Effects of Geoduck Biological Sample Handling and Transport Time on Mean Weight Estimation

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ABSTRACT

Bureau, D., and Curtis, D.L. 2014. Effects of geoduck biological sample handling and transport time on mean weight estimation. Can. Tech. Rep. Fish. Aquat. Sci. 3094: vi + 17 p.

An experiment was conducted to determine if tagging and transport time of geoduck (*Panopea generosa*) biological samples account for differences in mean weight estimates observed between biological samples and commercial harvest data for the Haida Gwaii and Prince Rupert regions. Tagging caused a greater initial weight loss in geoducks treated as biological samples than was observed in geoducks treated as commercial catch. Temperature differences between biological and commercial treatments did not affect the rate of weight loss after tagging. Longer transport time was responsible for a greater weight loss in the biological treatment than in the commercial treatment. Correction factors, based on transit time data and results of the experiment, were calculated to account for the effects of tagging and increased transport time of biological samples. The correction factors were applied to biological sample data from 1994 to 2010 for Haida Gwaii and Prince Rupert regions. Comparisons of weight-loss-corrected biological sample mean weights to commercial harvest mean weights showed no differences for the Prince Rupert and Haida Gwaii regions.

RÉSUMÉ

Bureau, D. et Curtis, D. L. 2014. Effets de la manipulation et de la durée du transport des échantillons biologiques de panopes sur l'estimation moyenne du poids. Rapp. tech. can. sci. halieut. aquat. 3094 : vi + 17 p.

Une expérience a été menée afin de déterminer si le marquage et la durée de transport des échantillons biologiques de panopes (*Panopea generosa*) pouvaient être responsables des différences dans les estimations de poids moyen observées entre les échantillons biologiques et les données des pêcheurs commerciaux pour les régions de Haida Gwaii et de Prince Rupert. Le marquage a entraîné une plus grande perte de poids initiale chez les panopes traitées comme échantillons biologiques que celle observée chez les panopes traitées comme prises commerciales. Les différences de température entre les traitements biologiques et commerciaux n'ont pas affecté le taux de perte de poids après le marquage. Un temps de transport plus long a causé une plus grande perte de poids dans le traitement biologique que dans le traitement commercial. Des facteurs correctifs, basés sur les données de temps de transit et les résultats de l'expérience, ont été calculés afin de tenir compte des effets du marquage et du temps de transport accru des échantillons biologiques. Les facteurs correctifs ont été appliqués aux données des échantillons biologiques de 1994 à 2010 pour les régions de Haida Gwaii et de Prince Rupert. Les comparaisons des poids moyens des échantillons biologiques corrigés selon la perte de poids attendue avec les poids moyens de la pêche commerciale ne montrent aucune différence pour les régions de Prince Rupert et de Haida Gwaii.

INTRODUCTION

The commercial fishery for the Pacific geoduck clam (*Panopea generosa*) began in British Columbia (BC) in 1976 and has since grown to be one of the highest valued fisheries in BC, with an estimated landed value of CAD $46.6 million in 2012 (BC Agriculture 2012). Geoduck harvest options are calculated on a by-geoduck-bed basis and, since 2007, have been based on estimates of current biomass and regional exploitation rates of 1.2 – 1.8% (Bureau et al. 2012).

Geoduck biomass is estimated for each bed as the product of bed area, geoduck density on the bed, and mean geoduck weight for the bed (Bureau et al. 2012). Since 2001, mean geoduck weight has been estimated from fishery-dependent data, i.e., number and weight of geoducks when landed at a landing port, as recorded on commercial harvest logbooks (Bureau et al. 2012). Concerns were raised regarding whether mean weight estimates based on commercial harvest data were representative of geoduck populations. Fishery-independent dive surveys are conducted to estimate geoduck density on the beds, which historically included collection of biological samples for age determination. Biological samples therefore provide an additional source of mean weight information for some surveyed geoduck beds.

In 2002, Hand and Bureau (2012) presented a comparison of mean weights estimated from fishery-dependent data and from biological samples from survey areas. They noted that the biological sample mean weight was almost always lower than the estimate from commercial catch, and suggested that future work should investigate why this is the case. Mean weight could be higher in commercial samples if size selectivity (avoidance of small clams) is occurring in the commercial fishery, as biological samples could include smaller animals than the size-threshold for harvest (Hand and Bureau 2012). Alternatively, mean weight could be higher in commercial samples because biological samples take longer to arrive at processing plants where they are weighed, and the longer transport time could cause greater weight loss in the biological samples (Hand and Bureau 2012).

Bureau et al. (2012) compared mean weight of geoducks estimated from biological samples and commercial harvest data. First, they developed correction factors for biological samples to account for weight loss occurring between validation at the landing dock and arrival at processing plants (dock-plant). They then compared biological sample mean weights, corrected for dock-plant weight loss, to commercial harvest data for beds where both data sources were available. Results showed lower estimated mean weights for biological samples than for commercial harvest data from the Haida Gwaii and Prince Rupert regions (Bureau et al. 2012). Therefore, based on observed differences between biological sample and commercial catch mean weights, Bureau et al. (2012) recommended applying mean weight correction factors of -10% and -8% to mean weights estimated from commercial harvest data for the Haida Gwaii and Prince Rupert regions, respectively, until further work was conducted. No differences were found between mean weight estimated from the two sources of data for other regions of BC (Central Coast and South Coast) and consequently no correction factors were recommended for those regions.

The source of the differences observed for the Haida Gwaii and Prince Rupert regions was unclear. Geoduck biological samples are subject to more handling and longer transport times than the commercial catch. In the commercial geoduck fishery, geoducks are individually harvested by divers using a stinger (a pressurized water jet used to loosen the substrate around the geoduck). Geoducks are put into bags and brought onto the boat where they are rubber-banded, counted, and packed into “cages” (plastic crates used for live transport). Cages are generally kept on deck or in the hold of the fishing vessel and geoducks are kept cool by covering cages with tarps or wet burlap, using salt water spray systems or keeping geoducks submerged in seawater in the fishing vessel’s hold. At the end of the fishing day, geoducks are either offloaded at a dock (typical for the fishery in the South Coast) or transhipped to a packer vessel which then transports the catch to the nearest approved dock for offloading (typical for the fishery in the North Coast). Geoducks are kept in the holds of the packer vessel during transit. When geoducks are offloaded at a dock, weight of landed geoducks for each fishing vessel is recorded by third-party dock-side validators.

