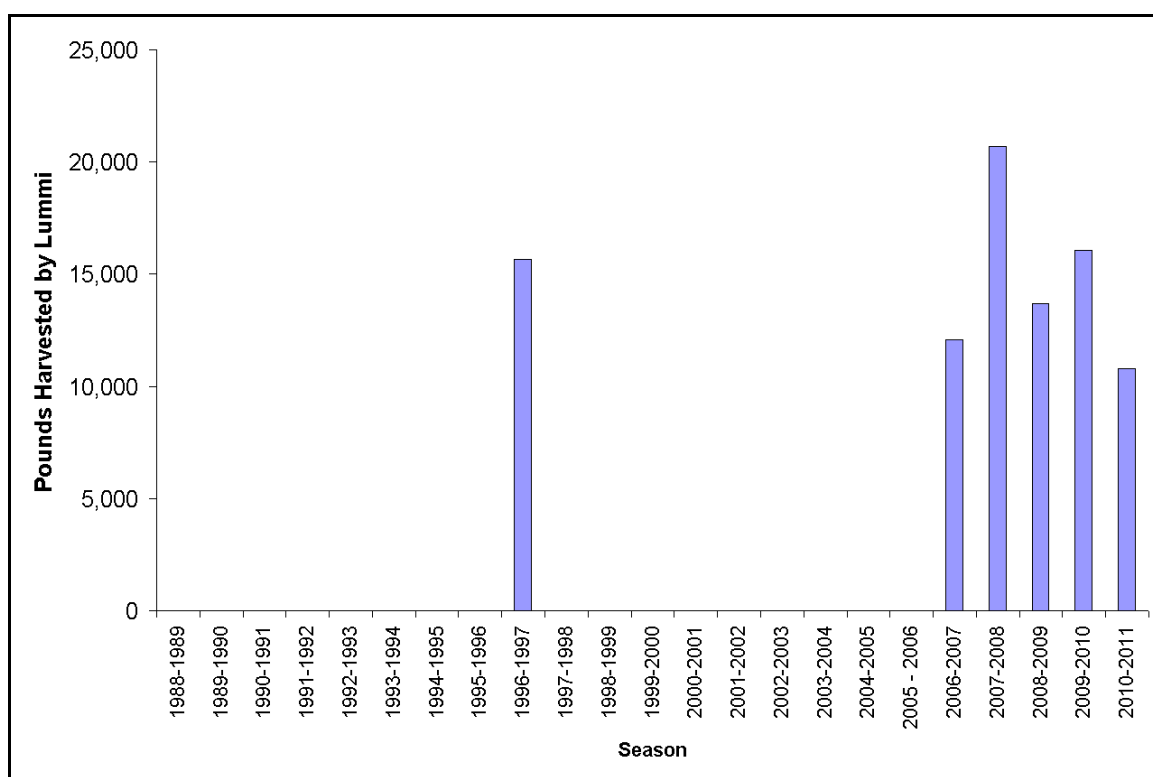


Figure 6. Recorded landings from Birch Bay State Park since 1988

Survey History

LNR has conducted stock assessment surveys at BBSP using Lummi protocols on three occasions: in 2003, 2004, and 2005. In addition, LNR jointly surveyed BBSP with WDFW personnel after a mass mortality-event was reported in 2006. WDFW separately surveyed BBSP in 2003, 2005, 2007, 2009, and also in 2011 (with participation by some LNR staff). Historically, WDFW have used the Campbell protocol referenced in the Region 1 Bivalve agreement to conduct surveys. In 2011, this approach was changed by agreement with the tribe so that the overall survey effort could be reduced while the original 30% precision goal could be attained. This outcome was made possible by stratifying the area to be surveyed using geopositioned survey results from previous tribal and state surveys to delineate the area that encompassed the majority of the Manila clam

population. The results of past surveys were also used to estimate the percentage of the biomass at BBSP present outside of the survey area, and to extrapolate the final biomass estimate for BBSP. In 2011, the WDFW/LNR survey results indicated that a population biomass of 94,590 lbs was present at BBSP, and that this would equate to a tribal TAC allocation of 24,972 lbs (Alex Bradbury, WDFW, Pers. Comm.).

Portage Bay History

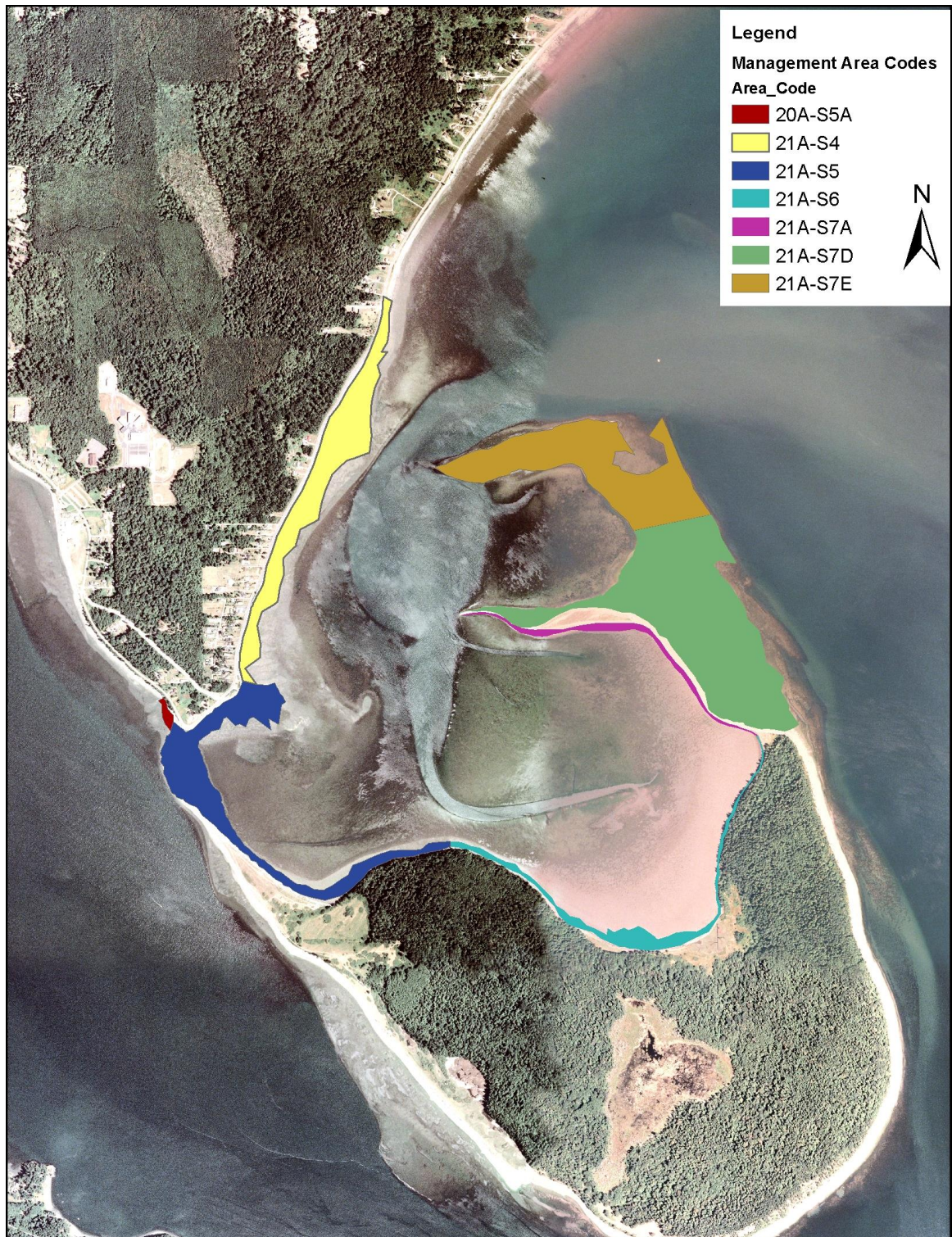


Figure 7. Portage Bay clam management area codes

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 8). 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 8. Map of Portage Bay and Hale Passage showing current growing area status and water quality monitoring stations (WADOH 2010c)

Landings History

Although clam harvests occurred in Portage Bay prior to 1989, no harvest records have been kept from that time period. Subsequent to 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 9). 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 when wholesale buyers exhibited a transitory preference for larger clams that were available from Lummi Bay, resulting in a shift in digger effort to Lummi Bay. In most seasons, buyers have preferred to buy the smaller and thinner-shelled clams from Portage Bay.

