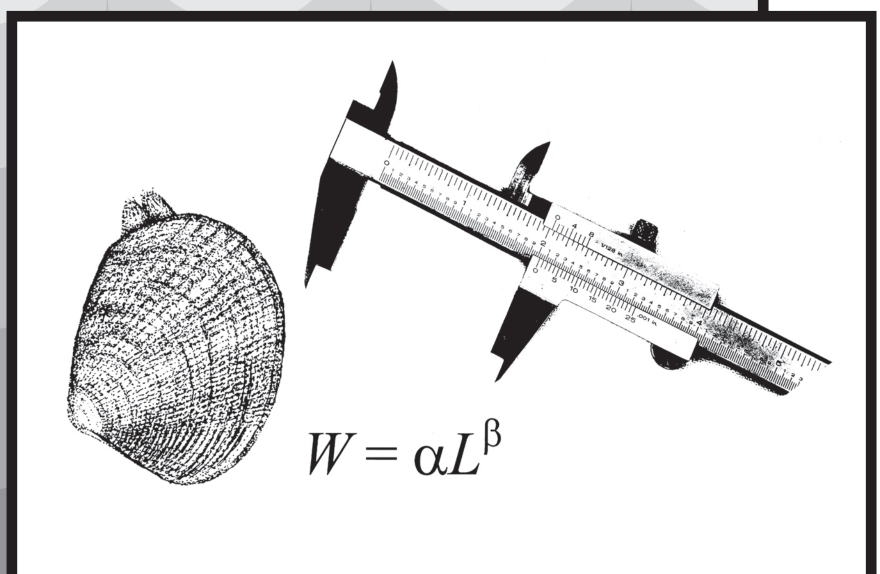
STATE OF WASHINGTON December 2005

Length-Weight Models for Intertidal Clams in Puget Sound (Bivalve Regions 1, 5, 6, 7, and 8)



by Alex Bradbury, Brady Blake, Camille Speck, and Doug Rogers

Washington Department of
FISH AND WILDLIFE
Fish Program
Fish Management Division

FPT 05-15

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ACKNOWLEDGEMENTS

We would like to thank Robert Conrad, Quantitative Services Manager for the Northwest Indian Fisheries Commission (NWIFC) for statistical advice, for providing the Monte Carlo simulation routine, and for reviewing a preliminary draft. Conrad also created the error-bar graphs used in this report. Pam Goodman, also of NWIFC, and Jennifer Cahalan (WDFW) provided valuable advice on “R” software programming. We thank shellfish biologist Eric Sparkman (currently with the Squaxin Tribe and formerly with the Skokomish Tribe) for sharing Skokomish tribal survey data. Randy Hatch (Point No Point Treaty Council) and Dr. Kenneth Chew (professor emeritus, University of Washington) provided us with information on published length-weight models and their current use in clam surveys. We thank Justin Secrist (WDFW) for editing and producing the final manuscript. Finally, we wish to thank the many WDFW biologists and technicians who performed the cold and dirty work of collecting and processing literally tens of thousands of clam samples used in our analyses.

INTRODUCTION

On Washington State public tidelands, intertidal clams are jointly managed by the Washington Department of Fish and Wildlife (WDFW), treaty tribes, and the Washington Department of Natural Resources. The state is divided into eight Bivalve Regions for management purposes (Figure 1). Annual plans negotiated between the state and tribes for each of these Regions define the biological survey methods, management procedures, and annual TACs (Total Allowable Catch) for the sport and commercial fisheries. Currently, TACs are calculated for only two clam species -- Manila clams (*Tapes philippinarum*) and native littleneck clams (*Protothaca staminea)* – but several other "passively managed" clam species are included in the survey estimates of biomass on these beaches. From the standpoint of sport and commercial fisheries, the most important of these other species are butter clams (*Saxidomus giganteus*), cockles (*Clinocardium nuttallii),* and eastern softshell clams (*Mya arenaria*). Two other passively managed intertidal species, geoducks (*Panopea abrupta*) and horse clams (*Tresus spp.)* live deep in the substrate and are thus not likely to be sampled in proportion to their abundance.

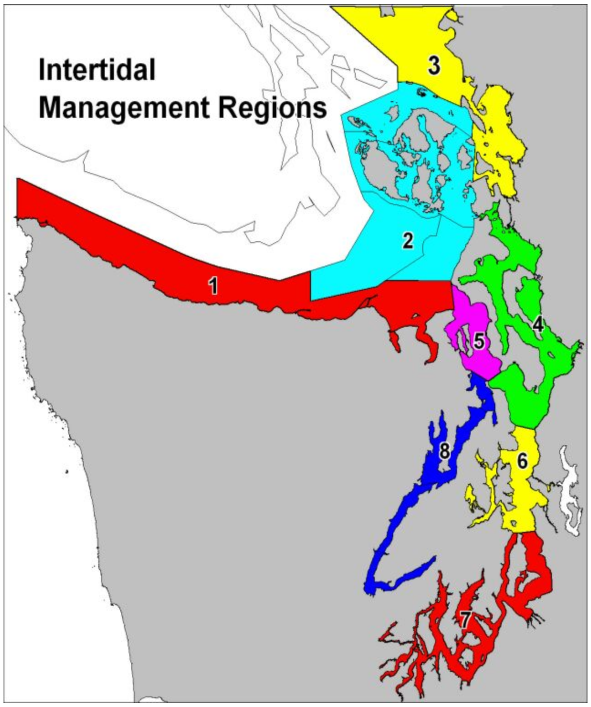

Figure 1. Bivalve Regions used for intertidal clam management in Puget Sound.

The annual TACs for Manila and native littleneck clams are calculated based on biological survey estimates of the clam biomass on individual beaches. WDFW and the treaty tribes conduct these surveys using similar but not identical methods. WDFW survey methods are detailed in a departmental Procedures Manual (Campbell 1996), and tribal methods are outlined in at least two technical reports and memoranda: Point No Point Treaty Council (1998) and Fyfe (2002).

All state and tribal surveys currently performed in Bivalve Regions 1, 5, 6, 7, and 8 involve a systematic random sampling design that covers either the entire public beach or the "productive" portion of the beach (i.e., the portion of the beach containing significant clam resource). Numerous sample digs – either 0.0929 m^2 (1 ft^2) for state surveys or 0.1858 m^2 (2 ft^2) for tribal surveys – are taken from the beach at low tides, during which most or all of the Manila and native littleneck habitat can be sampled. The mean density of clams per unit area is estimated for the beach, and total biomass is then estimated as the product of mean density, average weight per clam, and the area of the beach.

The only survey method that differs significantly between WDFW and tribes is the procedure used to estimate the average weight per clam. WDFW transports sampled clams to the laboratory and individually records the shell length and weight of each clam; mean weight per clam is therefore estimated as the average of all unbroken clams in the sample. Most tribal surveys, on the other hand, involve measuring the shell length of all sampled clams on the beach, and later applying an allometric length-to-weight model to estimate the weight of each clam.

Tribes that estimate clam weights from lengths rely on two models. For Manila clams, tribes use a length-to-weight model originally published as Appendix E of a Sea Grant Technical Report on Manila clam aquaculture in Puget Sound (Anderson *et al.* 1982; reproduced here as Appendix Table 1). The exact same model appears as Appendix F in the revised edition of the Sea Grant report (Toba *et al.* 1992). In this model – which henceforth we refer to as the "Sea Grant model" -- live weight of a clam is estimated as $W = 0.0001433L^{3.11}$, where W is weight in grams and L is length in millimeters. Unfortunately, neither the geographic source of the Manila clam samples, the sample size, nor the statistical error terms for this model are cited in either report.

For native littleneck clams, tribes rely on a computer spreadsheet developed by the Northwest Indian Fisheries Commission (Appendix Table 2). This spreadsheet was based on "…length/weight data for littleneck clams provided by the Washington Department of Fish and Wildlife…" (Point No Point Treaty Council 1998). Unfortunately, no details are cited, and WDFW biologists can no longer provide the data upon which this model is based. Presumably, it was estimated from native littleneck length-weight data taken during routine beach surveys.

But, as with the Manila model, no information is available on the geographic source of the native littleneck samples, the total sample size, or the statistical error terms of the model.

When using these length-to-weight models, managers make the tacit assumption that the model reliably estimates the weight of sampled clams on each surveyed beach. If this assumption is violated, the result will be either an overestimate or underestimate of the clam biomass on a given beach. In turn, unreliable biomass estimates produce TACs which are either undesirably high or low. In recent years, several tribal biologists have made empirical comparisons between Manila clam weights which have been measured in the field or laboratory and those derived from Anderson *et al.* (1982) model cited above. These comparisons raised doubts as to the reliability of the model on at least some beaches. The Skokomish Tribe abandoned the use of both the Sea Grant Manila clam model and the NWIFC native littleneck model beginning in 2002. Skokomish biologists began weighing sampled Manila and native littleneck clams taken during their beach surveys in order to estimate mean weight per clam. The Squaxin Tribe followed suit in 2003. Most tribes, however, are still using the Manila and native littleneck models cited above to estimate clam biomass on surveyed beaches.

In this report, we examine length and weight data from clams routinely sampled by WDFW in public beach surveys from 1994 through 2002 and within Bivalve Regions 1, 5, 6, 7, and 8. Our objective is to estimate beach-specific length-to-weight models for Manila clams, native littleneck clams, butter clams, cockles, and eastern softshell clams. We also examine the statistical confidence bounds of these beach-specific models and produce pooled regional models for each species where appropriate. We then make empirical comparisons using actual beach survey data for Manila and native littleneck clams; here we compare biomass estimates based on actual weighed samples against biomass estimates generated using length-weight models. We also test at selected beaches our assumption that length-weight relationships did not change significantly over the nine-year sampling period of this study. Finally, we make practical recommendations on how to make the most reliable estimates of mean weight per clam from survey data.

METHODS

Sampling Sites and Field Methods

Clams were sampled from 1994-2002 on a subset of public beaches in Bivalve Regions 1, 5, 6, 7, and 8 (Tables 1, 4, 7, 10 and 13). Samples were taken during routine clam population surveys on these beaches, which are used to estimate the biomass of clams prior to setting Total Allowable Catch (TAC) for each beach on an annual basis. These particular beaches were identified for biomass surveys by state and tribal shellfish managers because they were expected to provide significant recreational fisheries, tribal commercial fisheries, or both.

WDFW field sampling methods are fully described in Campbell (1996). Sampling protocols were developed to target Manila clams and native littleneck clams, although butter clams, cockles, eastern softshell clams, horse clams, varnish clams (*Nuttallia obscurata*), thin-shelled littleneck clams (*Protothaca tenerrima*), California softshell clams (*Cryptomya californica*), rough diplodon (*Diplodonta impolita*), and *Macoma* spp. also occur in samples. Surveys were conducted on those days when the tide was –0.3 m (–1.0 ft) or lower, and samples were taken during a 4-hour period centered on local low tide. Surveys were conducted from April through September, and efforts were made to sample individual beaches at roughly the same date each year. Survey boundaries were defined by the management need for a particular public tideland, but were generally based on legal property boundaries.

Following the methods described in Campbell (1996), clam surveys were conducted using a systematic line transect design beginning from a randomly selected starting point on the beach. Transects ran from the top of the productive "clam band" to the water, or to the bottom of the clam band, and were adjusted to accommodate changes in the shoreline such as peninsulas, embayments and spits. Generally, transects were placed every 30.48 m (100 ft) along the length of the beach, and samples were taken every 12.19 m (40 ft) along each transect. Sampling density with this design averaged about 27 samples hectare^{-1} (11 samples acre^{-1}), but sampling density was sometimes increased or decreased to reduce variance or maximize efficiency.

Each sample consisted of a circular 0.0929 m^2 (1 ft^2) hole, excavated with a shovel to about 0.3 m (1 ft) in depth. All excavated material was placed on a sorting board and was manually sifted to retain any clams that were present in the sample. Due to difficulty in sorting tiny clams from a variety of substrates, technicians were instructed to sort for clams at least 10 mm or larger, although smaller clams were sometimes retained as well.

Prior to 2002, all clams that were excavated during a survey were retained for length and weight sampling. In 2002, only a systematic subsample of clams was retained for length and weight measurement. On most beaches sampled in 2002, clams were retained for length and weight measurements from every third sample.

Once each survey was completed, clams from individual samples were placed in plastic bags, transported to the laboratory, and frozen prior to processing.

Tribal clam survey data for Potlatch East in 2002 was provided by Eric Sparkman, Skokomish Tribe shellfish biologist. Field methods were essentially similar to the WDFW methods described above and in Campbell (1996) except that they relied on samples which were 0.1858 m^2 (2 ft^2).

Laboratory Measurements

Laboratory methods are fully described in Campbell (1996). Clams were processed while still frozen, or in a partial state of thawing. Care was taken not to allow samples to thaw completely, in order to conserve the fluids normally contained within the valves. We tested the null hypothesis that the fresh weights of Manila clams were equal to the frozen weights (Appendix 1).

For the purposes of this analysis, all clams with broken valves were discarded. Clams were measured with steel calipers to the nearest 0.1 mm in 1994-1997 and in 2000; in 1998, 1999, 2001, and 2002, length was measured to the nearest 0.01 mm. Clams were weighed on an electronic balance to the nearest 0.001 g in 1994-1997, to the nearest 0.01 g in 1998-2001, and to the nearest 0.1 g in 2002.

Analytical Methods

We first eliminated all records of sampled clams that were broken, crushed, or otherwise un-measurable or un-weighable. Following this initial data cleansing, we used an *ad hoc* data graphing procedure to visually eliminate obvious outliers which we felt could only be explained by an error in laboratory processing or data keypunching.

An initial decision was made to pool the data on individual beaches from all years 1994-2002 before proceeding with data analysis. This decision was based on exploratory analyses that suggested that for many beaches and species, survey data from a single year did not provide nearly enough samples needed to produce model parameter estimates of reasonable precision. Following this multi-year pooling, beaches where sample size for a clam species was less than 30 clams were eliminated from *all* analyses for that species.

An allometric growth model (Equation 1) (Quinn and Deriso 1999) was used to describe the relationship between total weight and shell length:

$$W = \alpha L^{\beta} \qquad \text{(Equation 1)}$$

Where:

W is the total weight of a clam (g)
L is the shell length of a clam (mm)
α and β are parameters

Beach-specific models for Manilas, native littlenecks and cockles were estimated only for beaches where ≥100 clams were sampled, measured, and weighed. This rule was established after exploratory data analyses showed that the coefficient of variation (CV) of the model parameter α usually exceeded 0.30 when sample size dropped below 100 clams. CVs of this magnitude produced confidence bounds around weight-at-length estimates that we considered too wide for practical fisheries management use. However, data from beaches where sample size exceeded 100 clams were pooled with those from other beaches in the same Bivalve Region to produce regional models for these species.

Beach-specific models for butter clams were estimated only for beaches where ≥200 clams were sampled, measured, and weighed. This rule was established after exploratory data analyses showed that the CV of the model parameter α almost always exceeded 0.30 when sample size dropped below 200 clams. However, data from beaches where sample size exceeded 200 butter clams were pooled with those from other beaches in the same Bivalve Region to produce regional models for butter clams.

A nonlinear least squares procedure (R software, package *nls*) was used to estimate the best-fit model values for the parameters α, β, and their associated error terms. Bootstrapped 95% statistical confidence bounds on the estimated weight of clams at a given length were estimated using a Monte Carlo simulation method for two-parameter nonlinear models (Rubinstein 1981). This method empirically estimates the variance of a point estimate using the variance-covariance matrix of the model parameters and random normal variates. New values for both parameters were first generated assuming that they have a normal distribution. These new parameter estimates were then used to generate a series of new weight-at-length estimates. For each surveyed beach and species, we simulated 5,000 weight-at-length estimates and then used bootstrap procedures to generate approximate 95% confidence intervals. We used an Excel spreadsheet provided by Robert Conrad of the NWIFC to run the Monte Carlo simulations and bootstrap confidence intervals.

We used an *ad hoc* empirical method to evaluate the differences between beach-specific models. For Manilas and native littlenecks, we first compared the bootstrapped 95% confidence intervals (CIs) surrounding the model-predicted weights of 38 mm clams for all surveyed beaches in each Bivalve Region. We chose 38 mm because it represents a rough mid-point in the continuum of shell lengths of sampled clams and is also the legal minimum size for these species. When these 95% CIs overlapped for one or more beach-specific models, we considered that the models did not differ significantly. In such cases, we pooled the models to produce a region-wide model, and also included any data from beaches sampled within the Region where fewer than 100 clams were sampled. Since sampled butter clams, cockles, and eastern softshells tended to be much larger than Manilas and natives, we compared the 95% CIs surrounding the predicted weight of these three species at 60 mm.

Empirical Model Comparisons

For Manila and native littleneck clams, we compared the beach-specific models, regional models, the Sea Grant Manila model (Anderson *et al.* 1982), and the NWIFC native littleneck model to actual survey data in which all clam samples were measured and weighed. In this exercise, we posed the question: What would our survey estimates of Manila and native littleneck harvestable biomass have been had we estimated clam weights using models, rather than actually weighing clam samples? Since annual clam TACs (Total Allowable Catch) are based entirely on the biomass of legal Manila and native littleneck clams (i.e., clams ≥ 38mm), we confined our comparisons to these two species.

Survey data in which clams were weighed provided a "best" estimate of mean weight per legal clam as well as an estimate of total legal clam biomass for each surveyed beach. We treated these estimates based on actual weighed samples as a yardstick for comparing model-based estimates of mean weight per clam and total biomass. To generate model-based estimates, we converted measured lengths for all legal clams taken in each survey to weights using the models. Then we simply substituted these model-estimated weights for actual sample weights, and estimated mean weight per legal clam and total legal clam biomass for each survey in the routine manner used by WDFW and tribes (i.e, total biomass = mean density **X** mean weight per clam **X** total area surveyed). We then compared these model-based estimates against the actual survey estimates to evaluate the efficiency of the models.

Survey data from both WDFW and tribes were used in the comparisons. We chose survey data from six beaches to make the comparisons for each of the two species. Beaches were chosen in part to represent the geographic range of each species. We also attempted to choose beaches of differing sizes, and with a range of clam densities and sample sizes for the comparisons.

Change in Length-Weight Relationships over Time

As noted above, we chose to pool length-weight data for the entire sampling period 1994-2002 in order to increase the sample sizes at each beach for modeling purposes. This approach, however, assumes that there were no significant changes in the length-weight relationship over this nine-year time period. We decided to test this assumption for Manila clams at three public beaches: Quilcene Tidelands Section 10, Dosewallips State Park, and Potlatch State Park. We chose Manila clams for the test because of their commercial and recreational importance, but also because their short life span and fast growth makes them a more likely candidate for short-term morphological changes than the other species we sampled. We selected the three beaches above for testing in part because sample sizes were extremely large for most of the sampling period, increasing our ability to detect statistically significant differences from year to year if they existed (i.e., 95% CIs were relatively narrow for most years sampled). We also selected these beaches because they have been heavily harvested by sport and commercial diggers since 1999 or 2000. As a result, overall clam density has been reduced and the substrate has been repeatedly disturbed, two factors that might be likely to produce morphological changes in clam populations.

We created separate Manila clam length-weight models for each survey year (1994-2002) on these three beaches, following the procedures described above. We also created models using survey data from 2003 and 2004 in order to obtain a longer time sequence of estimates for comparison. In order to test for significant differences in the Manila clam length-weight relationship from year to year, we compared the bootstrapped 95% CIs surrounding the estimated weight of 38 mm clams as described above.

RESULTS

LENGTH-WEIGHT MODELS

Manila Clams

Samples of 73,423 Manila clams from 55 public beaches (Table 1) were used to construct length-weight models. A total of 29 public beaches contained sample sizes ≥ 100 Manila clams with which to estimate the parameters for beach-specific models (Table 2). CVs of the α parameter for these beaches averaged 0.10, ranging from 0.03 to 0.34. The other 26 beaches had sample sizes that did not permit beach-specific models to be estimated, but which could be pooled to create regional models. The variance-covariance matrices of the model parameter estimates are given in Appendix Table 3.

Only six beaches surveyed in **Bivalve Region 1 (Strait of Juan de Fuca)** contained Manila clams, and sample size per beach never exceeded 100 clams (Table 1). No beach-specific models were therefore estimated for these beaches. All six samples were instead pooled to create a regional model (n = 357 clams, Table 3, Figure 2).

In **Bivalve Region 5 (Admiralty Inlet),** only two of the 11 surveyed beaches had sample sizes exceeding 100 Manila clams (Oak Bay County Park and South Indian Island County Park), allowing beach-specific models to be estimated (Table 2). The other nine beach samples were pooled to produce a common model, whose 95% confidence bounds around the predicted weight of 38 mm clams overlapped those of both beach-specific models (Figure 3). All 11 beach samples were therefore pooled to produce a regional model for Bivalve Region 5 (n = 1,824 clams, Table 3, Figure 2).

All three surveyed beaches in **Bivalve Region 6 (Central Puget Sound)** contained fewer than 100 Manila clams in their samples (Table 1). A pooled regional model was therefore created (n = 223 clams, Table 3, Figure 2).

In **Bivalve Region 7 (Southern Puget Sound)**, four of five surveyed beaches had sample sizes exceeding 100 Manila clams, for which beach-specific models were estimated (Table 2). An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of 38mm Manila clams existed among all four beaches (Figure 3), and data were therefore pooled along with Beach 280570 to produce a regional model (n = 1,421 clams, Table 3, Figure 2).

Table 1. Public beaches providing samples for length-weight models of Manila clams. Bold type indicates that sample size n ≥ 100 clams, allowing for estimation of beach-specific model parameters.