Geoduck biological samples are harvested in the same manner as the commercial catch, usually on the last day of a geoduck density dive survey, however, handling practices differ. Once geoducks are brought aboard the boat, they are first banded and then individually double-tagged before being packed into cages. Tagging consists of drying a portion of each valve of the bivalve shell with compressed air, followed by gluing a plastic tag on each valve. Tagging is conducted by a crew of two, each person tagging one side of each geoduck, which is thus handled twice during tagging. This handling often causes geoducks to retract their necks, leading to water loss. Cages of biological samples are typically kept on the deck of the survey vessel. Since no packer vessel is available to carry geoduck biological samples to the offloading dock, samples are transported by the survey vessel to a landing port where they are weighed and validated in the same manner as the commercial catch. Geoducks from biological samples are then shipped to a processing facility where individual geoduck weight and shell measurements are recorded.

Biological sample mean weight is estimated from individual geoduck weights measured at processing plants while commercial harvest mean weights are estimated from dock-side data. Bureau et al. (2012) developed correction factors to account for weight loss between the dock and processing facilities (dock-plant). However, weight loss due to tagging and longer transit time of biological samples (tag-transit) was not taken into account due to the lack of data.

Differences in mean weight between biological samples and commercial harvest data were observed only for the Haida Gwaii and Prince Rupert regions. When the commercial fishery operates in these two regions, geoducks are usually landed in Prince Rupert. Whereas biological samples from the Haida Gwaii and Prince Rupert regions are typically transported to Port Hardy for offload, a greater distance from survey grounds than Prince Rupert. Therefore, geoduck biological samples have a longer transit time before dock-side validation than the commercial catch.

Another compounding factor could be that geoduck surveys are conducted in the summer while the commercial fishery operates year round. Transport of biological samples on the deck of a survey vessel during hot summer days could also contribute to weight loss and a decrease in mean weight of biological samples.

The extra handling that geoduck biological samples are subjected to, combined with longer transit time and warmer transit conditions, may all contribute to increased weight loss and account for lower weight estimates. Analyses presented in Bureau et al. (2012) did not take into account the possible effects of increased handling and transport time of biological samples on mean weight estimates. An experiment was designed and conducted to determine if handling and transport time of geoduck biological samples can account for differences in mean weight estimates observed between biological samples and commercial harvest data for the Haida Gwaii and Prince Rupert regions. This report presents results of the weight loss experiment, the correction factors derived to account for tag-transit and dock-plant weight loss in biological samples, followed by a comparison of mean weight estimates from commercial catch and corrected biological samples, for Haida Gwaii and Prince Rupert regions.

METHODS

WEIGHT LOSS EXPERIMENT

A sample of 611 geoducks was harvested from the south side of Gabriola Island, BC (49° 07.6N, 123° 45.1W) on April 19, 2012, from the commercial geoduck vessel Hideaway II. Harvest was done by commercial geoduck divers using typical harvest gear (stinger). Harvested geoducks were banded, placed into individually labelled cages (numbered sequentially) and transported to the Pacific Biological Station (PBS) in Nanaimo, BC, where individual cage weights were recorded at the time of landing.

Cages were separated into two treatment groups to mimic handling and transport conditions of biological samples (“biological treatment”) and commercial catch (“commercial treatment”). Even-numbered cages were assigned to the biological treatment (16 cages, 303 geoducks in total) and odd-numbered cages to the commercial treatment (16 cages, 308 geoducks in total) to ensure that cages in each treatment group spanned the same harvest-time window. To mimic the handling and transport of biological samples, geoducks were individually tagged on both valves by drying a small portion of each valve with an air gun then applying gel cyanoacrylate glue and a small plastic tag (4 mm X 9 mm) with a unique identification number. One departure from normal practices was that geoducks were not tagged on the harvest vessel because pre-tagging cage weights were required to determine tagging-related weight loss. Biological treatment geoducks were tagged in the first four hours of the experiment and, once tagged, were re-packed in cages and kept un-refrigerated (at room temperature) for the duration of the experiment to mimic the transport conditions of biological samples on survey vessels. To mimic handling and transport of commercial catch, the commercial treatment cages were kept refrigerated (4-6 °C) and geoducks were not tagged or handled after being packed in cages on the harvest vessel. The two experimental treatments were thus Biological = tagged and kept at room temperature while Commercial = not tagged and refrigerated.

Individual cage weights were recorded when the geoducks arrived at PBS (elapsed time = 0 at 16:00, April 19) and every 4 h thereafter over a 64 h period. The duration of the experiment was chosen to provide experimental measurements for a longer period than transport time of biological samples. Temperatures of geoducks in three randomly selected cages from each treatment were recorded using an infrared temperature gauge after 2.5 h elapsed time and at each weighing interval thereafter.

CALCULATIONS OF RELEVANT TRANSPORT TIMES

Transport time, defined as the time from geoducks being loaded onto a packer boat to offload at a dock, for all North Coast commercial geoduck fishery landings for the 2009, 2010 and 2011 fishing seasons were obtained from Archipelago Marine Research. Three years of data were used to include all three North Coast geoduck rotational areas. Average transport times for the commercial fishery were calculated for each Rotational Area (i.e., Haida Gwaii, Prince Rupert and Central Coast regions) and for the North Coast overall. Transport time of biological samples was calculated as the time from 16:00 on the day a sample was taken to the time the sample was weighed at the dock when landed. Transport times of samples collected between 2007 and 2012 were used. These calculated transport times were used to examine the effect of transport time in the weight loss experiment described above.

STATISTICAL ANALYSES

Weight Loss Experiment Analyses

Percent weight loss was calculated for each cage and time interval as:

$$\%WL_{ct} = \frac{W_{ct} - W_{c0}}{W_{c0}} \times 100 \qquad \text{Equation 1}$$

where $\%WL_{ct}$ is the percent weight loss for cage *c* at time *t*, W_{ct} is the weight of cage *c* at time *t* and W_{c0} is the weight of cage *c* at time = 0 (when initial cage weights were recorded) and is thus expressed in terms of initial wet weights.