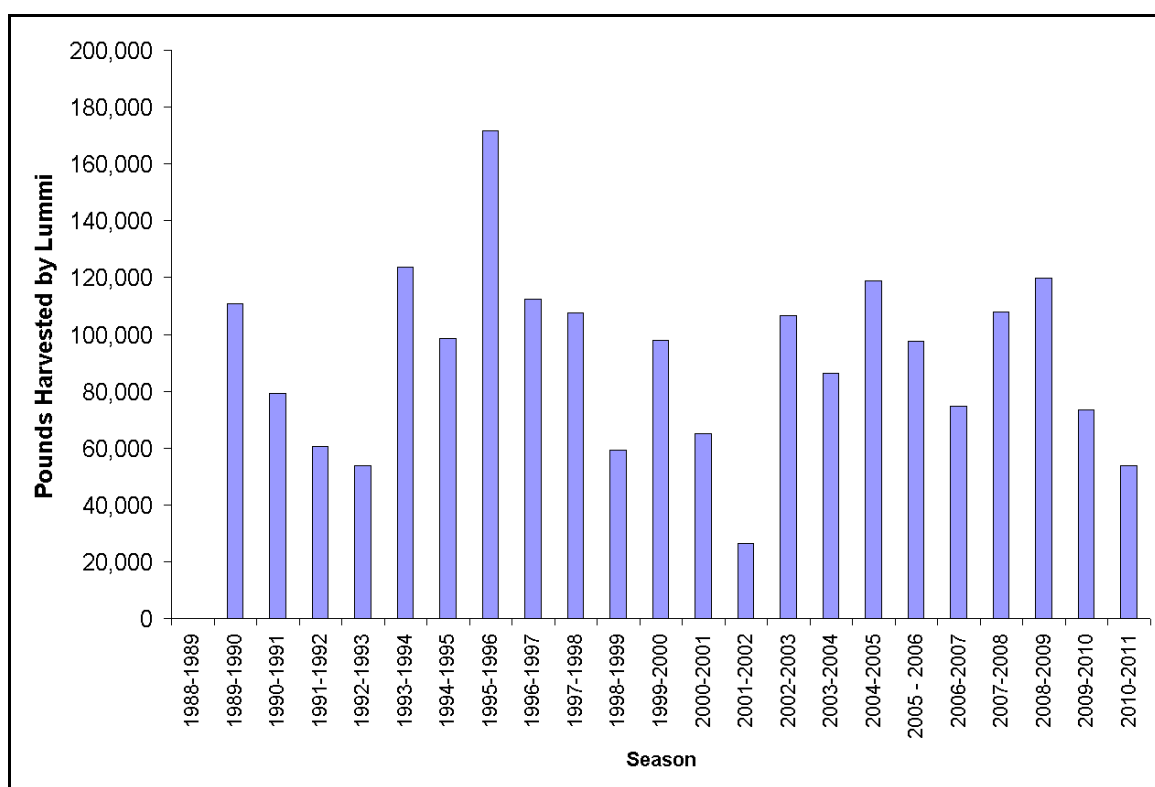


Figure 9. Recorded landings from Portage Bay clam management areas since 1989

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.

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

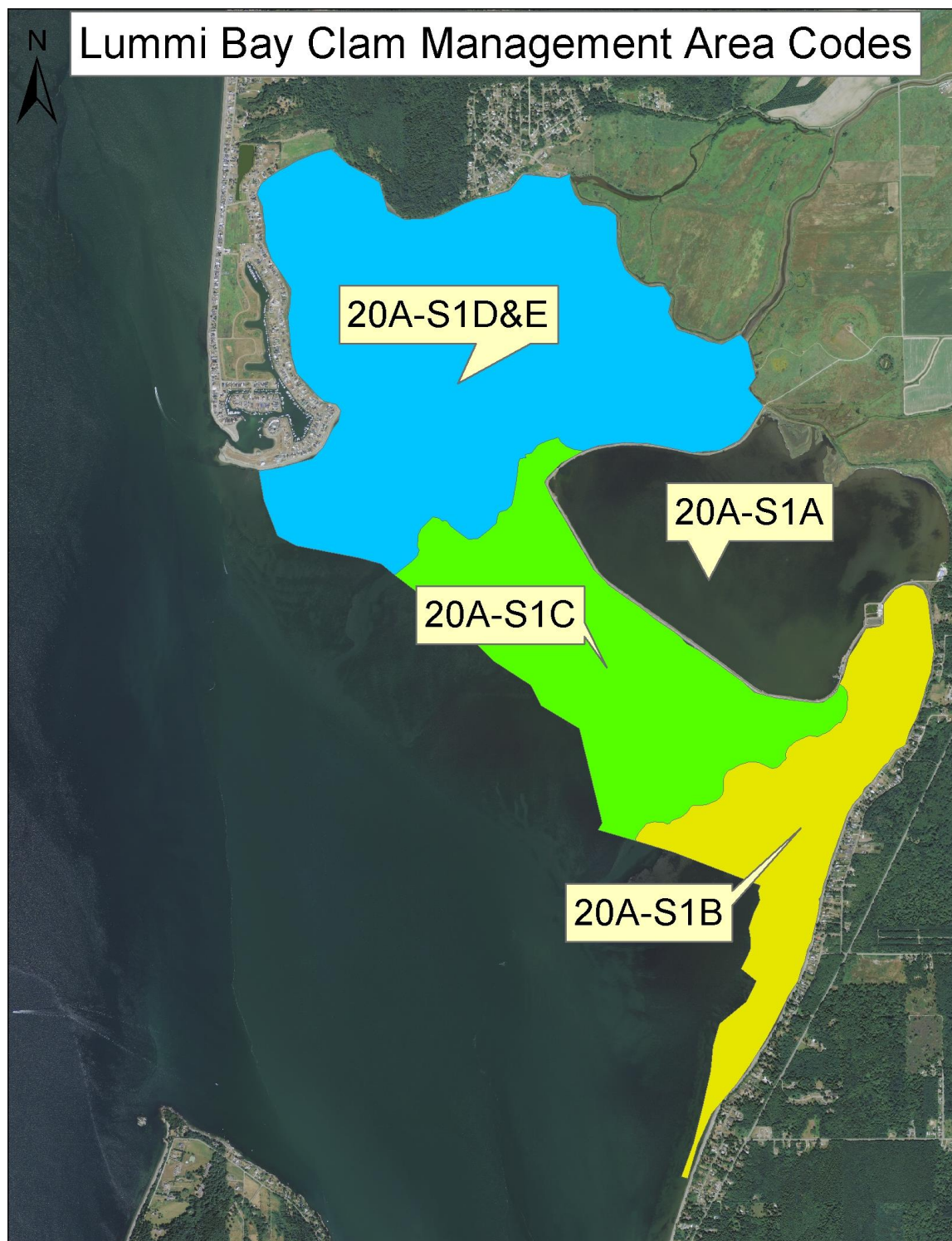


Figure 10. Lummi Bay clam management area codes

Growing Area Status

Lummi Bay has been an approved shellfish growing area (Figure 11) during the period of record.



