CLAM POPULATION VARIABILITY WITHIN A PUGET SOUND BIVALVE MANAGEMENT REGION

Julie S. Barber, Todd Mitchell, Jim Gibson, Tiffany Hoyopatubbi,
Tanisha Gobert, and Annitra Ferderer

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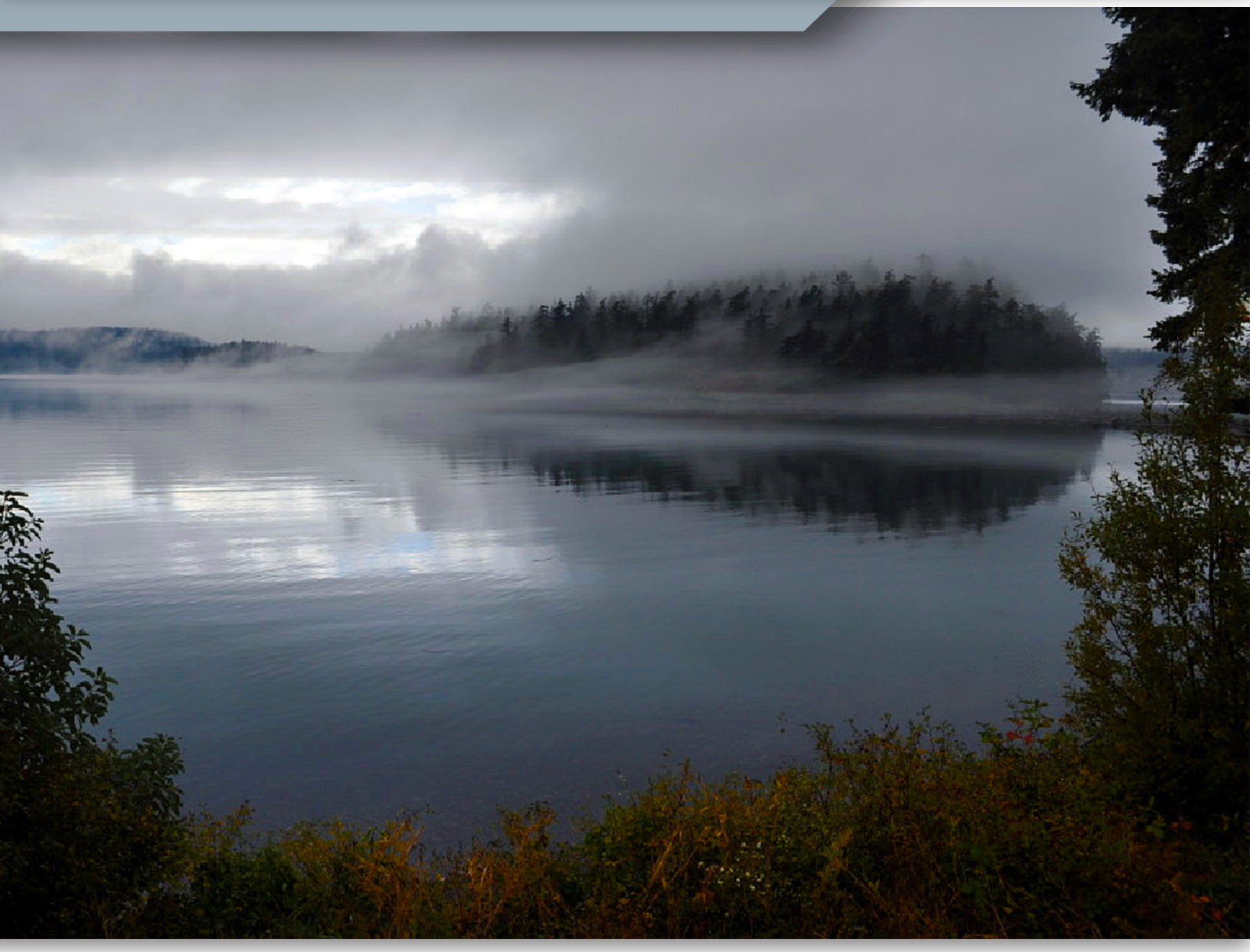

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Table of Contents

Abstract…… 4
Introduction…… 5
Methods…… 7
Individual beach surveys…… 7
Temperature data…… 8
Length-weight models…… 8
Temporal change in biomass of *Saxidomus gigantea*…… 9
Clam weight frequency distributions…… 10
Clam biomass among sites…… 10
Results…… 10
Individual beach surveys…… 10
Temperature data…… 11
Length-weight models…… 11
Temporal change in biomass of *Saxidomus gigantea*…… 14
Clam weight frequency distributions…… 18
Clam biomass among sites…… 18
Discussion…… 22
Individual beach surveys…… 22
Temperature data…… 24
Length-weight models…… 24
Temporal change in biomass of *Saxidomus gigantea*…… 26
Clam weight frequency distributions…… 26
Clam biomass among sites…… 27
Conclusions…… 28
Acknowledgements…… 29
References…… 29

Front cover photo: Jim Gibson

List of Tables

Table 1: Beach area surveyed by year and site ……..……..…… 7

Table 2: Estimated biomass (kg) of legal-sized clam species and suggested total allowable catch (TAC) for the annual harvest …… 10

Table 3: Region 4 and beach-specific length-weight model parameter values …… 14

Table 4: Variance-covariance matrices for Region 4 and beach-specific models by species……... 14

Table 5: Mode estimated weight of clams at 38 mm and 60 mm…….. 16

Table 6: Kolmogorov-Smirnov results comparing size frequency distributions of clam species on individual beaches…….. 22

Table 7: Kruskal-Wallis and post-hoc Conover-Inman results on differences in weight of clams per m^2 quadrat by site ……..…….…….…... 23

List of Figures

Figure 1: Location of beaches surveyed in 2010 and 2011…….. 6

Figure 2: Example of a survey designed in ArcGIS 9.3……..... 8

Figure 3: Biomass of clam species at Lone Tree Point and Blowers Bluff in 2011…….. 9

Figure 4: 2011 cockle (*Clinocardium nuttallii*) biomass at Blowers Bluff……... 11

Figure 5: 2011 biomass of common clam species at Lone Tree Point…….. 12

Figure 6: Intertidal temperature from Lone Tree Point……. 13

Figure 7: May 2011 intertidal temperature from Lone Tree Point and verified tide data from Port Townsend…….……...…. 13

Figure 8: *Saxidomus gigantea* length-weight models and predicted weights with 95% confidence intervals…….……. 15

Figure 9: *Saxidomus gigantea* Region 4 length-weight model compared to beach-specific models 16

Figure 10: *Clinocardium nuttallii* length-weight models and predicted weights with 95% confidence intervals…….…….. 17

Figure 11: *Clinocardium nuttallii* Region 4 length-weight model compared to beach-specific models…….……... 18

Figure 12: *Leukoma staminea* length-weight models and predicted weights with 95% confidence intervals…….……. 19

Figure 13: *Tresus capax* length-weight models and predicted weights with 95% confidence intervals…….……. 19

Figure 14: Temporal change in *S. gigantea* biomass from 2007 to 2011 at Lone Tree Point……... 20

Figure 15: Box plots of clam weight by species and beach……... 21

Figure 16: Distribution of *S. gigantea* total weight per m^2 quadrat by site…… 24

Figure 17: Distribution of *C. nuttallii* total weight per m^2 quadrat by site……. 25

Figure 18: Distribution of *L. staminea* total weight per m^2 quadrat by site……..... 26

Figure 19: Distribution of *T. capax* total weight per m^2 quadrat by site…… 27

CLAM POPULATION VARIABILITY WITHIN A PUGET SOUND BIVALVE MANAGEMENT REGION

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ABSTRACT

Puget Sound beaches support extensive recreational and commercial shellfisheries that are of significant economic, cultural, and ecological value. In order to best co-manage bivalve resources, state and tribal managers divide public tidelands into eight distinct bivalve management regions. We used data gathered during our annual bivalve surveys to examine how clam populations vary within one of these regions. Specifically, we were interested in quantifying the following: temporal change in clam biomass at a single beach, differences in weight frequency distributions of clam species among multiple beaches, and variation in clam biomass among beaches within a management region. We also collected temperature data at one of the surveyed beaches and developed length-weight models within Bivalve Management Region 4, which was one of the few management regions lacking length-weight models for hardshell clam species. The Region 4 length-weight model was sufficient at predicting weights for various clam species at all of the individual beaches except one, where the beach-specific model for *Clinocardium nuttallii* was significantly different from the Region 4 model. Butter clam (*Saxidomus gigantea*) biomass decreased significantly from 2007 to 2011 at one beach within our management region. Individual beaches within this region had significantly different weight distributions when compared to one another for all considered clam species. We also found that biomass per m^2 quadrat varied significantly by species and beach within the management region. Ultimately, our goal is to combine these data with information on harvesting and environmental factors (e.g. current regime, temperature, larval supply, competition) to determine what drives clam variability within a management region.

INTRODUCTION

Hardshell clam populations within the Puget Sound region support extensive recreational and commercial shellfisheries. Not only are these fisheries economically important - where commercial shellfish harvest (including crustaceans and farmed bivalves) in Washington is worth nearly $100 million a year - but these fisheries are also culturally and ecologically valuable (Dethier 2006). Extensive literature exists on bivalve populations within Puget Sound, including reviews of aquaculture techniques, ecology, and fisheries (e.g. Cheney & Mumford 1986, Goodwin & Pease 1991, Toba et al. 1992, Baker 1995, Dethier 2006, Dumbauld et al. 2009, Straus et al. 2009, Dethier et al. 2012). However, the focus of the majority of these publications is placed on oysters (native, *Ostrea lurida*, or non-native, *Crassostrea gigas*), geoduck (*Panopea abrupta*), and manila clams (*Venerupis philippinarum*). Despite the ecological and economic importance of other native intertidal clam species (i.e. butter clams, *Saxidomus gigantea*; cockles, *Clinocardium nuttallii*; native littlenecks, *Leukoma staminea*; or horse clams, *Tresus capax*) very little research has been conducted on how their populations vary regionally and/or temporally (but see Dethier 2006). Understanding how and why these clam populations differ by beach could assist in the development of better management practices of the resource and lead to more sustainable fisheries.

Natural variation in clam populations is an important factor affecting the nearshore ecology of marine and estuarine habitats (e.g. Eggleston et al. 1992, Turner et al. 1997, Seitz et al. 2001, Seitz & Lipcius 2001, Riisgaard et al. 2004, Beukema et al. 2010). Variation in bivalve populations can affect biological processes such as predator-prey relationships and competition (Peterson 1982, Sponaugle & Lawton 1990, Seitz & Lipcius 2001, Riisgaard et al. 2004, Burnaford et al. 2011), physical processes such as flow and sediment transport (Widdows et al. 2000, Wood & Widdows 2002), and even human-related processes such as the intensity of clam fisheries (Beukema & Dekker 2006). While these studies quantified aspects of clam population variability on spatial and temporal scales within their specific study regions (Beukema et al. 2001, Seitz et al. 2001), these results are probably not applicable in different marine environments. Although the biology and ecology of native clam populations in Puget Sound has been investigated by some researchers (e.g. Cheney & Mumford 1986, Parker et al. 2003, Dethier et al. 2012), few research projects have compared clam population variability on individual beaches (but see Dethier 2006 for general descriptions of Sound-wide variability).

Marine Protected Areas (MPAs) or no-take marine reserves are increasingly used as a marine conservation method (e.g. Lester et al. 2009, Selig & Bruno 2010). While some controversy exists over the effectiveness of MPAs at enhancing fish yields for highly mobile species (Hilborn et al. 2004), there is evidence that no-take marine reserves are effective tools for managing fisheries of more sedentary species (Castilla 1999, Hilborn et al. 2004). In addition to being a conservation and management tool, no-take marine reserves act as "baselines" (e.g. Dayton et al. 2000) that allow for a better understanding of the impacts of fishing on particular environments (Castilla & Defeo 2001, Hilborn et al. 2004).

The Swinomish Indian Tribal Community (SITC) utilizes many beaches for commercial, recreational, ceremonial, and subsistence hardshell clam harvests within Puget Sound. Two beaches located within some of the Tribe's more popular clam digging areas, however, are effectively marine reserves, although no official designation exists or is being planned. Currently, Kiket Island (KI) is co-managed by Washington State Parks and the SITC as Kukutali Preserve, yet the uplands were only recently acquired in 2011 (Figure 1). Several decades prior to that time, the uplands were privately owned and the tidelands were generally not accessible to public or tribal clam diggers, generating a de-facto intertidal marine reserve. Currently, the SITC manages the tidelands on their Reservation (including KI) and does not open the beaches at KI for harvest. An exception is when the Tribe opens the beach for biennial elder harvests; these openings are rare and typically attract few diggers. Blowers Bluff (BB, Figure 1) is a public beach that has experienced extremely low to non-existent harvest pressure in the past decades due to poor water quality and inaccessibility (Washington Department of Fish and Wildlife, unpublished data) (since the completion of this analysis BB has been opened for a commercial clam bait fishery). Thus, these two beaches provided us with the opportunity to compare population variability of clams on non-harvested (or minimally harvested) beaches with clam populations from more heavily harvested beaches.

In order to best co-manage bivalve resources in Puget Sound, Washington state and tribal managers divide public tidelands into eight distinct bivalve management regions. Annual beach surveys are conducted on the more intensively harvested beaches within each region by the Washington Department of Fish and Wildlife (WDFW) and/or treaty tribes to determine the biomass of clams on beaches and establish the annual total allowable catch (TAC) (Campbell 1996, Point No Point Treaty Council 1998). In 2005, Bradbury et al. used annual survey data to develop length-weight models for intertidal clam species in Bivalve Management Regions 1, 5, 6, 7, and 8. However, the vast majority of beaches

Figure 1: Location of beaches surveyed in 2010 and 2011 within Bivalve Management Region 4. BB = Blowers Bluff, KI = Kiket Island, LT = Lone Tree Point, MD = Madrona, MN = Monroe Landing. Tide data in Figure 7 are from NOAA Port Townsend Buoy.

utilized by the SITC are located within Region 4; currently, no length-weight model exists for clam species in this bivalve region. Robust length-weight models can be useful for managers if the survey team only has time to measure the length of specimens or if a broken clam can be measured but not accurately weighed. For these reasons, length-weight models for the various clam species found within Region 4 would be beneficial.