To investigate the effects of tagging prior to transport and holding conditions/transport time on weight loss, a Repeated Measures ANOVA was carried out using a multivariate approach on the data collected between 4 and 64 h, with ‘Tagging’ as the between subject effect and ‘Time’ as the within subjects effect. The within subjects effect (Time) and the within subjects interaction term (Time*Tagging) did not meet the assumption of sphericity (Mauchly’s Criterion, $p < 0.05$) and degrees of freedom were corrected based on the Univariate Greenhouse-Geisser estimate of the epsilon statistic ($\varepsilon = 0.1218206$). Between 4 and 64 h, both samples were handled the same way, i.e., cage weights recorded every 4h and the only experimental difference between the treatments was temperature.

Further select comparisons were made using Welch’s two-sample t-tests with an α value that was Bonferoni corrected to 0.001 to account for multiple tests (Quinn and Keough 2003). The effect of tagging (handling and an associated increase in temperature) on weight loss in the Biological treatment was investigated by comparing weight loss after tagging (elapsed time = 4 h) between treatments. Results from the transport-time data were used to guide which experimental time intervals should be compared to most-closely match the transport time of commercial catch and biological samples from a given location. In order to generate correction factors that accounted for the effects of tagging and time, the slope and intercept of percent weight loss over time for each treatment was determined using linear regression. Data from 0 h were excluded to account for the effect of tagging related weight loss during the first 4h for the Biological treatment.

Mean Weight from Biological Samples vs. Commercial Harvest Comparisons

Geoducks in the commercial fishery are only weighed when landed at the dock. Biological samples are weighed twice, first when landed at a dock and again when geoducks arrive at a processing facility where individual weights and shell measurements are taken. The dock-plant weight loss was taken into account in analyses presented in Bureau et al. (2012). They calculated correction factors to account for dock-plant weight loss for each biological sample as:

$$CF_s = Mean\left(\frac{DW_c}{PW_c}\right) \qquad \text{Equation 2}$$

where CF_s is the correction factor for sample *s*, DW_c is the dock weight of cage *c* and PW_c is the plant weight of cage *c*, calculated as the sum of the individual geoduck weights measured at the processing facility in cage *c*.

The sample-specific dock-plant weight loss correction factor was then used to convert the individual geoduck plant weights to dock-weight equivalents.

$$DWE_g = PW_g \times CF_s \quad \text{Equation 3}$$

where DWE_g is the Dock Weight Equivalent of geoduck *g* and PW_g is the individual plant weight for geoduck *g* (Bureau et al. 2012).

Results from the present experiment showed that tagging and transport time to the dock (tag-transit) were responsible for additional weight loss in biological samples compared to the commercial catch. Tag-transit correction factors were calculated to account for this weight loss for Haida Gwaii and Prince Rupert regions (see Results and Discussion).

Geoduck biological sample data collected from Haida Gwaii and Prince Rupert regions between 1994 and 2010 were used. Both tag-transit (this study) and dock-plant (Bureau et al. 2012) correction factors were applied to individual plant geoduck weight measurements. By doing this, differences in weight loss attributable to the increased transit time, as well as the additional handling due to tagging are accounted for, creating an individual weight estimate that is equivalent to the landed weight from the commercial harvest. Mean geoduck weights from biological samples were then estimated on a by-geoduck-bed basis. Mean weight from commercial harvest data were calculated using 1997-2011 logbook data (years where piece-count data is available on logbooks) as in Bureau et al. (2012). Only geoduck beds where both a mean weight from biological samples and a bed-specific estimate of mean weight from commercial harvest data were available were used. The data set was analyzed using paired t-tests (where mean weight from biological sample and commercial harvest were paired by bed) to determine if mean weight between biological samples (corrected for tag-transit and dock-plant weight losses) and commercial harvest data were different for the Haida Gwaii and Prince Rupert regions.

Since biological samples are expected to contain some pre-recruits that would not be harvested in the commercial fishery, potential differences could be due to the presence of juveniles in biological samples and not necessarily to size-selectivity within the fishable size classes. Estimates of mean weight used in geoduck biomass calculations should reflect the mean weight of geoducks that are counted on density surveys, since that is the detectable, and therefore fishable, population. Analyses were therefore run using all geoducks in biological samples and also with two levels of pre-recruit cut-offs: 462g and 10 years, as in Bureau et al. (2012), to determine if potential differences could be due to size-selectivity in the commercial fishery.

The timing of recruitment events on a bed vs. time of commercial harvest and biological sample collection may account for some differences in mean geoduck weight estimates (Bureau et al. 2012). Data were therefore also analyzed, as described above, using only commercial harvest data that occurred in the same year as a biological sample was taken. Data were only available for Haida Gwaii for this analysis as no beds in Prince Rupert region were commercially harvested in the same year as a biological sample was collected.

RESULTS

WEIGHT LOSS RELATED TO TAGGING AND TRANSPORT OF BIOLOGICAL SAMPLES

Experimental Weight Loss

Temperature at t = 0 h was not recorded but is assumed to have been the same between treatments as they had been handled and treated in the same manner on the harvest vessel until that time. The average air temperature on the day of collection was approximately 9.0°C (http://climate.weather.gc.ca). Following tagging, the temperature of geoducks in the biological treatment stayed between 13.7 ± 0.5°C and 15.4 ± 0.5°C. Temperature of the commercial treatment was held between 4.2 ± 0.2°C and 5.8 ± 0.5°C.

There were statistically significant effects of both tagging (RM ANOVA, $F(1, 30) = 5.5224$, $p = 0.0225$) and time (RM ANOVA, $F(1.7055, 51.165) = 691.4743$, $p < 0.0001$) on weight loss. Tagging of the Biological treatment caused a statistically significant weight loss of 3.2 ± 0.3% (one-sample t-test, % loss ≠ 0, t = -11.866, $p < 0.001$) during the first 4.25 h of the experiment. This weight loss was significantly greater, statistically, than that of the Commercial treatment (1.8 ± 0.2% loss) over the same time period (Welch's two-sample t-test, t = -4.400, $p < 0.001$; Figure 1).