Figure 11. Map of Lummi Bay showing current growing area status and water quality monitoring stations (WADOH 2010d)

Landings History

Prior to the 1994 season, Manila clams were not harvested from Lummi Bay. In 1994, the Lummi Bay Manila clam population was discovered and 780 lbs were harvested. Subsequently, digger effort quickly ramped up and eventually Lummi Bay became the dominant fishery for Manila clams, peaking during the 2001—2002 season at 377,000 lbs (Figure 12). Since 2000, total landings from Lummi Bay management areas have averaged 201,000 lbs per year.

The lowest annual harvest during this period was 45,000 lbs recorded for the 2003—2004 season. The reduced harvest in that season resulted from a reduction in effort caused solely by the increased reluctance of wholesale buyers to purchase clams from Lummi Bay that were deemed to be less marketable that year due to their larger size and thicker shells. This pattern of buyer preference was the inverse of that two seasons prior when Lummi Bay clams were strongly preferred.

The 2005—2006 season was impacted by a significant winterkill 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 live closer to the surface they are more vulnerable to wintertime freeze events than adults. As a consequence, it is likely that seed clams that settled in 2005 were the most badly effected year-class. Clams from that year-class would have reached legal size in the 2008—2009 season. The 2005 winterkill was equivalent to losing almost an entire year's harvest as well as disrupting recruitment for the following three years.

The other notable years for reduced landings were the 2007—2008 season, and the 2010-2011 season, when less than 110,000 lbs were landed from Lummi Bay in each season. These catch reductions were due to the reduced harvest targets based on the stock assessment survey results from the preceding year.

The 2008—2009 season landing of 295,00 lbs was the second highest on record but exceeded the recommended harvest targets arising from the 2008 survey. Compounding this issue was the fact that no stock assessment survey was conducted in 2009. This circumstance arose because of logistical constraints created by the Lummi Intertidal Baseline Inventory project that was being undertaken at the same time. As a result, harvest targets for the 2009-2010 season could not be derived using up-to-date empirical data and the management policy decision was taken to carry over the previous year's targets. An unreported winterkill is also suspected to have occurred on Portage Bay beaches and in central Lummi Bay (S1C) during the winter of 2008—2009. These circumstances combined to result in an unforeseen, severe, and widespread decline in stock abundance on most Reservation beaches that was finally detected during the 2010 survey. This resulted in the dramatic reduction in harvest for the 2010-2011 season.

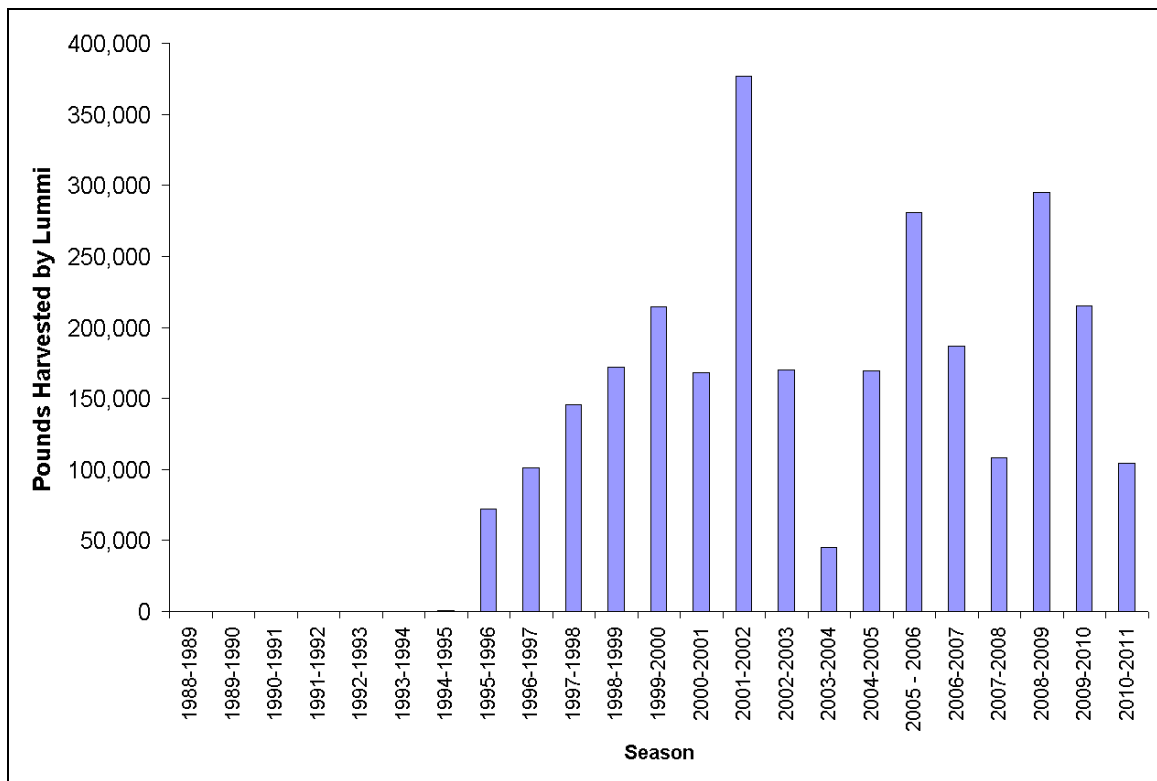


Figure 12. Recorded landings from Lummi Bay clam management areas since 1989

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 setback by the 2005 winterkill event, and again by an even more severe mortality event in the winter of 2008—2009.

Harvest effort in S1B (Robertson Road) has been sporadic over the years and 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 might be targeting this area in particular, probably due to ease of access.

General Harvest Strategy

Openings during the season 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. There is also a schism within the clam digger community between those who consider themselves to be ‘fulltime’ clam diggers (usually those that participate in the fishery both during the nighttime winter tides and the daytime spring tides) and others diggers who only participate primarily during the daytime tide series. The fulltime diggers are seeking to have more of the catch allocation set-aside for them rather than being left available for part-time diggers to harvest during the daylight tides.

2010 – 2011 Season Landings by Area

Table 1. 2010—2011 Season Landings by Management Area

On-Reservation				Off-Reservation			
Lummi Bay		Portage Bay		Birch Bay State Park		Semiahmoo/Drayton Harbor	
20A-S1B	34,867	21A-S4	6,442	20A-060	10,808	20A-001	0
20A-S1C	3,613	21A-S5	8,442				
20A-S1D	65,588	21A-S6	10,863				
		21A-S7A	0				
		21A-S7D	27,488				
		21A-S7E	682				
Total	104,068	Total	53,917	Total	10,808	Total	0

Approximately one third of the On-Reservation harvest was taken from Portage Bay, and the remaining two-thirds was harvested from Lummi Bay (Table 1). Landings from Reservation beaches during the 2010—2011 season totaled 157,985 lbs of Manila clams. This harvest was approximately 110,000 lbs lower than average, and is the 2nd-lowest annual harvest during the 16-year period of record. Lummi tribal diggers also harvested an additional 10,808 lbs of Manila clams off-reservation at Birch Bay State Park.

2011 Survey Aims

The purpose of the 2011 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 2011—2012 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, 2008, and 2010.

Field Protocol

Due to the size of the area to be covered at most beaches, and limitations in staff availability, it was not possible to use the Campbell clam surveying protocol to survey on-Reservation beaches. Instead, the Lummi survey protocol was developed to attain a maximum precision of $\pm 30\%$ for the final estimate of biomass despite employing a much larger block size. This is attainable because the very large areas to be surveyed still require a large number of samples to be excavated, even with large block sizes, and also by using larger sampling units that lower the detection threshold and reduce sample variance.