During the spring and summer of 2010 and 2011 SITC Fisheries and/or Water Resources conducted intertidal clam surveys on five beaches for fisheries management

Table 1: Beach area (m^2) surveyed by year and site. LT = Lone Tree, KI = Kiket Island, MD = Madrona, MN = Monroe Landing, BB = Blowers Bluff.

2010	Area (m^2)
KI	32,267.9
LT	30,347.0
MD	33,446.9
MN	32,483.8
2010 total area	128,545.6
2011	
BB	88,718.0
LT	27,316.7
MN	65,202.2
2011 total area	181,237.0
Total area surveyed	438,328.2

purposes (Figure 1, Table 1). These data were primarily collected to quantify clam biomass on individual beaches, however, we also collected data at BB in preparation for the opening of the bait clam fishery and at KI to utilize the clam data as a control (no-take beach) with which to compare population structure. We also used these data to build length-weight models to supplement Bradbury et al. (2005) by filling in the gap for Region 4 beaches. In addition to developing beach-specific bivalve population reports and the Region 4 length-weight model, we were also interested in improving our understanding of the variation in clam populations among the beaches used by Swinomish tribal members. Thus, we used the survey data to address the following questions: (1) did butter clam, *S. gigantea*, biomass change temporally at Lone Tree Point; (2) was there a significant difference in weight frequency distributions of clam species on individual beaches; and (3) how did clam biomass by quadrat differ among sites? When appropriate, we compared results from BB and KI to the results from harvested beaches. The ultimate goal of this project is to determine what factors drive the variability documented within the management region. The purpose of this particular report is to begin addressing our larger question by characterizing clam population variability within a management region.

METHODS

Individual beach surveys

We sampled clams in 2010 and 2011 on five different beaches within Bivalve Management Region 4 (Figure 1, Table 1). Lone Tree Point (LT = both years combined, LT10 = surveyed in 2010, LT11 = surveyed in 2011) and Monroe Landing (MN) were sampled in 2010 and 2011, KI and Madrona (MD) were surveyed in 2010, and BB was sampled in 2011. For the sake of brevity, we will only discuss the 2011 surveys when presenting examples of population reports developed from these beach surveys. Although we surveyed MN in 2010 and 2011, we only measured clam lengths in 2011. Thus, we estimated 2011 weights using the 2010 MN length-weight model (Barber & Gibson 2010); we did not use estimated weights from MN 2011 in any analyses that required original weight data. Qualitative beach descriptions were completed in order to document basic differences among the beaches including information on habitat type, slope, beach area, and clam diversity. For the purposes of our study, a "population" of clams is defined as the individuals located within the boundaries of a particular public or tribal beach.

Field sampling procedures followed a combination of methods described in Campbell (1996) and Point No Point Treaty Council (1998), as well as ArcGIS methods developed by the Swinomish Water Resources Program and Swinomish Planning (T. Mitchell & E. Haskins, personal communication). Modifications that Swinomish Fisheries applied to these procedures are described in this report.

Prior to conducting the actual beach survey, we collected waypoints on the beach to delineate the upper clam boundary [~ +1.5 m above mean lower low water (MLLW), see Campbell 1996 for definition] using a handheld Garmin GPS 76. Swinomish Water Resources collected the upper clam boundary information for the KI and LT11 surveys using a Trimble ProXR. These waypoints were uploaded to ArcGIS 9.3 and a line was drawn between waypoints to define the upper clam boundary. This line served as the starting point for mapping transects in GIS. The first transect was placed a random number of meters (between 0 - 30.5 m) down the upper clam boundary line from the beginning of the beach area to be surveyed. Once the first transect line was added (perpendicular to the beach edge), subsequent transect lines were placed 30.5 m apart until transects adequately covered the survey area (Figure 2). Next, we placed a waypoint a random number of meters (0- 12.2 m) down each of the transect lines. Using the "divide and place point" command in ArcGIS, every subsequent waypoint on that particular transect was placed exactly 12.2 m down the line from the previous point. The last point automatically placed on the transect line was always deleted because the point was usually not 12.2 m away from the previous point (Figure 2). Waypoints were then uploaded to the Garmin GPS unit for use in the field (MN DNR 2001).

On the day of the survey, the surveyor used the GPS unit to mark the waypoints with labeled stakes. These marked points were subsequently dug by field crew members

using a 0.18 m^2 (Fisheries 2010) or 0.093 m^2 (Water Resources both years, Fisheries 2011) quadrat for collecting samples. Diggers followed the methods described in Campbell (1996) and Point No Point Treaty Council (1998). At the end of the survey, samples were either immediately processed at the site or brought back to the office and frozen for measuring and weighing at a later date (Bradbury et al. 2005). Clam length was recorded as "broken" if a valve was broken but the other valve could still be measured accurately or as an "estimate" if we could not obtain an accurate measurement of the length but could attempt to estimate the length by putting the broken valve(s) back together.

It should be noted that during the 2011 BB survey, one of the technicians dug the wrong size (0.18 m^2) quadrat for several samples before the problem was noticed and corrected (correct size = 0.093 m^2). At this point samples had been combined into one container and we did not have a way to distinguish the samples that were dug by this technician. During the analysis, however, several quadrats appeared as outliers due to the particularly high biomass values. We assumed that these outliers were from the incorrectly-sized samples and rectified the problem by dividing the biomass in half.

The Swinomish Water Resources team used slightly different methods for the KI and LT11 surveys. Their transects were placed 15.2 m apart and their quadrats were always 15.2 m apart after the first random number down the transect line between 0 – 15.2 m. All other methods were similar between agencies.

Analysis

Upon completion of a beach survey, we mapped out the sampled waypoints in ArcGIS 9.3 and calculated the total area of the beach surveyed (Campbell 1996). Clam biomass data were also linked to the latitude and longitude of the point where the clams were sampled. These geo-referenced data allowed us to predict clam biomass in ArcGIS throughout the entire survey area using the interpolation command (inverse distance weighting) from the spatial analyst package.

Species biomass was qualitatively examined by creating pie charts of the sampled weight of clam species by beach. Next, the total biomass of different clam species within the area surveyed was determined by multiplying the total area surveyed (m^2) by the estimated weight of clams per 0.18 m^2 or 0.093 m^2 (quadrat size varied depending on the year or department conducting the survey). We calculated biomass for all size classes of clams as well as for legal size classes. Total allowable catch (TAC) for legal-sized clams was determined for all harvestable species [we used a 20% harvest rate (10% for treaty harvest) for all species but *T. capax* which we harvested at a 3% TAC (Zhang & Campbell 2002, Barber & Gibson 2010)].

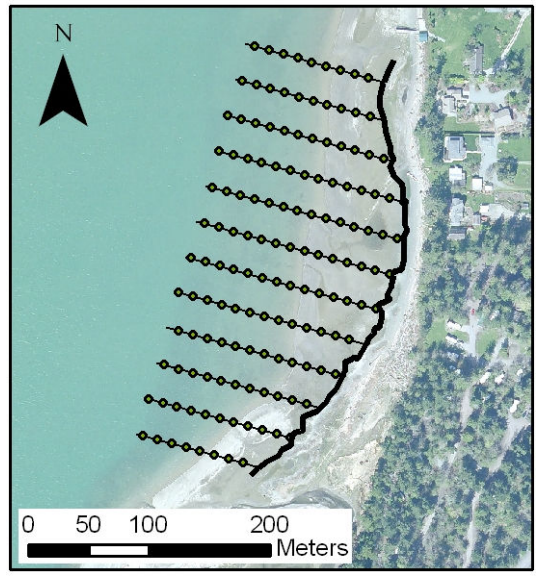

Figure 2: Example of a survey (Lone Tree Point 2010) designed in ArcGIS 9.3 prior to data collection. Thick black line = upper clam boundary, thin black lines = transect lines, and points = quadrat locations.

Temperature data

A temperature logger (Hobo Pendant, Onset Corporation) was placed under a bivalve anti-predator net at +0.3 m above MLLW at LT (the nets on the beach were for a different project that is not discussed in this report). Temperature was logged every half hour and a logger has been deployed continuously since 3 March 2011. For a more specific example of the temperature environment at this site, we plotted the temperature and tides during the largest low tides (~ -0.91 m below MLLW) of the season from 16 May 2011 through 20 May 2011.

Length-weight models

Length-weight Region 4 models were developed by combining data from the five beaches into a single dataset by clam species. Estimated weight or length data were excluded from analyses. Due to faulty electronic calipers, the KI survey dataset had a number of incorrect length values associated with correct weight values; these data were also excluded from analysis.

To minimize error, Bradbury et al. (2005) recommended n >200 for *S. gigantea* and n >100 for other clam species. Based on these recommendations we were only able to develop Region 4 models for *S. gigantea, C. nuttallii,* and *L. staminea*. Although we were just short of 100

clams for *T. capax* (n = 90), we decided to develop the model in order to improve our understanding of the length-weight relationship for this species. This model most likely has a greater degree of error associated with it and should be considered preliminary. All data were analyzed using the SYSTAT 13 non-linear regression command; variance-covariance matrices were estimated using R software (R 2010). Bootstrapped 95% statistical confidence bounds (on predicted weight) were calculated using a Monte Carlo simulation (Bradbury et al. 2005). As with Bradbury et al. (2005), we used an Excel spreadsheet developed by the Northwest Indian Fisheries Commission (NWIFC) for the bootstrapping and Monte Carlo simulations (R. Conrad, personal communication).

Once the length-weight models were developed, we plotted the actual weights against the predicted weights to look for any direction of bias the models produced. For example, if the model always predicted clams weighed less than their actual weight, Figure 8B would show the majority of the data points below the actual vs. actual weight line. In this case the model's error appeared to be evenly distributed until the heavier clam weights (>250 g) were predicted; at this point the model tended to predict that larger clams weighed less than their true weights (Figures 8B & 8C).

If the required sample size was met, individual beach models were also developed to test for differences among the beaches and the Region 4 model. In order to compare these models within a species, we plotted mode estimated weight for 60 mm clams with the 95% confidence intervals (CI) for each individual beach model and for the Region 4 model. Following Bradbury et al.'s (2005) method, we determined if the CI's overlapped for all the beaches. If overlap occurred then we assumed there was no difference among individual beaches and the Region 4 model (Bradbury et al. 2005). This analysis could only be completed for *S. gigantea* and *C. nuttallii*; we still developed a beach model for MN *S. gigantea* although n = 198 instead of the recommended 200. Mode estimated weight, rather than mean, was selected as the parameter because of the distribution pattern of the predicted numbers (G. Johnson, NWIFC, personal communication).

Temporal change in biomass of *Saxidomus gigantea*

In order to assess how clam populations change temporally, we looked at butter clam, *S. gigantea,* data collected during the 2010 and 2011 surveys at LT. We also used data from an additional clam survey that had been conducted in 2007, but this survey only collected data on clam length. Using the LT beach-specific length-weight model we developed for this report, we estimated all *S. gigantea* weights from the 2007 survey for this particular analysis. We also used the LT length-weight model to estimate weights for broken clams that were measured but not weighed in the 2010 and 2011 surveys.

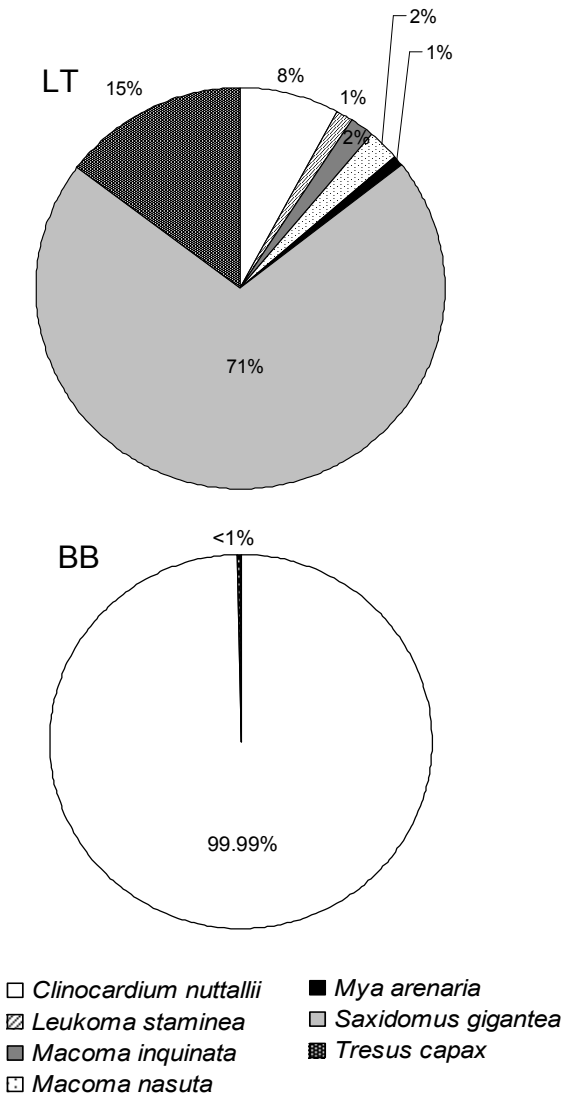

Figure 3: Biomass proportions of clam species at Lone Tree Point (LT) and Blowers Bluff (BB) in 2011. The following species comprised <1% of the total biomass found on the beaches: LT = *Venerupis philippinarum, Protothaca tenerrima, Macoma* sp., *Macoma balthica,* and *Cryptomya californica* and BB = *S. gigantea, C. californica, M. balthica, M. inquinata, M. nasuta, and Macoma* sp.

To begin this analysis, we determined the area where the three surveys overlapped. In ArcGIS 10.0, we used the 2011 survey area polygon to "clip" the 2010 and 2007 survey area polygons, resulting in a new polygon of the overlap area. The overlap polygon was then used to clip waypoints containing the clam biomass data such that

Table 2: Estimated biomass (kg) of legal-sized clam species and suggested total allowable catch (TAC) for the annual harvest (20% for all species but *Tresus capax* which is 3%). Only 2011 survey results are shown. Biomass is not standardized to the area surveyed (see Table 1 for survey areas). N/A indicates when a particular species was not present on the beach.