Between 4 and 64 h, both treatments were handled in the same fashion and the only difference between treatments was temperature. No statistically significant interaction was detected between tagging and time (RM ANOVA, $F(1.7055, 51.165) = 1.86949$, $p = 0.1704$) for this period, suggesting that the rate of weight loss for the biological and the commercial treatments was similar (Figure 1). In other words, geoducks lost weight at the same rate whether they were refrigerated or not.

Estimated Weight Loss Based on Transit Time

Although the effects of tagging are significant, differences in transport time likely have a larger effect on weight loss than tagging or temperature (Figure 1). For the three North Coast regions combined, average transport time of biological samples (35.6 ± 5.3 h) was much longer than transport of commercial catches (14.9 ± 0.1 h, Table 1). By region, average transport time of biological samples for the Prince Rupert (45.6 ± 7.8 h) and Haida Gwaii (48.4 h, one sample) regions were much longer than average transport time of commercial catches (10.7 ± 0.2 h and 17.2 ± 0.1 h, respectively) for differences of 34.9 h and 31.2 h respectively. These differences are because commercially harvested geoducks (from Haida Gwaii and Prince Rupert regions) are mostly transported to Prince Rupert, while biological samples are typically transported to Port Hardy which is farther away from the harvest locations than Prince Rupert. For Central Coast, the difference in average transport time of commercial catches vs. biological samples (16.7 ± 0.1 h vs. 22.4 ± 1.4 h respectively) is less (5.7 h) since geoducks are shipped to Port Hardy in both cases.

Linear regression equations and average transit times (Table 1) were used to estimate the percent weight loss from harvest to landing dock for commercial catch (% Weight Loss = -2.057 - 0.109*Time) and biological samples (% Weight Loss = -3.092 - 0.112*Time). For biological samples, the combined effects of tagging and increased transport time was estimated to result in a 4.6 and 5.0% greater weight loss (relative to initial weight), for Haida Gwaii and Prince Rupert respectively, compared to commercial catches (Table 1).

Mean transit times of commercial catch and biological samples (Table 1) for each area were also used to establish which of the 4 h experimental sampling intervals best represented the transit times from each area and the weight loss between Biological and Commercial experimental treatments at these sampling intervals was compared. Representing all of the North Coast combined, weight loss for the 16 h Commercial treatment (4.0 ± 0.3%) was significantly less (C16 vs. B36, Welch's two-sample t-test, t = -6.215, $p < 0.001$) than the 36 h Biological treatment (7.1 ± 0.4%). Representing the Haida Gwaii, weight loss for the 16 h Commercial treatment (4.0 ± 0.3%) was significantly (C16 vs. B48, Welch's two-sample t-test, t = -9.146, $p < 0.001$) less than for the 48 h Biological treatment (8.5 ± 0.4%). For Prince Rupert, weight loss for the 12 h Commercial treatment (3.4 ± 0.3%) was significantly (C12 vs. B44, Welch two-sample t-test, t = -9.118, $p < 0.001$) lower than for the 44 h Biological treatment (7.9 ± 0.4%).

Correction Factors to Account for Weight Loss due to Tagging and Transit Time for Biological Samples

Tagging and longer transit time of biological samples appear to be responsible for greater weight loss in the biological treatment than in the commercial treatment. The difference in weight loss between biological and commercial treatments for the Haida Gwaii and Prince Rupert regions (based on transit time data, Table 1) was used to derive tag-transit weight correction factors for those two regions to standardize biological sample data to dock-side validated commercial landings.

For Haida Gwaii:

$$CSW_g = DWE_g * \frac{100 - \%WL_c}{100 - \%WL_b} = DWE_g * \frac{96.1}{91.5} = DWE_g * 1.050 \qquad \text{Equation 4}$$

For Prince Rupert:

$$CSW_g = DWE_g * \frac{100 - \%WL_c}{100 - \%WL_b} = DWE_g * \frac{96.8}{91.8} = DWE_g * 1.054 \qquad \text{Equation 5}$$

Where CSW_g is the Corrected Sample Weight of geoduck *g* to account for weight loss due to tag-transit, DWE_g from Equation 3 is the sample weight of geoduck *g* corrected for dock-plant weight loss. $\%WL_c$ and $\%WL_b$ are the estimated percent Weight Loss between harvest and dock for commercial *c* and biological *b* treatments respectively, based on average transit times and regression equations derived from experimental results (Table 1).

COMPARISON OF MEAN GEODUCK WEIGHT FROM BIOLOGICAL SAMPLE DATA TAKING TAG-TRANSIT AND DOCK-PLANT WEIGHT LOSS INTO ACCOUNT VS. COMMERCIAL HARVEST DATA

Dock to plant weight loss correction factors ranged from 0.991 to 1.071 per sample with an average of 1.035 ± 0.001 and 1.049 ± 0.002 (mean ± SE) for Haida Gwaii and Prince Rupert respectively (Table 2). Biological sample mean weights corrected for tag-transit and dock-plant weight loss and mean weights from commercial harvest data for the Prince Rupert and Haida Gwaii regions are presented in Table 3. For the Prince Rupert region, paired t-tests showed that mean weight from commercial harvest (1076.8 g) was not significantly different from biological sample weights (t = 1.411, $p = 0.169$ when all sample geoducks included (1042.9 g), t = 0.584, $p = 0.564$ when only geoducks > 10 years included (1064.1 g) and t = 0.604, $p = 0.551$ when only geoducks > 462.2 g included (1064.5 g)). For Haida Gwaii, paired t-tests showed that mean weight from commercial harvest (1267.3 g) was not significantly different from biological sample weights (t = 2.705, $p = 0.014$ when all sample geoducks included (1189.8 g), t = 1.346, $p = 0.193$ when only geoducks >10 years included (1228.6 g) and t = 1.955, $p = 0.065$ when only geoducks > 462.2g included (1212.0 g)).