Similar to the Campbell protocol, the Lummi protocol 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 is maintained by using distant visual reference points, such as mountain peaks, houses etc, and walking directly toward that same reference point after each sampling station is excavated. The spacing between the transect lines is similarly determined using a pre-determined 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 are 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 separates each sample station. The number of paces between stations in each transect line is 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 are not possible due to the limitations on the precision of the relatively inexpensive handheld GPS unit used to spatially geolocate each station.

At each sample station, a quadrat is established, using either a 2.25 ft² (Portage Bay) or a 9 ft² (Lummi Bay) square frame constructed out of PVC pipe. The size of the quadrat being used is noted at the bottom of each data sheet. The position of each sample station is determined using a hand-held WAAS enabled Garmin

GPS unit ("Etrex Legend", "Etrex Summit", etc), set to display decimal degrees (NAD 83), and recorded on a data sheet. The Etrex has a theoretical accuracy of ± 9 ft with WAAS enabled, but typical operating accuracies vary between 10 and 25 feet.

The top 4 - 6 inches of the substrate is excavated using various implements, such as specially sharpened, cut-down rakes. All Manila clams found in the quadrat are removed to the best ability of each digger as the ground is excavated, and then piled on a plastic bag to ensure none re-bury themselves while the rest of the quadrat was being excavated. The shells of the manila clams are then measured, to the nearest 1mm, with a pair of plastic calipers with 1mm graduations.

The clamshell dimension chosen for measurement in the Lummi surveys protocol is shell width rather than shell length as is more customarily the case. This is 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 Manila clam are recorded on the data sheet beside the GPS coordinates for that quadrat. Other species of clams, such as native littleneck clams (*Leukoma staminea*), Mahogany clams (*Nuttalia obscurata*), Softshell clams (*Mya arenaria*), butter clams (*Saxidomus giganteus*), and cockles (*Clinocardium nuttalli*), are also counted but no size measurements are recorded for these non-target species. Macoma clams (*Macoma* spp.) are also encountered frequently but these are not recorded. However, counts of species other than Manila clams and Cockles are probably incomplete because they typically live deeper in the substrate than Manila clams and could easily be missed using this protocol.

The identification of Manila clams is primarily based on external morphology. In particular, this is accomplished using the presence of a 'scooped out' hollow found immediately posterior to the dorsal hinge. The same part of the shell in native littleneck shells usually has a ridge extending up to the hinge and looks less 'scooped out'. Any clams that are particularly difficult to identify using the overall shell shape, and the 'scooped out hollow' characteristic, are opened up and internal shell characteristics are 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 are returned to the excavated holes and given the opportunity to rebury themselves.

Data Processing

GPS co-ordinates, quadrat size, and individual shell widths are entered into a custom-built Microsoft Access database. In the past, Length-weight data attributed to an unsourced WDFW Manila clam survey in Birch Bay was 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. Based on these samples, beach-specific shell-width-weight relationships were derived and are now 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 only half of the clams that were recorded to be equal to the legal size threshold were actually legal sized, and the remaining half would have been marginally sublegal. Unfortunately, it is not possible to determine which of these threshold-sized individuals were sublegal afterward. Including these 'sublegal' clams would artificially inflate the final biomass estimate and, conversely, excluding all of the threshold clams would underestimate the final biomass estimate. Consequently, the approach used in our analysis is 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 Bay and Portage Bay beaches, while the more globular-shaped clams at Lummi Bay had a threshold shell width of 21mm.

Sub-legal clam weights in each quadrat are determined by subtracting the legal-sized clam weight for each quadrat, from the total clam weight for each quadrat. Legal sized clam densities for each quadrat are then 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 is then used to export a table with the following columns: latitude, longitude, and legal pounds per square foot. This table is imported into ESRI ArcMap 10 GIS software and displayed using the GPS coordinates to determine the spatial location of each quadrat. At this point, the data is 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 are obviously out of their correct place are then 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 is used instead, and the revised data is re-imported into the ArcMap GIS software. This process is performed iteratively to ensure data integrity and accuracy. From the revised file, a final point shapefile is finally created and used as the basis for subsequent 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 measured clam densities could result in significant bias since clam densities also vary spatially. Consequently, spatial analysis of the data is 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 is analyzed using Thiessen polygons (Dolphin, 2004a). The software used is ArcGIS 10 (ESRI), which includes ArcMap, ArcCatalog, and ArcToolbox.

Firstly, polygon shapefiles are created within ArcMap that connect up all the end points of the transect lines on each beach that form polygons enclosing the entire surveyed area for each beach. These survey area polygons are 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 the extent included more than one management area. The 'snapping' feature of the shapefile editor was used to get the best possible accuracy.

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.

A Thiessen polygon layer is then created from the survey data point shapefile using the Thiessen Polygon Tool in ArcToolbox. The Thiessen polygon layer produced by this tool includes all of the attribute fields from the original point shapefile and covers the entire vertical and horizontal extent of the data. To reduce the output to match the shape of the survey area, this Thiessen polygon layer is clipped to match the survey area polygon layer using the Intersect Tool in ArcToolbox. The result of this process is a new polygon shapefile that has a polygon surrounding the area represented by each of the survey points, and limited to the boundaries of the survey area.

The attribute table for the new shapefile contains all of the fields from the original point shapefile, as well as from the survey area polygon shapefile. The Leg_Lbs_Ft field contains the surveyed legal-sized Manila clam densities (lbs/ft²). The Xtools extension for ArcGIS is then used to add attribute fields to the shapefile table, which represent the Area (ft²) and Acreage of each polygon within the layer.

This shapefile is used as the basis for estimating biomass in the total surveyed area, and is also subsequently clipped into separate management areas, using the management area polygons derived earlier, to calculate 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 Area field in the final Thiessen polygon table is summed to calculate the surveyed area in square feet.

Further operations necessary for further analysis

It is necessary to export the attribute table into a format compatible with spreadsheet software (e.g., Microsoft Excel) to perform further mathematical operations. We export the data as a dbf table for this purpose, and then open the file in Excel.

In the spreadsheet workbook, the area column is summed to derive a grand total for the area surveyed. A 'Proportion' column is then added to the spreadsheet. The values in the proportion column are calculated by dividing each polygon's area by the grand total of the surveyed area, and the values are rounded to 5 decimal places. Note that the summed values in the 'Proportion' column equal 1.

Another new column is then created which is named 'Proportion Squared'. This column contains values that are calculated by squaring the values in the 'Proportion' column.

The final column to be added to the spreadsheet is named 'Biomass' and the values in this column are calculated by multiplying the value in the 'Proportion' column by the corresponding clam density value from the 'Leg_Lbs_Ft' column.

To calculate the spatially weighted average clam density

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

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

Where X_i represents 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 is calculated by summing all of the values in the 'Biomass' column.

Precision of the estimate

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

95% Confidence Intervals are calculated by the following equation:

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

And the Standard Error is calculated using the equation:

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

...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 unmodified standard deviation of the observations in Equation 3. Instead, the spatially weighted standard deviation of the spatially weighted average has to be calculated, which first requires calculating the spatially weighted variance.

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

$$\mathbf{\text{Var}_w = s^2 \cdot \left(\sum_{i=1}^n w_i^2 \right)} \quad \dots \text{Equation 4}$$

...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 Leg_Lbs_Ft 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.

The weighted standard deviation (s_w) is finally obtained by calculating the square root of the weighted variance.

Once the weighted standard deviation is known, the spatially weighted standard error of the weighted mean is calculated using equation 3, and then the half-width of the spatially weighted 95% confidence interval is calculated 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 are 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 are put in a column beside the size-frequency data, and the collective weight of all individuals within that size increment is calculated in the next column. The cumulative weight of individuals that are estimated to have a shell-length of 38mm or larger is 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 grow during the following year, the 'population' represented by each size-frequency distribution was 'grown out' using the spreadsheet. To do this it is necessary to make predictions about growth rates and natural mortality rates that will occur over the following year.