	Saxidomus gigantea		*Clinocardium nuttallii*		*Leukoma staminea*		*Tresus capax*	
Beach name	Biomass	TAC	Biomass	TAC	Biomass	TAC	Biomass	TAC
Lone Tree Point	55,147	11,029	5,848	1,170	809	162	11,365	341
Monroe Landing	83,212	16,642	37,194	7,439	n/a		27,906	837
Blowers Bluff	n/a		237,664	47,532	n/a		n/a	

only the waypoints within the overlap region were displayed.

Because the Swinomish Fisheries LT10 survey used 0.185 m^2 quadrats, while the Swinomish Water Resources LT11 and 2007 survey used 0.093 m^2 quadrats, we divided the biomass from each 2010 quadrat in half so all data were normalized by quadrat size. Data were multiplied out to 1 m^2 to simplify visualization of the results. Since the data did not meet the assumption of normality for running an ANOVA, a non-parametric Kruskal-Wallis test was used to determine if there was a difference in the weight of butter clams per quadrat by year (Sokal & Rohlf 1995). Follow-up pairwise comparisons were made using the Conover-Inman test (SYSTAT 13).

Clam weight frequency distributions

The non-parametric Kolmogorov-Smirnov (KS) test was used to investigate differences in clam weight frequency distributions by species and beach. Multiple pairwise comparisons (KS test) were conducted on the frequency data; thus, a Bonferroni-adjusted alpha value was used in the analysis (see Table 6 for specific values, Sokal & Rohlf 1995). Data from 2010 and 2011 at LT were combined for this analysis.

Clam biomass among sites

Total clam weight by species per quadrat was compiled from the clam survey datasets in order to compare clam biomass (g) per quadrat by site. Quadrat data from LT10, MD, and MN were divided in half to match the 0.093 m^2 quadrats used in 2011 surveys. All quadrat data were multiplied out to 1 m^2 to simplify explanation of the results. We used beach/region appropriate length-weight models to estimate weights for broken clams that were accurately measured but not weighed in the surveys. Because we found no difference between LT10 and LT11 for *S. gigantea* or *C. nuttallii* we combined these data together by species for this site (Kruskal-Wallis test, *S. gigantea* $\chi^2 = 3.84$, $p = 0.05$; *C. nuttallii* $\chi^2 = 0.822$, $p = 0.364$). Note that the values reported in this Kruskal-Wallis test are different from the values reported in the temporal change in *S. gigantea* biomass despite the fact the same statistical test was used; this is due to the fact that we only used data from an overlapping area for the temporal change study whereas we used data from the entire surveyed area for this particular analysis. We found a significant difference between LT10 and LT11 for *L. staminea* (Kruskal-Wallis test, $\chi^2 = 4.13$, $p = 0.042$); thus, these two years were considered separately in this analysis. No *T. capax* were recorded during the LT10 survey; LT11 data are shown for this species. Only 2010 weight data from MN were used in this analysis because all the 2011 weights were all estimated from actual lengths (Barber & Gibson 2010).

Despite data transformations, an ANOVA could not be used to test for differences in the mean weight of clams per quadrat by site because the data failed to meet the assumptions of normality or homogeneity. Consequently, we used the non-parametric Kruskal-Wallis test and the post-hoc Conover-Inman test to investigate differences by beach (Sokal & Rohlf 1995). Due to the non-normal distribution of these data and our use of non-parametric statistics, data were plotted using histograms rather than the mean and standard error. Because each site had different sample sizes, we standardized the data by using proportions rather than count in the histograms.

Unless otherwise noted, SYSTAT 13 was used for all data analyses.

RESULTS

Individual beach surveys

Beach descriptions

Blowers Bluff was the largest area sampled, while the LT11 survey was the smallest area surveyed (Table 1). Blowers Bluff (Figure 1) is distinctly different from all the other beaches in that it is uniformly sandy and a very wide beach (~0.74 km wide at the widest spot) with an exceptionally gradual slope. Although eight species of clams were recorded on this beach, the only species in high abundance was the cockle, *C. nuttallii*; all other clam species were found in very low abundances or only recorded once (Figures 3 & 4). Cockles were virtually non-existent at the higher elevations on BB and became more abundant as the depth increased (Figure 4).

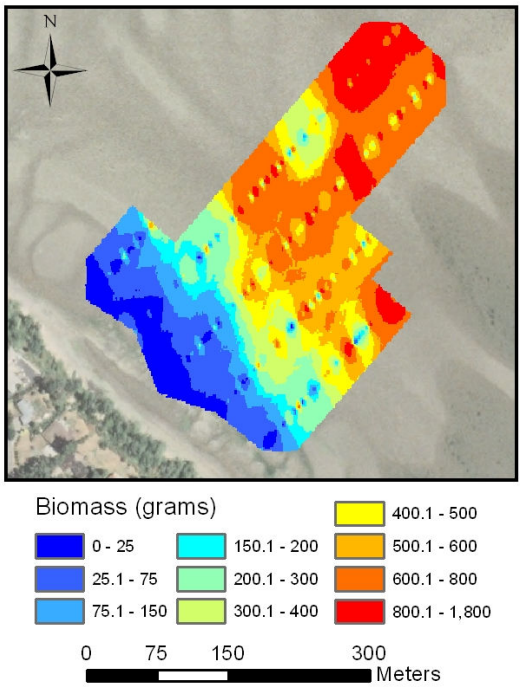

Figure 4: 2011 biomass of cockles, *Clinocardium nuttallii*, at Blowers Bluff. Biomass (g) data were interpolated in ArcGIS 9.3 using inverse distance weighting. Analysis was masked by the area surveyed.

Monroe Landing is similar to BB in that it is a gradually sloping, wide beach; however, MN is not as wide (~0.32 km) as BB. The primary substrate on this beach ranges from mud to sand and supports a greater variety of clam species than BB (10 species recorded in relatively high abundances) as well as an eelgrass (*Zostera marina*) bed at lower elevations.

Madrona ranges in habitat type from sandy areas to mixed cobbles/pebbles and sand. The beach is very narrow (~0.01 km wide) and long with a more pronounced slope. Eight species of clams were recorded here in various abundances. Pacific blue mussels, *Mytilus trossulus*, were not formally recorded in our surveys, however, it should be noted that relatively large mussel mats were found at higher elevations on BB, MN, and MD.

Kiket Island (KI) and LT are located on the Swinomish Reservation and have similar habitat types. Both beaches have areas of mixed cobble/pebble and sand as well as areas with soft sediments such as sand and mud. Eelgrass (*Z. marina* and *Z. japonica*) beds were found at lower elevations on both beaches. The beaches vary in width, but at their widest parts KI is ~0.08 km and LT is ~0.07 km. Eight species of clams were recorded on KI and 12 species were recorded on LT (Figures 3 & 5). Butter clams (*S. gigantea*) were clearly the most abundant clam at LT, favoring the southern extent of the surveyed beach (Figure 5). Indeed, most clam species were found in higher concentrations along the southern portion of the beach at LT (Figure 5).

Of all the beaches surveyed in 2011, BB had the most resources available for harvest (Table 2). Specifically, 237,664 kg of *C. nuttallii* were estimated to be found within the area of the beach we surveyed. The beach had not been harvested prior to this survey and this survey was used to estimate TACs for the new bait clam fishery. Thus, we determined that 47,533 kg were available for harvest or 23,767 kg for the 50% tribal treaty harvest (for an explanation of treaty tribe fishing rights refer to United States v. Washington 1998).

Temperature data

Temperature was logged every half hour for 130 days from 22 March 2011 to 30 July 2011 (Figure 6). As expected, intertidal temperature was the highest during the large low tides in the middle of the day (Figure 7). On 16 May 2011 there was little intertidal temperature fluctuation despite the large tide exchange (-0.7 m MLLW) while on May 20, 2011 the temperature changed greatly during a similar exchange (Figure 7). The 16 May low tide occurred earlier in the day than the 20 May low tide.

Length-weight models

Saxidomus gigantea

We used 916 length-weight measurements of butter clams, *S. gigantea,* to develop the length-weight model for Region 4 (Figure 8A, Tables 3 & 4). The model's error appeared to be evenly distributed until heavier clam weights (>250 g) were predicted; at this point the model tended to predict that larger clams weighed less than their true weights (Figures 8B & 8C). Individual beach models were built for three beaches with butter clams including LT (n = 439), MN (n = 198), and MD (n = 216) (Figure 9, Tables 3-5). The butter clam sample size was not large enough to develop a model for KI. Following methods in Bradbury et al. (2005), we determined that the length-weight models from individual beaches were not different from the Region 4 model because the 95% confidence bounds on the predicted weight of *S. gigantea* overlapped for all beaches (Figure 8D, Table 5). Despite this overlap it should be noted that the MD length-weight model tended to predict that larger butter clams would weigh more than the Region 4 model predictions (Figure 9). Furthermore, we did not meet the minimum sample size requirement (n = 200) to develop a beach-specific model for the MN sample (n = 198) (Bradbury et al. 2005). Because we

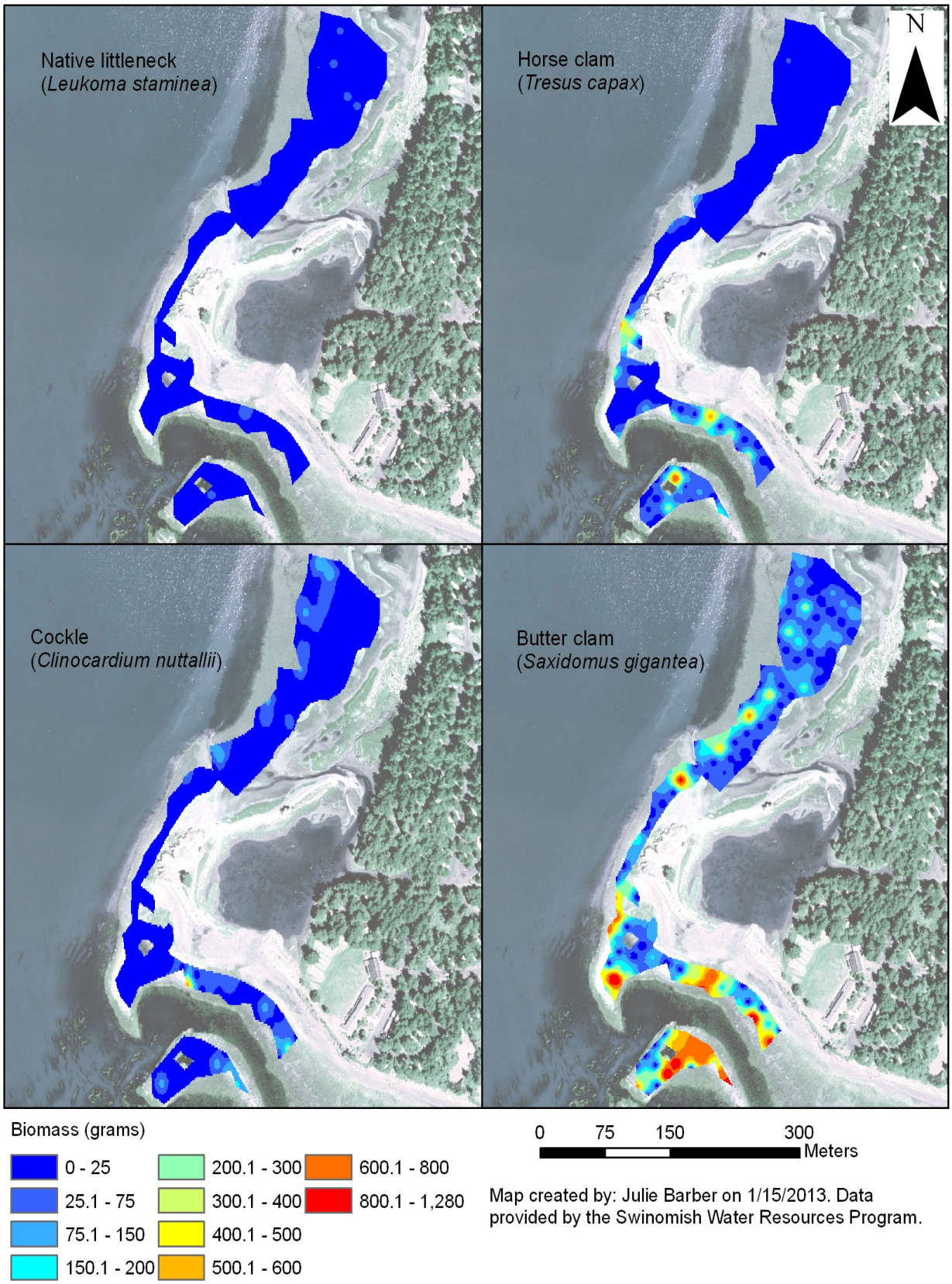

Figure 5: 2011 biomass of common clam species at Lone Tree Point. Biomass (g) data were interpolated in ArcGIS 10.1 using inverse distance weighting. Analysis was masked by the area surveyed.

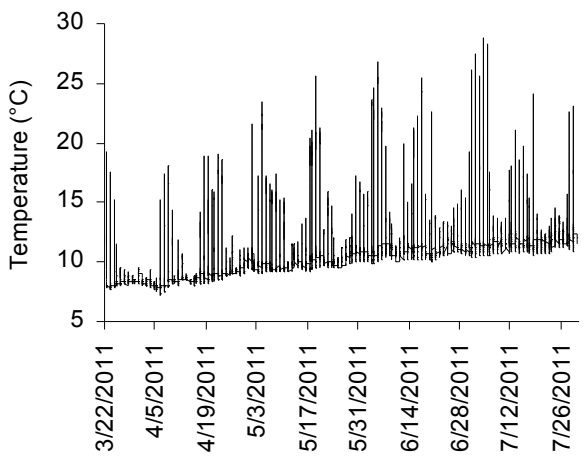

Figure 6: Intertidal temperature from Lone Tree Point from March 2011 through the end of July 2011. Temperature logger was located at +0.3 m above mean lower low water.

were so close to meeting the suggested minimum sample size, we decided to run the model for this beach anyway for the purpose of assessing trends. Because of the smaller sample size the individual model for this beach may have a slightly higher degree of error associated with it, although the confidence bounds are actually broader at MD, which met the required sample size (Figure 8D).