BIDN	Beach Name	Bivalve Region	n (sample size)
250014	Dungeness	1	35
250016	Cline Spit	1	49
250050	Sequim Bay State Park	1	41
250055	North Sequim Bay State Park	1	88
250057	Pitship Point	1	61
250110	Maynard	1	83
250280		5	62
250290		5	32
250310		5	36
250315		5	57
250320		5	47
250330		5	39
250340		5	45
250350		5	89
250400	**Oak Bay County Park**	**5**	**311**
250410	**South Indian Island County Park**	**5**	**1,061**
250470	Port Townsend Ship Canal	5	45
250510	**Wolfe Property State Park**	**8**	**5,954**
250512	**Shine Tidelands State Park**	**8**	**1,220**
260350	Point White	6	89
260510	Bremerton Coal Dock	6	40
260545	Silverdale	6	94
270050	Brown Point (DNR 57-B)	8	62
270052		8	70
270112		8	38
270114	North Frenchman's Point	8	41
270170	**Point Whitney Tidelands**	**8**	**1,621**
270171	**Point Whitney Lagoon**	**8**	**2,602**
270201	**Dosewallips State Park (Approved)**	**8**	**12,061**
270202	**Dosewallips State Park (Restricted)**	**8**	**4,775**
270293	**Triton Cove Tidelands**	**8**	**272**
270300	**Eagle Creek**	**8**	**284**
270312	South Lilliwaup	8	58
270380	**DNR 44-A Dewatto**	**8**	**313**
270440	**Potlatch State Park**	**8**	**4,570**
270442	**Potlatch DNR Tidelands**	**8**	**1,516**
270444	**Potlatch East**	**8**	**650**
270480	**Rendsland Creek**	**8**	**803**
270501	**Quilcene Tidelands Sec. 1**	**8**	**6,899**
270502	**Quilcene Tidelands Sec. 2**	**8**	**2,719**
270503	**Quilcene Tidelands Sec. 3**	**8**	**1,985**
270504	**Quilcene Tidelands Sec. 4**	**8**	**1,563**
270505	**Quilcene Tidelands Sec. 5**	**8**	**2,186**
270506	Quilcene Tidelands Sec. 6	8	72
270507	Quilcene Tidelands Sec. 7	8	97
270508	**Quilcene Tidelands Sec. 8**	**8**	**2,355**
270509	**Quilcene Tidelands Sec. 9**	**8**	**2,682**
270510	**Quilcene Tidelands Sec. 10**	**8**	**10,203**
270801	**Dabob Broad Spit**	**8**	**829**
270802	**East Dabob**	**8**	**1,098**
280570		7	77
280580	**Cutts Island State Park**	**7**	**137**
280680	**Penrose Point State Park**	**7**	**511**
280712	**North Bay Coast**	**7**	**475**
281043	**Oakland Bay (Ogg)**	**7**	**221**
TOTAL	55 beaches		73,423

Table 2. Parameter estimates of beach-specific length-weight models for Manila clams. Only beaches shown in Table 1 with n ≥ 100 clams were used to estimate beach-specific parameters.

				α			β			Predicted weight at 38 mm		
BIDN	Beach Name	Bivalve Region	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper
250400	Oak Bay County Park	5	311	0.00032555	0.000045	0.1375	2.932270	0.036561	0.0125	13.96	13.21	14.11
250410	South Indian Island County Park	5	1,061	0.00030100	0.000022	0.0735	2.960225	0.019270	0.0065	14.29	14.02	14.38
250510	Wolfe Property State Park	8	5,954	0.00025142	0.000008	0.0315	3.008857	0.008303	0.0028	14.25	14.18	14.29
250512	Shine Tidelands State Park	8	1,220	0.00019234	0.000012	0.0644	3.077640	0.017143	0.0056	14.00	13.81	14.07
270170	Point Whitney Tidelands	8	1,621	0.00020240	0.000013	0.0651	3.052106	0.017771	0.0058	13.42	12.27	13.48
270171	Point Whitney Lagoon	8	2,602	0.00014188	0.000009	0.0637	3.153640	0.017658	0.0056	13.61	13.47	13.66
270201	Dosewallips State Park (Approved)	8	12,061	0.00021980	0.000006	0.0278	3.053000	0.007481	0.0025	14.63	14.57	14.66
270202	Dosewallips State Park (Restricted)	8	4,775	0.00022224	0.000010	0.0437	3.044974	0.011726	0.0039	14.36	14.26	14.41
270293	Triton Cove Tidelands	8	272	0.00027403	0.000044	0.1611	2.986203	0.043230	0.0145	14.30	13.25	14.43
270300	Eagle Creek	8	284	0.00019587	0.000033	0.1680	3.061113	0.046597	0.0152	13.42	12.46	13.57
270380	DNR 44-A Dewatto	8	313	0.00013491	0.000021	0.1525	3.177560	0.040226	0.0127	14.12	13.19	14.26
270440	Potlatch State Park	8	4,570	0.00018142	0.000007	0.0403	3.078427	0.010826	0.0035	13.24	13.16	13.29
270442	Potlatch DNR Tidelands	8	1,516	0.00012435	0.000008	0.0654	3.183239	0.017480	0.0055	13.29	13.12	13.35
270444	Potlatch East	8	650	0.00014659	0.000016	0.1091	3.146480	0.029714	0.0094	13.70	13.26	13.81
270480	Rendsland Creek	8	803	0.00019660	0.000021	0.1080	3.064580	0.028893	0.0094	13.64	13.18	13.75
270501	Quilcene Tidelands Sec. 1	8	6,899	0.00008669	0.000003	0.0297	3.291000	0.008151	0.0025	13.69	13.64	13.73
270502	Quilcene Tidelands Sec. 2	8	2,719	0.00015575	0.000008	0.0545	3.139609	0.015108	0.0025	13.71	13.66	13.75
270503	Quilcene Tidelands Sec. 3	8	1,985	0.00017577	0.000013	0.0767	3.124924	0.021245	0.0068	15.19	14.95	15.28
270504	Quilcene Tidelands Sec. 4	8	1,563	0.00014668	0.000014	0.0963	3.181691	0.026851	0.0084	15.59	15.20	15.68
270505	Quilcene Tidelands Sec. 5	8	2,186	0.00011750	0.000008	0.0695	3.250881	0.019521	0.0060	16.06	15.84	16.13
270508	Quilcene Tidelands Sec. 8	8	2,355	0.00016725	0.000015	0.0880	3.148336	0.025218	0.0080	15.74	15.40	15.82
270509	Quilcene Tidelands Sec. 9	8	2,682	0.00020554	0.000017	0.0845	3.086269	0.023880	0.0077	15.44	15.15	15.50
270510	Quilcene Tidelands Sec. 10	8	10,203	0.00022665	0.000009	0.0393	3.057039	0.010976	0.0036	15.30	15.23	15.34
270801	Dabob Broad Spit	8	829	0.00027776	0.000025	0.0883	2.988981	0.024204	0.0081	14.64	14.35	14.73
270802	East Dabob	8	1,098	0.00023671	0.000019	0.0801	3.038909	0.021510	0.0071	14.96	14.66	15.03
280580	Cutts Island State Park	7	137	0.00013108	0.000026	0.2003	3.172116	0.053361	0.0168	13.45	11.93	13.64
280680	Penrose Point State Park	7	511	0.00032813	0.000030	0.0899	2.933686	0.023360	0.0080	14.15	13.75	14.27
280712	North Bay Coast	7	475	0.00019509	0.000031	0.1569	3.064116	0.040122	0.0131	13.52	12.44	13.64
281043	Oakland Bay (Ogg)	7	221	0.00067941	0.000231	0.3404	2.750713	0.091226	0.0332	15.05	9.68	15.20

Table 3. Parameter estimates of regional length-weight models for Manila clams. Beaches sampled in each Bivalve Region are listed in Table 1.

			α			β			Predicted weight at 38 mm		
REGION	number beaches	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper
Bivalve Region 1	6	357	0.00040880	0.000057	0.1399	2.893000	0.035790	0.0124	15.20	14.16	15.37
Bivalve Region 5	11	1,824	0.00029950	0.000017	0.0552	2.960000	0.014370	0.0049	14.21	14.03	14.28
Bivalve Region 6	3	223	0.00028390	0.000044	0.1547	2.980000	0.039640	0.0133	14.49	13.32	14.65
Bivalve Region 7	5	1,421	0.00030520	0.000022	0.0725	2.952000	0.018770	0.0064	14.06	13.78	14.15
Bivalve Region 8 *	21	47,357	0.00018210	0.000002	0.0126	3.095000	0.003389	0.0011	14.12	14.10	14.13
Quilcene Tidelands Sections 3-10	8	21,143	0.00018500	0.000005	0.0250	3.115000	0.006977	0.0022	15.42	15.38	15.45

* Except Quilcene Tidelands Sections 3-10 and East Dabob

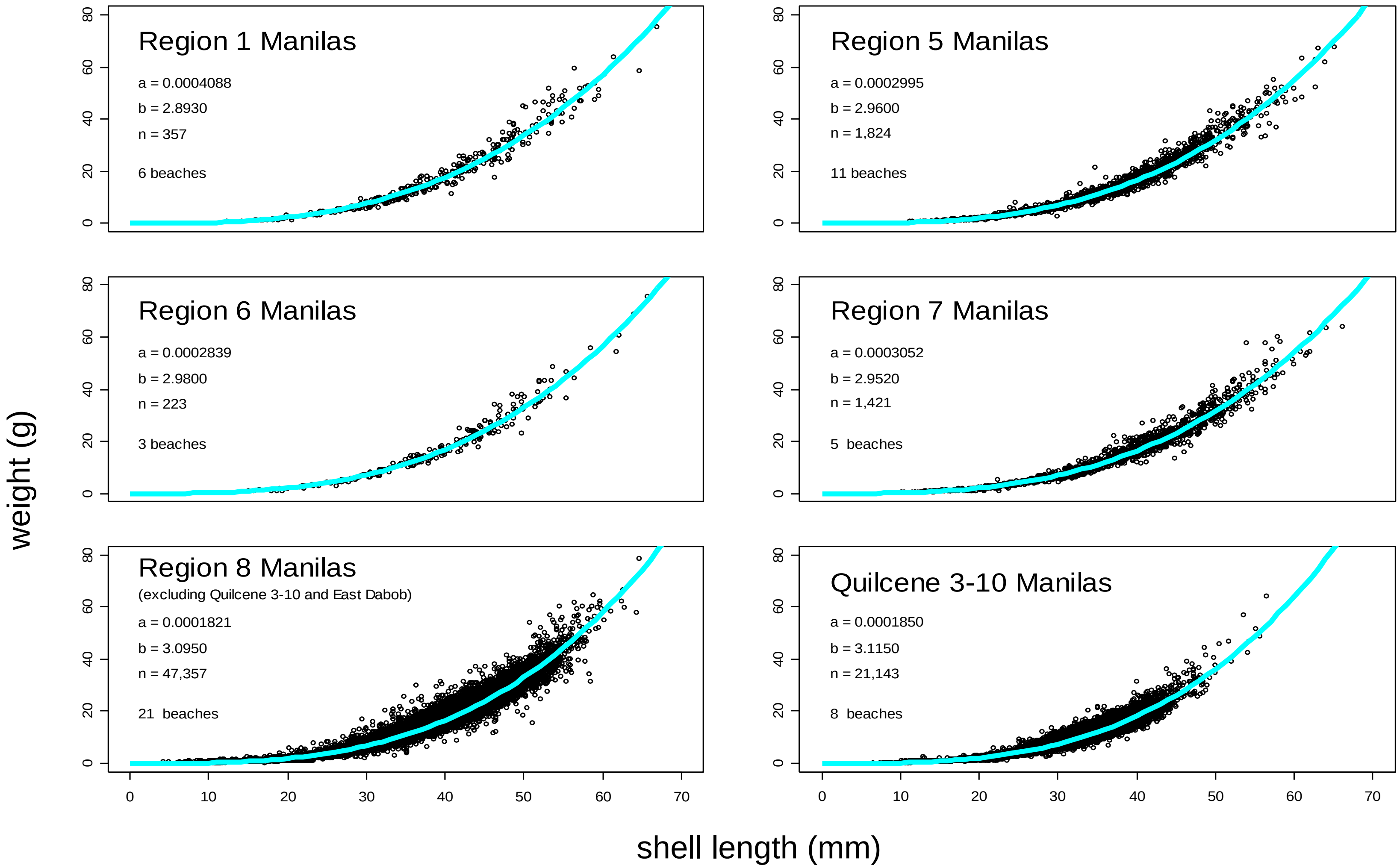

Figure 2. Manila clam length-weight relationships based on regional models. Model parameter estimates are given in Table 3.

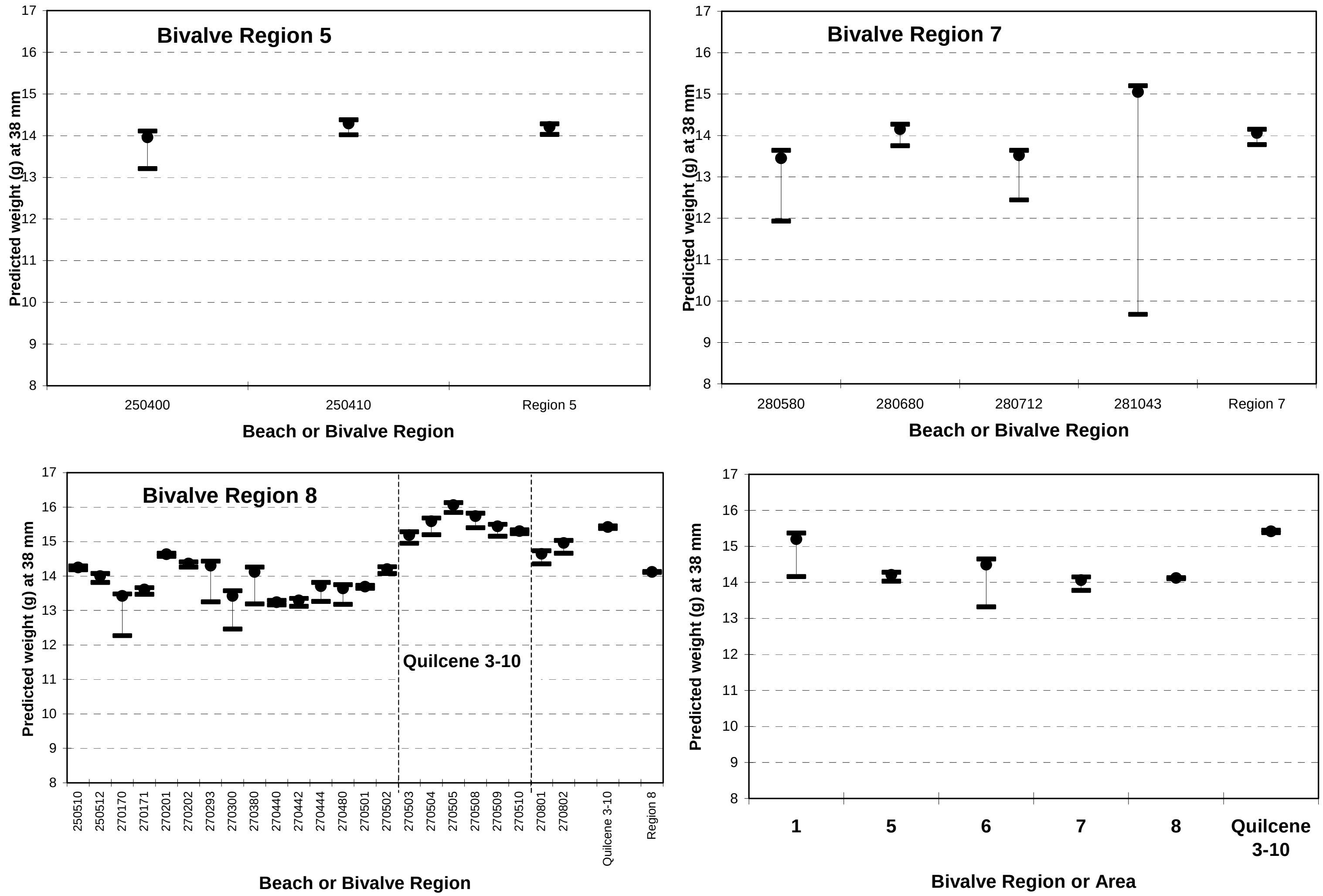

Figure 3. The predicted weight of 38mm Manila clams (represented by black dots) based on beach-specific and regional length-weight models. Bars represent approximate 95% confidence bounds on the predicted weight. Data from Tables 2 and 3.

Manila clam sample sizes on **Bivalve Region 8 (Hood Canal)** beaches permitted 23 beach-specific models to be estimated (Table 2). An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of a 38mm Manila clams existed for all these beaches *except* East Dabob and Quilcene Tidelands 3, 4, 5, 8, 9, and 10 (Table 2, Figure 3). The models for all seven of these beaches predicted significantly higher weights for a 38mm clam than the other 16 beaches in the region (Table 2, Figure 3). Quilcene Tidelands 3, 4,5, 8, 9, and 10 are all adjacent beaches, along with Quilcene Tidelands 6 and 7, where sample sizes were <100 clams; all eight of these beaches were therefore pooled to produce a Quilcene Tidelands 3-10 regional model (*n* = 21,143 clams, Table 3, Figure 2). All 21 other beach samples in Region 8 except Quilcene 3-10 and East Dabob were pooled to produce a common regional model (*n* = 47,357 clams, Table 3, Figure 2).

The regional models for Manila clams (Table 3) all exhibited an unbroken continuum of overlapping 95% confidence bounds on the predicted weight of a 38mm Manila clams *except* the Quilcene Tidelands 3-10 model, where a small gap in the continuum of confidence bounds suggested that clams from these beaches are significantly heavier at this size (Figure 3). The pooled model for Region 1, however, estimated a weight on 38mm clams that was very similar to Quilcene Tidelands 3-10, even though the confidence bounds didn't overlap (Figure 3). The conclusion that Quilcene Bay Manila clams have a different length-weight relationship compared to other Hood Canal beaches is not unexpected: Manila clams there have long been noted for their unusual morphology – a laterally compressed clam that is roughly walnut-shaped, rather than dorsally compressed and flattened. The regional Manila clam models for Bivalve Regions 1, 5, 6, 7, 8 (excluding Quilcene Tidelands 3-10), and for Quilcene Tidlelands 3-10 are all shown for comparison in Figure 4. Also shown in Figure 4 is the Manila clam model currently used by some tribes from Anderson *et al.* (1982).

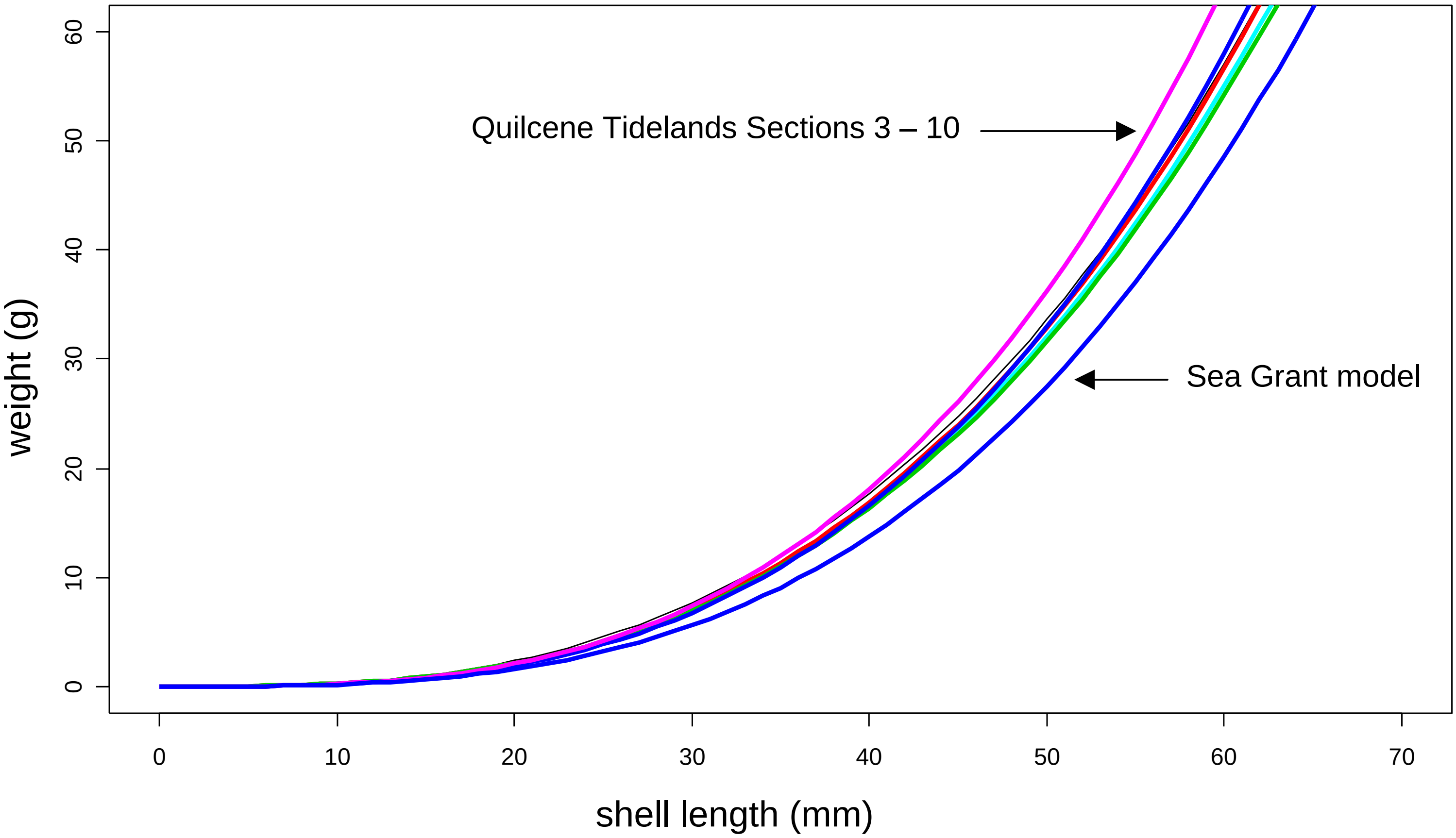

Figure 4. Manila clam length-weight relationships based on regional models. Regional model parameter estimates are shown in Table 3. Overlapping curves in the middle are those for Bivalve Regions 1, 5, 6, 7 and 8. Also shown is the Sea Grant model for Manila clams. (Anderson *et al.* 1982)

Native Littleneck Clams

Samples of 44,070 native littleneck clams from 57 public beaches (Table 4) were used to construct length-weight models. A total of 46 public beaches contained sample sizes ≥ 100 native littleneck clams with which to estimate the parameters for beach-specific models (Table 5). CVs of the α parameter for these beaches averaged 0.13, ranging from 0.04 to 0.33. Another 11 beaches had sample sizes that did not permit beach-specific models to be estimated, but which could be pooled to create regional models. The variance-covariance matrices of the model parameter estimates are given in Appendix Table 4.

All eight beaches surveyed in **Bivalve Region 1 (Strait of Juan de Fuca)** had sample sizes exceeding 100 native littleneck clams, permitting the estimation of beach-specific models. Native littlenecks at three beaches in Sequim Bay (Sequim Bay State Park, North Sequim Bay State Park, and Pitship Point, 250050-250056) appear to be significantly heavier at 38 mm than clams at four other Region 1 beaches (Figure 5); only the large confidence interval surrounding the weight of 38 mm clams at Old Town (250013) overlaps these two beach groups. Data were pooled to produce a regional model (n = 7,818 clams, Table 6, Figure 6).