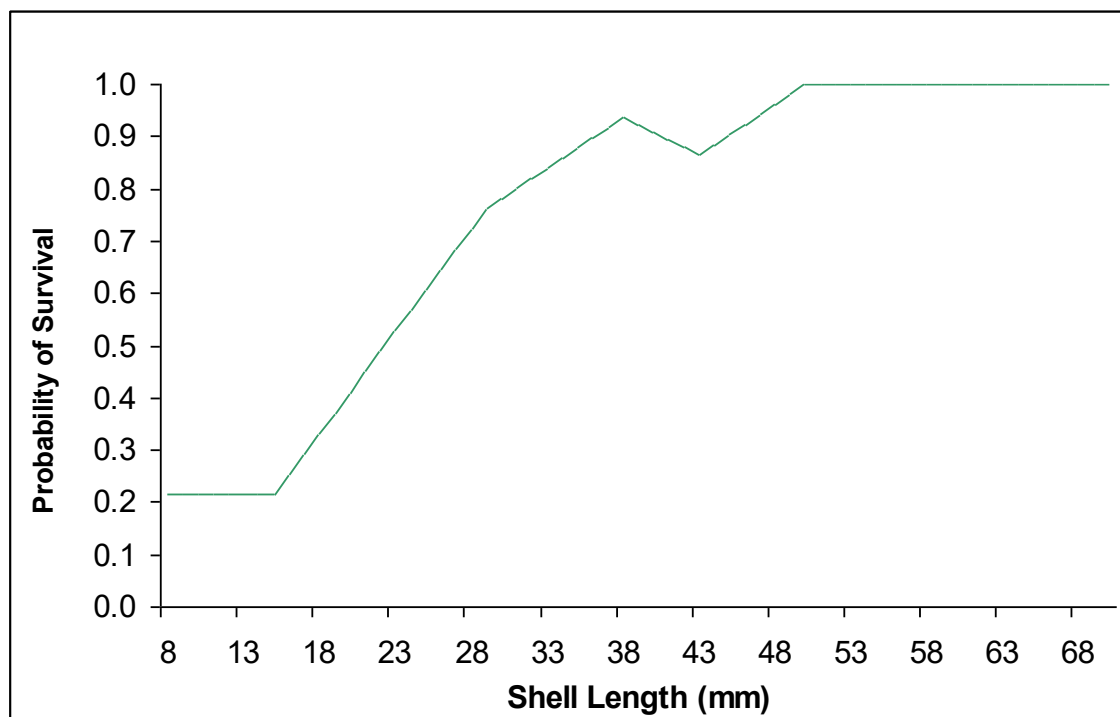


Figure 13. Survival rates used in calculating Production Estimates (from Dolphin, 2004b)

Clam survival and growth rates were obtained from a 2004 grow-out experiment in Lummi Bay (Dolphin 2004b), and these are incorporated into production rate calculations. Figure 13 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.

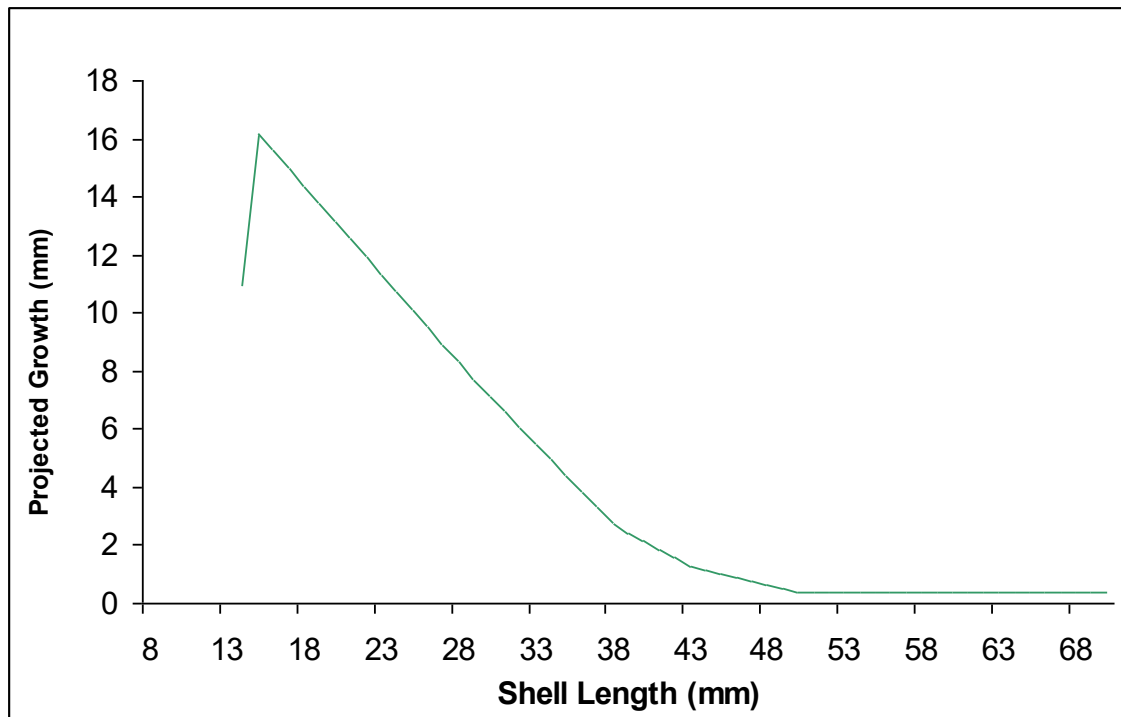


Figure 14. Annual size-specific growth rates used in calculating production estimates

Annual growth rates used to ‘grow-out’ the observed size-frequency distribution by one year are shown in Figure 14. The relationships in Figure 13 and Figure 14 are converted to equivalent shell widths 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 the clams that will exceed the legal-size threshold next year is then divided by the same ‘sampled area’ in order to predict the clam density that is expected to be present the following year. The predicted sample estimate is 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 can then be predicted by multiplying next year’s calculated clam density by the area surveyed. 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, the LNR Shellfish Biologist conducted an independent resurvey of a section of Lummi Bay in 2010. No statistical difference was found to exist between the results of the resurvey and the contractor. In addition, an LNR shellfish technician was assigned to accompany the contractor in the field during 2011 for a portion of the time.

Results

Survey activities began on June 13 and ended on September 13. Clam populations were surveyed in Lummi Bay and in the two most important of Portage Bay beaches (Portage Spit and Brant Flats). The survey of Brant Island was begun but not completed. Survey results are presented in Table 2. Clam density maps for Lummi Bay, Portage Spit, and the Brant area are presented in Figure 15, Figure 16, and Figure 17 respectively.