Bureau et al. (2012) noted that the timing of recruitment events on a bed, commercial harvest and biological sample collection could account for some differences in mean geoduck weight estimates. Haida Gwaii data were therefore also analyzed using only commercial harvest data that occurred in the same year as a biological sample was taken (Table 4) to eliminate the possible effect of recruitment event timing. Paired t-tests showed that mean weight from commercial harvest (1312.4 g) was not different from biological sample weights (t = 2.228, p = 0.048 when all sample geoducks were included (1244.9 g), t = 0.880, p = 0.398 when only geoducks >10 years included (1289.1 g) and t = 1.673, p = 0.123 when only geoducks > 462.2g included (1263.3 g)). No beds in Prince Rupert region were commercially harvested in the same year as a biological sample was collected.

DISCUSSION

Calculations of geoduck harvestable biomass and fishery harvest options must rely on estimates of mean weight that are representative of geoducks counted during density dive surveys. Concerns over the representativeness of commercial catch data to estimate geoduck mean weight were raised because juvenile geoducks are sometimes too small to be seen by harvesters and because of concerns over size selectivity in the fishery. However, juveniles that are too small to be seen by harvesters are likely also too small to be seen by survey divers. After correcting for dock-to-plant weight loss and excluding pre-recruits from analyses Bureau et al. (2012) observed differences between mean weights estimated from biological samples and commercial catch data for the Haida Gwaii and Prince Rupert regions; size selectivity was suggested as a possible cause for the difference. However, the effects of tagging (unique to biological samples) and transport time to the landing dock (which is longer for biological samples compared to commercial catches) were not taken into account due to lack of data. The fact that differences between mean weight estimates for commercial catch and biological samples were only observed for regions where differences in transport time are greatest suggested that transport time could have an effect on weight estimates.

Experimental results showed that both tagging and transit time result in a statistically significant weight loss in geoducks while there was no evidence that holding temperature had an effect on the rate of weight loss. It is not possible to partition out the weight loss associated with handling during tagging from any potential losses associated with an increase in temperature. However, geoducks often retract their siphons during handling, causing water loss, suggesting that handling may be the primary cause of weight loss during tagging. Although handling and time are likely the biggest factors contributing to weight loss, geoducks that had been refrigerated (commercial treatment) were more firm and responsive than non-refrigerated geoducks (biological treatment) at the end of the experiment. Based on differences in handling (tagged vs. untagged) and the increased transit time associated with the transport of biological samples to Port Hardy, rather than Prince Rupert, biological samples likely have an increased weight loss compared to the commercial catch prior to dock-side validation.

Tag-Transit weight loss correction factors were thus derived for both regions, based on transport time data for commercial catch and biological samples. Correcting for differences in weight loss, i.e., tag-transit and dock-plant, between commercial catch and biological sample data is critical before comparing these two data sources. Mean weight estimates from biological samples, corrected for both tag-transit and dock-plant weight loss, and commercial harvest data were then compared for the Haida Gwaii and Prince Rupert regions. For both Haida Gwaii and Prince Rupert regions, once biological sample data were corrected for tag-transit and dock-plant weight loss, no significant differences were observed between mean weight estimated from commercial harvest data and biological samples whether pre-recruits were included in the analyses or not. Similar results were obtained for Haida Gwaii when considering only commercial harvest data from the same year as a biological sample was taken. The lack of difference between geoduck mean weight estimated from biological samples and commercial catch data also suggests that size selectivity might not be occurring in the commercial fishery. If size selectivity is occurring in the commercial fishery, its effect on mean weight estimates is likely minimal since it could not be detected once tag-transit and dock-plant correction factors were applied.

Bureau et al. (2012) noted a number of reasons that make commercial harvest data preferable over biological sample data for geoduck mean weight estimation. Commercial harvest data offer better spatial representation within a bed and a larger number of geoducks within a bed than biological samples. The substantially larger sample size in commercial catch produces more precise estimates of mean weight. Commercial harvest data also provide bed-specific mean weight estimates for a much greater number of beds than do biological samples. Mean weight estimates from commercial harvest data are updated yearly while few biological samples are collected in a given year. The only way to update estimates of mean weight from biological samples is to collect new samples at great expense and fewer and fewer biological samples are being collected. Timing between commercial harvest, recruitment events and biological sampling dates can lead to differences in mean weight estimates. The increased temporal resolution of commercial harvest data is also better able to capture variations in recruitment events that can lead to higher (or lower) estimates of biomass.

CONCLUSIONS

There was no evidence that the temperature at which geoducks were kept had an effect on the rate of weight loss between treatments over the course of the experiment. However, tagging and longer transport time of geoduck biological samples from harvest to the landing dock accounted for significantly greater weight loss in biological samples than in commercially harvested geoducks for the Haida Gwaii and Prince Rupert regions. The fact that differences in mean weight estimates were not observed for the Central Coast (Bureau et al. 2012), where differences in transport time of commercial catch vs. biological samples are less (Table 1), suggested that increased transport time of biological samples coming from Prince Rupert and Haida Gwaii regions might account for the differences in mean weight observed by Bureau et al. (2012). When weight loss associated with tagging and transit time of biological samples were taken into account, no differences in mean weights were observed between commercial harvest data and biological samples for the Prince Rupert and Haida Gwaii regions.

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Table 1: Mean transit time and estimated percent weight loss of geoduck commercial catch and biological samples, by region and for all North Coast regions combined. Estimated percent weight loss calculated from weight loss over time linear regressions.

	Transit Time (h)								Estimated Weight Loss (%)*			
	Central Coast		Prince Rupert		Haida Gwaii		All North Coast		Central Coast	Prince Rupert	Haida Gwaii	All North Coast
	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n				
Commercial	16.7 ± 0.1	1403	10.7 ± 0.2	1325	17.2 ± 0.1	1229	14.9 ± 0.1	3957	-3.9	-3.2	-3.9	-3.7
Biological	22.4 ± 1.4	4	45.6 ± 7.8	4	48.4	1	35.6 ± 5.3	9	-5.6	-8.2	-8.5	-7.1
Difference	5.7		34.9		31.2		20.73		-1.7	-5.0	-4.6	-3.4

* Based on weight loss over time linear regression equations.

Table 2: Mean Dock-to-Plant weight loss correction factors, by biological sample, to account for weight lost between landing dock and measurement of individual weights at a processing facility for the Prince Rupert and Haida Gwaii regions. n is the number of weights recorded at the dock, typically the number of cages or in some cases the total weight of the sample.