Table 4. Public beaches providing samples for length-weight models of native littleneck clams. Bold type indicates that sample size n ≥ 100 clams, allowing for estimation of beach-specific model parameters.

BIDN	Beach Name	Bivalve Region	n (sample size)
250013	**Old Town**	**1**	**135**
250014	**Dungeness**	**1**	**1,102**
250016	**Cline Spit**	**1**	**195**
250050	**Sequim Bay State Park**	**1**	**2,165**
250055	**North Sequim Bay State Park**	**1**	**2,203**
250056	**South Pitship Point**	**1**	**577**
250057	**Pitship Point**	**1**	**889**
250110	**Maynard**	**1**	**552**
250260	**Fort Flagler State Park**	**5**	**1,820**
250280		**5**	**1,143**
250290		**5**	**579**
250300	**Mystery Bay State Park**	**5**	**576**
250310		**5**	**1,705**
250315		**5**	**1,180**
250320		**5**	**1,533**
250325		**5**	**905**
250330		**5**	**936**
250340		**5**	**1,256**
250350		**5**	**1,058**
250400	**Oak Bay County Park**	**5**	**2,372**
250410	**South Indian Island County Park**	**5**	**3,338**
250470	**Port Townsend Ship Canal**	**5**	**299**
250510	**Wolfe Property State Park**	**8**	**3,889**
250512	**Shine Tidelands State Park**	**8**	**2,747**
260231	**Blake Island State Park Certified**	**6**	**314**
260232	Blake Island State Park Prohibited	6	56
260350	**Point White**	**6**	**594**
260380	**Illahee State Park**	**6**	**557**
260510	**Bremerton Coal Dock**	**6**	**187**
260545	Silverdale	6	46
270010	DNR 59-A Case Shoal	8	53
270050	**Brown Point (DNR 57-B)**	**8**	**292**
270051		**8**	**502**
270052		**8**	**458**
270110	West Quilcene Bay	8	45
270112	Southwest Quilcene Bay	8	35
270114	North Frenchmans Point	8	35
270170	**Point Whitney Tidelands**	**8**	**130**
270201	**Dosewallips State Park (Approved)**	**8**	**122**
270202	**Dosewallips State Park (Restricted)**	**8**	**207**
270230	**Kitsap Memorial State Park**	**8**	**268**
270293	Triton Cove Tidelands	8	91
270300	**Eagle Creek**	**8**	**478**
270370	**DNR-48**	**8**	**378**
270380	**DNR 44-A Dewatto**	**8**	**235**
270440	**Potlatch State Park**	**8**	**2,215**
270442	**Potlatch DNR Tidelands**	**8**	**1,358**
270444	**Potlatch East**	**8**	**390**
270480	**Rendsland Creek**	**8**	**289**
270801	Dabob Broad Spit	8	34
270802	East Dabob	8	33
280570		7	41
280580	**Cutts Island State Park**	**7**	**127**
280680	**Penrose Point State Park**	**7**	**902**
280712	North Bay Coast	7	70
280975	**Hope Island State Park**	**7**	**260**
281140	**Frye Cove County Park**	**7**	**114**
TOTAL	57 beaches		44,070

Table 5. Parameter estimates of beach-specific length-weight models for native littleneck clams. Only beaches shown in Table 4 with n ≥ 100 clams were used to estimate beach-specific parameters.

				α			β			Predicted weight at 38 mm		
BIDN	Beach Name	Bivalve Region	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper
250013	Old Town	1	135	0.00024292	0.000049	0.2036	3.096015	0.054713	0.0177	18.90	16.78	19.13
250014	Dungeness	1	1,102	0.00011876	0.000013	0.1124	3.243979	0.028816	0.0089	15.83	15.17	15.95
250016	Cline Spit	1	195	0.00032162	0.000071	0.2218	2.986954	0.059025	0.0198	16.83	14.47	17.03
250050	Sequim Bay SP	1	2,165	0.00037039	0.000025	0.0683	2.967550	0.017500	0.0059	18.06	17.70	18.16
250055	North Sequim Bay SP	1	2,203	0.00031710	0.000020	0.0630	3.014708	0.016374	0.0054	18.36	18.07	18.45
250056	South Pitship Point	1	577	0.00028930	0.000040	0.1397	3.035493	0.036493	0.0120	18.06	17.06	18.23
250057	Pitship Point	1	889	0.00023936	0.000016	0.0662	3.066588	0.017592	0.0057	16.73	16.49	16.83
250110	Maynard	1	552	0.00018556	0.000021	0.1117	3.139806	0.029298	0.0093	16.93	16.34	17.04
250260	Fort Flagler SP	5	1,820	0.00028100	0.000020	0.0710	3.034000	0.017480	0.0058	17.45	16.99	17.60
250280		5	1,143	0.00018106	0.000014	0.0768	3.143169	0.019917	0.0063	16.72	16.36	16.82
250290		5	579	0.00017559	0.000014	0.0805	3.145066	0.021171	0.0067	16.33	15.98	16.43
250300	Mystery Bay SP	5	576	0.00018658	0.000020	0.1072	3.133978	0.028298	0.0090	16.67	16.08	16.80
250310		5	1,705	0.00017465	0.000012	0.0659	3.150795	0.016747	0.0053	16.59	16.27	16.69
250315		5	1,180	0.00016312	0.000016	0.0962	3.167941	0.024729	0.0078	16.49	15.92	16.61
250320		5	1,533	0.00019646	0.000015	0.0770	3.120569	0.019733	0.0063	16.71	16.34	16.82
250325		5	905	0.00016021	0.000013	0.0805	3.168450	0.020616	0.0065	16.22	15.82	16.33
250330		5	936	0.00030562	0.000031	0.1003	3.008576	0.025592	0.0085	17.30	16.68	17.43
250340		5	1,256	0.00023087	0.000018	0.0780	3.087131	0.020067	0.0065	17.39	16.98	17.51
250350		5	1,058	0.00016121	0.000012	0.0732	3.164546	0.019294	0.0061	16.09	15.80	16.18
250400	Oak Bay CP	5	2,372	0.00039109	0.000019	0.0478	2.941924	0.012490	0.0042	17.37	17.20	17.46
250410	South Indian Island CP	5	3,338	0.00031595	0.000015	0.0470	2.987806	0.012250	0.0041	16.58	16.42	16.66
250470	Port Townsend Ship Canal	5	299	0.00045763	0.000107	0.2345	2.912458	0.057608	0.0198	18.26	15.11	18.54
250510	Wolfe Property SP	8	3,889	0.00035955	0.000014	0.0378	2.957488	0.010237	0.0035	16.90	16.82	16.96
250512	Shine Tidelands SP	8	2,747	0.00034520	0.000017	0.0500	2.968212	0.013204	0.0044	16.87	16.71	16.94
260231	Blake Island SP Certified	6	314	0.00037040	0.000065	0.1762	2.958466	0.045162	0.0153	17.47	15.84	17.65
260350	Point White	6	594	0.00034468	0.000038	0.1116	2.980650	0.029343	0.0098	17.63	16.99	17.74
260380	Illahee SP	6	557	0.00021470	0.000029	0.1357	3.094600	0.034175	0.0110	16.62	15.52	16.78
260510	Bremerton Coal Dock	6	187	0.00048410	0.000111	0.2291	2.882762	0.057259	0.0199	17.34	14.39	17.56
270050	Brown Point (DNR 57-B)	8	292	0.00058763	0.000110	0.1866	2.856181	0.047763	0.0167	19.11	16.98	19.33
270051		8	502	0.00031351	0.000045	0.1420	3.004649	0.035984	0.0120	17.50	16.28	17.69
270052		8	458	0.00018294	0.000022	0.1185	3.151349	0.030476	0.0097	17.41	16.59	17.55
270170	Point Whitney Tidelands	8	130	0.00019458	0.000058	0.3001	3.140166	0.078645	0.0250	17.78	12.66	18.08
270201	Dosewallips SP (Approved)	8	122	0.00022468	0.000074	0.3307	3.077954	0.087728	0.0285	16.37	11.15	16.62
270202	Dosewallips SP (Restricted)	8	207	0.00029142	0.000053	0.1804	3.019473	0.047921	0.0159	17.16	15.61	17.34
270230	Kitsap Memorial SP	8	268	0.00043489	0.000064	0.1477	2.914391	0.038409	0.0132	17.48	16.32	17.65
270300	Eagle Creek	8	478	0.00018742	0.000020	0.1085	3.131316	0.028579	0.0091	16.58	15.98	16.71
270370	DNR-48	8	378	0.00037447	0.000060	0.1604	2.964706	0.041134	0.0139	18.07	16.65	18.24
270380	DNR 44-A Dewatto	8	235	0.00040662	0.000066	0.1615	2.947839	0.041291	0.0140	18.46	16.93	18.67
270440	Potlatch SP	8	2,215	0.00024421	0.000016	0.0647	3.046006	0.016870	0.0055	15.84	15.59	15.92
270442	Potlatch DNR Tidelands	8	1,358	0.00022839	0.000021	0.0923	3.066489	0.024249	0.0079	15.96	15.53	16.04
270444	Potlatch East	8	390	0.00024918	0.000038	0.1520	3.050836	0.039864	0.0131	16.45	15.35	16.59
270480	Rendsland Creek	8	289	0.00071357	0.000147	0.2055	2.776848	0.055223	0.0199	17.39	15.38	17.61
280580	Cutts Island SP	7	127	0.00014066	0.000040	0.2856	3.212138	0.073277	0.0228	16.70	12.46	16.99
280680	Penrose Point SP	7	902	0.00030897	0.000026	0.0848	2.992751	0.022217	0.0074	16.51	16.11	16.63
280975	Hope Island SP	7	260	0.00030858	0.000048	0.1557	3.006227	0.038616	0.0128	17.32	15.83	17.53
281140	Frye Cove CP	7	114	0.00025739	0.000073	0.2842	3.059853	0.071809	0.0235	17.56	12.69	17.82

Table 6. Parameter estimates of regional length-weight models for native littleneck clams. Beaches sampled in each Bivalve Region are listed in Table 4.

			α			β			Predicted weight at 38 mm		
REGION	number beaches	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper
Bivalve Region 1	8	7,818	0.00027910	0.000010	0.0352	3.038000	0.009087	0.0030	17.59	17.46	17.65
Bivalve Region 5	14	18,700	0.00021850	0.000004	0.0184	3.093000	0.004684	0.0015	16.82	16.75	16.86
Bivalve Region 6	6	1,754	0.00036780	0.000024	0.0660	2.958000	0.016770	0.0057	17.32	16.98	17.43
Bivalve Region 7	6	1,514	0.00022710	0.000014	0.0617	3.081000	0.015690	0.0051	16.73	16.45	16.85
Bivalve Region 8	23	14,284	0.00027220	0.000005	0.0170	3.034000	0.004404	0.0015	16.90	16.85	16.94

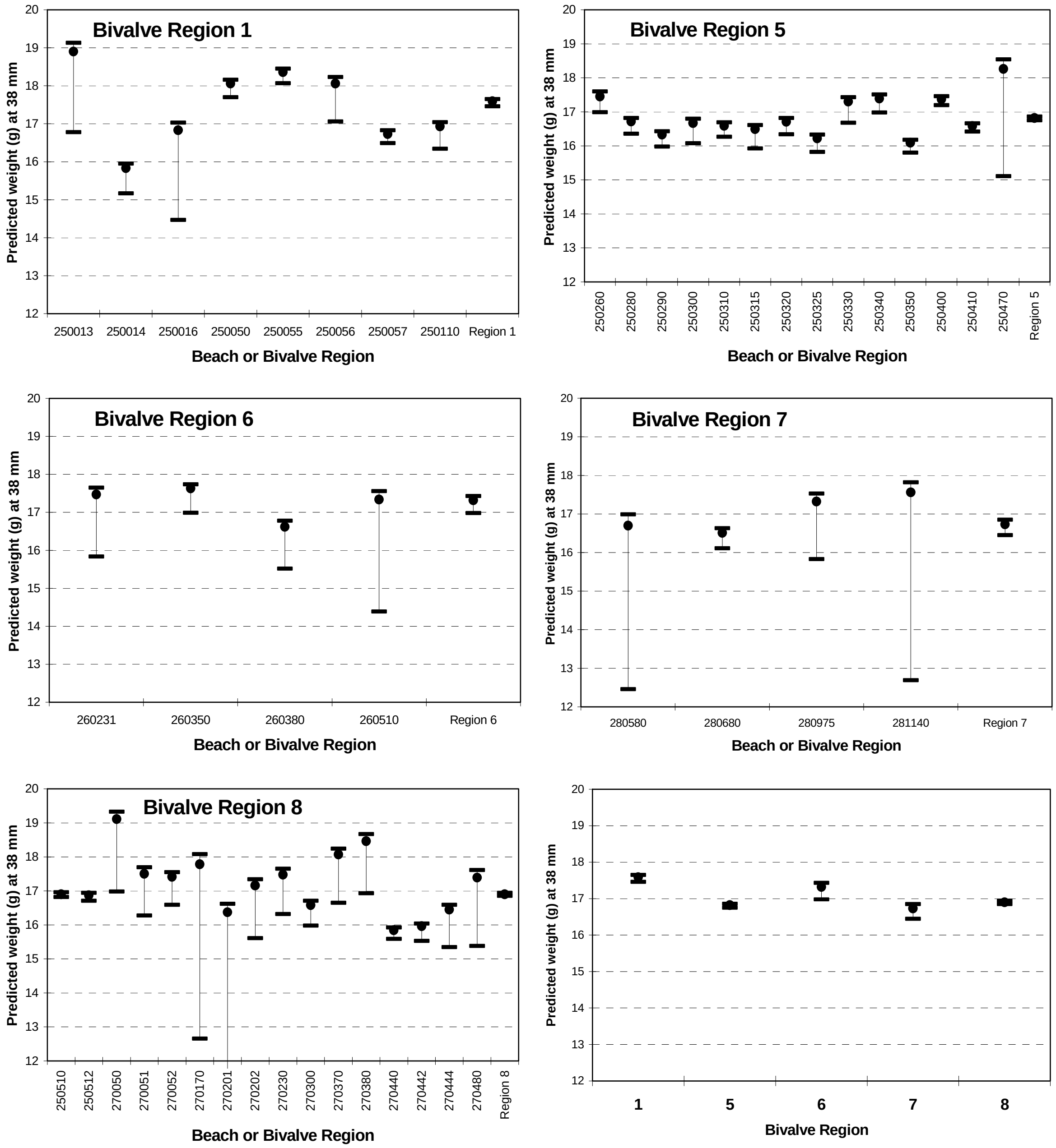

Figure 5. The predicted weight of 38mm native littleneck clams (represented by black dots) based on beach-specific and regional length-weight models. Bars represent approximate 95% confidence bounds on the predicted weight. Data from Tables 5 and 6.

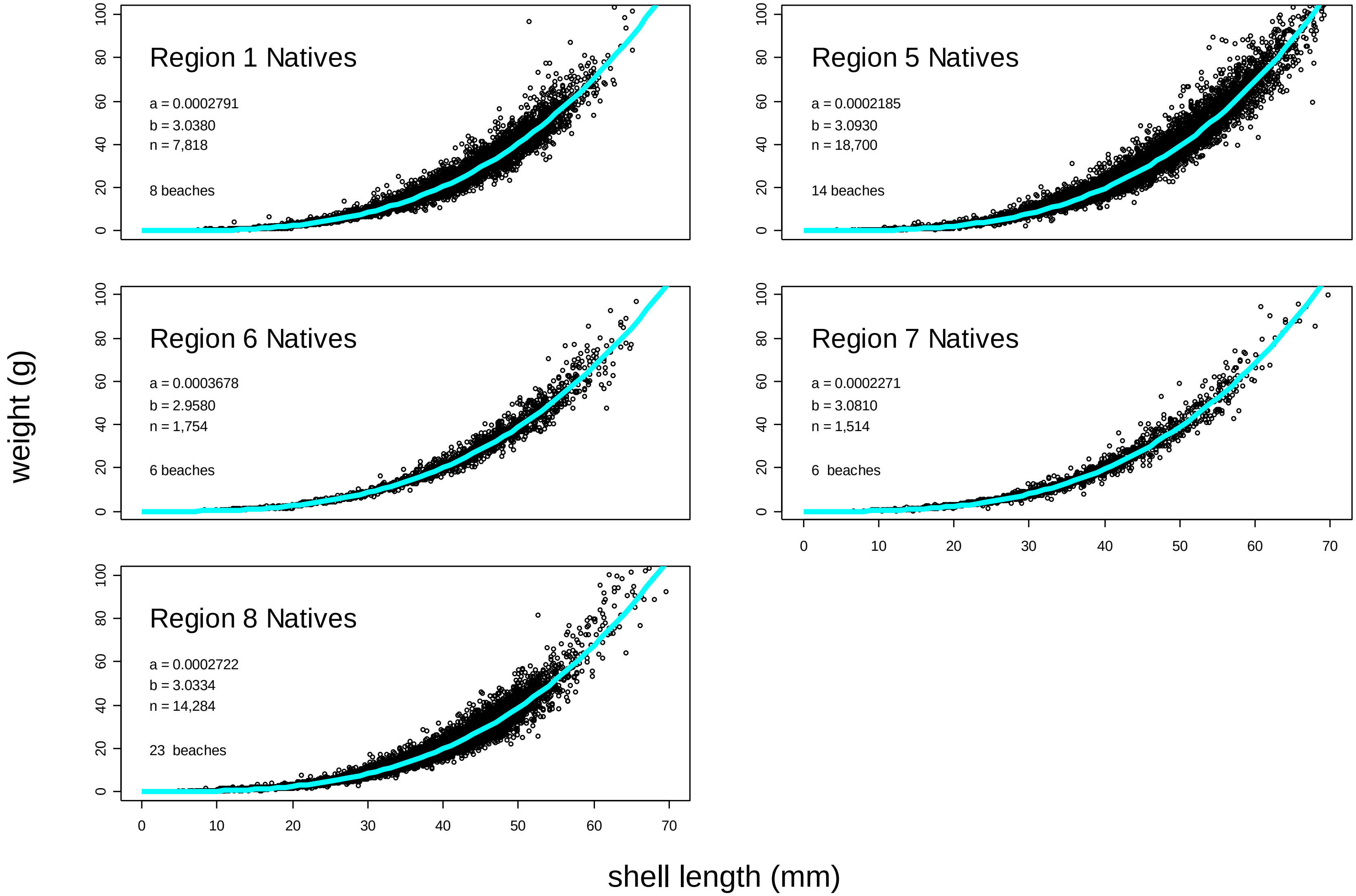

Figure 6. Native littleneck clam length-weight relationships based on regional models. Model parameter estimates are given in Table 6.

In **Bivalve Region 5 (Admiralty Inlet),** all 14 of the surveyed beaches had sample sizes exceeding 100 native littleneck clams, allowing beach-specific models to be estimated. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of 38mm clams existed among all 14 beaches (Figure 5), and data were therefore pooled to produce a regional model (*n* = 18,700 clams, Table 6, Figure 6).

In **Bivalve Region 6 (Central Puget Sound)**, four of six surveyed beaches had sample sizes exceeding 100 native littleneck clams, for which beach-specific models were estimated. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of 38mm clams existed among all four beaches (Figure 5), and data were therefore pooled along with Blake Island State Park (Prohibited) and Silverdale to produce a regional model (*n* = 1,754 clams, Table 6, Figure 6).

In **Bivalve Region 7 (Southern Puget Sound)**, four of six surveyed beaches had sample sizes exceeding 100 native littleneck clams, for which beach-specific models were estimated. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of 38mm clams existed among all four beaches (Figure 5), and data were therefore pooled along with Beach 280570 and North Bay Coast to produce a regional model (*n* = 1,514 clams, Table 6, Figure 6).

Native littleneck clam sample sizes on the 23 surveyed **Bivalve Region 8 (Hood Canal)** beaches permitted 16 beach-specific models to be estimated. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of a 38mm clams existed among all these beaches (Figure 5), and data were therefore pooled (along with the seven Region 8 beaches with sample sizes <100) to produce a regional model (*n* = 14,284 clams, Table 6, Figure 6).

The regional models for native littleneck clams in Bivalve Regions 5, 7 and 8 had overlapping 95% confidence bounds on the predicted weight of a 38mm clams (Table 6, Figure 5). Region 1 native littlenecks were significantly heavier at 38 mm than in any of the other Regions, and Region 6 native littlenecks were significantly heavier at 38 mm than those in Regions 5, 7 and 8. The regional native littleneck clam models for Bivalve Regions 1, 5, 6, 7, 8 are all shown for comparison in Figure 7. Also shown in Figure 7 for comparison is the NWIFC native littleneck clam model (Appendix Table 2) currently used by some tribes. For convenience in plotting, we fit the NWIFC spreadsheet conversions (Appendix Table 2) to the nonlinear model (Equation 1), and the resulting parameter estimates were: $\alpha = 0.0001688$ and $\beta = 3.154$.