Clinocardium nuttallii

A Region 4 length-weight model for cockles, *C. nuttallii*, was developed from 1,434 individual samples (Figure 10A, Tables 3 & 4). Blowers Bluff cockles comprised 71% of the samples used in this regional model. The actual weight versus predicted weight plots revealed two biases in the model: (1) the model predicted that cockles <75 g weighed more than their actual weight and (2) the model predicted that cockles >125 g weighed less than their actual weights. (Figures 10B & 10C). Lone Tree Point (n = 124), MN (n = 187), and BB (n = 1022) all had large enough sample sizes to permit the development of individual beach models (Figure 11, Table 5); KI and MD did not meet the minimum sample size requirements for model development. When comparing these beach models to the Region 4 model, it became evident that the Region 4 model predicted that the smallest cockles (<50 mm) weighed slightly more than the actual weight of cockles at MN, while predicting that larger cockles (>80 mm) weigh less than the actual weight of cockles at MN (Figure 11). Furthermore, the LT model predicted that larger cockles weighed more than the Region 4 model predictions (Figure 11). These results are the same when comparing BB to LT and MN, primarily due to the fact that the Region 4 model is extremely similar to the BB model. Using predicted weights from these models, we determined that the 95% confidence intervals overlapped

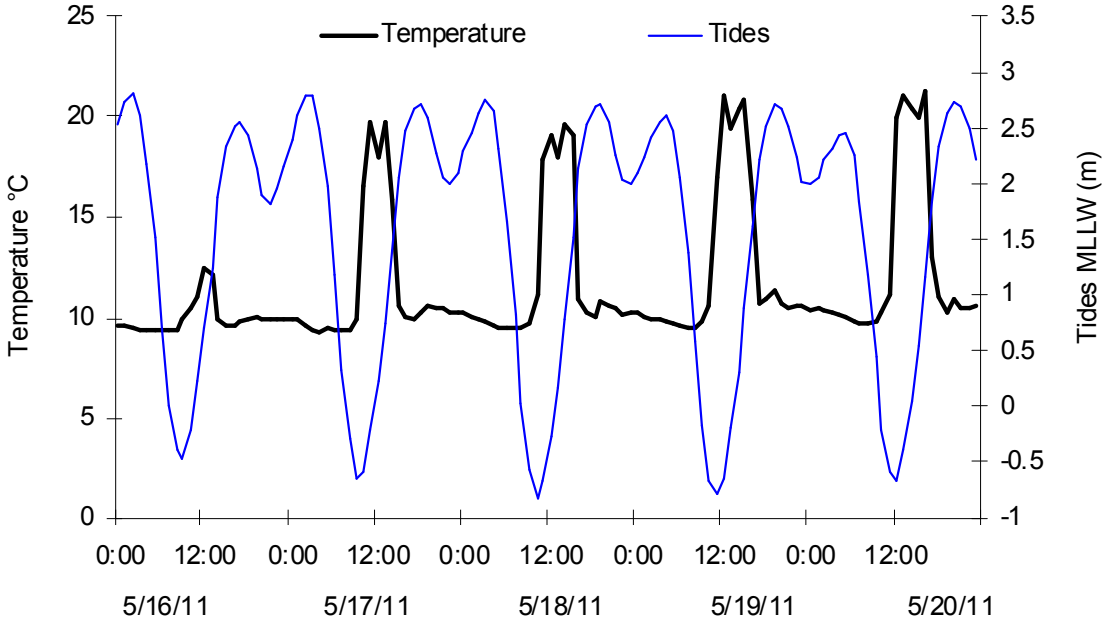

Figure 7: Intertidal temperature from Lone Tree Point and verified tide data (MLLW = mean lower low water) from the Port Townsend Station (ID 9444900, Figure 1) for a range of dates in May 2011. Temperature logger was located at +0.3 m above MLLW. Selected date range covers the largest daytime low tides of the year.

Table 3: Length-weight model parameter values. Calculations are based on compiled data from beaches that were surveyed in 2010 and 2011. LT = Lone Tree, KI = Kiket Island, MD = Madrona, MN = Monroe Landing, BB = Blowers Bluff.

Clam species or beach	α	s.e.	β	s.e.	n	R^2	Beach data used in model
Region 4 models							
Saxidomus gigantea	0.000204	0.000028	3.0744	0.0306	916	0.9344	LT, MD, MN, KI
Clinocardium nuttallii	0.003336	0.000501	2.4420	0.0352	1434	0.8931	LT, MD, MN, KI, BB
Leukoma staminea	0.000667	0.000218	2.8332	0.0830	138	0.9147	LT, MD, MN, KI
Tresus capax	0.000168	0.000118	3.0251	0.1503	90	0.9596	LT, MD, MN
S. gigantea beach-specific models							
LT	0.000214	0.000044	3.0630	0.0437	439	0.9503	
MD	0.000113	0.000032	3.2177	0.0644	216	0.9291	
MN	0.000195	0.000048	3.0782	0.0559	198	0.9497	
C. nuttallii beach-specific models							
LT	0.000911	0.000222	2.7721	0.0590	124	0.9740	
MN	0.000369	0.000094	2.9480	0.0597	187	0.9521	
BB	0.002500	0.000529	2.5115	0.0495	1022	0.8269	

for all beaches except the Region 4 model and MN (Figure 10D). Therefore, the length-weight models from all the individual beaches except MN were similar to the Region 4 length-weight model (Figures 10D & 11, Table 5). The MN length-weight model predicts that 60 mm cockles will weigh less than cockles on other Region 4 beaches (Figure 10D).

Leukoma staminea

The native littleneck clam, *L. staminea*, Region 4 length-weight model was developed from 138 samples of clams (Figure 12A, Tables 3 & 4). The model did not appear to be biased at predicting weights from known lengths (Figures 12B & 12C). Unfortunately, we did not have large enough samples sizes to develop beach-specific models (>100 individuals required, Bradbury et al. 2005).

Tresus capax

For descriptive purposes only, we developed a Region 4 length-weight model for the horse clam, *T. capax*, from 90 individual samples (Figure 13A). The residuals indicated that the model predicted that lighter clams (<100 g) weighed more than their actual weight and the heavier horse clams (>300 g) weighed less than their actual weight (Figure 13B & 13C). No individual beach models were be developed for horse clams.

Temporal change in biomass of *Saxidomus gigantea*

The three years of surveys overlapped on a 12,055 m^2 section of the beach north of the point at LT (Figure 14). Biomass changed significantly throughout these three

Table 4: Variance-covariance matrices for Region 4 models and beach-specific models.

Species/Beach		a	b
Region 4			
Saxidomus gigantea	a	0.00000000	-0.00000084
	b	-0.00000084	0.00093865
Clinocardium nuttallii	a	0.00000025	-0.00001763
	b	-0.00001763	0.00123938
Leukoma staminea	a	0.00000005	-0.00001808
	b	-0.00001808	0.00689229
Tresus capax	a	0.00000001	-0.00001771
	b	-0.00001771	0.02260368
S. gigantea beach-specific models			
LT	a	0.00000000	-0.00000177
	b	-0.00000177	0.00191305
MD	a	0.00000000	-0.00000205
	b	-0.00000205	0.00414732
MN	a	0.00000000	-0.00000270
	b	-0.00000270	0.00312397
C. nuttallii beach-specific models			
LT	a	0.00000005	-0.00001308
	b	-0.00001308	0.00347935
MN	a	0.00000001	-0.00000558
	b	-0.00000558	0.00356165
BB	a	0.00000028	-0.00002617
	b	-0.00002617	0.00245074

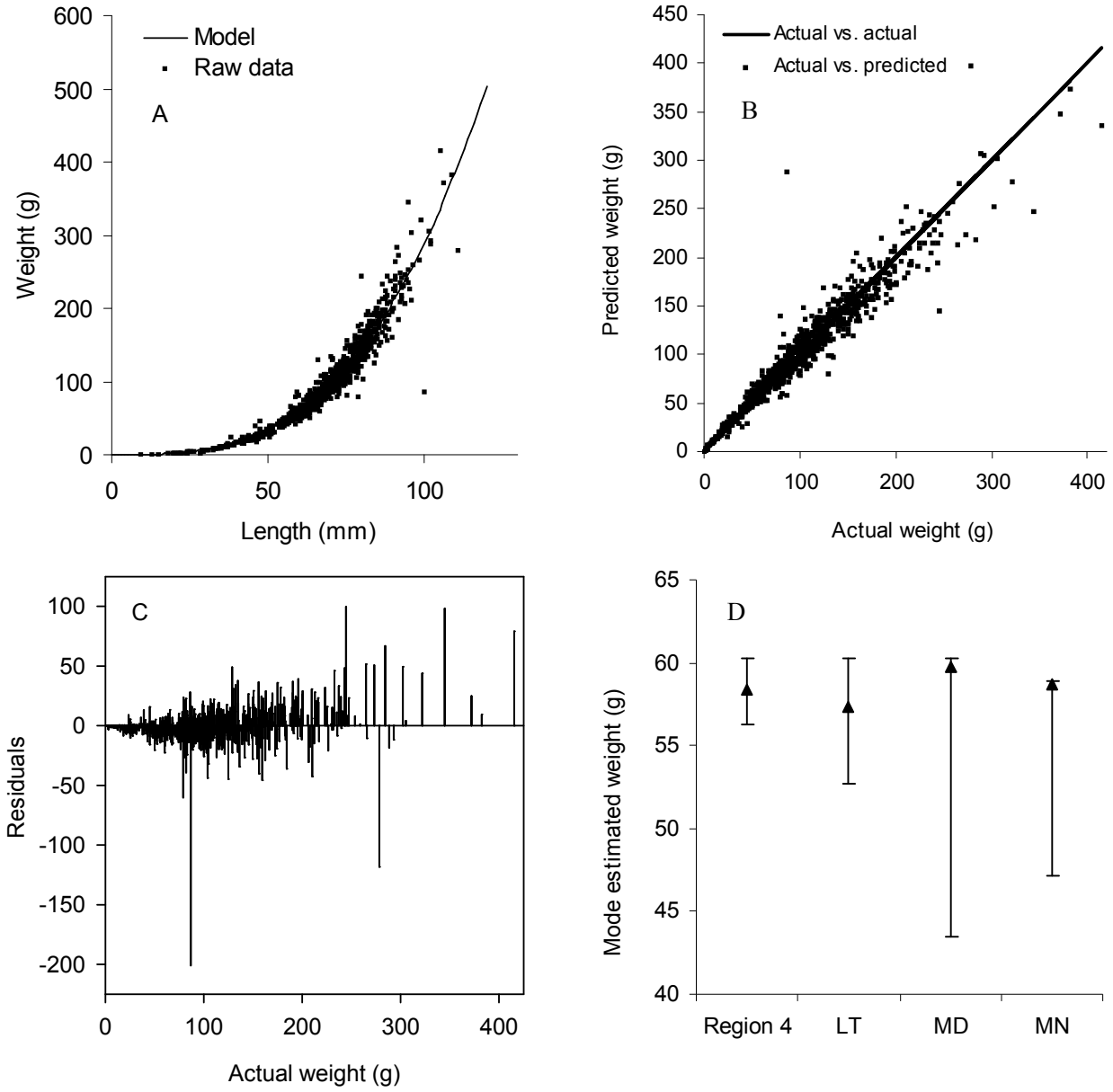

Figure 8: A: Region 4 *Saxidomus gigantea* length-weight (LW) model based on data collected off of four beaches in 2010 and 2011 (n = 916). B: Region 4 *S. gigantea* predicted versus actual weight. C: Region 4 *S. gigantea* LW model residuals. D: Mode estimated weight of 60 mm *S. gigantea* based on LW models from Region 4 and beach-specific models. Error bars = 95% confidence intervals on mode estimated weight. LT = Lone Tree Point, MD = Madrona, MN = Monroe Landing.

Table 5: Mode estimated weight of clams at 38 mm and 60 mm. Beach-specific model results are only listed when the sample size was large enough to conduct the analysis. CI = confidence interval

	38 mm			60 mm				
		95% CI			95% CI			
Species	Mode estimated weight (g)	lower	upper	Mode estimated weight (g)	lower	upper	n	Years included in analysis
Saxidomus gigantea								
Lone Tree Point	14.49	12.80	15.05	57.31	52.76	60.32	439	2010, 2011
Madrona	13.91	9.71	14.02	59.71	43.49	60.22	216	2010
Monroe Landing	14.34	10.95	14.62	58.74	47.10	58.87	198	2010
Region 4	14.55	13.40	14.97	58.43	56.30	60.28	916	2010, 2011
Clinocardium nuttallii								
Lone Tree Point	21.96	17.62	22.21	77.65	64.47	78.24	124	2010, 2011
Monroe Landing	16.62	12.83	17.17	60.57	52.61	65.44	187	2010
Blowers Bluff	21.99	19.33	23.57	72.76	63.36	73.42	1022	2011
Region 4	23.98	21.87	24.41	70.92	68.87	73.77	1434	2010, 2011
Leukoma staminea								
Region 4	19.89	12.78	20.25	n/a			138	2010, 2011
Tresus capax[A]								
Region 4	n/a			34.17	-50.24	41.28	90	2010, 2011

[A]*Tresus capax* sample size is potentially too small. These data should not be considered seriously for management purposes.