Table 2. Summary of 2011 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	432	2.25	25.5	0.043448	15.26%	40,873	48,230	55,588
S6					Not Surveyed			
S7A					Not Surveyed			
S7D	622	2.25	37.3	0.071239	11.85%	102,088	115,808	129,527
S7E					Not Surveyed			
All Combined	1054		62.8			142,961	164,038	185,115
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	283	9	186.4	0.02756	16.87%	182,962	218,663	254,364
S1C	184	9	255.3	0.01284	23.84%	108,749	142,793	176,836
S1D & S1E	397	9	869.7	0.02114	17.85%	657,842	800,795	943,728
All Combined	1,063		1,398.1			952,643	1,167,399	1,382,154

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

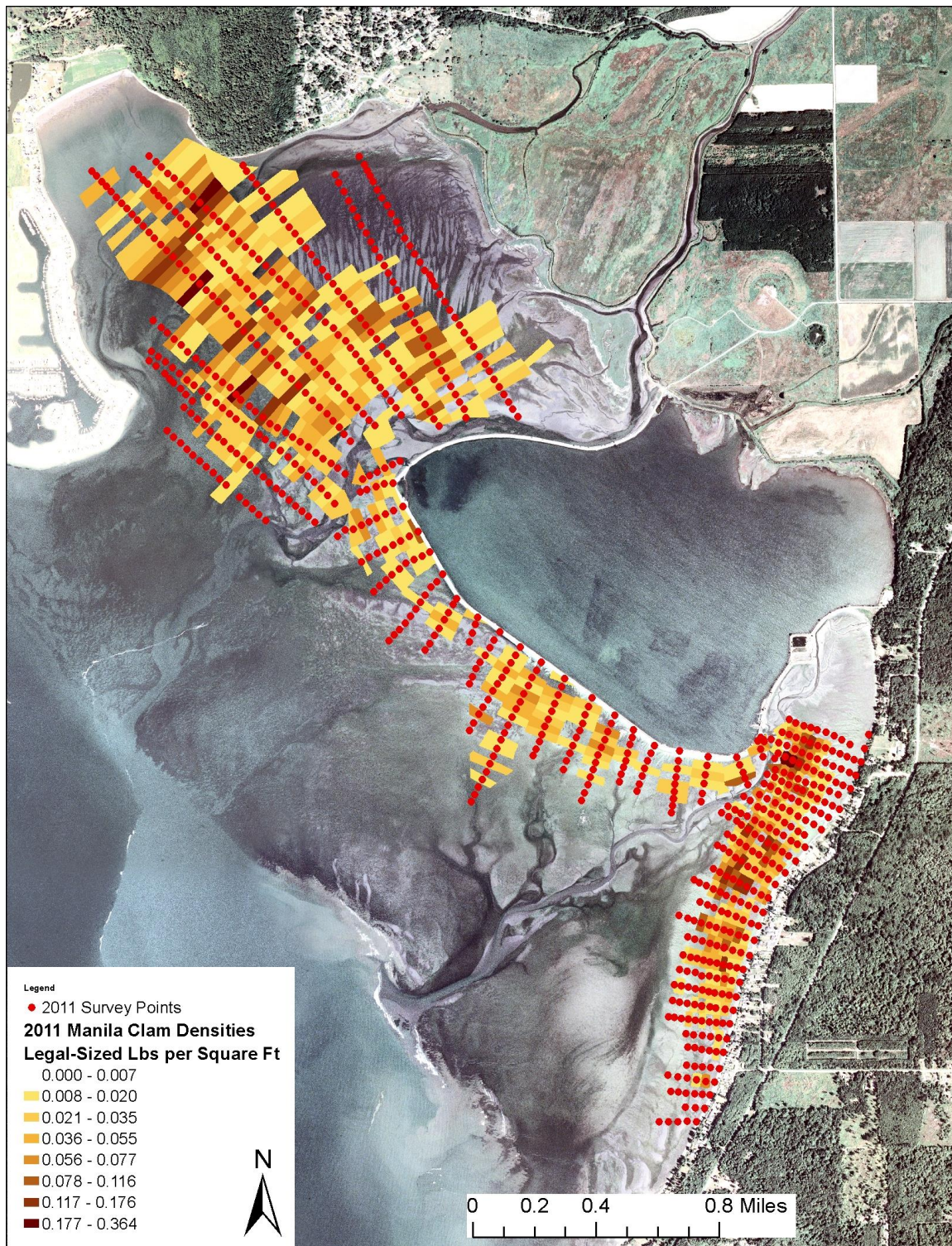


Figure 15. Legal-sized Manila clam densities in Lummi Bay based on 2011 survey data

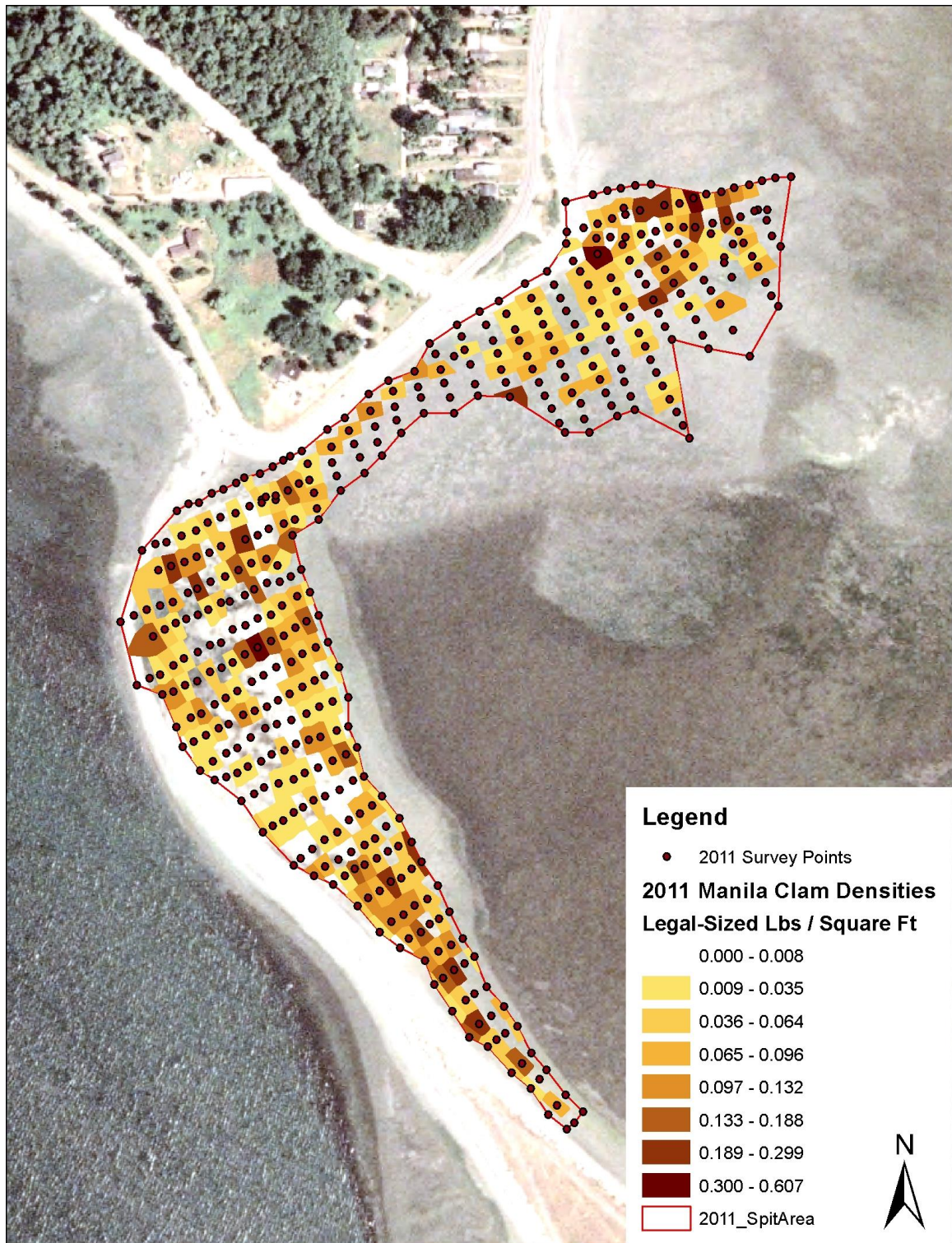


Figure 16. Legal-sized Manila clam densities at Portage Spit based on 2011 survey data.