Biological Sample		n	Dock-Plant Weight Loss Correction Factor, Mean ± SE	Weight Loss Factor Source
Year	Location			
Prince Rupert		**233**	**1.049 ± 0.002**	
1996	Otter Pass	21	1.027 ± 0.003	Sample
1996	W Aristazabal Is	1	1.020	Sample
1997	Anderson / Laredo	14	1.044 ± 0.003	Sample
1997	Principe Ch	16	1.044 ± 0.003	Sample
1998	Dundas Is	13	1.031 ± 0.004	Sample
1998	Moore Is	17	1.068 ± 0.003	Sample
2004	SE Prescott Is	24	1.071 ± 0.007	Sample
2004	Tree Nob Group	24	1.029 ± 0.004	Sample
2006	Griffith Harbour	19	1.050 ± 0.005	Sample
2006	Melville / Baron Is	25	1.062 ± 0.006	Sample
2007	Otter Pass	31	1.061 ± 0.004	Sample
2007	Clifford Bay	28	1.043 ± 0.004	Sample
Haida Gwaii		**157**	**1.035 ± 0.001**	
1994	Burnaby Is	1	0.991	Sample
1995	Hotspring Is	1	1.044	Sample
1996	Houston Stewart Ch	1	1.088	Sample
1997	Cumshewa Inlet	35	1.028 ± 0.001	Sample
1998	Selwyn Inlet	N/A	1.035 ± 0.001	Region
2000	Gowgaia Bay	1	1.050	Sample
2000	Hippa Is	22	1.059 ± 0.004	Sample
2000	Tasu Sound	24	1.045 ± 0.002	Sample
2002	Parry Pass	24	1.023 ± 0.003	Sample
2006	Poole Inlet	25	1.027 ± 0.002	Sample
2010	Hippa Is	23	1.029 ± 0.001	Sample
Entire North Coast		**1228**	**1.048 ± 0.001**	

Table 3: Mean geoduck weight from biological samples, corrected for tag-transit and dock-plant weight loss, and from dock-side validated commercial harvest data (1997-2011) for beds in Prince Rupert and Haida Gwaii regions. n for commercial data is the number of landings while n for biological samples is the number of geoducks.