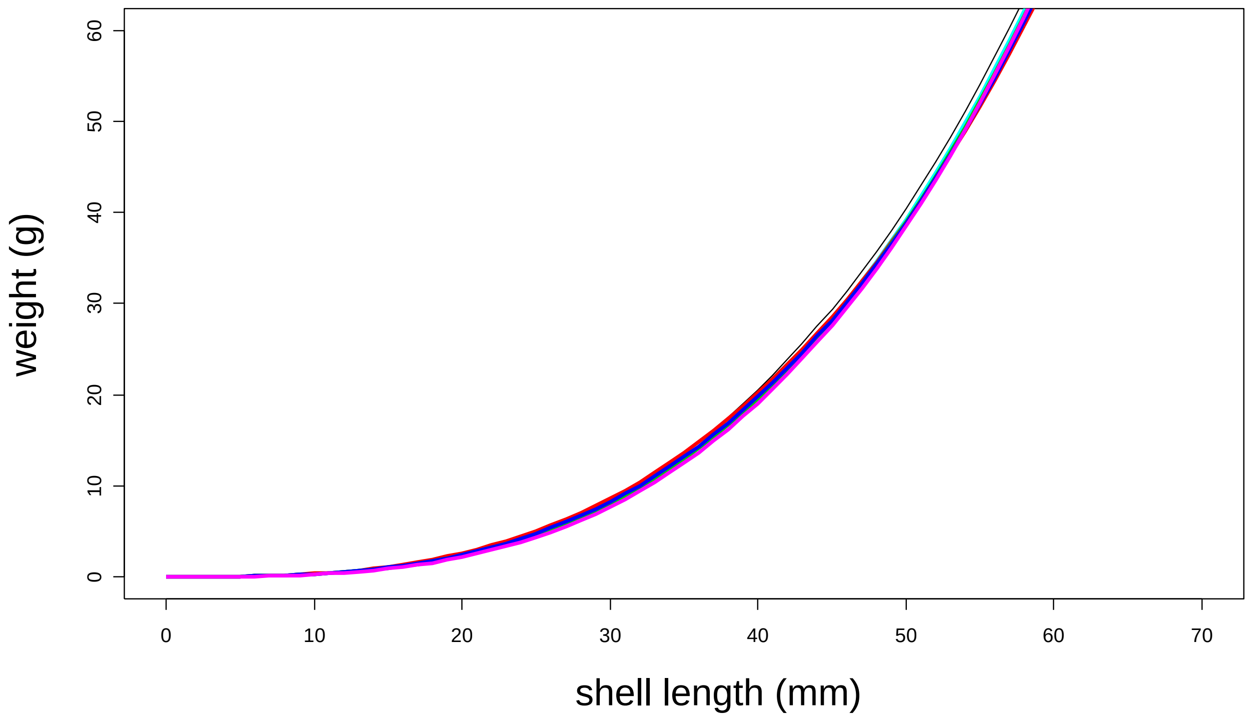

Figure 7. Native littleneck clam length-weight relationships based on regional models. Regional model parameter estimates are shown in Table 6. Six virtually overlapping curves are shown: Regional models for Bivalve Regions 1, 5, 6, 7 and 8, as well as the NWIFC native littleneck model (Appendix Table 2).

Butter Clams

Samples of 7,647 butter clams from 25 public beaches (Table 7) were used to construct length-weight models. Only 10 public beaches contained sample sizes ≥ 200 butter clams with which to estimate the parameters for beach-specific models (Table 8). CVs of the α parameter for these beaches averaged 0.15, ranging from 0.08 to 0.25. Another 15 beaches had sample sizes that did not permit beach-specific models to be estimated, but which could be pooled to create regional models. The variance-covariance matrices of the model parameter estimates are given in Appendix Table 5.

Only one beach in **Bivalve Region 1 (Strait of Juan de Fuca)** – Dungeness -- had a sample exceeding 200 butter clams, therefore permitting the estimation of a beach-specific model. Data from the other two beaches in the Region (Sequim Bay and North Sequim Bay State Park) were pooled with the Dungeness data to produce a regional model (n = 309 clams, Table 9, Figure 8). Note in Figure 9, however, that the beach-specific model for Dungeness predicts a weight at 60 mm that is almost 4 g lighter than the weight predicted by the Region 1 model. The other two beaches used in the Region 1 model were Sequim Bay State Park and North Sequim Bay State Park, suggesting that a 60 mm butter clam at these two adjacent beaches may be heavier than those at Dungeness (although the 95% confidence intervals shown in Figure 9 overlap).

Table 7. Public beaches providing samples for length-weight models of butter clams. Bold type indicates that sample size n ≥ 200 clams, allowing for estimation of beach-specific models.

BIDN	Beach Name	Bivalve Region	n (sample size)
250014	**Dungeness**	**1**	**200**
250050	Sequim Bay State Park	1	52
250055	North Sequim Bay State Park	1	57
250260	**Fort Flagler State Park**	**5**	**386**
250400	**Oak Bay County Park**	**5**	**523**
250410	**South Indian Island County Park**	**5**	**703**
250470	Port Townsend Ship Canal	5	142
250510	**Wolfe Property State Park**	**8**	**1,063**
250512	**Shine Tidelands State Park**	**8**	**1,323**
260231	**Blake Island State Park Certified**	**6**	**277**
270051		8	196
270052		8	132
270170	Point Whitney Tidelands	8	51
270230	Kitsap Memorial State Park	8	127
270293	Triton Cove Tidelands	8	35
270300	Eagle Creek	8	93
270370	DNR-48	8	116
270380	DNR 44-A Dewatto	8	74
270440	**Potlatch State Park**	**8**	**647**
270442	**Potlatch DNR Tidelands**	**8**	**823**
270444	**Potlatch East**	**8**	**318**
270480	Rendsland Creek	8	54
280580	Cutts Island State Park	7	47
280680	Penrose Point State Park	7	70
280975	Hope Island State Park	7	138
TOTAL	25 beaches		7,647

Table 8. Parameter estimates of beach-specific length-weight models for butter clams. Only beaches shown in Table 7 with n ≥ 200 clams were used to estimate beach-specific parameters.

				α			β			Predicted weight at 38 mm			Predicted weight at 60 mm		
BIDN	Beach Name	Bivalve Region	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper	predicted weight (g)	95% CI lower	95% CI upper
250014	Dungeness	1	200	0.00005665	0.000013	0.2211	3.344779	0.051139	0.0153	10.90	8.96	11.13	50.21	42.84	50.71
250260	Fort Flagler State Park	5	386	0.00024850	0.000052	0.2098	3.036525	0.046268	0.0152	15.57	12.80	16.02	62.33	52.84	63.15
250400	Oak Bay County Park	5	523	0.00039283	0.000039	0.0982	2.898105	0.022956	0.0079	14.88	14.12	15.11	55.91	54.15	56.32
250410	South Indian Island County Park	5	703	0.00009632	0.000014	0.1423	3.238526	0.033369	0.0103	12.59	11.50	12.80	55.25	51.95	55.64
250510	Wolfe Property State Park	8	1,063	0.00016440	0.000014	0.0836	3.100724	0.020362	0.0066	13.01	12.60	13.10	53.64	52.63	53.88
250512	Shine Tidelands State Park	8	1,323	0.00009380	0.000007	0.0757	3.240867	0.018041	0.0056	12.36	12.00	12.50	54.32	53.35	54.56
260231	Blake Island State Park Certified	6	277	0.00012028	0.000030	0.2513	3.192550	0.057424	0.0180	13.30	10.30	13.60	57.15	46.17	57.72
270440	Potlatch State Park	8	647	0.00011268	0.000010	0.0932	3.205675	0.022100	0.0069	13.07	12.50	13.24	56.50	55.11	56.84
270442	Potlatch DNR Tidelands	8	823	0.00007841	0.000008	0.1023	3.295298	0.024448	0.0074	12.60	11.90	12.80	56.74	55.16	57.04
270444	Potlatch East	8	318	0.00006708	0.000013	0.2007	3.325917	0.048114	0.0145	12.04	10.30	12.20	55.02	49.07	55.41

Table 9. Parameter estimates of regional length-weight models for butter clams. Beaches sampled in each Bivalve Region are listed in Table 7.

			α			β			Predicted weight at 38 mm			Predicted weight at 60 mm		
REGION	number beaches	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper	predicted weight (g)	95% CI lower	95% CI upper
Bivalve Region 1	3	309	0.00006742	0.000015	0.2212	3.319000	0.050870	0.0153	11.81	9.72	12.07	53.76	46.05	54.33
Bivalve Region 5	4	1,754	0.00013200	0.000010	0.0786	3.169000	0.017630	0.0056	13.39	12.86	13.65	56.96	55.39	57.40
Bivalve Region 7	3	255	0.00065710	0.000213	0.3234	2.827531	0.070621	0.0250	19.25	11.76	19.85	70.05	47.34	71.02
Bivalve Region 8	14	5,052	0.00007324	0.000003	0.0446	3.310000	0.010480	0.0032	12.41	12.19	12.53	56.29	55.84	56.48

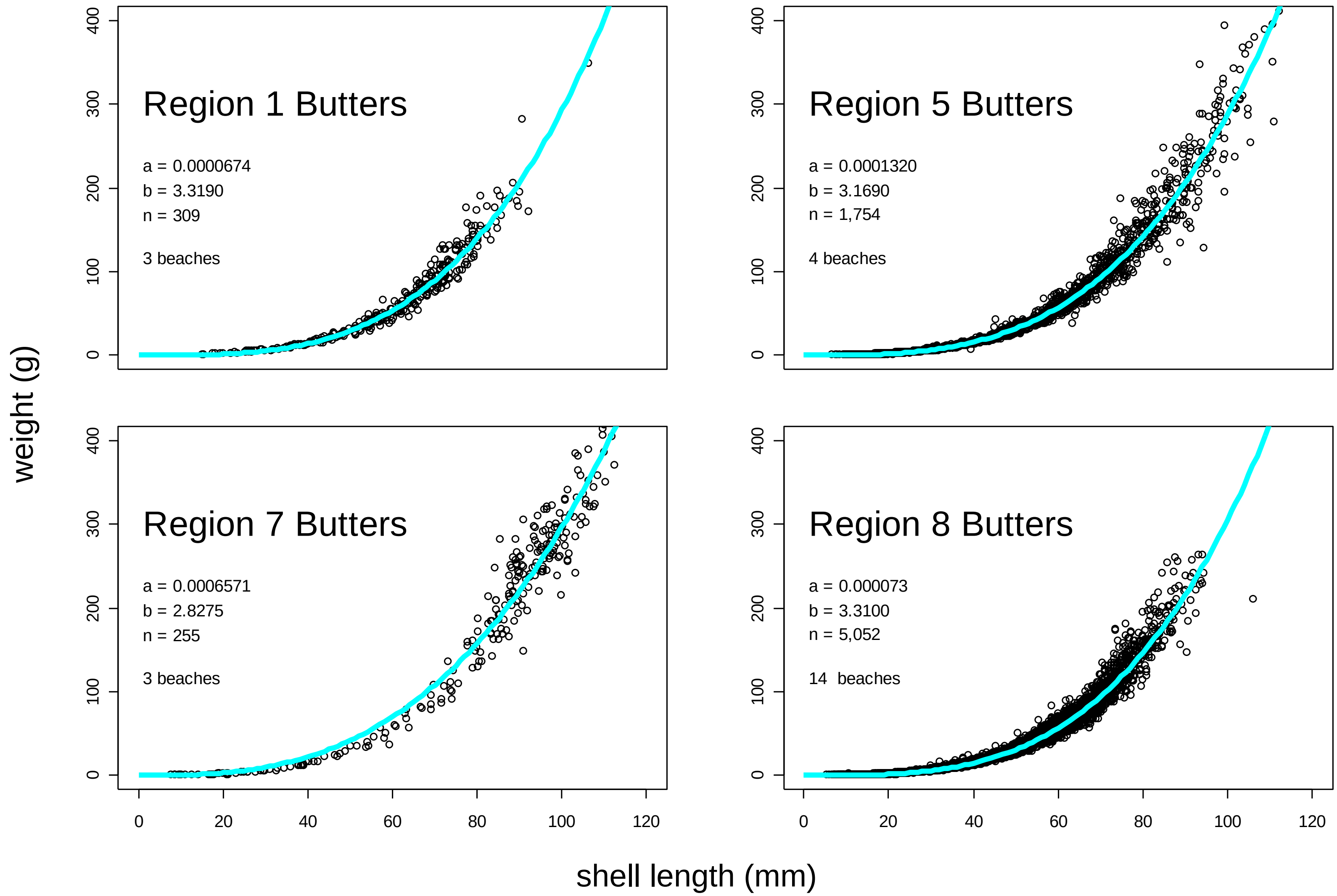

Figure 8. Butter clam length-weight relationships based on regional models. Model parameter estimates are given in Table 9.

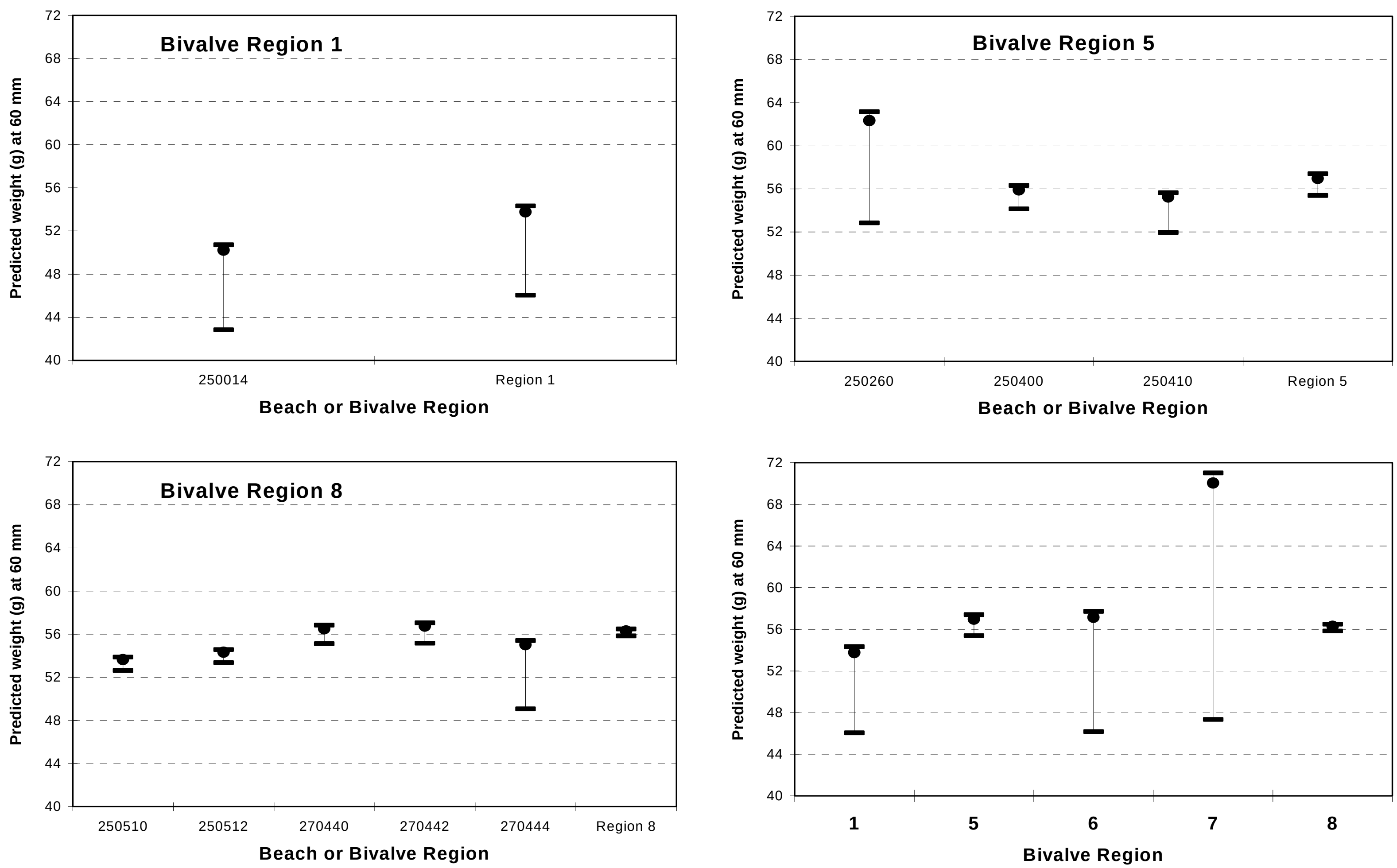

Figure 9. The predicted weight of 60mm butter clams (represented by black dots) based on beach-specific and regional length-weight models. Bars represent approximate 95% confidence bounds on the predicted weight. Data from Tables 8 and 9.

In **Bivalve Region 5 (Admiralty Inlet),** only three of the surveyed beaches had sample sizes exceeding 200 butter clams, allowing beach-specific models to be estimated. All three 95% confidence intervals around the predicted weight of 60mm clams overlapped (Figure 9), and data were pooled – along with Port Townsend Ship Canal data -- to produce a regional model (n = 1,754 clams, Table 9, Figure 8).

In **Bivalve Region 6 (Central Puget Sound)**, only one beach containing butter clams was surveyed (Blake Island State Park Certified), and a beach-specific model was estimated.

In **Bivalve Region 7 (Southern Puget Sound)**, only three beach surveys contained butter clams, and none had sample sizes ≥ 200. The data from these three beaches were pooled to produce a regional model (n = 255 clams, Table 9, Figure 8).

In **Bivalve Region 8 (Hood Canal)** there were only five beaches where sample size exceeded 200 butter clams, and beach-specific models were estimated for these sites. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of a 60 mm clams existed among these five beaches (Figure 9), and data were therefore pooled (along with the nine other Region 8 beaches with sample sizes <200) to produce a regional model (n = 5,052 clams, Table 9, Figure 8).

The regional models for butter clams in Bivalve Regions 1, 5, 6, 7, and 8 all exhibited an unbroken continuum of overlapping 95% confidence bounds on the predicted weight of a 60 mm clams (Table 9, Figure 9). The two Regions with the largest sample sizes (Regions 5 and 8) predict very similar weights at 60 mm with narrow confidence bounds. The butter clam models for Bivalve Regions 1, 5, 7, and 8 are all shown for comparison in Figure 10.

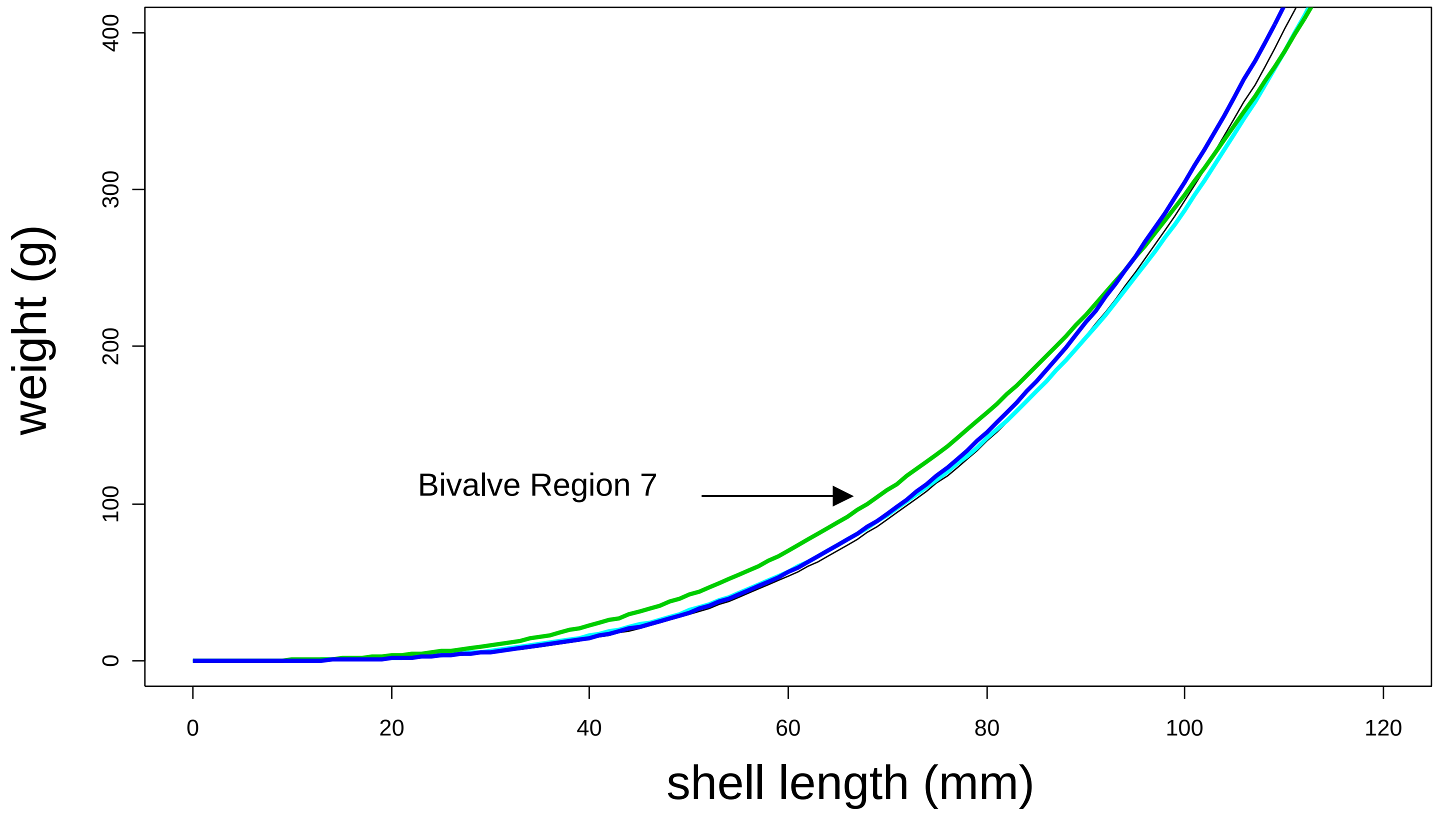

Figure 10. Butter clam length-weight relationships based on regional models. Regional model parameter estimates are shown in Table 9. Four curves are shown: Regional models for Bivalve Regions 1, 5, 7, and 8.

Cockles

Samples of 2,695 cockles from 20 public beaches (Table 10) were used to construct length-weight models. Only nine public beaches contained sample sizes ≥ 100 cockles with which to estimate the parameters for beach-specific models (Table 11). CVs of the α parameter for these beaches averaged 0.16, ranging from 0.10 to 0.26. Another 11 beaches had sample sizes that did not permit beach-specific models to be estimated, but which could be pooled to create regional models. The variance-covariance matrices of the model parameter estimates are given in Appendix Table 6.

Only one beach in **Bivalve Region 1 (Strait of Juan de Fuca)** – Dungeness -- had a sample exceeding 100 cockles, therefore permitting the estimation of a beach-specific model. Data from the other four beaches in the Region (Cline Spit, Sequim Bay State Park, North Sequim Bay State Park and Pitship Point) were pooled with the Dungeness data to produce a regional model (n = 305 clams, Table 12, Figure 11). Note in Figure 12, however, that the beach-specific model for Dungeness predicts a weight at 60 mm that is about 3 g lighter than the weight predicted by the Region 1 model. This suggests that a 60 mm cockle at the other four Region 1 beaches may be heavier than those at Dungeness (although the 95% confidence intervals shown in Figure 12 overlap).

Table 10. Public beaches providing samples for length-weight models of cockles. Bold type indicates that sample size n ≥ 100 clams, allowing for estimation of beach-specific model parameters.