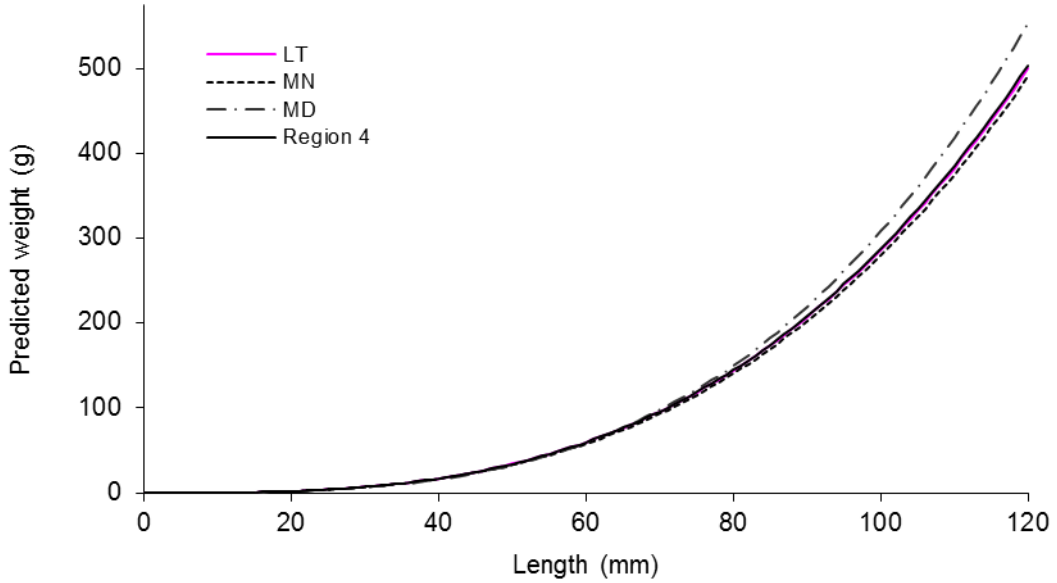

Figure 9: Region 4 *Saxidomus gigantea* length-weight model compared to beach-specific models. Sample sizes: Lone Tree Point (LT) = 439, Monroe Landing (MN) = 198, Madrona (MD) = 216, Region 4 = 916.

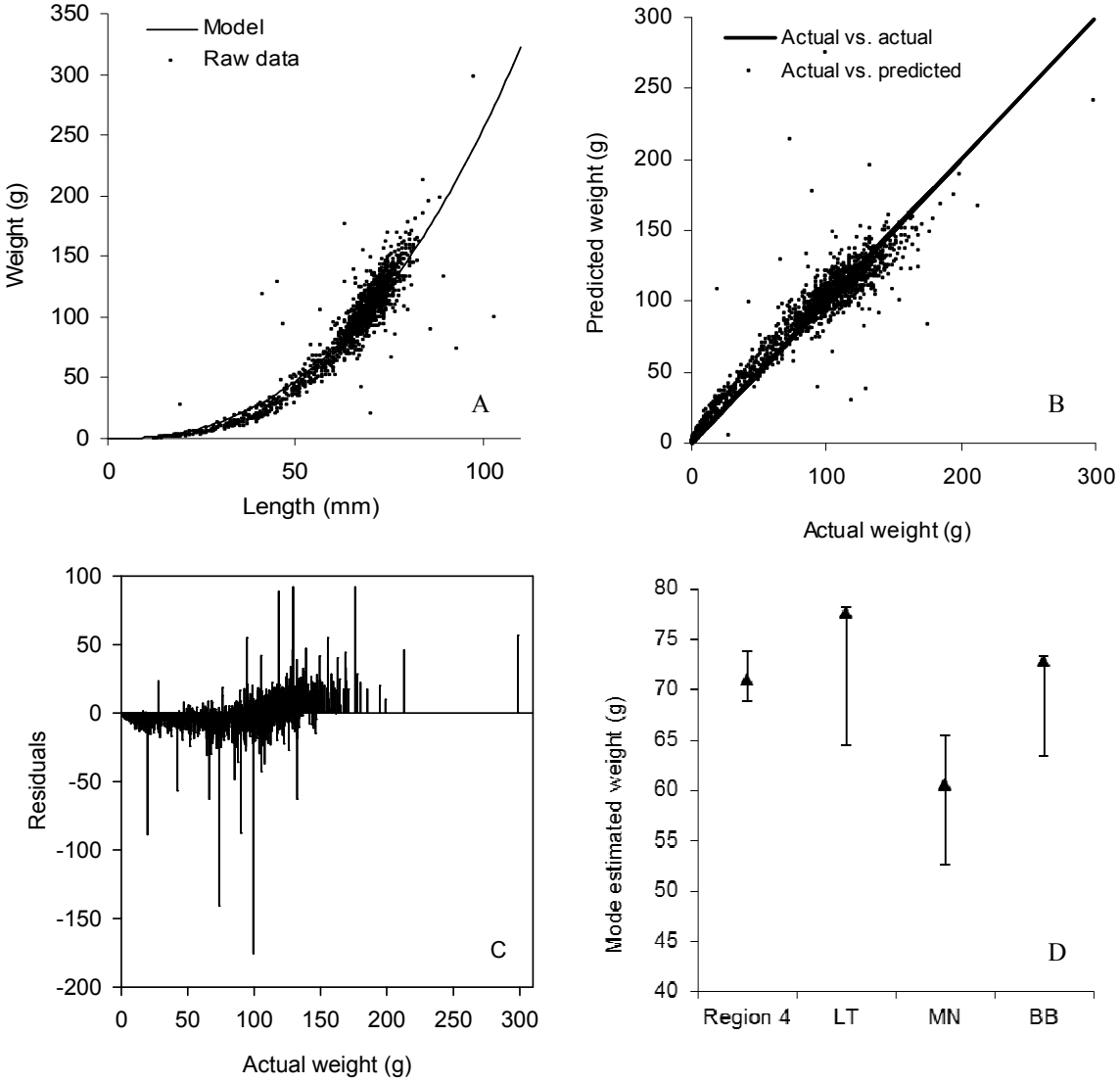

Figure 10: A: Region 4 *Clinocardium nuttallii* length-weight (LW) model based on data collected off of five beaches in 2010 and 2011 (n = 1434). B: Region 4 *C. nuttallii* predicted versus actual weight. C: Region 4 *C. nuttallii* LW model residuals. D: Mode estimated weight of 60 mm *C. nuttallii* based on LW models from Region 4 and beach-specific models. Error bars = 95% confidence intervals on mode estimated weight. LT = Lone Tree Point, MN = Monroe Landing, BB = Blowers Bluff.

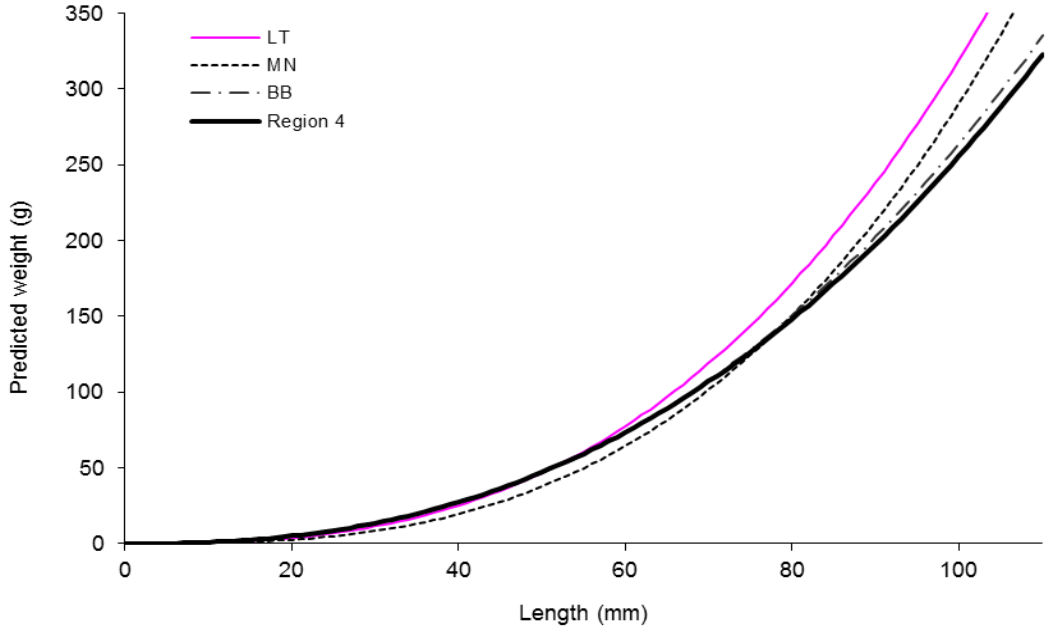

Figure 11: Region 4 *Clinocardium nuttallii* length-weight model compared to beach-specific models. Sample sizes: Lone Tree Point (LT) = 124; Monroe Landing (MN) = 187; Blowers Bluff (BB) = 1022; Region 4 = 1434.

years ($\chi^2 = 6.15$, p = 0.04). Follow-up tests revealed that there was a significant decline in *S. gigantea* biomass from 2007 (n = 48) to 2011 (n = 47) ($t = 2.5$, $p = 0.01$), but 2007 to 2010 (n = 36) and 2010 to 2011 were similar ($t = 1.3$, $p = 0.17$; $t = 0.96$, $p = 0.34$; respectively) (Figure 14). The decline seemed to be distributed somewhat evenly across the survey area (Figure 14).

Clam weight frequency distributions

Saxidomus gigantea

All beaches had statistically different weight distributions except LT and MN (Figure 15 & Table 6). Of all the beaches, KI had the heaviest butter clams as well as a broader distribution of various clam weights. Lone Tree Point and MN, on the other hand, had the lightest clams (Figure 15). Madrona had the most narrow distribution of clam weight (Figure 15).

Clinocardium nuttallii

Pairwise comparisons demonstrated that the weight frequency of cockles differed significantly among all beaches except KI and LT, which were statistically similar (Figure 15 & Table 6). Blowers Bluff had significantly heavier cockles than all the other beaches in this analysis (Figure 15 & Table 6). Both BB and MD had very narrow distributions of clam weight, while KI, LT, and MN had relatively broad weight distributions and similar means (although the median weight is much lighter at MN compared to KI and LT) (Figure 15).

Leukoma staminea

Weight distributions for the native littleneck, *L. staminea*, were similar between LT and MD (Figure 15 & Table 6). Mean and median clam weights were the highest at KI (Figure 15). Kiket Island also had a slightly broader distribution of clam weight than the other beaches (Figure 15 & Table 6).

Tresus capax

The weight distributions between LT and MN were significantly different (Figure 15 & Table 6). Monroe Landing had a more expansive distribution with a higher mean and median weight, whereas LT had a more narrow distribution consisting primarily of lighter horse clams (Figure 15).

Clam biomass among sites

Saxidomus gigantea

Lone Tree Point and MD had significantly more quadrats with higher weights of butter clams than KI and MN (Figure 16, Table 7). There was no statistical difference between LT and MD or between KI and MN. The majority (>70%) of the quadrats sampled at KI and MN did not have butter clams present (Figure 16). Lone Tree

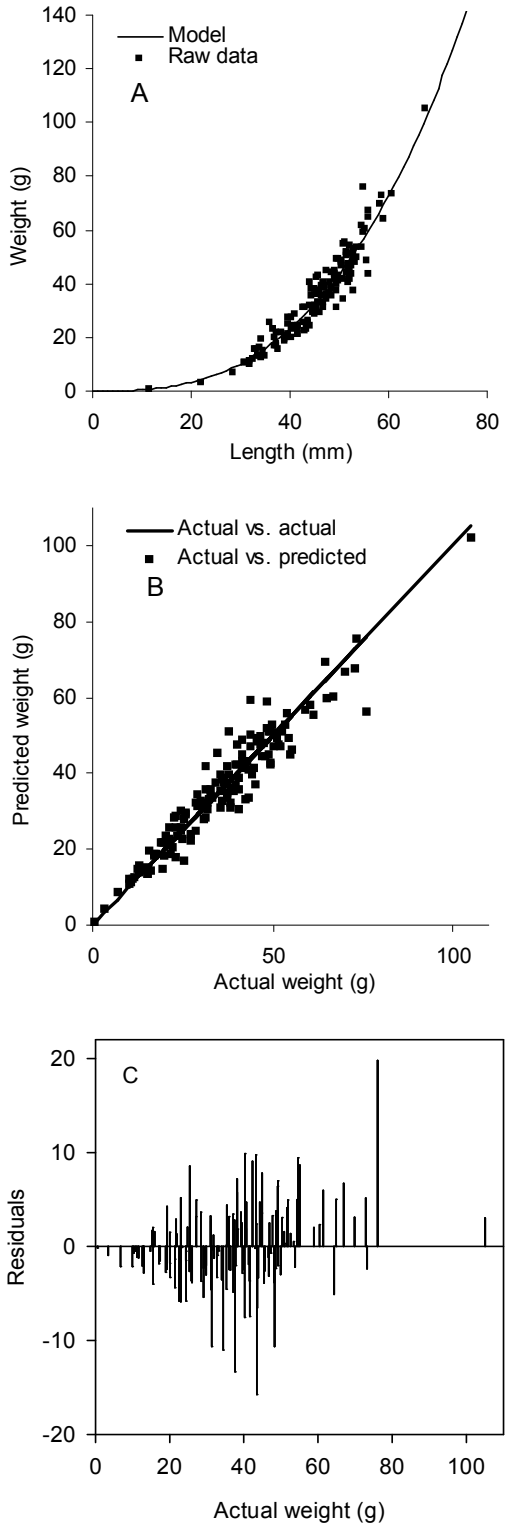

Figure 12: A: Region 4 *Leukoma staminea* length-weight (LW) model based on data collected off of four beaches in 2010 and 2011 (n = 138). B: Region 4 *L. staminea* predicted versus actual weight. C: Region 4 *L. staminea* LW model residuals.