Location	Bed Code	Mean Weight from Commercial Harvest Data (g)		Biological Sample Year	Mean Weight from Biological Samples Corrected for Tag-Transit and Dock-Plant Weight Loss (g)					
					All Sizes		> 10 yrs		>462.2g	
		n	Mean ± SE		n	Mean ± SE	n	Mean ± SE	n	Mean ± SE
Prince Rupert										
W Aristazabal Is	06-13-15	21	990.9 ± 31.0	1996	147	918.8 ± 21.3	144	927.0 ± 21.2	144	929.9 ± 20.7
W Aristazabal Is	06-13-36	49	1154.8 ± 16.6	1996	144	1180.4 ± 23.0	143	1182.5 ± 23.0	144	1180.4 ± 23.0
W Aristazabal Is	06-13-38	43	1269.6 ± 34.0	1996	144	1191.8 ± 30.3	130	1253.9 ± 28.4	140	1215.5 ± 28.7
Anderson / Laredo	06-11-02	108	1074.8 ± 14.2	1997	100	637.2 ± 26.2	48	777.5 ± 40.7	60	791.0 ± 29.6
Anderson / Laredo	06-13-18	71	1117.6 ± 15.0	1997	99	1270.7 ± 29.4	96	1290.6 ± 27.6	97	1287.2 ± 27.6
Anderson / Laredo	06-14-01	45	1116.3 ± 18.3	1997	100	1046.7 ± 22.4	100	1046.7 ± 22.4	100	1046.7 ± 22.4
Principe Ch	05-13-03	15	1024.3 ± 43.7	1997	105	908.8 ± 24.1	105	908.8 ± 24.1	98	942.4 ± 22.2
Principe Ch	05-13-04	87	1025.5 ± 13.4	1997	98	939.8 ± 25.8	86	989.1 ± 24.4	93	967.3 ± 24.0
Principe Ch	05-13-14	16	1053.2 ± 28.0	1997	100	967.3 ± 24.4	99	972.9 ± 24.0	97	983.0 ± 23.5
Dundas Is	03-01-03	73	955.0 ± 17.3	1998	219	805.1 ± 17.2	212	817.2 ± 17.1	192	857.6 ± 16.3
Dundas Is	03-01-04	60	994.0 ± 15.1	1998	95	868.1 ± 34.4	76	965.7 ± 33.8	80	963.4 ± 30.4
Moore Is	106-02-03	91	1148.0 ± 11.8	1998	101	1111.0 ± 31.0	95	1128.2 ± 31.6	100	1117.1 ± 30.7
Moore Is	106-02-06	39	1101.0 ± 20.1	1998	100	1133.8 ± 26.6	94	1155.2 ± 26.7	99	1142.1 ± 25.6
Moore Is	106-02-15	43	1125.0 ± 21.3	1998	110	1149.2 ± 23.8	97	1194.1 ± 23.1	110	1149.2 ± 23.8
SE Prescott Is	04-09-08	35	1074.4 ± 21.8	2004	141	1170.9 ± 23.6	140	1176.2 ± 23.2	140	1176.2 ± 23.2
SE Prescott Is	04-09-09	37	899.0 ± 26.6	2004	146	921.3 ± 18.3	145	927.2 ± 17.5	142	938.5 ± 16.5
Tree Nob Group	04-02-05	54	1125.6 ± 29.4	2004	140	1353.4 ± 23.1	139	1360.6 ± 22.2	139	1360.6 ± 22.2
Tree Nob Group	04-02-09	23	1065.2 ± 21.9	2004	138	991.8 ± 23.3	137	995.4 ± 23.2	134	1007.5 ± 22.6
Tree Nob Group	04-13-03	107	1075.0 ± 15.4	2004	177	868.4 ± 14.9	175	875.2 ± 14.2	172	884.3 ± 13.4
Griffith Harbour	05-20-01	281	1044.6 ± 8.1	2006	293	1069.5 ± 16.8	289	1076.0 ± 16.7	290	1076.7 ± 16.4
Griffith Harbour	05-20-05	110	1002.5 ± 11.5	2006	169	889.1 ± 19.3	166	899.4 ± 18.7	160	915.7 ± 18.2
Melville / Baron Is	04-01-03	37	1136.4 ± 28.7	2006	86	1165.7 ± 31.9	86	1165.7 ± 31.9	85	1174.9 ± 30.9
Melville / Baron Is	04-01-05	41	1086.6 ± 18.8	2006	126	1044.8 ± 23.4	126	1044.8 ± 23.4	125	1049.1 ± 23.2
Melville / Baron Is	04-01-06	65	1170.4 ± 20.0	2006	136	937.1 ± 24.6	136	937.1 ± 24.6	130	960.3 ± 23.8
Melville / Baron Is	04-01-07	66	1158.6 ± 18.6	2006	110	1231.7 ± 24.6	110	1231.7 ± 24.6	110	1231.7 ± 24.6
Otter Pass	06-09-01	32	1063.1 ± 24.6	2007	153	1088.8 ± 21.1	148	1112.6 ± 18.9	148	1112.6 ± 18.9
Otter Pass	06-09-08	26	1137.2 ± 28.8	2007	166	1185.8 ± 26.1	151	1244.8 ± 23.0	162	1208.5 ± 24.0
Otter Pass	06-09-14	33	1040.3 ± 25.9	2007	127	1126.6 ± 25.8	126	1132.3 ± 25.3	126	1132.3 ± 25.3
Otter Pass	06-09-39	38	997.4 ± 26.2	2007	127	1069.1 ± 18.6	127	1069.1 ± 18.6	127	1069.1 ± 18.6
Haida Gwaii										
Burnaby Is	02-13-02	25	1457.9 ± 34.9	1994	485	1479.3 ± 17.4	476	1493.6 ± 17.0	477	1501.3 ± 15.9
Hotspring Is	02-11-11	19	1151.3 ± 25.2	1995	507	993.9 ± 16.9	420	1095.4 ± 16.2	444	1081.0 ± 15.3
Houston Stewart Ch	02-18-10	49	1206.4 ± 25.3	1996	150	1229.3 ± 28.3	139	1268.1 ± 27.7	147	1249.8 ± 26.3
Houston Stewart Ch	02-31-02	106	1037.3 ± 9.1	1996	179	923.2 ± 22.4	166	963.5 ± 20.9	163	980.9 ± 19.1
Houston Stewart Ch	02-31-03	60	1062.5 ± 15.0	1996	149	1006.4 ± 22.2	141	1032.7 ± 21.3	146	1018.5 ± 21.5
Cumshewa Inlet	02-03-01	119	1322.4 ± 15.9	1997	200	1199.9 ± 28.5	168	1273.2 ± 29.9	196	1215.6 ± 27.9
Cumshewa Inlet	02-03-02	124	1434.2 ± 17.3	1997	198	1275.1 ± 27.5	194	1292.1 ± 26.5	195	1291.6 ± 26.2
Cumshewa Inlet	02-03-03	96	1391.4 ± 18.3	1997	202	1091.6 ± 22.5	109	1231.0 ± 31.1	198	1105.3 ± 21.8
Selwyn Inlet	02-06-04	16	1198.7 ± 17.5	1998	112	1068.8 ± 23.8	112	1068.8 ± 23.8	111	1073.9 ± 23.4
Selwyn Inlet	02-06-20	43	1225.0 ± 18.9	1998	112	1110.6 ± 27.5	111	1119.1 ± 26.4	110	1124.9 ± 26.0
Selwyn Inlet	02-08-06	24	1104.2 ± 29.6	1998	107	1015.8 ± 27.2	107	1015.8 ± 27.2	107	1015.8 ± 27.2
Gowgaia Bay	02-38-01	38	1418.3 ± 29.3	2000	100	1373.5 ± 38.7	97	1388.8 ± 38.7	100	1373.5 ± 38.7
Gowgaia Bay	02-40-01	39	1596.9 ± 25.6	2000	104	1798.1 ± 51.0	96	1860.0 ± 50.1	103	1811.5 ± 49.7
Hippa Is	02-87-04	52	1096.0 ± 24.2	2000	149	976.8 ± 22.0	139	1009.6 ± 20.9	142	1002.9 ± 20.8
Parry Pass	01-02-01	52	1093.7 ± 17.3	2002	441	1095.6 ± 15.6	431	1115.3 ± 14.6	428	1120.2 ± 14.5
Poole Inlet	02-14-02	71	1437.3 ± 14.9	2006	133	1171.3 ± 27.3	125	1202.8 ± 26.2	131	1184.2 ± 26.2
Poole Inlet	02-14-03	58	1533.0 ± 19.6	2006	148	1442.7 ± 37.0	136	1529.7 ± 29.8	143	1485.9 ± 32.7
Poole Inlet	02-14-04	61	1323.9 ± 17.6	2006	75	1334.9 ± 34.2	73	1346.3 ± 34.1	75	1334.9 ± 34.2
Poole Inlet	02-14-05	55	1566.5 ± 22.1	2006	76	1617.7 ± 45.7	70	1682.7 ± 38.8	75	1637.7 ± 41.6
Hippa Is	02-87-02	40	1023.0 ± 35.3	2010	156	703.3 ± 14.2	156	703.3 ± 14.2	138	736.0 ± 13.7
Hippa Is	02-87-05	96	934.1 ± 12.2	2010	301	1078.2 ± 15.7	287	1109.5 ± 13.8	290	1105.6 ± 13.9

Table 4: Mean weight from geoduck biological samples for Haida Gwaii, corrected for tag-transit and dock-plant weight loss, and dock-side validated commercial harvest data from the same year in which biological sampling occurred. For Prince Rupert, no beds were commercially harvested the same year as a biological sample was collected. n for commercial data is the number of landings while n for biological samples is the number of geoducks.