BIDN	Beach Name	Bivalve Region	n
250014	**Dungeness**	**1**	**135**
250016	Cline Spit	1	38
250050	Sequim Bay State Park	1	65
250055	North Sequim Bay State Park	1	34
250057	Pitship Point	1	33
250260	Fort Flagler State Park	5	69
250400	**Oak Bay County Park**	**5**	**173**
250410	**South Indian Island County Park**	**5**	**284**
250470	Port Townsend Ship Canal	5	49
250510	**Wolfe Property State Park**	**8**	**151**
250512	**Shine Tidelands State Park**	**8**	**249**
260231	Blake Island State Park Certified	6	31
270050	**Brown Point (DNR 57-B)**	**8**	**186**
270230	Kitsap Memorial State Park	8	47
270300	**Eagle Creek**	**8**	**105**
270440	**Potlatch State Park**	**8**	**403**
270442	**Potlatch DNR Tidelands**	**8**	**389**
270444	Potlatch East	8	70
270480	Rendsland Creek	8	91
280680	Penrose Point State Park	7	93
TOTAL	20 beaches		2,695

Table 11. Parameter estimates of beach-specific length-weight models for cockles. Only beaches shown in Table 10 with n ≥ 100 clams were used to estimate beach-specific parameters.

				α			β			Predicted weight at 38 mm			Predicted weight at 60 mm		
BIDN	Beach Name	Bivalve Region	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper	predicted weight (g)	95% CI lower	95% CI upper
250014	Dungeness	1	135	0.00040714	0.000104	0.2551	2.923862	0.061620	0.0211	16.94	13.09	17.28	64.39	52.62	65.26
250400	Oak Bay County Park	5	173	0.00047357	0.000059	0.1242	2.910462	0.029293	0.0101	18.76	17.50	19.12	70.90	67.75	71.69
250410	South Indian Island County Park	5	284	0.00038966	0.000051	0.1317	2.956951	0.031172	0.0105	18.28	17.02	18.60	70.56	67.10	71.33
250510	Wolfe Property State Park	8	151	0.00032646	0.000062	0.1905	2.981774	0.048519	0.0163	16.76	14.94	17.04	65.44	58.93	66.48
250512	Shine Tidelands State Park	8	249	0.00044351	0.000054	0.1208	2.903048	0.029598	0.0102	17.10	16.13	17.37	64.41	62.01	65.16
270050	Brown Point (DNR 57-B)	8	186	0.00039375	0.000073	0.1848	2.954550	0.043365	0.0147	18.31	15.88	18.68	70.61	63.69	71.35
270300	Eagle Creek	8	105	0.00126142	0.000237	0.1876	2.674600	0.044139	0.0165	21.19	18.24	21.63	71.90	64.31	72.76
270440	Potlatch State Park	8	403	0.00045608	0.000050	0.1089	2.917473	0.026465	0.0091	18.54	17.55	18.77	70.27	68.09	70.74
270442	Potlatch DNR Tidelands	8	389	0.00048242	0.000047	0.0983	2.914969	0.023982	0.0082	19.43	18.58	19.65	73.57	71.62	74.05

Table 12. Parameter estimates of regional length-weight models for cockles. Beaches sampled in each Bivalve Region are listed in Table 10.

			α			β			Predicted weight at 38 mm			Predicted weight at 60 mm		
REGION	number beaches	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper	predicted weight (g)	95% CI lower	95% CI upper
Bivalve Region 1	5	305	0.00022980	0.000032	0.1382	3.074000	0.032980	0.0107	16.50	15.22	16.76	67.20	63.68	67.76
Bivalve Region 5	4	575	0.00061840	0.000062	0.1009	2.848000	0.023270	0.0082	19.52	18.50	19.88	71.69	69.18	72.31
Bivalve Region 8	9	1,691	0.00046200	0.000023	0.0507	2.914000	0.012080	0.0041	18.54	18.19	18.72	70.17	69.53	70.48

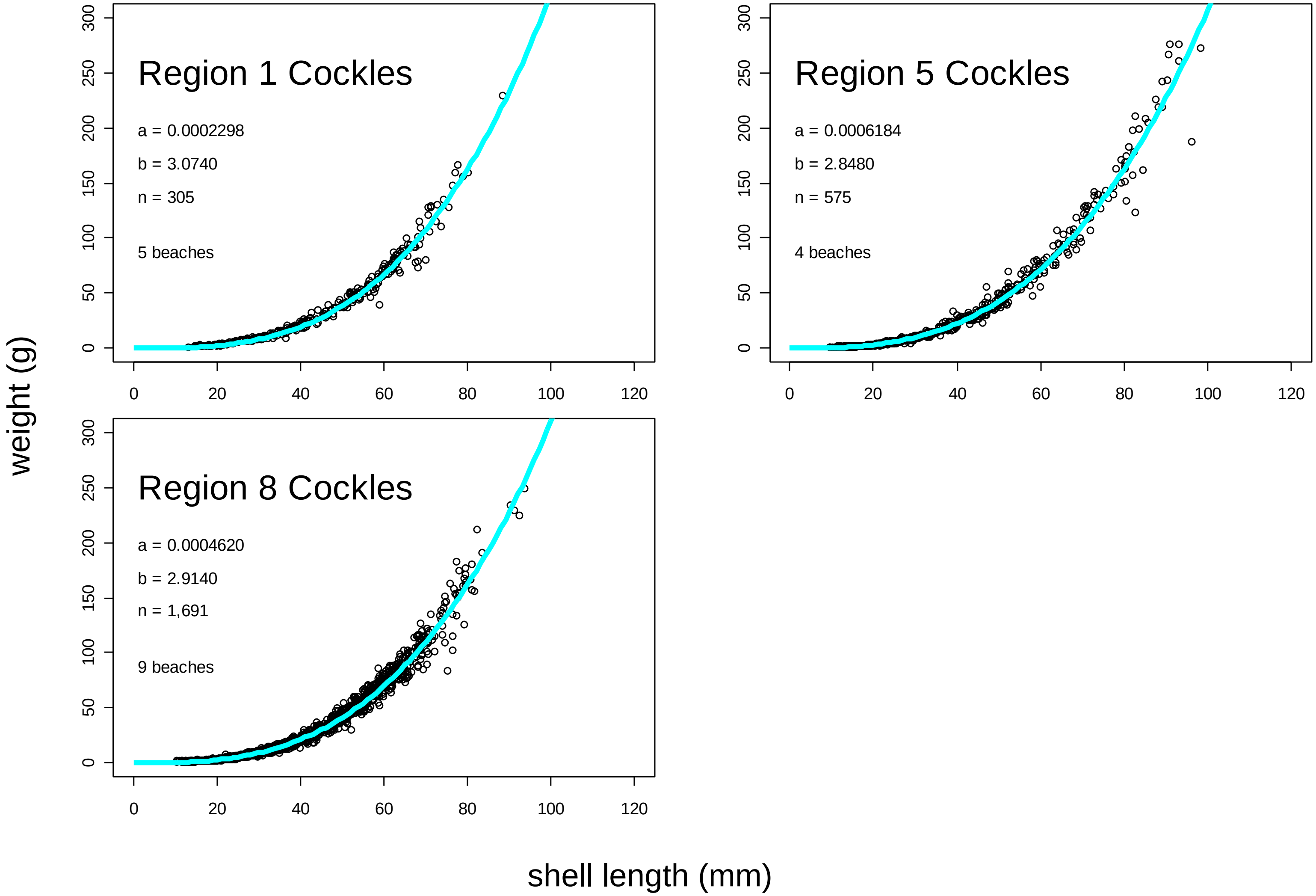

Figure 11. Cockle length-weight relationships based on regional models. Model parameter estimates are given in Table 12.

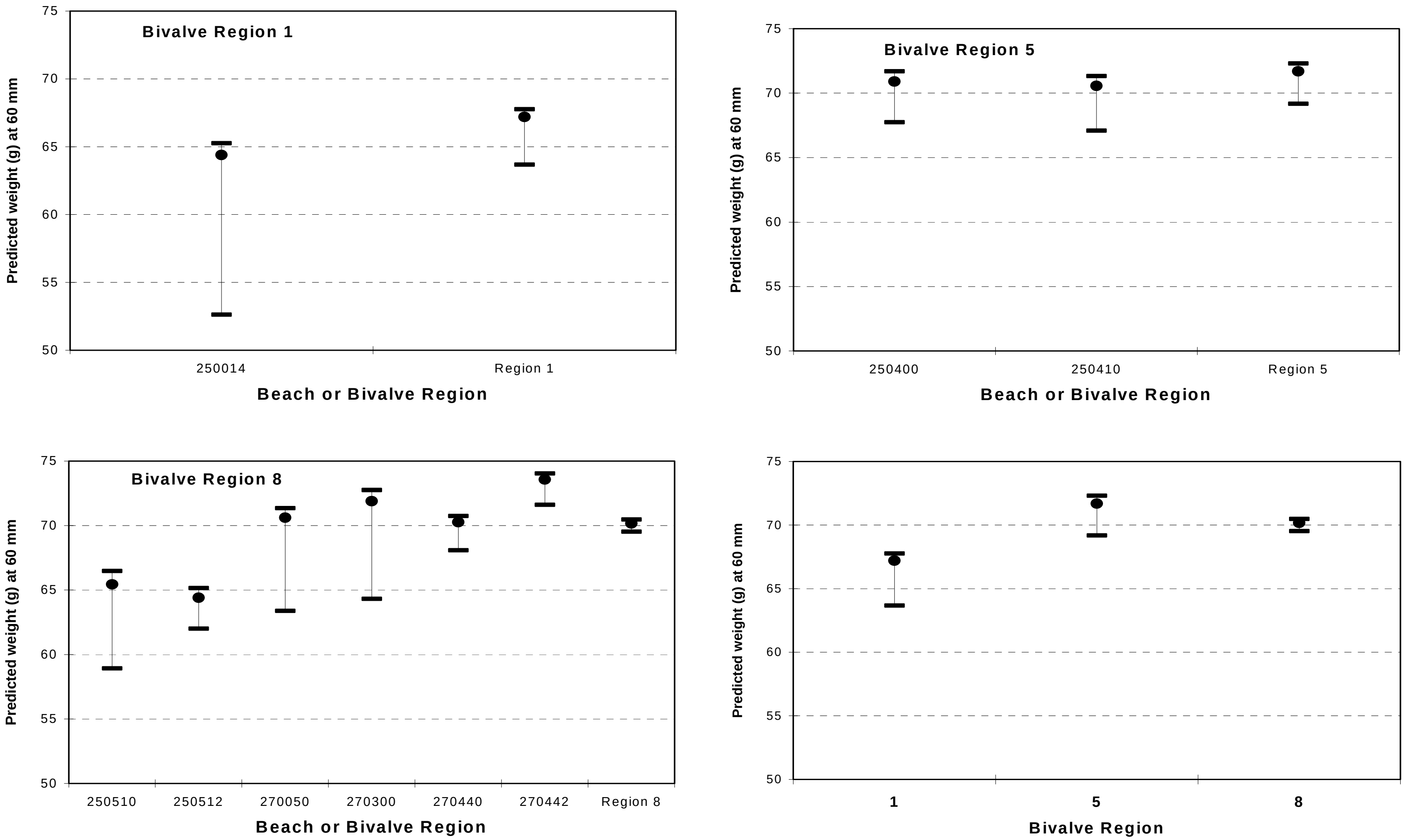

Figure 12. The predicted weight of 60mm cockles (represented by black dots) based on beach-specific and regional length-weight models. Bars represent approximate 95% confidence bounds on the predicted weight. Data from Tables 11 and 12.

In **Bivalve Region 5 (Admiralty Inlet),** only two of the surveyed beaches had sample sizes exceeding 100 cockles, allowing beach-specific models to be estimated. The 95% confidence intervals around the predicted weight of 60 mm clams overlapped (Figure 12), and data were pooled – along with data from Fort Flagler State Park and Port Townsend Ship Canal -- to produce a regional model (*n* = 575 clams, Table 12, Figure 11).

In **Bivalve Region 6 (Central Puget Sound)**, only one beach containing cockles was surveyed (Blake Island State Park Certified), and a beach-specific model was estimated.

In **Bivalve Region 7 (Southern Puget Sound)**, only one beach survey contained cockles (Penrose Point State Park), and a beach-specific model was estimated.

In **Bivalve Region 8 (Hood Canal)** six beaches had sample sizes exceeding 100 cockles, and beach-specific models were estimated for these sites. An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of a 60 mm cockle existed among these six beaches (Figure 12), and data were therefore pooled (along with the three other Region 8 beaches with sample sizes <100) to produce a regional model (*n* = 1,691clams, Table 12, Figure 11).

The regional models for cockles in Bivalve Regions 5 and 8 had overlapping 95% confidence bounds on the predicted weight of a 60 mm cockle (Table 12, Figure 12), while cockles of the same length in Region 1 were significantly lighter. The regional cockle models for Bivalve Regions 1, 5, and 8 are all shown for comparison in Figure 13.

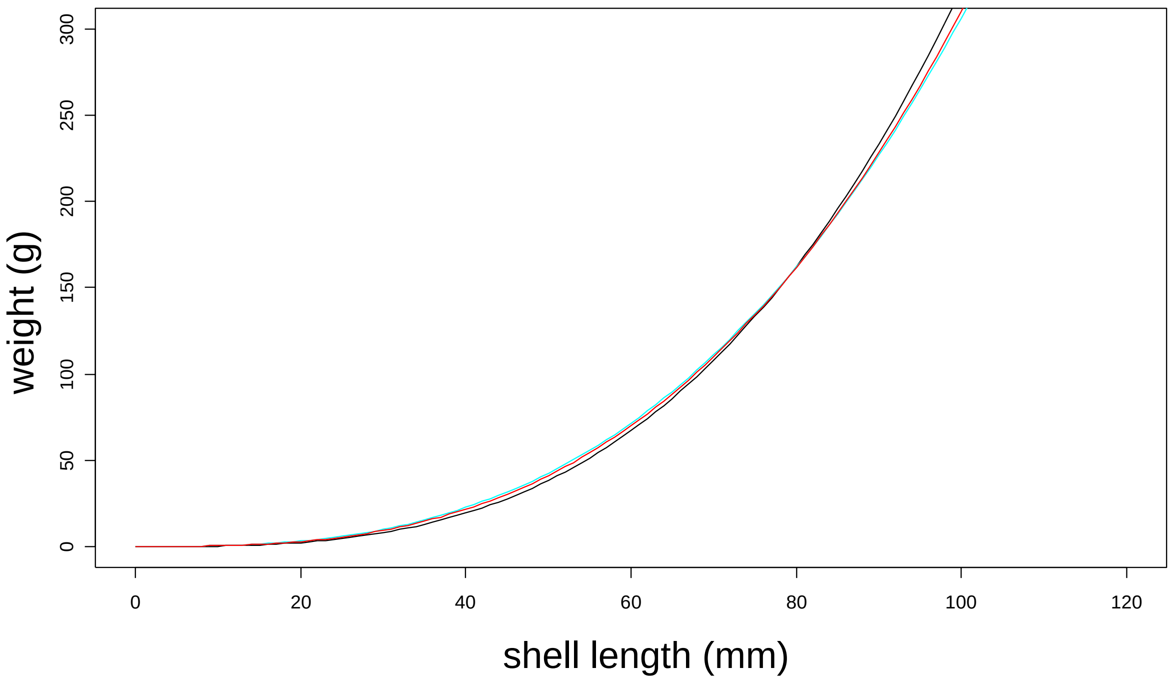

Figure 13. Cockle length-weight relationships based on regional models. Regional model parameter estimates are shown in Table 12. Three virtually overlapping curves shown: Regional models for Bivalve Regions 1, 5 and 8.

Eastern softshell clams

Samples of 7,094 eastern softshell clams from 24 public beaches (Table 13) were used to construct length-weight models. Only 11 public beaches contained sample sizes ≥ 100 eastern softshells with which to estimate the parameters for beach-specific models (Table 14). CVs of the α parameter for these beaches averaged 0.26, ranging from 0.07 to 0.57. Another 13 beaches had sample sizes that did not permit beach-specific models to be estimated, but which could be pooled to create regional models. The variance-covariance matrices of the model parameter estimates are given in Appendix Table 7.

No beaches in **Bivalve Region 1 (Strait of Juan de Fuca)** had sample sizes exceeding 100 eastern softshells. Data from two beaches in the Region (Dungeness, Sequim Bay State Park) were pooled to produce a regional model (n = 117 clams, Table 15, Figure 14).

In **Bivalve Region 5 (Admiralty Inlet),** only one of the surveyed beaches – South Indian Island County Park -- had a sample size exceeding 100 eastern softshells, allowing a beach-specific model to be estimated (Table 14). Note, however, the large CV of the α parameter (0.44) and the corresponding large 95% CI surrounding the estimated weight at 60 mm associated with this model (Figure 15). The data from this beach were pooled with data from the other three surveyed beaches in Region 5 to produce a regional model (n = 331 clams, Table 15, Figure 14).

Table 13. Public beaches providing samples for length-weight models of eastern softshell clams. Bold type indicates that sample size n ≥ 100 clams, allowing for estimation of beach-specific parameters.

BIDN	Beach Name	Bivalve Region	n (sample size)
250014	Dungeness	1	75
250050	Sequim Bay State Park	1	42
250260	Fort Flagler State Park	5	33
250400	Oak Bay County Park	5	36
250410	**South Indian Island County Park**	**5**	**179**
250470	Port Townsend Ship Canal	5	83
250510	**Wolfe Property State Park**	**8**	**452**
250512	**Shine Tidelands State Park**	**8**	**105**
270051		8	31
270052		8	84
270171	Point Whitney Lagoon	8	36
270201	**Dosewallips State Park (Approved)**	**8**	**152**
270202	Dosewallips State Park (Restricted)	8	36
270230	Kitsap Memorial State Park	8	36
270300	**Eagle Creek**	**8**	**215**
270312	South Lilliwaup	8	46
270440	**Potlatch State Park**	**8**	**2,644**
270442	**Potlatch DNR Tidelands**	**8**	**1,885**
270444	**Potlatch East**	**8**	**300**
270480	**Rendsland Creek**	**8**	**185**
270501	**Quilcene Tidelands Sec. 1**	**8**	**265**
280680	**Penrose Point State Park**	**7**	**100**
280975	Hope Island State Park	7	44
281140	Frye Cove County Park	7	30
TOTAL	24 beaches		7,094

Table 14. Parameter estimates of beach-specific length-weight models for eastern softshell clams. Only beaches shown in Table 13 with n ≥ 100 were used to estimate beach-specific parameters.

				α			β			Predicted weight at 60 mm		
BIDN	Beach Name	Bivalve Region	n	parameter estimate	SE	CV	parameter estimate	SE	CV	predicted weight (g)	95% CI lower	95% CI upper
250410	South Indian Island County Park	5	179	0.00017710	0.000079	0.4438	2.981000	0.102100	0.0343	35.39	9.54	36.18
250510	Wolfe Property State Park	8	452	0.00016940	0.000029	0.1737	2.981000	0.040210	0.0135	33.85	30.77	34.32
250512	Shine Tidelands State Park	8	105	0.00038910	0.000133	0.3413	2.796435	0.080217	0.0287	36.52	23.33	37.31
270201	Dosewallips State Park (Approved)	8	152	0.00015490	0.000038	0.2434	2.983630	0.055714	0.0187	31.29	25.58	31.84
270300	Eagle Creek	8	215	0.00010610	0.000021	0.2020	3.085000	0.048140	0.0156	32.46	28.53	32.96
270440	Potlatch State Park	8	2,644	0.00016010	0.000012	0.0735	2.995000	0.019350	0.0065	33.88	33.17	34.15
270442	Potlatch DNR Tidelands	8	1,885	0.00033610	0.000025	0.0732	2.812000	0.017500	0.0062	33.62	33.09	33.80
270444	Potlatch East	8	300	0.00012460	0.000027	0.2201	3.036000	0.051070	0.0168	31.19	27.16	31.55
270480	Rendsland Creek	8	185	0.00020270	0.000044	0.2179	2.940000	0.051110	0.0174	34.25	29.73	34.80
270501	Quilcene Tidelands Sec. 1	8	265	0.00030470	0.000082	0.2678	2.840712	0.061025	0.0215	34.28	26.66	34.86
280680	Penrose Point State Park	7	100	0.00039840	0.000229	0.5743	2.792802	0.126501	0.0453	36.84	-10.90	37.98

Table 15. Parameter estimates of regional length-weight models for eastern softshell clams. Beaches sampled in each Bivalve Region are listed in Table 13.