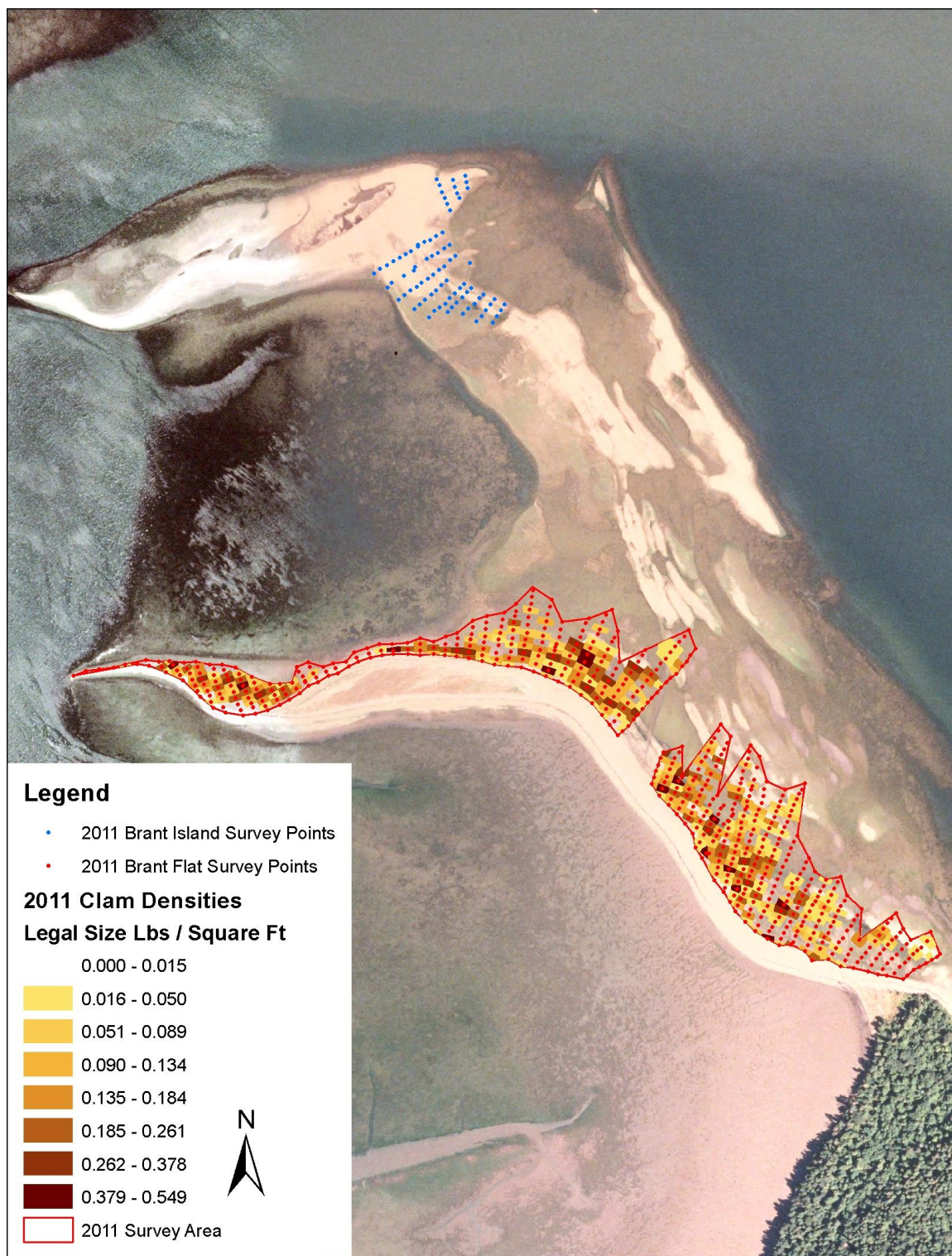


Figure 17. Legal-sized Manila clam densities surveyed at Brant Flats in 2011

Although most beaches are surveyed annually, and large proportions of the area are typically surveyed each year, the full extent of the beach area that is surveyed differs from year to year. Consequently, it is not always meaningful to directly compare the different survey results across years. However, a meaningful comparison can still be made between the clam densities found inside the sections of the beach that are common to multiple surveys. By restricting the analysis for subsequent surveys to just those results that are located within the common area, an index of clam biomass can be produced that approximates the total biomass present each year. Figure 18 shows the relative change in the biomass present in the each management area surveyed in Lummi Bay, and Figure 19 shows relative change in biomass in management areas in Portage Bay.

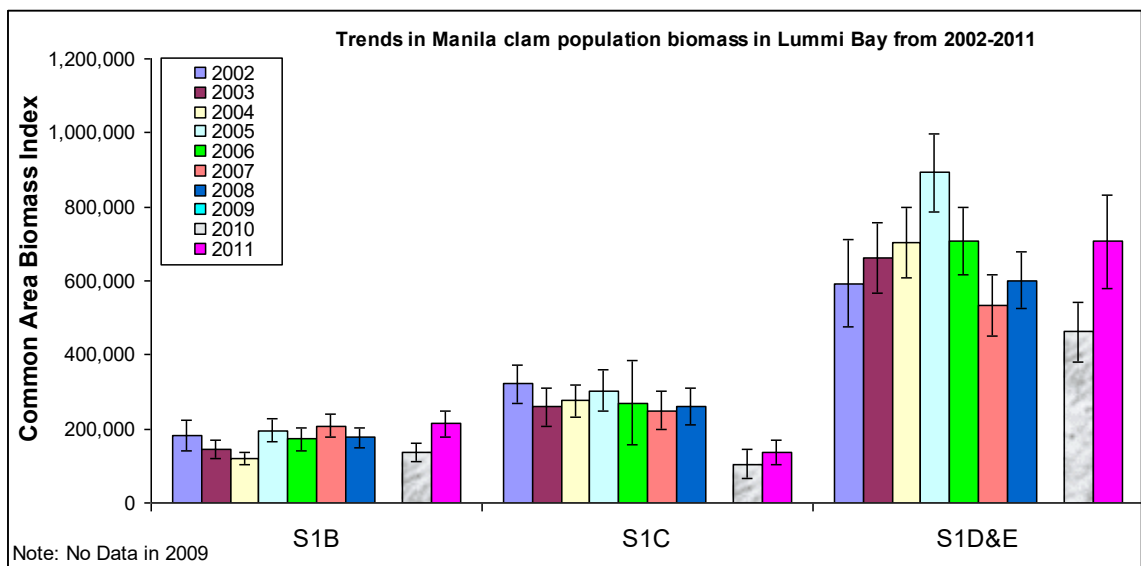


Figure 18. Relative change in legal clam biomass in Lummi Bay management areas from 2002 to 2011 (Error bars indicate 95% Confidence Limits)