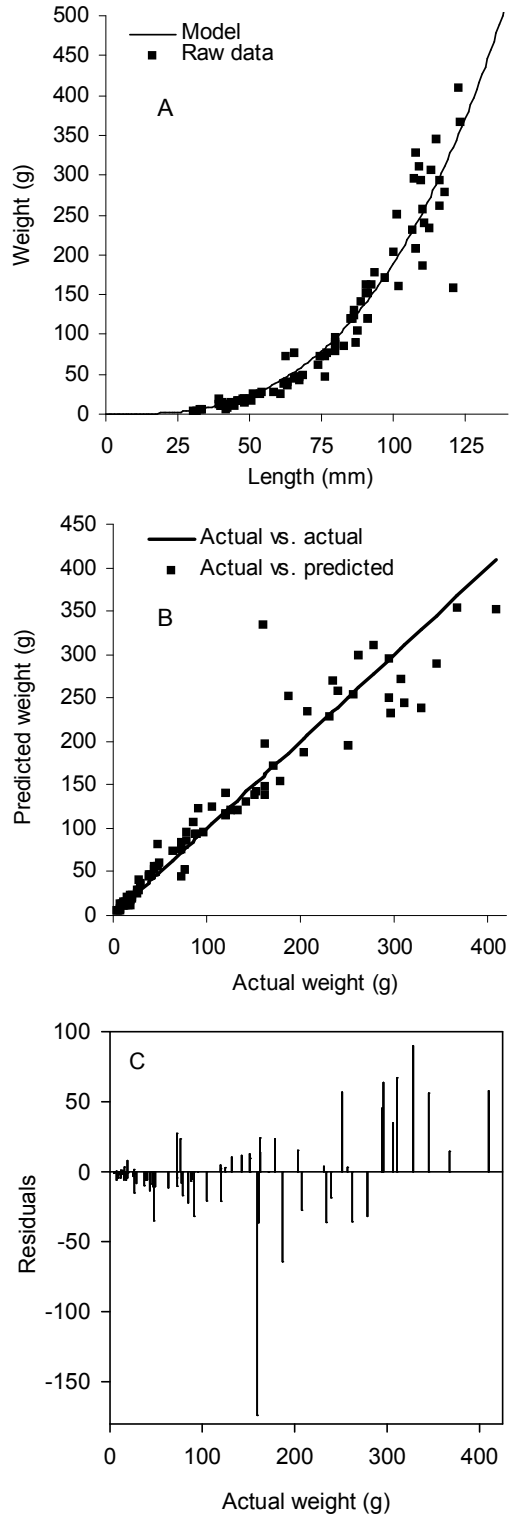

Figure 13: A: Region 4 *Tresus capax* length-weight (LW) model based on data collected off of three beaches in 2010 and 2011 (n = 90). B: Region 4 *T. capax* predicted versus actual weight. C: Region 4 *T. capax* LW model residuals.

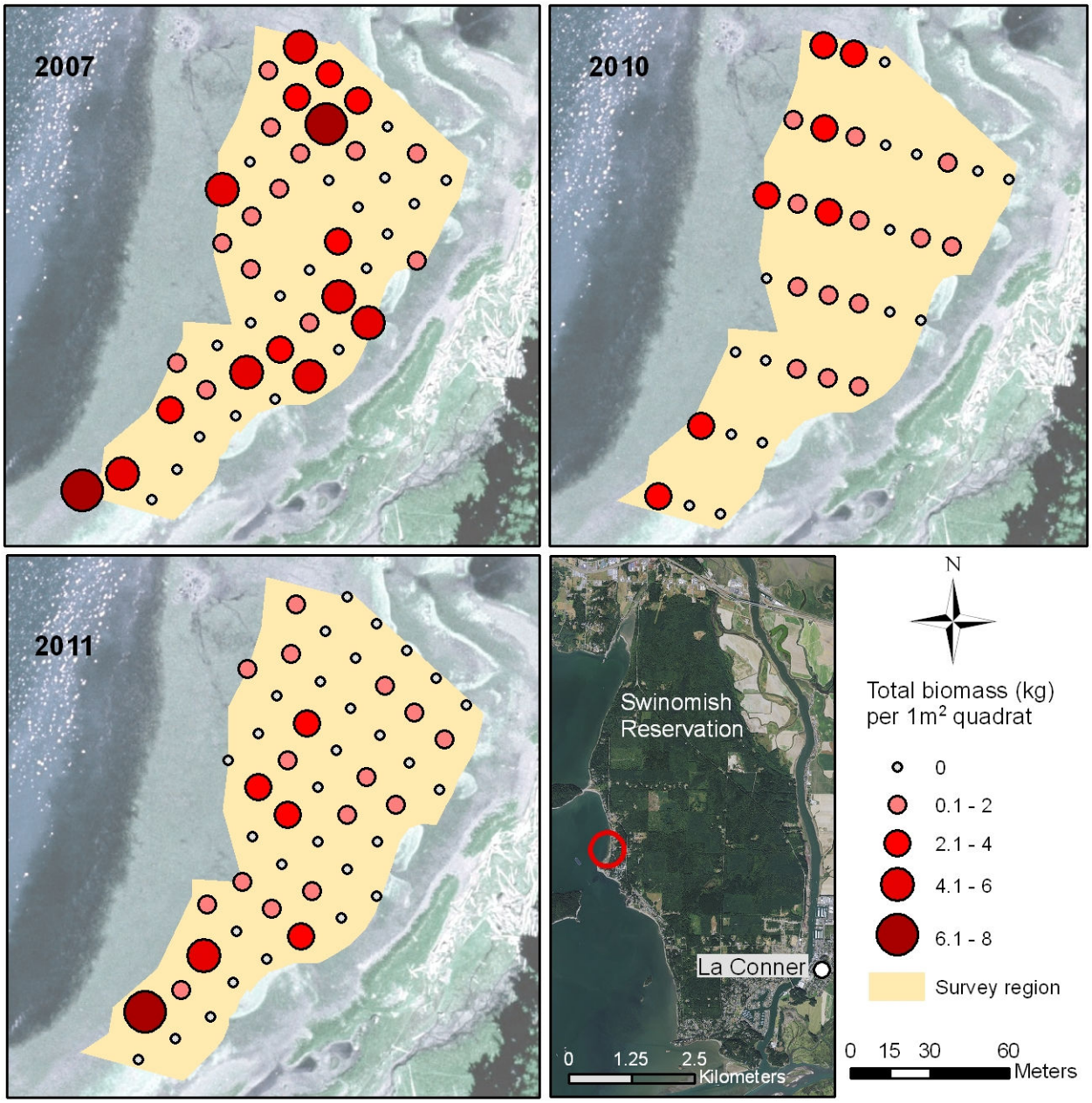

Figure 14: Temporal comparison of butter clam, *Saxidomus gigantea*, biomass from 2007 to 2011 at Lone Tree Point (LT). Points represent biomass (kg) per m^2. All 2007 weights were estimated using the beach-specific LT length-weight model.

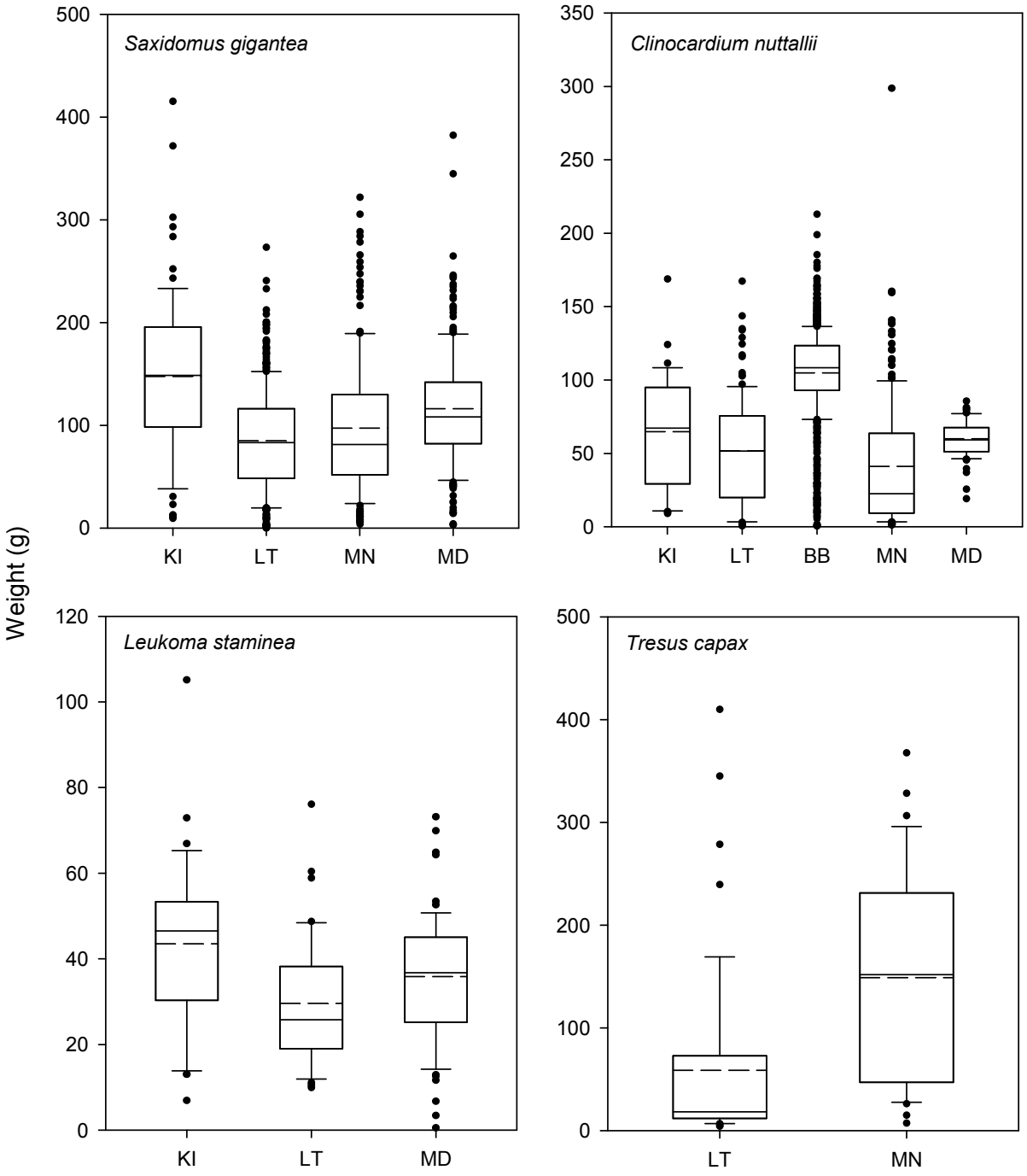

Figure 15: Distribution of clam weights for four different species. Mean = dashed line, median = solid line. Sites go from north to south in the following order on the graphs (left to right): KI = Kiket Island, LT = Lone Tree Point, BB = Blowers Bluff, MN = Monroe Landing, MD = Madrona. Sample sizes: *S. gigantea*, KI(76), LT(439), MN(199), MD(216); *C. nuttallii*, KI(33), LT(124), BB(1022), MN(187), MD(75); *L. staminea*, KI(32), LT(41), MD(66); *T. capax*, LT(47), MN(39). If there was no clam data from a particular beach the species was either not present or found in such low quantities they could not be used in this analysis. Note the variable scales.

Table 6: Kolmogorov-Smirnov results comparing size frequency distributions of clam species on individual beaches. LT = Lone Tree Point, MD = Madrona, MN = Monroe Landing, KI = Kiket Island, BB = Blowers Bluff.

	Saxidomus gigantea		*Clinocardium nuttallii*		*Leukoma staminea*		*Tresus capax*	
Bonferroni *p* -value	0.0083		0.0050		0.0167		0.05	
	D	*p*	D	*p*	D	*p*	D	*p*
LT vs. MD	0.2564	<0.0000	0.3822	<0.0000	0.2916	0.0224		
LT vs. MN	0.1104	0.0725	0.2601	0.0001			0.5657	<0.0000
MD vs. MN	0.2956	<0.0000	0.5777	<0.0000				
KI vs. LT	0.4687	<0.0000	0.2346	0.1143	0.4718	0.0005		
KI vs. MD	0.3321	<0.0000	0.3806	0.0022	0.3627	0.0056		
KI vs. MN	0.4160	<0.0000	0.3494	0.0021				
BB vs. LT			0.6596	<0.0000				
BB vs. MD			0.8448	<0.0000				
BB vs. MN			0.7130	<0.0000				
BB vs. KI			0.5266	<0.0000				

Blank spaces indicate that no clams were found on a particular beach or the sample size was too small to allow for analysis.

Point and MD have a much higher frequency of occurrence of quadrats weighing 0 - 4 kg.

Clinocardium nuttallii

Blowers Bluff had a significantly higher weight of cockles per quadrat than all the other beaches (Figure 17, Table 7) and less than 20% of the quadrats were zeros at BB. Also, the BB data were distributed more broadly across a wider range of weight compared to the other beaches (Figure 17). There was no significant difference between KI and LT or MN and MD. Kiket Island and LT had significantly lower weights per quadrat than MD and MN. Over 70% of the quadrats at KI and LT were zeros. While some quadrats at BB contained >19 kg of cockles, no quadrats exceeded 6.5 kg at the other sites.

Leukoma staminea

There were significantly more quadrats at MD with heavier weights of native littlenecks than LT10, LT11, and KI (Figure 18, Table 7). Although KI had several instances where quadrats contained very high weights of this clam species, there was no significant difference between KI and both survey years at LT. Although our initial analysis of LT10 versus LT11 found a significant difference between the weight of quadrats by year, the follow-up Conover-Inman test did not find this difference. Thus, we conclude that there was no difference in the weight of clams per m^2 by year at LT. (Figure 18, Table 7). Native littlenecks were not present in 81%, 92%, and 88% of the quadrats dug at LT10, LT11, and KI, respectively. At MD, however, *L. staminea* were not present in 65% of the quadrats (Figure 18); indicating a higher likelihood of quadrats containing native littlenecks at this beach.

Tresus capax

No difference was detected between *T. capax* weights per quadrat at LT and MN (Figure 19, Table 7). This clam was not commonly found in quadrats at either of the beaches (e.g. LT = 75% of the 151 sampled quadrats did not contain *T. capax*) (Figure 19).

DISCUSSION

Individual beach surveys

Of all the beaches we surveyed, BB was the most unique in terms of habitat because the substrate was 100% sand, while all the other beaches had more variable habitat types consisting of mixtures of sand, shell litter, and gravel or mud. Clam species such as *S. gigantea, L. staminea,* and *T. capax* are probably more vulnerable to predation in very sandy habitats (especially at a younger age), thus, their biomass may be higher in areas where sand is mixed with gravel (Cheney & Mumford 1986, Kozloff 1993). These species also tend to be buried deeper in the substrate (~50-300 mm below the surface depending on the species) than cockles. It is possible that a dynamic beach surface (such as 100% sand) unearths clams or never allows juveniles to obtain their proper burial depth. This could lead to increases in predation and lower overall biomass (Hunt 2004). In contrast, *C. nuttallii* are usually found just below the surface or sometimes at the surface; they also possess a large muscular foot to assist in escaping from predators such as moonsnails (*Euspira lewissi*) or seastars (*Pycnopodia helianthoides*) (Cheney & Mumford 1986, Kozloff 1993, Dethier 2006). If the beach is subject to physical disturbances, as sandy beaches can be, the cockle can easily rebury itself or move to a more suitable area where it can dig more readily. Consequently, cockles are probably the dominant clam species at BB due to the sediment composition.