REGION	number beaches	n	α parameter estimate	α SE	α CV	β parameter estimate	β SE	β CV	Predicted weight at 60 mm: predicted weight (g)	95% CI lower	95% CI upper
Bivalve Region 1	2	117	0.00033330	0.000170	0.5098	2.837202	0.113782	0.0401	36.97	2.40	37.89
Bivalve Region 5	4	331	0.00014600	0.000041	0.2817	3.023000	0.064820	0.0214	34.65	26.01	35.23
Bivalve Region 7	3	174	0.00035600	0.000139	0.3899	2.823295	0.085190	0.0302	37.30	18.32	38.13
Bivalve Region 8	15	6,472	0.00023410	0.000009	0.0367	2.899000	0.008644	0.0030	33.44	33.23	33.57

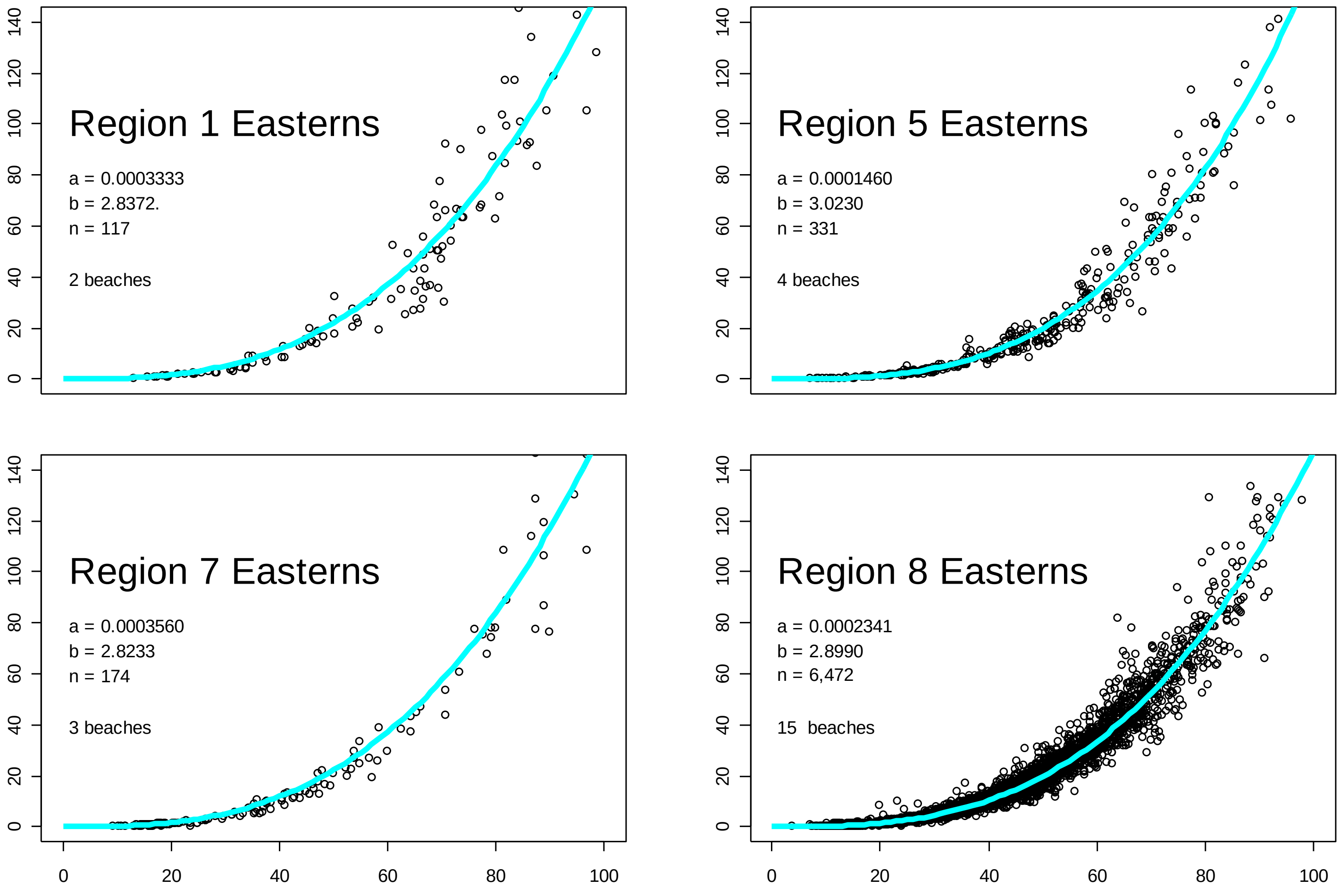

Figure 14. Eastern softshell clam length-weight relationships based on regional models. Model parameter estimates are given in Table 15.

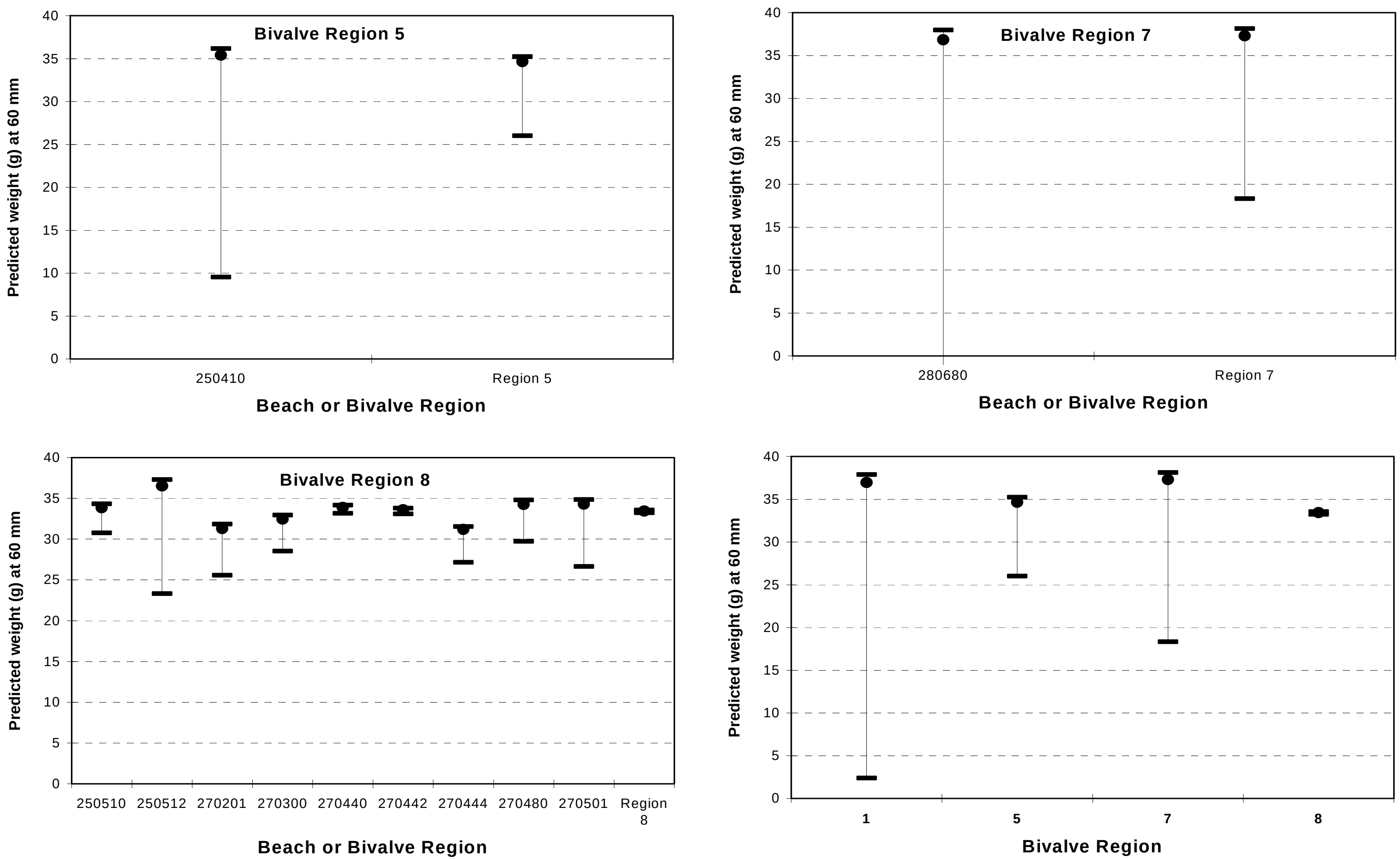

Figure 15. The predicted weight of 60mm eastern softshell clams (represented by black dots) based on beach-specific and regional length-weight models. Bars represent approximate 95% confidence bounds on the predicted weight. Data from Tables 14 and 15.

In **Bivalve Region 7 (Southern Puget Sound)**, only one beach – Penrose Point State Park -- had a sample size ≥ 100 eastern softshells, and a beach-specific model was estimated (Table 14). Note, however, the large CV of the α parameter (0.57) and the corresponding large 95% CI surrounding the estimated weight at 60 mm associated with this model (Figure 15). The data from this beach were pooled with data from Hope Island State Park and Frye Cove County Park to produce a regional model (*n* = 174 clams, Table 15, Figure 14).

In **Bivalve Region 8 (Hood Canal)** nine beaches had sample sizes exceeding 100 eastern softshells, and beach-specific models were estimated for these sites (Table 14). An unbroken continuum of overlapping 95% confidence intervals around the predicted weight of a 60 mm eastern softshell existed among these nine beaches (Figure 15), and data were therefore pooled (along with the six other Region 8 beaches with sample sizes <100) to produce a regional model (*n* = 6,472 clams, Table 15, Figure 14).

The regional models for eastern softshells in Bivalve Regions 1,5,7 and 8 had overlapping 95% confidence bounds on the predicted weight of a 60 mm eastern softshell (Table 15, Figure 15), and the regional models are all shown for comparison in Figure 16.

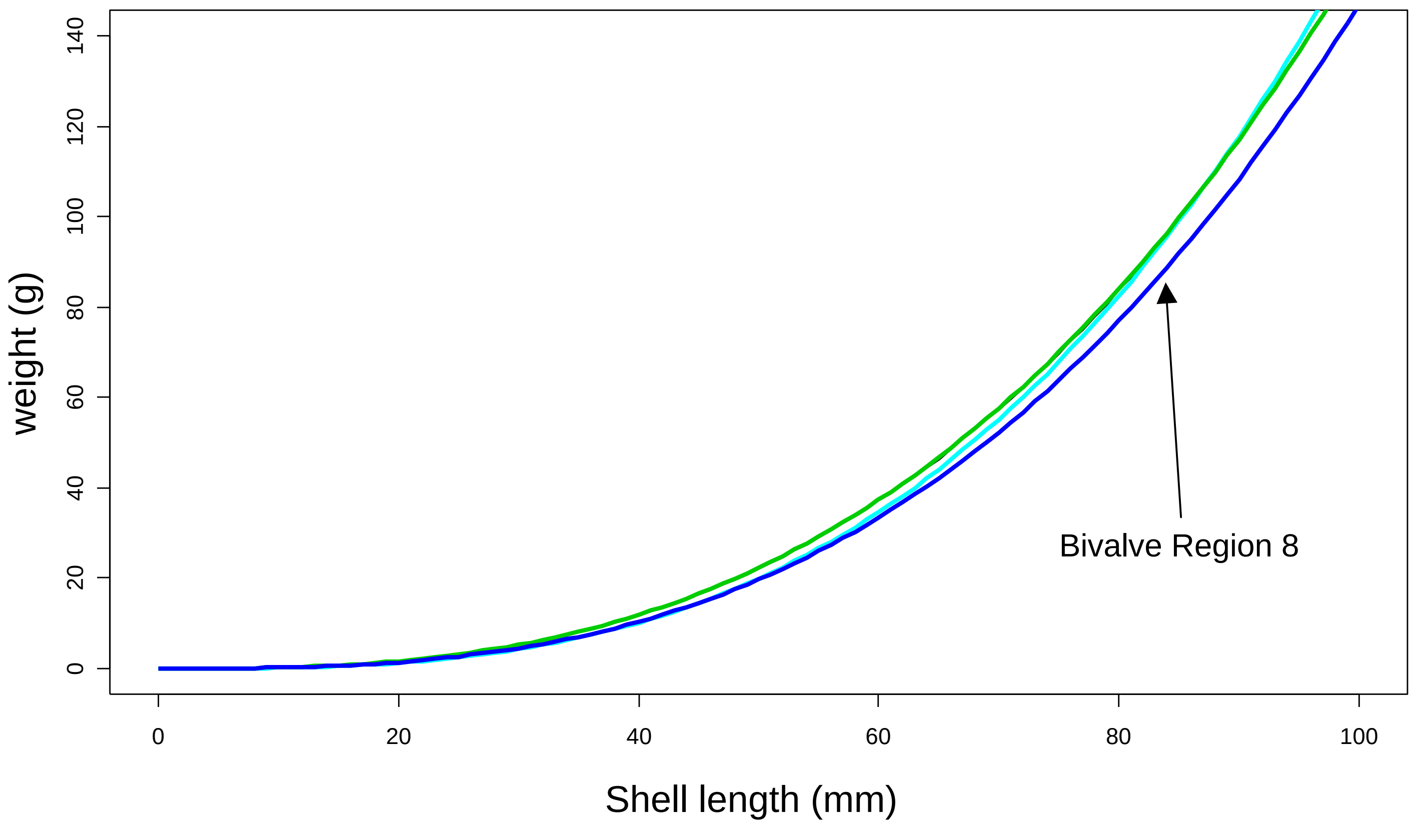

Figure 16. Eastern softshell clam length-weight relationships based on regional models. Regional model parameter estimates are shown in Table 15. Four curves are shown: Regional models for Bivalve Regions 1, 5, 7 and 8.

Empirical Model Comparisons

Manila Clams

We compared the estimated mean weight of legal Manila clams (≥ 38 mm) based on clams weighed in the laboratory with model-based estimates of mean weight from survey data on six public beaches (Table 16).

Mean legal Manila clam weights estimated with the beach-specific models given in Table 2 were fairly close to those based on actual sample weights from all six surveys. Mean weight based on the beach-specific models underestimated the surveyed mean weight in three of the six surveys, and overestimated mean weight on the other three beaches. The highest discrepancy between the two estimates occurred at Wolfe Property State Park, where the beach-specific model overestimated mean weight by 3.5%. The average difference between the model-based and actual survey data was 0.24%.

Regional models for Manila clams (given in Table 3) also provided estimates of mean weight that were fairly close to the actual survey estimates (Table 16). The biggest discrepancy occurred at Potlatch State Park, where the Bivalve Region 8 model overestimated mean weight by almost 10%. All other differences between the two estimates, however, were less than 5%.

The "Sea Grant model" (Anderson *et al.* 1982) consistently underestimated the mean weight of legal Manila clams in all six surveys (Table 16). The biggest discrepancy was at Quilcene Tidelands Section 10, where the Sea Grant model estimate was almost 25% lower than the estimate based on actual sampled clam weights. On average, the Sea Grant model underestimated mean legal Manila weight by about 17%, and the closest agreement between the estimates (at Potlatch State Park) still involved a 9% underestimate.

The effect of these discrepancies on Manila clam biomass estimates at the same six public beaches is shown in Table 17. In each case, the biggest differences occurred using the Sea Grant model, and biomass was consistently underestimated using that model. Averaged over all six beaches, the Sea Grant model underestimated biomass by about 4,000 pounds. At Quilcene Tidelands Section 10, the Sea Grant model would have underestimated legal Manila clam biomass by 11,387 pounds compared to the actual survey estimate. At Oakland Bay (Ogg Property), use of the Sea Grant model would have resulted in an underestimate of 4,802 pounds. Had the Sea Grant model been used to make these survey estimates, the 2001 TACs at these two beaches would have been reduced by 3,758 pounds and 1,585 pounds, respectively (based on the current 33% annual harvest rate for Manila clams).

Table 16. A comparison of the estimated mean weight per legal Manila clam (≥ 38 mm) based on actual weighed samples and on length-weight models. Data from WDFW surveys in 2001 and Skokomish Tribe survey of Potlatch East in 2002. "Difference (%)" is the difference between the modeled mean weight and the actual survey mean weight, expressed as a percentage. WDFW models are from this report; Sea Grant model is from Anderson *et al.* (1982).

Beach Name	BIDN	survey date	number legal clams measured	ESTIMATED MEAN WEIGHT PER LEGAL CLAM (g) Actual survey (weighed samples)	WDFW beach-specific model	difference(%)	WDFW regional model	difference(%)	Sea Grant model	difference(%)
South Indian Island County Park	250410	08/18/2001	50	24.15	23.44	-2.94	23.30	-3.52	19.78	-18.10
Wolfe Property State Park	250510	06/03/2001	143	20.56	21.28	3.50	21.36	3.89	17.79	-13.47
Potlatch State Park	270440	07/19/2001	98	18.33	18.79	2.51	20.08	9.55	16.72	-8.78
Potlatch East	270444	06/10/2002	27	21.84	21.82	-0.09	22.29	2.06	18.57	-14.97
Quilcene Tidelands Sec. 10	270510	09/14/2001	309	13.66	13.44	-1.61	13.52	-1.02	10.28	-24.74
Oakland Bay-Ogg Property	281043	07/23/2001	151	19.91	19.93	0.10	19.02	-4.47	16.14	-18.94
AVERAGE DIFFERENCE (%)						**0.24**		**1.08**		**-16.50**
MAXIMUM DIFFERENCE (%)						**3.50**		**9.55**		**-24.74**

Table 17. A comparison of the estimated legal Manila clam (≥ 38 mm) biomass based on actual weighed samples and on length-weight models. "Difference (pounds)" is the difference between the modeled biomass and the estimated survey biomass. Estimates of mean weight per legal Manila clam are shown in Table 16.

Beach Name	BIDN	survey date	area surveyed (acres)	mean legal clam density (no./sq. ft)	ESTIMATED LEGAL MANILA BIOMASS (lbs) Actual survey (weighed samples)	WDFW beach-specific model	difference (pounds)	WDFW regional model	difference (pounds)	Sea Grant model	difference (pounds)
South Indian Island County Park	250410	08/18/2001	27.55	0.18	11,410	11,076	-334	11,012	-398	9,346	-2,064
Wolfe Property State Park	250510	06/03/2001	12.17	1.22	29,225	30,243	1,018	30,357	1,132	25,286	-3,939
Potlatch State Park	270440	07/19/2001	29.78	0.34	17,842	18,293	451	19,542	1,700	16,270	-1,572
Potlatch East	270444	06/10/2002	4.07	0.22	1,915	1,913	-2	1,954	39	1,628	-287
Quilcene Tidelands Sec. 10	270510	09/14/2001	9.46	3.72	46,117	45,385	-732	45,652	-465	34,730	-11,387
Oakland Bay-Ogg Property	281043	07/23/2001	4.13	3.21	25,360	25,376	16	24,226	-1,134	20,558	-4,802
MEAN ABSOLUTE ERROR (pounds)							**426**		**811**		**4,009**
MEAN ERROR (pounds)							**70**		**146**		**-4,009**

Using the beach-specific Manila clam models from this report, the largest discrepancy in estimated biomass would have been 1,018 pounds (at Wolfe Property State Park). At Potlatch East, the difference between the estimates of legal Manila clam biomass would have been only two pounds. Averaged over all six beaches, the beach-specific models overestimated biomass by only 70 pounds (Table 17), an indication that bias is generally lower with the beach-specific models than using either the regional or Sea Grant models. The absolute mean error on all six beaches using the beach-specific models was 426 pounds (Table 17), an indication that the overall *magnitude* of error is also less than either the regional or Sea Grant models.

Regional models did not perform as well as the beach-specific models except at Quilcene Tidelands Section 10, where the regional model underestimated biomass by only 465 pounds, whereas the beach-specific model underestimated biomass by 732 pounds. Averaged over all six beaches, the regional models overestimated biomass by 146 pounds, while the mean absolute error was 811 pounds; thus, both bias and the magnitude of error were generally higher using regional models than using the beach-specific models. Use of the regional models from this report would have resulted in differences of over 1,000 pounds at three beaches (Wolfe Property State Park, Oakland Bay, and Potlatch State Park). At the latter beach, the difference between the biomass estimated from the Bivalve Region 8 model and the actual survey samples would have amounted to an overestimate of 1,700 pounds.

Native littleneck clams

We compared the estimated mean weight of legal native littleneck clams ($\geq$ 38 mm) based on clams weighed in the laboratory with model-based estimates of mean weight from survey data on six public beaches (Table 18).

Mean legal native littleneck weights estimated with the beach-specific models given in Table 2 were fairly close to those based on actual sample weights from all six surveys. Mean weight based on the beach-specific models overestimated the surveyed mean weight in five of the six surveys, but the biggest such discrepancy amounted to only 6% above the surveyed weight (at Potlatch State Park), and four of the six estimates differed by less than 3%. Regional models differed a bit more from the actual surveys, overestimating mean weight at Potlatch State Park by almost 13%. All the other five estimates using regional models differed by less than 7% from the survey estimates. The NWIFC model overestimated mean weight at Potlatch State Park by almost 11%, but the other differences were all less than 5%.

Table 18. A comparison of the estimated mean weight per legal native littleneck clam (≥ 38 mm) based on actual weighed samples and on length-weight models. Data from WDFW surveys in 2001. "Difference (%)" is the difference between the modeled mean weight and the actual survey mean weight, expressed as a percentage. WDFW models are from this report. NWIFC model is shown in Appendix Table 2.

Beach Name	BIDN	survey date	number legal clams measured	ESTIMATED MEAN WEIGHT PER LEGAL CLAM (g)						
				Actual survey (weighed samples)	WDFW beach-specific model	difference(%)	WDFW regional model	difference(%)	NWIFC model	difference(%)
Sequim Bay State Park	250050	05/22/2001	92	37.29	38.32	2.76	38.05	2.04	36.25	-2.79
Fort Flagler State Park	250260	07/03/2001	194	48.74	48.27	-0.96	47.56	-2.42	46.92	-3.73
Oak Bay County Park	250400	07/24/2001	32	25.89	27.36	5.68	27.17	4.94	26.48	2.28
Kitsap Memorial State Park	270230	07/02/2001	17	24.69	25.17	1.94	24.74	0.20	24.15	-2.19
Potlatch State Park	270440	07/19/2001	157	26.43	28.03	6.05	29.84	12.90	29.31	10.90
Potlatch DNR Tidelands	270442	06/25/2001	110	26.05	26.36	1.19	27.75	6.53	27.19	4.38
AVERAGE DIFFERENCE (%)						**2.78**		**4.03**		**1.47**
MAXIMUM DIFFERENCE (%)						**6.05**		**12.90**		**10.90**

Table 19. A comparison of the estimated legal native littleneck clam (≥ 38 mm) biomass based on actual weighed samples and on length-weight models. "Difference (pounds)" is the difference between the modeled biomass and estimated survey biomass. Estimates of mean weight per legal native littleneck clam are shown in Table 18.

Beach Name	BIDN	survey date	area surveyed (acres)	mean legal clam density (no./sq. ft)	ESTIMATED LEGAL NATIVE LITTLENECK BIOMASS (lbs)						
					Actual survey (weighed samples)	WDFW beach-specific model	difference (pounds)	WDFW regional model	difference (pounds)	NWIFC model	difference (pounds)
Sequim Bay State Park	250050	05/22/2001	3.41	2.83	34,532	35,489	957	35,240	708	33,577	-955
Fort Flagler State Park	250260	07/03/2001	20.64	1.06	102,476	101,479	-997	99,984	-2,492	98,638	-3,838
Oak Bay County Park	250400	07/24/2001	6.95	0.59	10,262	10,846	584	10,770	508	10,497	235
Kitsap Memorial State Park	270230	07/02/2001	4.38	0.43	4,491	4,577	86	4,501	10	4,392	-99
Potlatch State Park	270440	07/19/2001	29.78	0.49	37,025	39,269	2,244	41,800	4,775	41,068	4,043
Potlatch DNR Tidelands	270442	06/25/2001	10.59	0.94	24,792	25,087	295	26,419	1,627	25,878	1,086
MEAN ABSOLUTE ERROR (pounds)							**861**		**1,687**		**1,709**
MEAN ERROR (pounds)							**528**		**856**		**79**

Native littleneck clam biomass estimates at the same six public beaches are shown in Table 19. The biggest discrepancies between the model-based estimates and the survey estimates occurred at Potlatch State Park. The Bivalve Region 8 model overestimated biomass there by 4,775 pounds, while the NWIFC model overestimated biomass by 4,043 pounds; the beach-specific model overestimated biomass by 2,244 pounds. At all the other five beaches, the beach-specific models differed from the survey estimates by less than 1,000 pounds.