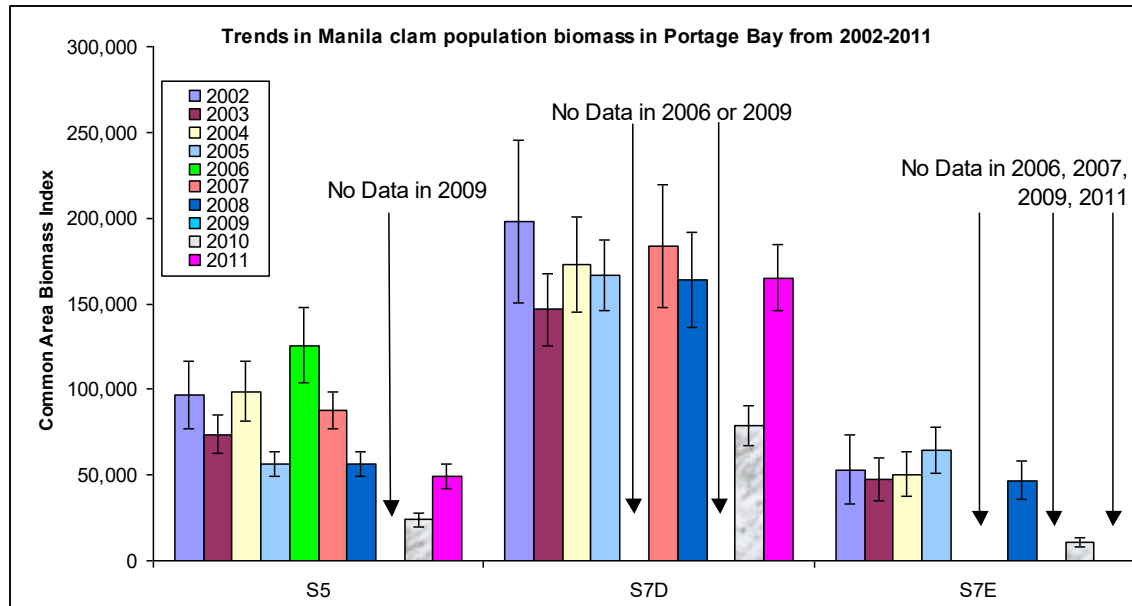


Figure 19. Relative change in legal clam biomass in Portage Bay from 2002 to 2011 (Error bars indicate 95% Confidence Limits)

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

	Lummi Bay			Portage Bay			Birch Bay State Park
	S1B	S1C	S1D&E	S5	S7D	S7E	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
2011	18,270	12,292	57,059	20,502	52,215	N/A	N/A

Production estimates for each beach, based on the 2011 survey data, are presented in Table 3 along with previous estimates that were derived from 2002 – 2010 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 these beaches has changed since 2002, the recommended harvest strategy for 2011–2012 does not directly reflect the anticipated production for the coming year. The recommended harvest amounts for all approved areas that have been surveyed in 2011 are detailed in Table 4 and these values are shown in context with previous harvests in Figure 20.

Table 4. Recommended harvest targets based on 2011 survey data, by beach

Management Area	2011 Recommended Harvest
North Lummi Bay (S1D&E)	114,190
Mid Lummi Bay (S1C)	5,000
South-East Lummi Bay (S1B)	34,562
Portage Spit (S5)	20,898
Brant Flat (S7D)	57,882
Brant Island (S7E)	0
Birch Bay State Park	24,972
Overall Total	257,504**

**Excludes clams harvested from S4, S6, or S7A

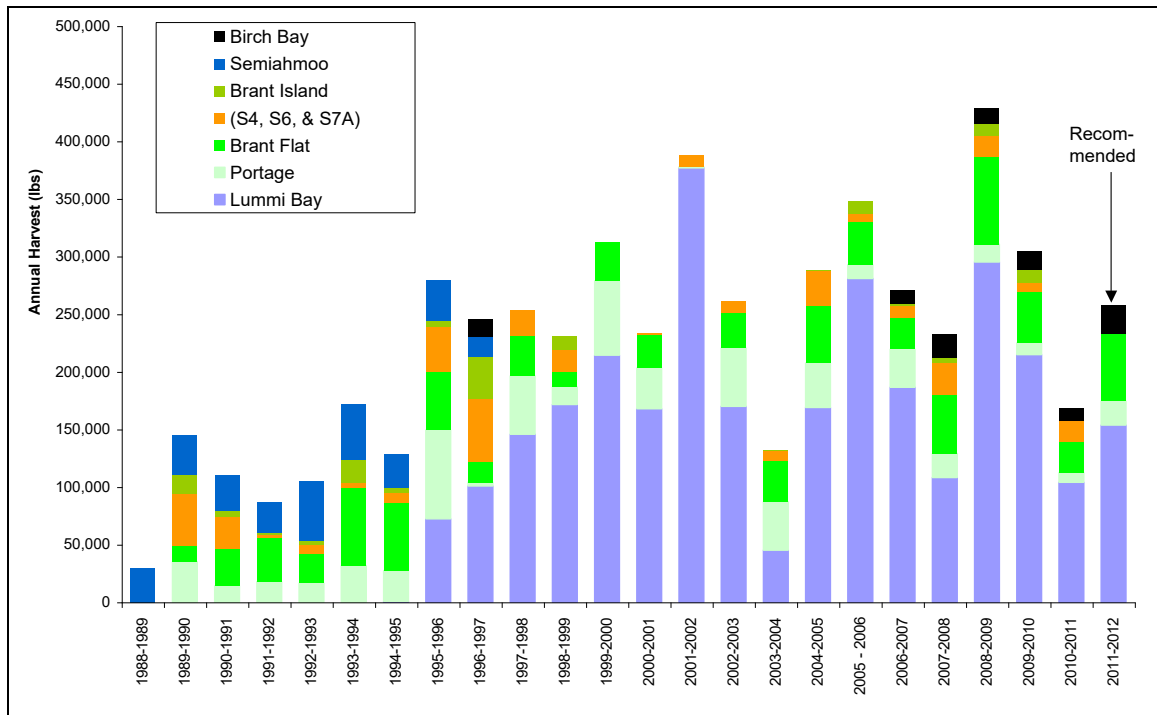


Figure 20. Comparison of proposed harvest targets to past landings (Proposed targets do not include any clams harvested in S4, S6, or S7A)

Discussion

Manila clam populations on some beaches in Portage Bay and Lummi Bay have recovered somewhat from the extreme low densities that were found in the 2010 survey. Northern Lummi Bay, Southern Lummi Bay (Robertson Road), and Brant Flats in particular have recovered well, while Portage Spit has improved slightly but remains below the longer-term average.

By contrast, clam densities at Central Lummi Bay have only improved slightly, and remain close to half of that found during surveys in most previous years. The long-term failure of the Central Lummi Bay management area to recover despite minimal harvest efforts suggests either that this area in particular is not receiving enough larval recruitment to maintain the population at historic levels, or that natural mortality rates in this area have increased above historic norms for the area.

Given that larval-source population locations, flow patterns, and freshwater inputs have not changed appreciably since 2002, it seems unlikely that the number of larvae passing over this beach during high tide would have changed greatly. However, it is possible that something about the area may have reduced the number of larvae choosing to settle onto the substrate, or decreased the likelihood of survival for those that settle in the area. One such possibility is that the substrates on this beach have changed in a way that has adversely impacted the Manila clam population.

Although we have little empirical data to evaluate this hypothesis, there is some reason to believe that the extent of the beach impacted by very soft substrates may be increasing over time. Very soft sediments may reduce larval survival by making it easy for predators such as waterfowl, crab, fish, etc to find and capture young clams.

The area of the tidelands immediately north of the boundary between S1C and S1B features a very soft mud layer that has been deposited over an undulating hard-packed sand layer. This results in highly variable soft substrate that can vary in hardness depending on whether you step on the crest or trough of the old sand 'dunes'. The existence of this soft layer probably resulted from a change in circulation patterns within Lummi Bay that were caused by the construction of the Seapond Aquaculture facility in 1971. The author's subjective impression is that the extent of soft mud may have increased over the past 10 years. Likewise, the survey contractor Wilbert LaClair has mentioned that there have been noticeable changes in the substrate in his lifetime, and that sand dollars have become much more widespread and abundant in recent years. It is possible that the substrate composition of this beach is still continuing to slowly change in response to the construction of the seapond. If so, then it is possible that the population of Manila clams in this area may continue to decline until the sediments in the area reach a final equilibrium state. One solution to this would be to add gravels to the remaining productive areas to enhance the survival of young clams. However, since more larvae appear to be settling in the northern and southern parts of

Lummi Bay, it seems probable that gravelling those beaches would result in a higher return on investment.

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