Table 7: Kruskal-Wallis (X^2) and post-hoc Conover-Inman results (*t*-statistic) on differences in weight of clams per m^2 quadrat by site. LT = Lone Tree Point (2010 and 2011 combined), MD = Madrona, MN = Monroe Landing, KI = Kiket Island, BB = Blowers Bluff, LT10 = Lone Tree surveyed in 2010, LT11 = Lone Tree surveyed in 2011.

	Saxidomus gigantea		*Clinocardium nuttallii*		*Leukoma staminea*		*Tresus capax*	
X^2	27.77		342.50		28.82		0.595	
p	<0.0000		<0.0000		<0.0000		0.44	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*
LT vs. MD	0.50	0.618	3.08	0.002				
LT vs. MN	3.50	<0.000	4.50	<0.000				
MD vs. MN	3.27	0.001	1.04	0.300				
KI vs. LT	4.28	<0.000	1.71	0.088				
KI vs. MD	3.77	<0.000	4.16	<0.000				
KI vs. MN	0.24	0.810	5.49	<0.000				
BB vs. LT			20.90	<0.000				
BB vs. MD			12.05	<0.000				
BB vs. MN			11.36	<0.000				
BB vs. KI			19.75	<0.000				
LT10 vs. LT11					1.84	0.067		
LT10 vs. MD					3.03	0.003		
LT11 vs. MD					5.21	<0.000		
KI vs. LT10					1.31	0.19		
KI vs. LT11					0.59	0.558		
KI vs. MD					4.65	<0.000		

Monroe Landing is similar to BB in that both beaches are quite wide with a very gradual slope, however, the lower elevation sites at MN support an extensive eelgrass (*Z. marina*) bed, the middle range elevations (~ +0.6 – 1.2 m) support wide beds of ghost shrimp (*Neotrypaea californiensis*), and the higher elevations have patchy mussel beds (*Mytilus trossulus*) (J. Barber, personal observation). Similarly, MD, KI, and LT also support diverse habitat types. While other variables such as competition, temperature, predation, and exposure most likely play an important role in determining clam diversity and abundance, we believe that substrate type is one of the more important factors.

Although we used our biomass data to describe clam species abundance and diversity on these beaches, the biomass data were primarily used for setting the TAC for each species on the beach. While the public beach boundaries of BB encompass 1.1 km^2, we were only able to survey 0.088 km^2 (8%) of the beach area in 2011. Understanding that we would not be able to survey the entire beach area, our team focused on surveying the known productive area of the beach (although it is likely that other productive areas exist within the beach boundaries). Thus, our BB data were skewed toward an area of higher cockle abundance on the beach. Unpublished results from our 2012 survey confirm that cockle densities are quite patchy along this beach (J. Barber, unpublished data). Despite this natural patchiness, our 2011 survey purposefully covered the area most likely to be targeted by fishermen as this beach opened for a new commercial bait clam fishery shortly after our survey was conducted. By targeting the area of higher cockle abundance we were able to set the most reasonable TAC limits for this new fishery.

The 2010 MN survey covered approximately 49.8% of the area that was surveyed in 2011 (Table 1). Neither survey covered the entire area of this public beach, although the 2011 survey only missed the far western border of the beach. We did not target any particular area of MN on these surveys however, so there is less of a chance that the data are biased toward high abundance regions. The MD survey covered the entire area of the public beach.

Our surveys at LT and KI were on Reservation beaches, therefore, there were no public beach boundaries to set survey limits. The areas that were surveyed at KI were selected based on previous knowledge of the more dense clam beds on the island by the authors. But the survey was also conducted in regions where clam biomass was unknown or known to be less dense. Thus, the KI survey was probably not biased because it covered both dense and less dense sections of clam populations. The same approach was used at LT, although due to lack of personnel only the northern part of LT was surveyed in 2010.

It should be noted that all of our surveyed beaches were located in the northern section of Region 4, yet the entire management region stretches south of the southernmost

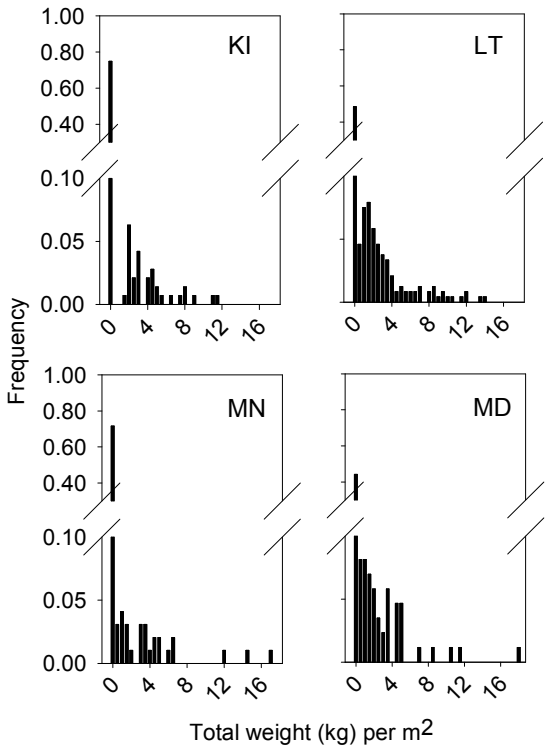

Figure 16: Distribution of *Saxidomus gigantea* total weight (kg) per m^2 quadrat. Data have been converted to proportion of occurrence by sample size in order to allow for comparisons among beaches. Sample sizes: Kiket Island (KI) = 143, Lone Tree Point (LT) = 240, Monroe Landing (MN) = 98, Madrona (MD) = 86.

tip of Whidbey Island. Future analyses will expand our dataset to include beaches located within the central section of Region 4 (Cama Beach and Saratoga Pass).

Temperature data

Our temperature dataset was not quite long or broad enough yet to be useful in understanding possible relationships between clam populations and intertidal temperature. It would be ideal in the future to place temperature loggers at several different elevations along the beach in order to obtain a better description of how the intertidal temperature varies by elevation, and thus, the various regions occupied by clam species.

Length-weight models

Bradbury et al. (2005) developed their length-weight models from a very large dataset involving years of repeated sampling from over 50 public beaches. The models presented in our report are based off of two years of data collection and five beaches. Furthermore, the surveyed beaches were all in the northern section of Region 4, rather than from representative beaches throughout the entire management region. Despite this, we did meet the recommended sample size for developing a Region 4 model for all considered species but *T. capax*. Although our dataset is not as large or as powerful as WDFW's, we believe our Region 4 model is robust enough to prove useful to managers within the region. Furthermore, we plan on continually updating our models with additional data as we continue to survey the beaches throughout each field season.

All of the models, with the exception of the *L. staminea* model, showed slight biases in their ability to predict the weight of clams that were either very small or very large (Figures 8, 10, & 13). These sizes are infrequently obtained during clam surveys; we do not use sieves to collect samples on juvenile clams and larger clams are uncommon. As expected, the models were the most accurate at predicting clam weights within the range of the most commonly surveyed clam sizes. Thus, in order to obtain the most accurate biomass estimates, surveyors would ideally measure and weigh all their samples and use the models only to complete data gaps from broken clams.

Saxidomus gigantea parameter estimates for Region 4 were within the range of values estimated for other bivalve management regions, as were the predicted weights [note that Bradbury et al. (2005) used mean predicted weight while we used mode predicted weight]. Even though no significant difference existed among beach-specific models and the Region 4 model, we would encourage use of the beach-specific models (for all species) whenever possible. The Region 4 model will be useful when it is necessary to predict clam weights from beaches with smaller sample sizes (i.e. where a beach-specific model could not be developed).

Parameter values for *C. nuttallii* also closely resembled parameter values from other bivalve management regions (Bradbury et al. 2005). The Region 4 model predicted that 38 mm cockles generally weighed more than cockles found in other management regions; this is not particularly surprising as the Region 4 model is driven by BB cockles which are heavier than the cockles on all the other surveyed beaches. Because the predicted weight confidence intervals (CI) from the Region 4 model did not overlap with the 95% CIs published in Bradbury et al. (2005), the Region 4 model is significantly different than the other regional models for smaller cockles. It should be noted, however, that our model tended to predict that smaller cockles (approximately <55 mm) weighed more than their actual weight (Figure 10B & 10C), thus the difference between the Region 4 model and the other models (Bradbury et al. 2005) may be erroneous. Conversely, CIs did overlap on weight predictions for 60 mm cockles. As a result, we assumed there was no difference in the weight

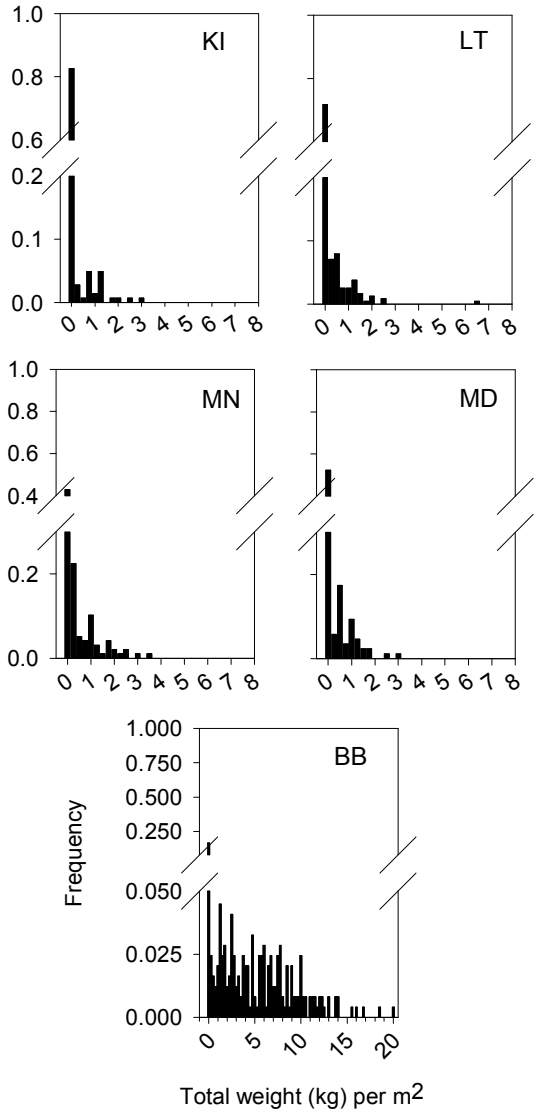

Figure 17: Distribution of *Clinocardium nuttallii* total weight (kg) per m^2 quadrat. Data have been converted to proportion of occurrence by sample size in order to allow for comparisons among beaches. Sample sizes: Kiket Island (KI) = 143, Lone Tree Point (LT) = 240, Monroe Landing (MN) = 98, Madrona (MD) = 86, Blowers Bluff (BB) = 246. Note scale differences on the axes.

predictions between our model and Bradbury et al.'s (2005) models for larger 60 mm cockles.

It is important to remember that BB *C. nuttallii* comprised 71% of the samples used in our Region 4 model, therefore BB cockles most likely drove much of the model's parameter estimates. This may also explain why the LT and MN models appeared to be so different from the Region 4 model (Figure 11). Moreover, the MN beach-specific model predicted that 60 mm cockles would weigh significantly less than the Region 4 prediction (Figure 10D); thus, the Region 4 model should never be used to predict the weight of cockles collected at MN. Although there was no significant difference among only the beach-specific models, the CIs overlapped just slightly between LT and BB versus MN, where the MN model consistently predicted that 60 mm cockles would weigh less than cockles on the other beaches (Figure 10D). This prediction makes sense when one considers the fact that BB had never been harvested at the time of the 2011 survey whereas MN was already a popular beach for clam harvesting (WDFW, unpublished data). It is well-known that species located within the boundaries of no-take marine reserves reach larger sizes within relatively short periods of time (Halpern & Warner 2002). Thus, one would expect the cockles at BB to be larger and heavier and the cockles on heavily-harvested beaches to be smaller and lighter. The relatively consistent harvest at MN is almost certainly one of the reasons behind the smaller-sized cockles (Figure 15B) and thus the different length-weight model on this beach.

Ideally, the length-weight model for *L. staminea* would have been developed from a larger sample size. However, this particular clam species appears to be declining throughout the northern area of Region 4 and we simply did not find many individuals across all surveyed beaches. Reasons for the decline of this species in the northern area of Puget Sound remain unknown. Although we met the recommended sample size of >100 individuals for model development, all of the regional models built by Bradbury et al. (2005) were built off of a minimum of 1,500 clams, possibly explaining some of the differences noted in our models. While our CIs on the predicted weight of a 38 mm clam overlapped with Bradbury et al.'s (2005), our Region 4 model tended to predict that *L. staminea* would weigh slightly more than the other regional models (see Bradbury et al. 2005 Table 6 for referenced parameters).