Averaged over all six beaches, all three models tended to slightly overestimate native littleneck biomass. The NWIFC model had the lowest mean error, overestimating biomass by only 79 pounds compared to 528 pounds and 856 pounds using the beach-specific and regional models (Table 19). This suggests that the NWIFC model involves the least overall *bias*. On the other hand, the mean *absolute* error was lowest using the beach-specific models (861 pounds) and highest (1,709 pounds) using the NWIFC model (Table 19), suggesting that the beach-specific models involve the lowest *magnitude* of error.

Change in Length-Weight Relationships over Time

Separate Manila clam length-weight models were created from each year of survey data from 1994 through 2004 at Quilcene Bay Section 10, Dosewallips State Park, and Potlatch State Park. Comparisons of the predicted weight of a 38 mm Manila clam based on each survey year model are shown in Tables 20, 21, and 22.

Model-predicted weights for Manila clams at Quilcene Bay Section 10 are shown in Table 20. The weight of a 38mm clam in 2003 and 2004 was significantly lower than all other years except 1996 (Table 20). This concurs with the observation of two of the authors that in recent years, Manila clams at Quilcene Bay seemed to be taking on a more normal, flattened morphology typical of the species on most other beaches.

Model-predicted weights for Manila clams at Dosewallips State Park are shown in Table 21. Predicted weight at 38 mm in the years 2000-2004 were significantly lower than all other years except 1994.

Model-predicted weights for Manila clams at Potlatch State Park are shown in Table 22. These exhibit an unbroken continuum of overlapping 95% CIs. Thus, we could detect no significant change in the weight-length relationship of Manila clams at Potlatch State Park based on the period surveyed.

These data suggest that at least at Quilcene Bay Section 10 and Dosewallips State Park, some change in the morphology of Manila clams – in both cases a dorsal compression of the shell -- may have occurred over the past decade. This apparent trend, however, is not definitive, and further surveys would be needed to confirm if any long-term change in morphology has actually taken place.

From a practical fisheries management standpoint, the effect of using a multi-year length-weight model to estimate biomass on such a beach would depend on two factors: **1)** How long the trend existed in the data (i.e., how much of the change is incorporated into the multi-year model), and: **2)** The magnitude of the change in morphology. For example, if we had used the multi-year, beach-specific model for Manila clams at Quilcene Bay Section 10 (Table 2) to estimate clam weight during our 2004 survey there, we would have overestimated mean legal clam weight – and therefore total biomass -- by 8.5% (mean weight per legal Manila clam from the actual survey was 12.9 g, whereas the beach-specific model estimate would have been 14.0 g). If we had used the beach-specific Manila clam model for Dosewallips State Park (again from Table 2) to estimate mean weight of legal clams in our 2004 survey, the difference between the two estimates would have been less than 1%. Even though the magnitude of the apparent change in both beaches is roughly equal – 38 mm clams weigh about 7-8% less in recent years – the change in weight at Quilcene appears *only in the last two years of data* (2003 and 2004), whereas the change occurred at Dosewallips in the last five years (since 2000). Thus, the multi-year model for Dosewallips incorporates much of the data from the “lighter clam” time period.

Table 20. Predicted weight of a 38 mm Manila clam at Quilcene Bay Sec. 10 (270510), based on length-weight models created from individual survey years. No survey was conducted in 2000.

survey year	predicted weight at 38 mm	95% CI lower	95% CI upper	n
1994	14.89	14.53	14.97	1,510
1995	15.40	15.11	15.48	1,898
1996	14.14	13.95	14.20	1,268
1997	15.22	14.87	15.29	1,851
1998	15.52	14.72	15.62	722
1999	15.50	14.71	15.58	1,239
2001	15.40	14.64	15.51	647
2002	15.21	14.50	15.32	929
2003	14.32	13.30	14.44	674
2004	13.93	13.00	14.04	644

Table 21. Predicted weight of a 38 mm Manila clam at Dosewallips State Park (270201), based on length-weight models created from individual survey years.

survey year	predicted weight at 38 mm	95% CI lower	95% CI upper	n
1994	14.66	14.41	14.73	1,615
1995	14.98	14.79	15.04	1,926
1996	14.78	14.56	14.85	1,905
1997	14.88	14.69	14.94	2,183
1998	15.20	14.74	15.30	968
1999	16.12	14.65	16.29	557
2000	13.75	13.36	13.87	728
2001	13.10	12.99	13.16	1,882
2002	14.35	13.35	14.50	297
2003	14.16	13.10	14.35	196
2004	13.77	13.15	13.91	193

Table 22. Predicted weight of a 38 mm Manila clam at Potlatch State Park (270440), based on length-weight models created from individual survey years.

survey year	predicted weight at 38 mm	95% CI lower	95% CI upper	n
1994	13.46	13.05	13.55	599
1995	13.11	12.56	13.22	579
1996	13.34	13.06	13.43	645
1997	13.15	12.98	13.22	1,147
1998	13.32	12.48	13.43	411
1999	13.50	12.44	13.65	358
2000	13.32	12.76	13.43	368
2001	13.15	11.86	13.31	378
2002	12.92	5.22	13.12	85
2003	14.81	10.11	15.05	90
2004	13.83	13.41	13.96	180

SUMMARY AND RECOMMENDATIONS

We examined the allometric length-to-weight relationship of 134,929 clams gathered from 70 public beaches over the period 1994-2002. Our primary objective was to develop beach-specific and regional models for Manila clams, native littleneck clams, butter clams, cockles, and eastern softshell clams. The models presented here can be used to reliably estimate the wet weight of individual clams sampled during bivalve population surveys in cases where it is not feasible to actually weigh them.

A second objective of this report was to compare our length-weight models to two models currently used by some treaty tribes to estimate Manila clam and native littleneck clam weights from length measurements taken in the field. We found that the Manila clam model used by some tribes and documented in two Washington Sea Grant publications (Anderson *et al.* 1982; Toba *et al.* 1992) consistently underestimated Manila clam weight at size. This bias was significant from a fisheries management standpoint, underestimating Manila clam biomass by 16% on average, and in one case by as much as 24%. Our conclusion corroborates that of the Skokomish Tribe, which discontinued use of the Sea Grant Manila clam model beginning in 2002. The Sea Grant model appeared in a publication for clam farmers, and may have been based on Manila clams grown under aquaculture conditions that differed significantly from those found on the beaches we sampled. Our Manila clam samples were drawn almost entirely from naturally occurring populations on public beaches, and we recommend that in this management context, use of the Sea Grant model be discontinued immediately. We also found that the beach-specific models developed here generally performed better than the regional models, in terms of both a lower mean error and lower mean absolute error.

We found that the NWIFC native littleneck model currently used by many tribes (Appendix Table 2, this report) closely agreed with our models for this species; differences, where they existed, were not significant from a fisheries management perspective. This similarity between the NWIFC native littleneck model and our models should not be surprising, since data for the NWIFC model were drawn from WDFW beach surveys. Based on our empirical studies on six beaches, the NWIFC model performed better than either our beach-specific models or regional models, exhibiting the lowest mean error. This suggests that on average, the *bias* involved with the NWIFC model is lower than that using our beach-specific or regional models. Our beach-specific models performed better than the NWIFC in terms of mean absolute error, an indication that the overall *magnitude* of error is lowest with the beach-specific models. However, this advantage largely disappears if the data from Potlatch State Park are removed from the analysis. In any case, the differences between our beach-specific models and the NWIFC model are slight, and there is no compelling reason to discontinue use of the NWIFC native littleneck length-weight model.

A final objective was to determine if clam length-weight relationships changed significantly over time. We tested this at three Manila clam beaches where sample sizes were generally large enough to provide enough statistical precision to detect changes. At Quilcene Bay Section 10, an area noted in the past for its unusually squat, heavy clams, we found evidence in the last two years (2003 and 2004) that Manila clam morphology may be shifting to a flatter, lighter clam that is similar to those at most other beaches. We found evidence of a similar change at Dosewallips State Park, although that shift appears to have occurred five years ago. At Potlatch State Park, we detected no significant shift in Manila clam morphology. Although the significance and mechanism of such morphological changes are currently unknown, our findings suggest that clams on these and other beaches should be analyzed for length-weight changes over time as more survey data accumulates. These analyses can be used to confirm apparent trends over time, and to produce updated models for management use.

Based on our findings here, we make the following recommendations for fisheries managers who are attempting to estimate mean weight per clam in population surveys:

When it is possible to accurately weigh the individual clams sampled during population surveys, this remains the preferred method for estimating mean weight per clam. Using this method requires managers to make no assumptions about a model's reliability over time or space, and permits a simple calculation of the sample variance surrounding mean weight.
If accurate weights for individual clams cannot be reliably taken, then it is preferable to estimate weight from measured shell length using one of the models presented in this report for Manila clams, butter clams, cockles, and eastern softshells. For native littlenecks, the NWIFC model currently in use should continue to be used. The use of models implicitly assumes that the model makes reasonably reliable predictions about weight-at-size. Also, the sample variance surrounding mean weight cannot be easily estimated, since the samples are not true weights, and the variance of the length-weight model must therefore be factored into the variance calculation. From a practical fisheries management standpoint, this latter distinction is probably not important, since almost all of the variance surrounding clam biomass estimates is related to the variance of mean density, not mean weight.

When using our models for estimating weights of Manila clams, managers should choose the beach-specific models presented in this report whenever applicable (i.e., for surveys conducted on the beaches shown in Table 2). Our empirical comparisons for Manila clams (Tables 16 and 17) suggest that the differences between modeled weights and actual weights will typically be lowest when using beach-specific models. When a surveyed beach does *not* have a beach-specific Manila clam model associated with it -- and many tribal surveys are likely to take place on such beaches -- we recommend using the appropriate *regional model* from this report (Table 3). Again, our empirical comparisons suggest that using the regional models presented here will result in more reliable estimates of mean weight per Manila clam than the Sea Grant model currently used by some tribes.

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Appendix 1: A comparison of fresh and frozen weights of Manila clams sampled in a clam population survey

By

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INTRODUCTION

Each year, Washington Department of Fish and Wildlife (WDFW) and treaty tribes conduct a series of clam population surveys on selected public beaches. The primary objective of these surveys is to estimate the biomass of Manila clams and native littleneck clams that are of legal size (≥ 38 mm in shell length). These "legal biomass" estimates are then used to set Total Allowable Catches (TACs) on each beach. The estimated legal biomass on each beach is the product of three numbers: **1)** The surveyed area of the beach; **2)** The estimated density of "legal" clams on the surveyed beach; and **3)** The estimated average weight per "legal" clam on the surveyed beach.

Campbell (1996) describes in detail the methodology used by WDFW to perform clam population surveys. The estimated average weight per clam is based on random-systematic samples of clams that have been bagged and brought back to the laboratory for processing. Although it is feasible to *measure* the shell length of clam samples while still on the beach following a survey, it is not often practical to *weigh* clams accurately on the beach. Problems with field weights include wind, rain, and uneven surfaces (all of which may produce erroneous scale readouts) and a frequent inability to remove mud from the sampled clams. Neither is it usually practical to process the samples immediately upon returning to the laboratory after a survey. Samples are therefore frozen at the laboratory, and at some later date they are individually measured and weighed.

Thus, the weight recorded for each clam is a "frozen weight" and the tacit assumption is made that these frozen weights are the same as clam weights taken from fresh clams (which is how clams are weighed in both sport creel surveys and tribal commercial harvests). Campbell (1996) states that "Tests were performed which indicate that the weight of live clams and the weight of frozen clams are not statistically significant. Clams which have been frozen and thawed do weigh significantly less than either fresh or frozen clams." No details are available, however, on how these tests were performed or the statistical methods used to analyze them.

We decided to perform a simple test of this assumption that fresh and frozen clam weights were the same. The primary objective was to determine if there was a statistically significant difference between the fresh weight of individual Manila clams taken during routine WDFW surveys and their frozen weights. If any statistically significant difference was found, our secondary objectives were to determine the magnitude of the difference and if the bias in frozen weights resulted in a greater or lesser weight.

METHODS

We compared the fresh and frozen weights of individual Manila clams taken during a routine population survey at Point Whitney Tidelands (BIDN 270170.00). The survey was conducted on May 23, 2005 at a tide level of –0.70 m (–2.3 ft). The survey took approximately 2.5 hr, encompassing an area of 1.505 hectares (3.72 acres). Survey protocols followed those described in Campbell (1996). A total of 85 samples were dug, each 0.0929 m^2 (1 ft^2) in area. Following routine sampling protocols, all clams from every other sample were retained in a plastic sample bag with a tag identifying the individual sample. Following this sub-sampling routine, a total of 33 samples containing clams were retained for processing. The retained samples were bundled in a large plastic bag and placed in a refrigerator within 10 minutes of completing the survey. The clams were stored in the refrigerator for approximately three hr while a similar survey was performed on adjacent tidelands.

The initial processing of the fresh clam samples took approximately 2.5 hr. Each clam was measured, weighed and placed in a separate plastic bag with a unique identifying number. Shell lengths were recorded to the nearest 0.01 mm with Sylvac electronic calipers. Clam weights were recorded to the nearest 0.1 g using an Ohaus Scout II electronic balance. Once all clams were measured and weighed in their fresh state, they were frozen in the sample bags for ten days and re-processed in a frozen state on June 2, 2005. This processing session lasted 6 hr. The samples were removed from the freezer and allowed to partially thaw for approximately 10 minutes, a procedure which mimics the standard protocol for weighing clam samples. Typically, clams are covered with sand and mud after being retained on the beach. After the clams had partially thawed for 10 minutes, they were emptied into a strainer and washed under running water, then individually measured and weighed in their frozen state.

We used a paired *t*-test (Zar 1984) to test the null hypothesis that the fresh and frozen weights of the sampled Manila clams were equal:

$$H_0: \ \mu_d = 0$$

where μ_d is the mean population difference (i.e., $\mu_{fresh} - \mu_{frozen}$).

RESULTS

Using the paired *t*-test to compare the 367 paired weights, we rejected the null hypothesis that the fresh weights of Manila clams were equal to the frozen weights (t = 22.83, df = 366, α = 0.05, P = 2.23 X 10^{-72}).

In most cases, frozen weights were *lower* than fresh weights. Figure 17 shows the absolute difference (g) between the fresh and frozen weights of each clam plotted against the fresh weight. Figure 17 makes it clear that of the 367 clams, 280 clams weighed *more* when fresh, 81 clams weighed the same whether fresh or frozen, and only six clams weighed *less* when fresh. This consistent bias accounts for the very low *P*-value of the paired *t*-test results, and therefore the highly significant difference between fresh and frozen weights.

Despite this consistent bias in frozen clam weights, however, the *magnitude* of that bias is very small. Figure 18 shows the fresh and frozen weights of all 367 clams plotted against the line of equality (i.e., fresh weight = frozen weight). Departures from the line of equality are so small as to be indistinguishable in many cases. As Figure 17 shows, the greatest difference between fresh and frozen clams was a single clam that weighed 0.6 g more when fresh (a weight difference of 2.6%), and only three clams had fresh weights that were more than 0.3 g heavier than their frozen weights. On average, the difference between the fresh and frozen weights was less than 1% (i.e., clams tended to weigh 0.90 % more when fresh).

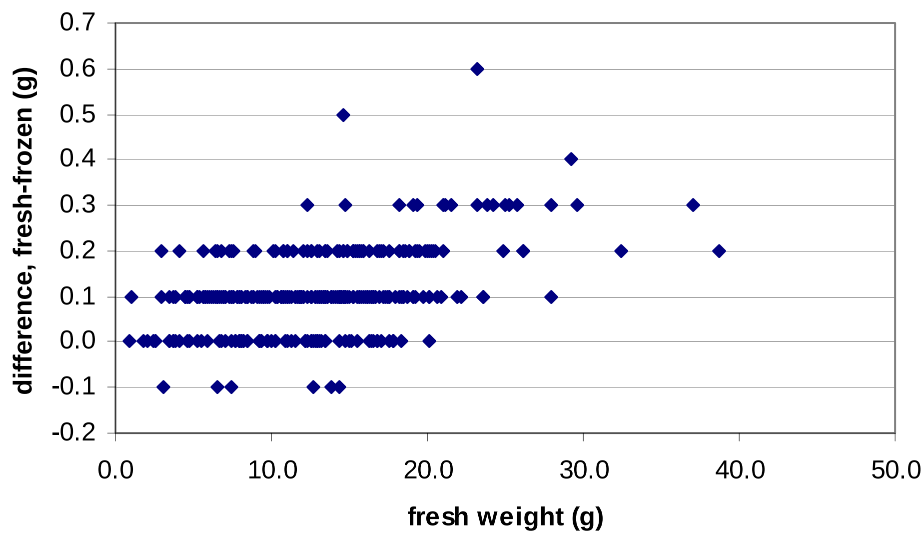
Since annual TACs are determined using only the average weight of "legal" clams – those ≥ 38 mm -- we also performed a second paired *t*-test using only "legal" clams from our sample. We rejected the null hypothesis that the fresh weights of 196 "legal" Manila clams were equal to the frozen weights (t = 18.44, df = 195, α = 0.05, P = 1.33 X 10^{-44}). Of the 196 "legal" clams, 163 clams weighed *more* when fresh, 30 clams weighed the same whether fresh or frozen, and only three clams weighed *less* when fresh. On average, the difference between the fresh and frozen weights was less than 1% (i.e., "legal" clams tended to weigh 0.76 % more when fresh).

DISCUSSION

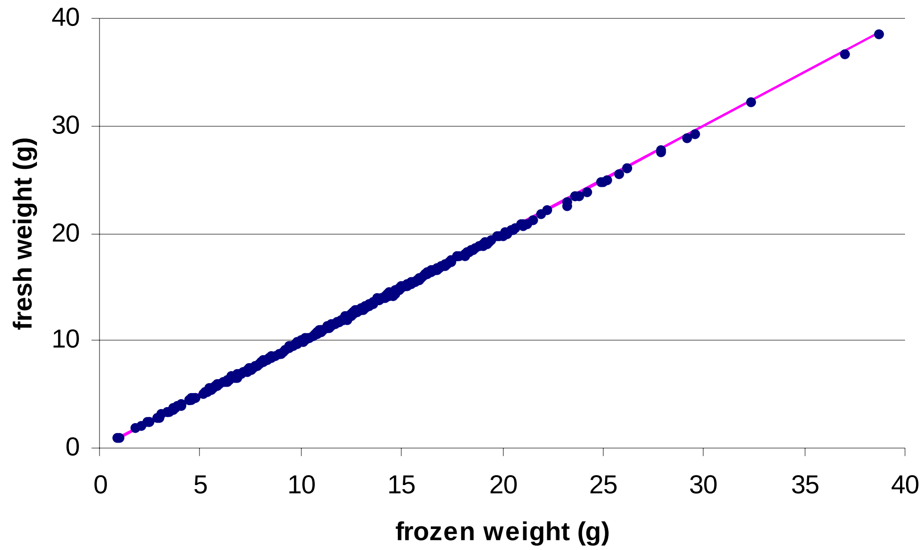
We compared the fresh and frozen weights of 367 Manila clams taken during a routine population survey. A paired *t*-test found a highly significant difference between the fresh and frozen weights of individual clams, with fresh clams generally weighing more than frozen clams. Although this bias was consistent, the magnitude of that bias was extremely small. On average, frozen weights underestimated fresh weights by less than 1%, and even the greatest difference in individual clam weights in this study underestimated fresh weight by only 2.6%. From a fisheries management standpoint, we consider differences of this magnitude to be negligible.

When storing and weighing the frozen clams for this test, we made every attempt to duplicate the routine methods used during WDFW clam surveys. Some minor differences in the processing routine were unavoidable, however. Normally, for example, the clams are washed off while frozen, immediately after removal from the sample bag. Water may thus glaze the clamshell, and minute amounts of sand may adhere to it, although the glaze usually has melted off by the time the clam is weighed. In this test, we were required to first wash the clams in their fresh state, so that the frozen clams were already clean and dry, and no glaze was produced. Another minor difference in this test was that clams were individually wrapped in plastic bags, perhaps providing increased insulation and therefore decreasing the partial thawing before the frozen clams were weighed. We believe that these unavoidable differences in processing methods are negligible from the standpoint of the weight data obtained.

Campbell (1996) reported that there were no significant differences between the weights of fresh and frozen clams, but provided no information on the statistical hypothesis test he used. Based on our results, we suspect that the test referred to may have compared the *unpaired mean weight* of a sample of clams when frozen against the *unpaired mean weight* of those same clams when fresh. If we had used a similar approach -- an unpaired two-sample *t*-test to compare the fresh and frozen weights in our sample -- we would not have rejected the null hypothesis of the two weights being equal ($t = 0.25$, $P = 0.80$). The paired *t*-test, however, is the proper statistical test to determine if there are significant differences in two measurements made of the same animal.



Appendix Figure 17. The absolute difference (g) between the fresh weights of 367 Manila clams and their frozen weights (y-axis), plotted against the fresh weights (x-axis).



Appendix Figure 18. Fresh weights (g) of 367 Manila clams (y-axis) plotted against their frozen weights. Also shown is the line of equality where fresh weight = frozen weight..

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Campbell, W.W. 1996. Procedures to determine intertidal populations of *Protothaca staminea*, *Tapes philippinarum*, and *Crassostrea gigas* in Hood Canal and Puget Sound, Washington. Washington Department of Fish and Wildlife, Procedures Manual MRD96-01.

Zar, J.H. 1984. Biostatistical analysis. 2nd ed. Prentice-Hall, Inc., New Jersey. 718 p.

Appendix Table 1. Sea Grant publication Manila clam length-weight model. Reproduced from Appendix E, Anderson *et al.* (1982). The same table appears as Appendix F in Toba *et al*. (1992).

$$\text{Live weight} = (1.433 \times 10^{-4}) \times (\text{length})^{3.11}$$

Length (mm)	Weight (g)
9	0.13
10	0.18
11	0.25
12	0.33
13	0.42
14	0.53
15	0.65
16	0.80
17	0.96
18	1.15
19	1.36
20	1.59
21	1.86
22	2.14
23	2.46
24	2.81
25	3.19
26	3.61
27	4.05
28	4.54
29	5.06
30	5.63
31	6.23
32	6.88
33	7.57
34	8.31
35	9.09
36	9.92
37	10.80
38	11.74
39	12.73
40	13.77
41	14.87
42	16.02
43	17.24
44	18.52
45	19.86
46	21.26
47	22.74
48	24.27
49	25.88
50	27.56
51	29.31
52	31.14
53	33.04
54	35.01
55	37.07
56	39.21

Appendix Table 2. NWIFC native littleneck length-weight model. Courtesy of Eric Sparkman, Skokomish Tribe.