			Mean Weight from Commercial Harvest Data (g)		Mean Weight from Biological Samples Corrected for Tag-Transit and Dock-Plant Weight Loss (g)					
					All Sizes		>462.2g		>10 yrs	
Year	Location	Bed Code	n	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n	Mean ± SE
1997	Cumshewa Inlet	02-03-01	17	1402.7 ± 34.9	200	1199.9 ± 28.5	196	1215.6 ± 27.9	168	1273.2 ± 31.1
1997	Cumshewa Inlet	02-03-02	22	1346.1 ± 27.1	198	1275.1 ± 27.5	195	1291.6 ± 26.2	194	1292.1 ± 27.7
1997	Cumshewa Inlet	02-03-03	34	1286.2 ± 27.1	202	1091.6 ± 22.5	198	1105.3 ± 21.8	109	1231.0 ± 30.6
2000	Gowgaia Bay	02-38-01	3	1281.2 ± 21.0	100	1373.5 ± 38.7	100	1373.5 ± 38.7	97	1388.8 ± 39.3
2000	Hippa Is	02-87-04	14	1085.8 ± 61.7	149	976.8 ± 22.0	142	1002.9 ± 20.8	139	1009.6 ± 22.8
2000	Tasu Sound	02-42-04	6	888.2 ± 99.3	150	828.6 ± 18.7	139	860.9 ± 17.3	147	837.9 ± 18.9
2000	Tasu Sound	02-42-08	1	1252.1	157	1204.7 ± 27.5	154	1221.7 ± 26.1	152	1227.3 ± 27.9
2000	Tasu Sound	02-45-03	5	1457.5 ± 48.0	149	1421.6 ± 33.4	146	1445.4 ± 31.1	145	1447.8 ± 33.9
2006	Poole Inlet	02-14-02	13	1377.2 ± 44.3	133	1171.3 ± 27.3	131	1184.2 ± 26.2	125	1202.8 ± 28.2
2006	Poole Inlet	02-14-03	18	1555.3 ± 32.7	148	1442.7 ± 37.0	143	1485.9 ± 32.7	136	1529.7 ± 38.6
2006	Poole Inlet	02-14-04	13	1271.8 ± 28.5	75	1334.9 ± 34.2	75	1334.9 ± 34.2	73	1346.3 ± 34.7
2006	Poole Inlet	02-14-05	11	1544.7 ± 56.6	76	1617.7 ± 45.7	75	1637.7 ± 41.6	70	1682.7 ± 47.6

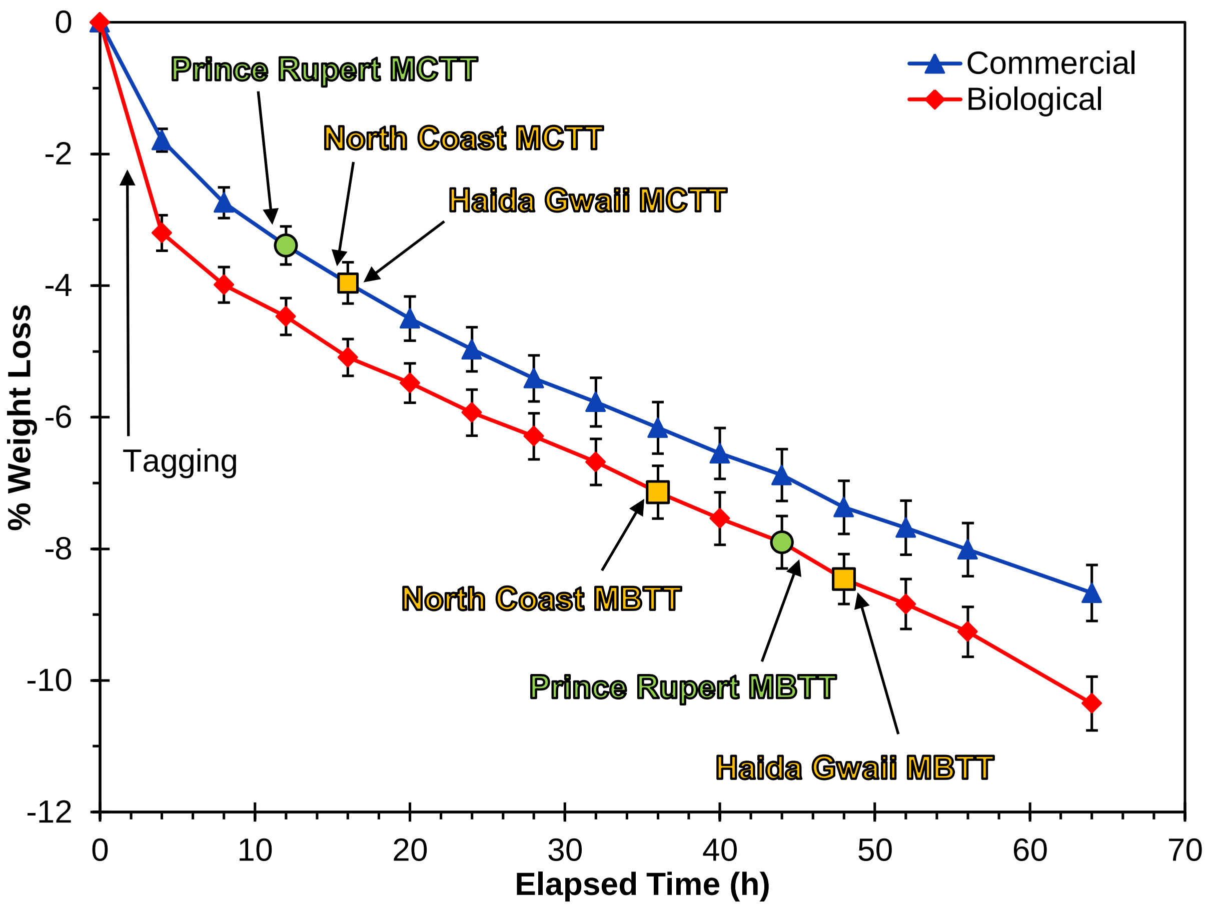

Figure 1: Mean percent weight loss ± SE in geoducks over time in the Biological (tagged and non-refrigerated) and Commercial (untagged and refrigerated) treatments. MCTT = Mean Commercial Transit Time and MBTT = Mean Biological Transit Time, based on transit time data (Table 1). n=16 cages for each treatment and time interval. Green circles are points that were compared for the Prince Rupert region. Orange squares from Biological treatment were each compared to the orange square in the Commercial treatment.