We had a very low sample size for the development of a *T. capax* Region 4 model, but this was not due to lack of clams. Monroe Landing and LT have substantial populations of this clam species. Nevertheless, valves of this large clam are easily broken or damaged in the digging process. Although we had high counts of this species we had very few individuals that were in the proper condition for obtaining accurate length and weight measurements. Finally, WDFW did not include *T. capax* in their length-weight calculations, so our Region 4 parameters could not be compared with other regional *T. capax* model parameters (Bradbury et al. 2005). The negative lower CI value from the predicted weight of a 60 mm *T. capax* most likely indicates that this model is not accurate and should not be used until we obtain a

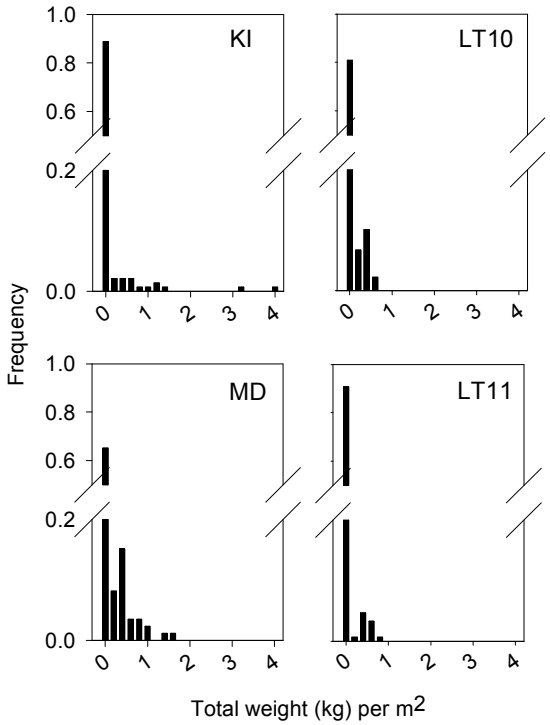

Figure 18: Distribution of *Leukoma staminea* total weight (kg) per m^2 quadrat. Data have been converted to proportion of occurrence by sample size in order to allow for comparisons among beaches. Sample sizes: Kiket Island (KI)= 143, Lone Tree Point 2010 (LT10) = 89, Madrona (MD) = 86, Lone Tree Point 2011 (LT11) = 151.

larger sample size (Table 5). Furthermore, our model tends to predict that smaller horse clams will weigh more than their actual weight (Figure 13); this error may be due to our small sample size.

Temporal change in biomass of *Saxidomus gigantea*

Butter clam, *S. gigantea*, biomass declined significantly over the course of four years within the overlapping area of the LT surveys. Nevertheless, we feel that this decline should be interpreted with caution because a three year dataset cannot provide conclusive information regarding how butter clam populations change through time. Using a ~40 yr. dataset on bivalve populations, Beukema et al. (1993, 2010) demonstrated that bivalve biomass in the Wadden Sea fluctuates dramatically on a temporal basis. Moreover, Dethier (2006) has shown that commercial and recreational landings of clams in Puget Sound also vary on decadal scales. It was impossible, however, to establish if this variability in landings was due to changes in harvester preference (target species may have shifted) or to true increases/decreases in clam biomass. Because our dataset is fishery-independent, we have the ability to track true temporal and spatial changes in clam biomass. While we could discuss potential reasons behind the four year decline recorded at LT, we feel that it is prudent to recognize that our dataset is not yet long enough to determine if this decline truly exists or if the butter clam biomass is simply in a downward trend of a naturally fluctuating population.

Although our current analysis only considered one species for four years at a single beach, we have recently obtained access to a ten-year dataset on local clam populations. For future analyses we plan on expanding our investigation to include multiple years, beaches, and species.

Clam weight frequency distributions

Butter clams, *S. gigantea*, on KI were found to be significantly heavier with a broader distribution of weight than the same species found at our other study sites. This result makes sense when one considers the fact that the beaches here have not had any significant harvest in ~20 years. As mentioned previously, when a species is not harvested, the individuals in the population grow to larger sizes (Halpern & Warner 2002); this is a likely explanation for our butter clam results. According to WDFW (unpublished data), MN receives heavier harvesting pressure than MD. Landings at LT are probably the most similar to landings at MN (J. Barber, personal observation). Likewise, the beach with the next heaviest clams was MD, followed by LT and MN which were statistically similar. Although we cannot prove that fishing pressure is the exact reason why the clams are larger at KI and MD when compared to LT and MN, heavier harvesting pressure at the latter beaches is one of the more compelling explanations.

Blowers Bluff cockles weighed considerably more than cockles on all the other beaches. The lack of previous harvest on this beach could explain the significantly heavier cockles (Halpern & Warner 2002), however this does not help explain why the weight distribution at BB was so narrow. One would expect that an unharvested population of clams would have a broader distribution of weight because many different size classes (or cohorts) would be represented; this assumption was not upheld in these data. It is possible that cockle recruitment at BB is highly variable as has been found for cockle recruitment in the Wadden Sea (Beukema et al. 2001). Indeed, if recruitment and/or subsequent survival at BB is temporally patchy, this may lead to a more narrow weight distribution representing the few cohorts that survived. Dethier (2010), however, found that variation in the abundance of infaunal recruits (including clams) in Puget Sound did not necessarily create similar patterns of variation in adult abundance. Nonetheless, she did find that beaches in the northern part of Puget Sound had a stronger relationship between recruit and adult assemblages than beaches in the southern part of the

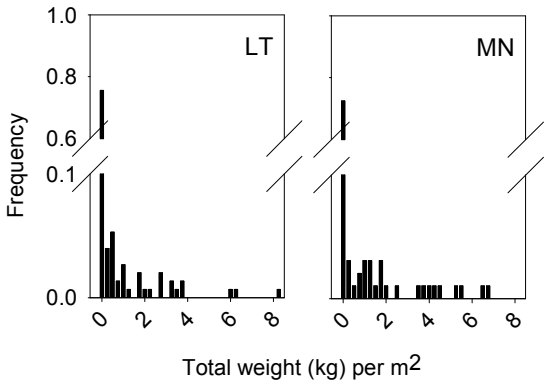

Figure 19: Distribution of *Tresus capax* total weight (kg) per m^2 quadrat. Data have been converted to proportion of occurrence by sample size in order to allow for comparisons among beaches. Sample sizes: Lone Tree Point (LT) = 151, Monroe Landing (MN) = 98.

Sound. Thus, because of BB's northern location, recruitment could still be a factor influencing the narrow distribution in the BB adult cockle biomass data.

Because KI is not currently harvested, one would expect the *C. nuttallii* to be particularly large there as well. However, KI and LT cockle weight distributions were statistically similar and smaller than BB. This is most likely due to the small sample size at KI (n = 33); there are very few cockles on this beach. Lone Tree Point (n = 124), on the other hand, is a heavily harvested beach but cockles are typically not the target species (J. Barber, personal observation). Thus, it is not surprising that these two beaches are statistically similar because they are geographically close to each other, they support similar habitats, and they experience low to no harvest for cockles. Monroe Landing is a popular beach for harvesting bait clams and this fishing pressure could be one reason why the mean and median weights were significantly lower here than at all the other beaches. Madrona receives relatively low harvest pressure (WDFW, unpublished data) which may explain the fact that the cockles are heavier here than the cockles at MN, but this does not explain the narrow weight distribution at MD. This distribution pattern could be due to the recruitment reasons explained above for BB or because the habitat at MD (patchy areas of sand but also cobble/pebble mixed with sand, and mussel beds) is less likely to support cockles.

For both *S. gigantea* and *C. nuttallii*, density-dependent growth could have been another factor affecting the weight of individuals on the beach. This is unlikely, however, because the beaches with the densest populations of clams (densest quadrats recorded at MD for *S. gigantea* and BB for *C. nuttallii*, Figures 16 and 17) also had the second heaviest clams or the heaviest clams, respectively. Furthermore, Jensen (1993) found density-dependent growth in the cockle, *Cerastoderma edule*, when >2000 individuals were recorded in a square meter and no signs of density-dependent growth in areas with <50 individuals. Neither *S. gigantea* or *C. nuttallii* reached densities as high as those reported in Jensen (1993), although one cannot assume that trends recorded in one species will be the same for another. While we cannot exclude density-dependent growth as a factor influencing our results, it seems unlikely that this is an explanation for the patterns in our data.

L. staminea were the heaviest at KI, which is not surprising given the lack of harvest on these beaches. Again, we do not have the data necessary to ascertain that the lack of harvest explains these results, but this is a common result when species are not harvested (Halpern & Warner 2002). Furthermore, it could also be likely that native littlenecks are lighter at LT and MD because these beaches are both subject to harvesting pressure and this is a target species. Although *L. staminea* are known to exhibit density-dependent growth (Peterson 1982), it is doubtful this was affecting the size of the individuals in our results because these clams were found in such low densities (mean density = 2.2 +/- 0.3 SE per m^2 for all beaches with native littlenecks, J. Barber, unpublished data). Total clam density is not likely to have been a factor as native littlenecks are usually found just below the surface while other species found in similar substrates and elevations are buried deeper or are directly on the surface (Cheney & Mumford 1986).

Horse clams, *T. capax*, were lighter at LT than at MN. Harvest levels are not likely to be the reason behind the differences seen here because both beaches receive fairly intense harvest efforts. The horse clams at LT were primarily found south of LT Point in areas where the habitat is mostly cobble and pebble mixed with sand, or even hard-packed clay. It is possible that the relatively hard-bottom habitat at LT limits the ability of individual clams to reach larger/heavier sizes. Conversely, MN does not have any large areas with mixtures of cobble, pebble, sand, and clay. This primarily sandy beach may offer clams the ability to reach larger sizes and thus heavier weights. Another possible factor limiting the size of horse clams at LT is density-dependent growth, which has been documented in another Pacific Northwest clam species (Peterson 1982). Indeed, *T. capax* south of the point at LT are densely packed into areas of good habitat whereas *T. capax* are seemingly more dispersed along the MN beach (J. Barber, personal observation).

Clam biomass among sites

While the butter clams at KI are quite heavy (i.e. large), the results from this analysis showed that there are simply not many butter clams on this beach (just over 70% of the quadrats did not contain butter clams). Likewise, MN had the same clam weight per quadrat as KI, meaning there were not as many butter clams per area on these beaches compared to LT or MD. The preferred butter clam habitat (mixed sand and gravel, Cheney & Mumford 1986) along both of these beaches can be quite patchy and when the clams are present they tend to be in these distinct areas. Lone Tree Point and MD, on the other hand, have larger areas of preferred habitat which probably explains the higher likelihood of encountering butter clams on these beaches (see Figure 5 for an example of butter clam density and distribution at LT).

The high biomass of *C. nuttallii* per quadrat on BB was unparalleled compared to the other surveyed beaches in 2010 and 2011. Although we have not yet tested reasons why BB is so different from our other beaches, we hypothesize that the differences could be due to substrate composition (see details in the individual beach survey discussion section). The biomass per quadrat values from KI and LT were statistically similar, which is likely explained by the fact that there are simply not many cockles on either beach (over 70% of quadrats were zeros at both beaches). Monroe Landing and MD had a higher biomass of cockles per quadrat compared to KI and LT. Perhaps the Penn Cove and Oak Harbor regions have a higher influx of cockle recruits compared to LT and KI which are located in Skagit Bay. Furthermore, the large population of BB cockles may be a source of larvae for MN and MD cockle populations; whereas LT and KI do not appear to be located near a beach with such a large population of cockles (J. Barber, personal observation).

Approximately one decade ago native littlenecks were quite common at LT (J. Barber & T. Mitchell, unpublished data), yet our data show that 81% and 91% of the quadrats sampled in 2010 and 2011, respectively, had no *L. staminea* present. Although there was no difference in quadrat biomass between these two years at LT, it is likely that a difference would have been recorded if our data extended into the past decade. Swinomish Fisheries and Water Resources are currently working on an analysis using data collected over the past decade to further investigate this trend in LT native littleneck populations (J. Barber & T. Mitchell, unpublished data). Kiket Island had similar amounts of *L. staminea* biomass per quadrat compared to the LT surveys. While the native littlenecks at KI are heavier than those at LT, there are not many individuals on the beach. It is interesting to note, however, that the two heaviest *L. staminea* quadrats from all of the surveyed beaches were recorded at KI. We are hesitant to suggest reasons why the *L. staminea* biomass per quadrat was higher at MD. The beaches (KI, LT, & MD) are somewhat comparable in substrate type and harvest effort is probably similar between LT and MD. Other possibilities for the difference among beaches could include differential recruitment and survival, variation in predator abundance and diversity, or lack of intra- or interspecific competition.

An interesting aspect of the results of the horse clam biomass per quadrat is that there was no difference between sites. However, there was a distinct difference in the weight distribution of *T. capax* at these sites where the clams were lighter at LT and heavier at MN. Combining these results with those of the weight distribution reveals what is easily observed in the field: LT has many small clams per quadrat while MN has one or two large clams in a single quadrat. As suggested in previous paragraphs, the size differences may be due to intraspecific competition at LT, harvest pressure, and/or different substrata at both beaches.

For all of these species, it is possible that interspecific competition played a role in the growth rate of individuals, and thus, overall biomass. Peterson (1982) found that *L. staminea* had depressed growth rates when placed in areas with high densities of a similar clam, *Chione undatella*. However, the four species we studied maintain relatively separate populations in terms of preferred elevation and burial depth (e.g. *S. gigantea* typically bury deeper and are found lower in intertidal elevation than *L. staminea*) (Cheney & Mumford 1986, J. Barber, personal observation). Furthermore, species not discussed in this document [e.g. softshell clams (*Mya arenaria*) or manila clams (*V. philippinarum*)], are found at very low densities on the studied beaches and are unlikely to exhibit a strong effect on the variability recorded in this study. Thus, while interspecific competition may be a factor, we believe it is an improbable explanation of the majority of the variation recorded on these beaches.

Conclusions

Throughout this discussion we have speculated over the various reasons why clam populations vary by beach. Ultimately, testing these hypotheses awaits further data on variables such as recruitment, harvest pressure, substrate type, exposure, predator densities, etc. The goal of this initial research was only to quantify the ways in which clam populations vary within a management region. Future studies could utilize multivariate analyses in an attempt to establish what factors play key roles in determining clam population variability.

With this goal in mind, we plan on initiating a juvenile clam recruitment study at LT and BB in 2013 to investigate the effects of recruitment on adult biomass at these beaches (but see Dethier 2010 for related results). We will also spend a field season quantifying the substrate types along these beaches. And finally, we can begin to investigate the effects of fishing pressure on clam populations because BB, previously a de-facto marine reserve due to difficult access and poor water quality, is now an important beach for a commercial bait clam fishery. Although it would have been ideal to have a multi-year pre-fishery dataset, we feel that a single year of pre-fishery data can still be informative when compared with post-fishery data. Currently, KI remains closed to harvest with an exception of a biennial opening for tribal elders, although in 2011 no diggers came to the beach and the beach was not opened for harvest in 2012. We will continue to collect clam population data at KI whether or not the KI beaches remain closed to harvest. If the Tribe decides to open the beaches for harvest we can use our data to make wise management decisions and to learn how the clam populations react to harvesting pressure. Conversely, if the Tribe maintains harvest closures we can continue to learn about natural clam population variability without the confounding factor of harvest pressure.

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