Length (mm)	Weight (g)
10	1.0
11	1.0
12	1.0
13	1.0
14	1.0
15	1.0
16	1.0
17	1.0
18	1.0
19	1.0
20	2.0
21	2.0
22	3.0
23	3.0
24	4.0
25	4.0
26	5.0
27	5.5
28	6.0
29	7.0
30	8.0
31	8.0
32	9.5
33	10.5
34	11.0
35	12.0
36	13.5
37	15.5
38	16.0
39	17.0
40	19.0
41	20.5
42	22.0
43	24.5
44	26.0
45	28.0
46	29.5
47	32.0
48	34.0
49	36.0
50	38.0
51	42.5
52	44.5
53	47.0
54	49.0
55	52.0
56	54.5
57	57.0
58	61.0
59	65.0
60	68.0
61	73.0
62	76.0
63	80.0
64	84.0
65	88.0
> 65	92.0

Appendix Table 3. Variance-covariance matrices of the model parameter estimates for Manila clams.

BIDN		a	b	BIDN		a	b	BIDN		a	b
250014	**a**	2.3771E-08	-1.9096E-05	**270112**	**a**	6.0587E-10	-1.2343E-06	**270510**	**a**	7.9458E-11	-9.7786E-08
	b	-1.9096E-05	1.5361E-02		**b**	-1.2343E-06	2.5266E-03		**b**	-9.7786E-08	1.2048E-04
250016	**a**	1.9605E-08	-1.7773E-05	**270114**	**a**	4.8626E-10	-6.8177E-07	**270801**	**a**	6.0211E-10	-5.9337E-07
	b	-1.7773E-05	1.6135E-02		**b**	-6.8177E-07	9.6046E-04		**b**	-5.9337E-07	5.8583E-04
250050	**a**	3.3873E-07	-8.3026E-05	**270170**	**a**	1.7339E-10	-2.3380E-07	**270802**	**a**	3.5924E-10	-4.0742E-07
	b	-8.3026E-05	2.0378E-02		**b**	-2.3380E-07	3.1582E-04		**b**	-4.0742E-07	4.6270E-04
250055	**a**	2.2064E-08	-1.3460E-05	**270171**	**a**	8.1766E-11	-1.5956E-07	**280570**	**a**	7.4333E-09	-5.4942E-06
	b	-1.3460E-05	8.2237E-03		**b**	-1.5956E-07	3.1179E-04		**b**	-5.4942E-06	4.0710E-03
250057	**a**	3.2152E-09	-3.5206E-06	**270200**	**a**	4.5579E-11	-4.6671E-08	**280580**	**a**	6.8952E-10	-1.3995E-06
	b	-3.5206E-06	3.8636E-03		**b**	-4.6671E-08	4.7864E-05		**b**	-1.3995E-06	2.8474E-03
250110	**a**	5.5004E-09	-3.6792E-06	**270201**	**a**	3.7442E-11	-4.5734E-08	**280680**	**a**	8.7067E-10	-6.8812E-07
	b	-3.6792E-06	2.4670E-03		**b**	-4.5734E-08	5.5969E-05		**b**	-6.8812E-07	5.4567E-04
250280	**a**	1.4882E-08	-9.7525E-06	**270202**	**a**	9.4491E-11	-1.1389E-07	**280712**	**a**	9.3648E-10	-1.2271E-06
	b	-9.7525E-06	6.4047E-03		**b**	-1.1389E-07	1.3749E-04		**b**	-1.2271E-06	1.6098E-03
250290	**a**	1.9120E-09	-4.6424E-06	**270293**	**a**	1.9494E-09	-1.9071E-06	**281043**	**a**	5.3493E-08	-2.1092E-05
	b	-4.6424E-06	1.1283E-02		**b**	-1.9071E-06	1.8688E-03		**b**	-2.1092E-05	8.3221E-03
250310	**a**	8.8667E-09	-8.3373E-06	**270300**	**a**	1.0830E-09	-1.5318E-06				
	b	-8.3373E-06	7.8536E-03		**b**	-1.5318E-06	2.1712E-03				
250315	**a**	6.6403E-08	-2.8693E-05	**270312**	**a**	1.8170E-09	-2.9058E-06				
	b	-2.8693E-05	1.2414E-02		**b**	-2.9058E-06	4.6540E-03	**Region 1**	**a**	3.2696E-09	-2.0444E-06
250320	**a**	7.7977E-09	-7.2901E-06	**270380**	**a**	4.2315E-10	-8.2674E-07	All 6 beaches	**b**	-2.0444E-06	1.2808E-03
	b	-7.2901E-06	6.8290E-03		**b**	-8.2674E-07	1.6181E-03	**Region 5**	**a**	1.2674E-09	-1.0840E-06
250330	**a**	2.5061E-09	-5.4264E-06	**270440**	**a**	5.3507E-11	-7.9105E-08	9 beaches	**b**	-1.0840E-06	9.2881E-04
	b	-5.4264E-06	1.1768E-02		**b**	-7.9105E-08	1.1720E-04	**Region 5**	**a**	2.7354E-10	-2.3747E-07
250340	**a**	8.4772E-10	-2.7943E-06	**270442**	**a**	6.6104E-11	-1.4198E-07	All 11 beaches	**b**	-2.3747E-07	2.0661E-04
	b	-2.7943E-06	9.2214E-03		**b**	-1.4198E-07	3.0554E-04	**Region 6**	**a**	1.9291E-09	-1.7393E-06
250350	**a**	4.3885E-09	-4.0065E-06	**270444**	**a**	2.5555E-10	-4.7452E-07	All 3 beaches	**b**	-1.7393E-06	1.5711E-03
	b	-4.0065E-06	3.6645E-03		**b**	-4.7452E-07	8.8292E-04	**Region 7**	**a**	4.8947E-10	-4.1478E-07
250400	**a**	2.0024E-09	-1.6342E-06	**270480**	**a**	4.5063E-10	-6.1269E-07	All 5 beaches	**b**	-4.1478E-07	3.5216E-04
	b	-1.6342E-06	1.3367E-03		**b**	-6.1269E-07	8.3481E-04	**Region 8**	**a**	5.2829E-12	-7.7819E-09
250410	**a**	4.8923E-10	-4.2576E-07	**270501**	**a**	6.6409E-12	-2.0977E-08	Except Quilcene 3-10 & E. Dabob	**b**	-7.7819E-09	1.1488E-05
	b	-4.2576E-07	3.7132E-04		**b**	-2.0977E-08	6.6446E-05	**Quilcene 3-10**	**a**	2.1329E-11	-3.2201E-08
250470	**a**	2.4836E-08	-1.7935E-05	**270502**	**a**	7.1926E-11	-1.2797E-07	All 8 beaches	**b**	-3.2201E-08	4.8685E-05
	b	-1.7935E-05	1.2981E-02		**b**	-1.2797E-07	2.2825E-04				
250510	**a**	6.2572E-11	-6.5615E-08	**270503**	**a**	1.8179E-10	-2.8616E-07				
	b	-6.5615E-08	6.8940E-05		**b**	-2.8616E-07	4.5133E-04				
250512	**a**	1.5326E-10	-2.1197E-07	**270504**	**a**	1.9972E-10	-3.7918E-07				
	b	-2.1197E-07	2.9389E-04		**b**	-3.7918E-07	7.2098E-04				
260350	**a**	4.2916E-09	-5.4251E-06	**270505**	**a**	6.6776E-11	-1.5939E-07				
	b	-5.4251E-06	6.8656E-03		**b**	-1.5939E-07	3.8106E-04				
260510	**a**	2.4187E-09	-3.7987E-06	**270506**	**a**	1.7889E-09	-5.1821E-06				
	b	-3.7987E-06	5.9775E-03		**b**	-5.1821E-06	1.5033E-02				
260545	**a**	6.8385E-09	-4.4967E-06	**270507**	**a**	4.9638E-09	-8.9704E-06				
	b	-4.4967E-06	2.9632E-03		**b**	-8.9704E-06	1.6230E-02				
270050	**a**	1.7049E-08	-1.0783E-05	**270508**	**a**	2.1648E-10	-3.7086E-07				
	b	-1.0783E-05	6.8279E-03		**b**	-3.7086E-07	6.3596E-04				
270052	**a**	1.0681E-09	-2.0809E-06	**270509**	**a**	3.0172E-10	-4.1460E-07				
	b	-2.0809E-06	4.0613E-03		**b**	-4.1460E-07	5.7027E-04				

Appendix Table 4. Variance-covariance matrices of the model parameter estimates for native littleneck clams.

BIDN		a	b	BIDN		a	b	BIDN		a	b
250013	**a**	2.4462E-09	-2.7038E-06	**250340**	**a**	3.2414E-10	-3.6102E-07	**270201**	**a**	5.5201E-09	-6.5135E-06
	b	-2.7038E-06	2.9936E-03		**b**	-3.6102E-07	4.0270E-04		**b**	-6.5135E-06	7.6962E-03
250014	**a**	1.7832E-10	-3.8458E-07	**250350**	**a**	1.3931E-10	-2.2754E-07	**270202**	**a**	2.7644E-09	-2.5175E-06
	b	-3.8458E-07	8.3038E-04		**b**	-2.2754E-07	3.7227E-04		**b**	-2.5175E-06	2.2964E-03
250016	**a**	5.0894E-09	-4.2077E-06	**250400**	**a**	3.4880E-10	-2.3296E-07	**270230**	**a**	4.1260E-09	-2.4651E-06
	b	-4.2077E-06	3.4839E-03		**b**	-2.3296E-07	1.5600E-04		**b**	-2.4651E-06	1.4753E-03
250050	**a**	6.3985E-10	-4.4236E-07	**250410**	**a**	2.2084E-10	-1.8184E-07	**270300**	**a**	4.1344E-10	-5.8057E-07
	b	-4.4236E-07	3.0625E-04		**b**	-1.8184E-07	1.5006E-04		**b**	-5.8057E-07	8.1674E-04
250055	**a**	3.9909E-10	-3.2685E-07	**250470**	**a**	1.1515E-08	-6.1785E-06	**270370**	**a**	3.6082E-09	-2.4693E-06
	b	-3.2685E-07	2.6812E-04		**b**	-6.1785E-06	3.3187E-03		**b**	-2.4693E-06	1.6920E-03
250056	**a**	1.6343E-09	-1.4741E-06	**250510**	**a**	1.8428E-10	-1.3881E-07	**270380**	**a**	4.3102E-09	-2.7081E-06
	b	-1.4741E-06	1.3317E-03		**b**	-1.3881E-07	1.0479E-04		**b**	-2.7081E-06	1.7049E-03
250057	**a**	2.5105E-10	-2.7836E-07	**250512**	**a**	2.9785E-10	-2.2771E-07	**270440**	**a**	2.4965E-10	-2.6636E-07
	b	-2.7836E-07	3.0949E-04		**b**	-2.2771E-07	1.7436E-04		**b**	-2.6636E-07	2.8459E-04
250110	**a**	4.2948E-10	-6.0677E-07	**260190**	**a**	4.4649E-09	-3.6052E-06	**270442**	**a**	4.4430E-10	-5.1087E-07
	b	-6.0677E-07	8.5836E-04		**b**	-3.6052E-06	2.9157E-03		**b**	-5.1087E-07	5.8804E-04
250260	**a**	3.9775E-10	-3.4839E-07	**260231**	**a**	4.2581E-09	-2.9453E-06	**270444**	**a**	1.4349E-09	-1.5090E-06
	b	-3.4839E-07	3.0557E-04		**b**	-2.9453E-06	2.0396E-03		**b**	-1.5090E-06	1.5891E-03
250280	**a**	1.9343E-10	-2.7677E-07	**260350**	**a**	1.4791E-09	-1.1278E-06	**270480**	**a**	2.1506E-08	-8.0905E-06
	b	-2.7677E-07	3.9668E-04		**b**	-1.1278E-06	8.6102E-04		**b**	-8.0905E-06	3.0496E-03
250290	**a**	1.9994E-10	-2.9910E-07	**260380**	**a**	8.4918E-10	-9.9534E-07	**280580**	**a**	1.6134E-09	-2.9406E-06
	b	-2.9910E-07	4.4822E-04		**b**	-9.9534E-07	1.1680E-03		**b**	-2.9406E-06	5.3695E-03
250300	**a**	3.9990E-10	-5.6538E-07	**260510**	**a**	1.2300E-08	-6.3475E-06	**280680**	**a**	6.8584E-10	-5.8118E-07
	b	-5.6538E-07	8.0078E-04		**b**	-6.3475E-06	3.2786E-03		**b**	-5.8118E-07	4.9361E-04
250310	**a**	1.3248E-10	-1.9261E-07	**270050**	**a**	1.2020E-08	-5.2322E-06	**280975**	**a**	2.3076E-09	-1.8537E-06
	b	-1.9261E-07	2.8047E-04		**b**	-5.2322E-06	2.2813E-03		**b**	-1.8537E-06	1.4912E-03
250315	**a**	2.4610E-10	-3.8766E-07	**270051**	**a**	1.9823E-09	-1.6007E-06	**281140**	**a**	5.3517E-09	-5.2503E-06
	b	-3.8766E-07	6.1150E-04		**b**	-1.6007E-06	1.2948E-03		**b**	-5.2503E-06	5.1566E-03
250320	**a**	2.2879E-10	-2.9827E-07	**270052**	**a**	4.7031E-10	-6.6042E-07	**Region 1**	**a**	9.6312E-11	-8.9106E-08
	b	-2.9827E-07	3.8940E-04		**b**	-6.6042E-07	9.2876E-04	All 8 beaches	**b**	-8.9106E-08	8.2570E-05
250325	**a**	1.6613E-10	-2.6548E-07	**270170**	**a**	3.4100E-09	-4.5884E-06	**Region 5**	**a**	1.6222E-11	-1.8844E-08
	b	-2.6548E-07	4.2501E-04		**b**	-4.5884E-06	6.1850E-03	All 14 beaches	**b**	-1.8844E-08	2.1937E-05
250330	**a**	9.4006E-10	-7.8414E-07	**270200**	**a**	2.1114E-09	-2.3298E-06	**Region 6**	**a**	5.8870E-10	-4.0666E-07
	b	-7.8414E-07	6.5497E-04		**b**	-2.3298E-06	2.5750E-03	All 6 beaches	**b**	-4.0666E-07	2.8131E-04
								Region 7	**a**	1.9618E-10	-2.1946E-07
								All 6 beaches	**b**	-2.1946E-07	2.4607E-04
								Region 8	**a**	2.1537E-11	-2.0399E-08
								All 23 beaches	**b**	-2.0399E-08	1.9393E-05

Appendix Table 5. Variance-covariance matrices of the model parameter estimates for butter clams.

BIDN		a	b	BIDN		a	b
250014	**a**	1.5691E-10	-6.4023E-07	**270300**	**a**	9.7387E-11	-3.2857E-07
	b	-6.4023E-07	2.6152E-03		**b**	-3.2857E-07	1.1110E-03
250050	**a**	2.6182E-09	-6.6610E-06	**270370**	**a**	9.1587E-10	-3.5194E-06
	b	-6.6610E-06	1.6957E-02		**b**	-3.5194E-06	1.3531E-02
250055	**a**	1.1699E-08	-1.1445E-05	**270380**	**a**	2.5123E-09	-5.4932E-06
	b	-1.1445E-05	1.1212E-02		**b**	-5.4932E-06	1.2018E-02
250260	**a**	2.7180E-09	-2.4108E-06	**270440**	**a**	1.1020E-10	-2.3179E-07
	b	-2.4108E-06	2.1407E-03		**b**	-2.3179E-07	4.8840E-04
250400	**a**	1.4884E-09	-8.8474E-07	**270442**	**a**	6.4398E-11	-1.9608E-07
	b	-8.8474E-07	5.2697E-04		**b**	-1.9608E-07	5.9770E-04
250410	**a**	1.8782E-10	-4.5707E-07	**270444**	**a**	1.8126E-10	-6.4753E-07
	b	-4.5707E-07	1.1135E-03		**b**	-6.4753E-07	2.3150E-03
250470	**a**	1.2511E-08	-1.0098E-05	**270480**	**a**	2.4292E-09	-8.1574E-06
	b	-1.0098E-05	8.1581E-03		**b**	-8.1574E-06	2.7409E-02
250510	**a**	1.8886E-10	-2.7965E-07	**280580**	**a**	7.1454E-08	-3.3318E-05
	b	-2.7965E-07	4.1459E-04		**b**	-3.3318E-05	1.5547E-02
250512	**a**	5.0392E-11	-1.2799E-07	**280680**	**a**	4.8936E-08	-3.4820E-05
	b	-1.2799E-07	3.2548E-04		**b**	-3.4820E-05	2.4791E-02
260231	**a**	9.1365E-10	-1.7351E-06	**280975**	**a**	2.3557E-07	-4.8598E-05
	b	-1.7351E-06	3.2976E-03		**b**	-4.8598E-05	1.0030E-02
270051	**a**	1.5983E-09	-2.4323E-06				
	b	-2.4323E-06	3.7053E-03				
270052	**a**	4.1497E-07	-5.7189E-05	**Region 1**	**a**	2.2243E-10	-7.5827E-07
	b	-5.7189E-05	7.8923E-03	All 3 beaches	**b**	-7.5827E-07	2.5880E-03
270170	**a**	1.1746E-10	-1.6984E-06	**Region 5**	**a**	1.0766E-10	-1.8273E-07
	b	-1.6984E-06	2.4574E-02	All 4 beaches	**b**	-1.8273E-07	3.1071E-04
270230	**a**	3.4092E-09	-5.7437E-06	**Region 7**	**a**	4.5137E-08	-1.5000E-05
	b	-5.7437E-06	9.6834E-03	All 3 beaches	**b**	-1.5000E-05	4.9873E-03
270293	**a**	2.1980E-06	-3.2510E-04	**Region 8**	**a**	1.0695E-11	-3.4234E-08
	b	-3.2510E-04	4.8106E-02	All 14 beaches	**b**	-3.4234E-08	1.0976E-04

Appendix Table 6. Variance-covariance matrices of the model parameter estimates for cockles.

BIDN		a	b	BIDN		a	b
250014	**a**	1.0789E-08	-6.3951E-06	**270050**	**a**	5.2938E-09	-3.1528E-06
	b	-6.3951E-06	3.7971E-03		**b**	-3.1528E-06	1.8805E-03
250016	**a**	1.0904E-08	-6.3947E-06	**270230**	**a**	1.0990E-07	-3.6447E-05
	b	-6.3947E-06	3.7569E-03		**b**	-3.6447E-05	1.2099E-02
250050	**a**	3.4452E-09	-3.1386E-06	**270300**	**a**	5.6008E-08	-1.0436E-05
	b	-3.1386E-06	2.8627E-03		**b**	-1.0436E-05	1.9483E-03
250055	**a**	7.4076E-09	-6.2846E-06	**270440**	**a**	2.4671E-09	-1.3134E-06
	b	-6.2846E-06	5.3374E-03		**b**	-1.3134E-06	7.0038E-04
250057	**a**	5.5809E-08	-1.8962E-05	**270442**	**a**	2.2500E-09	-1.1366E-06
	b	-1.8962E-05	6.4514E-03		**b**	-1.1366E-06	5.7515E-04
250260	**a**	4.3123E-07	-6.7802E-05	**270444**	**a**	1.4504E-08	-7.6263E-06
	b	-6.7802E-05	1.0674E-02		**b**	-7.6263E-06	4.0168E-03
250400	**a**	3.4622E-09	-1.7206E-06	**270480**	**a**	1.7777E-08	-7.7019E-06
	b	-1.7206E-06	8.5805E-04		**b**	-7.7019E-06	3.3443E-03
250410	**a**	2.6344E-09	-1.5979E-06	**280680**	**a**	2.4308E-08	-5.7315E-06
	b	-1.5979E-06	9.7172E-04		**b**	-5.7315E-06	1.3575E-03
250470	**a**	1.6399E-07	-4.0792E-05				
	b	-4.0792E-05	1.0159E-02				
250510	**a**	3.8670E-09	-3.0129E-06	**Bivalve Region 1**	**a**	1.0081E-09	-1.0462E-06
	b	-3.0129E-06	2.3541E-03	All 5 beaches	**b**	-1.0462E-06	1.0874E-03
250512	**a**	2.8685E-09	-1.5823E-06	**Bivalve Region 5**	**a**	3.8904E-09	-1.4497E-06
	b	-1.5823E-06	8.7602E-04	All 4 beaches	**b**	-1.4497E-06	5.4148E-04
260231	**a**	2.7129E-08	-1.6334E-05	**Bivalve Region 8**	**a**	5.4827E-10	-2.8257E-07
	b	-1.6334E-05	9.8426E-03	All 9 beaches	**b**	-2.8257E-07	1.4598E-04

Appendix Table 7. Variance-covariance matrices of the model parameter estimates for eastern softshell clams.

BIDN		a	b
250410	**a**	6.1762E-09	-8.0187E-06
	b	-8.0187E-06	1.0428E-02
250510	**a**	8.6531E-10	-1.1812E-06
	b	-1.1812E-06	1.6167E-03
250512	**a**	1.7625E-08	-1.0637E-05
	b	-1.0637E-05	6.4348E-03
270201	**a**	1.4209E-09	-2.0977E-06
	b	-2.0977E-06	3.1040E-03
270300	**a**	4.5916E-10	-1.0302E-06
	b	-1.0302E-06	2.3175E-03
270440	**a**	1.3857E-10	-2.2758E-07
	b	-2.2758E-07	3.7450E-04
270442	**a**	6.0576E-10	-4.3022E-07
	b	-4.3022E-07	3.0613E-04
270444	**a**	7.5248E-10	-1.4001E-06
	b	-1.4001E-06	2.6085E-03
270480	**a**	1.9505E-09	-2.2546E-06
	b	-2.2546E-06	2.6127E-03
270501	**a**	6.6586E-09	-4.9752E-06
	b	-4.9752E-06	3.7241E-03
280680	**a**	5.2371E-08	-2.8923E-05
	b	-2.8923E-05	1.6003E-02
Region 1	**a**	2.8879E-08	-1.9319E-05
All 2 beaches	**b**	-1.9319E-05	1.2946E-02
Region 5	**a**	1.6914E-09	-2.6635E-06
All 4 beaches	**b**	-2.6635E-06	4.2017E-03
Region 7	**a**	1.9256E-08	-1.1813E-05
All 3 beaches	**b**	-1.1813E-05	7.2573E-03
Region 8	**a**	7.3759E-11	-7.4122E-08
All 15 beaches	**b**	-7.4122E-08	7.4710E-05