Distribution, Growth and Mortality of Juvenile Clams in the San Juan Islands, WA

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Abstract

An understanding of the ecology and life history of juvenile organisms is crucial for understanding these aspects of the adult organism. Intertidal bivalves rely on the successful settlement of larvae and the survival and growth of juveniles. Determining the distribution of juvenile bivalves is important for understanding the distribution and predicting the presence of adult bivalves, for both ecological and commercial reasons. Measuring growth rates and mortality of juvenile bivalves can shed light on what is necessary to carry a juvenile bivalve through adulthood. I surveyed several sites in the San Juan Islands, WA, recording sediment type, tidal height, beach slopes and wave exposures to determine the abundance of juveniles at these sites and what factors can be used as indicators of juvenile presence. I found that surface granules, surface mud, beach slope and subsurface shell hash were correlated with patterns observed in clam assemblages. It also appears that a particular site is a better predictor of clam assemblages and physical features than tidal height. I also tested the response of several species of intertidal clams—*Tresus capax, Saxidomus giganteus, Macoma* spp., *Protothaca staminea, Venerupis philippinarium* and *Mya arenaria*—to increased sediment temperatures during low-tide of different lengths. I found that growth increased in ideal conditions from species that live lowest in the intertidal to those that live in the high intertidal. Mortality in elevated temperatures increased with decreasing intertidal elevation. Effects of predation were also tested—*Hemigrapsus nudus* and *Cancer productus* were found to prey on juvenile *Macoma* spp. *H. nudus*'s preference between *Macoma* spp. and *Ulva* depended on previous experience handling clams.

Introduction

Adult benthic bivalves' effects on intertidal marine ecosystems are far-reaching both ecologically and commercially. Bivalves' filter feeding activity is important for nutrient cycling and water quality regulation of nearshore systems (Masu et al. 2008). They also serve as food for various species of invertebrates and seabirds (Beukema et al. 2010), and as a resource for both commercial and recreational human harvesters.

Because adult benthic bivalves, particularly clams, provide important ecosystem benefits, much research has been done on various aspects of their distribution, life histories, and interactions with other species. Comparatively little work, however, has investigated the ecology of juvenile clams. A better understanding of the juvenile stage, as the gateway between settlement and adulthood, would improve current understanding of adult clams.

My study investigated the ecology of juvenile soft-sediment dwelling clams found in the San Juan Islands, WA. Determining distribution of juvenile clams is important to understanding distribution of adult clams. Krauszer (2011) found that medium wave exposure beaches with mud and shell hash sediment were suitable for inhabitation by juvenile clams. My study built upon those findings and attempted to characterize environments that are ideal for juvenile clams. Species of interest included both harvested and not-harvested species: *Macoma* spp., *Tresus capax, Mya arenaria, Saxidomus giganteus*, *Nutricola* spp. and littlenecks (both the native and Japanese varieties).

I also investigated growth rates of juvenile clams in ideal conditions. Growth rates of juveniles of a few species are known, particularly those of commercial importance. El-Wazzan and Scarpa (2009) found that juvenile individuals of *Mercenaria mercenaria* (6-

8mm) experienced a 0.22 mm daily average shell length increase. Other studies on hardshell clams and other commercially important species have sought to maximize growth via different feeding and temperature treatments. Goong and Chew (2001) compared growth of *Saxidomus giganteus* at several beaches in Puget Sound, but rather than directly determining a growth rate they assigned size classes to different ages of clams. Peterson (1982) found that growth rate declined as shell length increased in a study comparing growth rates of *Protothaca staminea* in varying densities but didn't calculate a control growth rate of the species.

Another aspect of juvenile clam ecology that I explored was causes of mortality. In a review of benthic bivalves, juvenile mortality was found to exceed 90% in the majority of species surveyed (Gosselin & Qian 1997). I exposed clams to stressors, both environmental and predatory, to elucidate possible causes for the high juvenile mortality observed by Gosselin and Qian and Dethier. Many studies have investigated the effects of thermal and nutritive stress on clam growth and mortality; my study will build on that body of research by using simulated low tides of different lengths. Other studies investigating biotic stressors have found that large crabs such as *Callinectes sapidus* can exert significant predation pressure on juvenile clams (Sponaugle and Lawton 1990). The shore crabs *Hemigrapsus nudus* and *H. oregonensis* are extremely common on the beaches of the San Juan Islands and could be a likely candidate for a predator of juvenile clams, though not an obvious one due to their small size and relatively non-aggressive behavior. Juvenile rock crabs, *Cancer productus*, are less common but much more voracious than *Hemigrapsus* spp. and their predation on juvenile clams was also investigated. Predation, in addition to environmental stressors, is expected to contribute considerably to juvenile clam mortality in the San Juan Islands.

Materials and Methods

Juvenile Clam Distribution

Several sites on San Juan Island and Lopez Island, Washington and in Anacortes, WA were surveyed to determine in which types of environments juvenile clams are found (Figure 1). At each site, horizontal transects were laid along the beach at three tidal heights—0’, +1’ and +3’ above MLLW. Tidal heights were determined using tide tables and a laser-surveying device. Beach sediments were characterized at 3 random locations along each transect using a 0.1 m^2 quadrat. I visually estimated the percent composition of different grain sizes (cobble, pebbles, granule, sand, mud, shell hash) in each quadrat both at the surface and subsurface (3-5 cm deep). Attention was also paid to percent cover of macroalgae such as *Ulva spp*, but the algae were removed to observe sediment composition. In addition, I took five quantitative sediment samples from each transect at arbitrary locations (only avoiding sediment where the quadrat had been laid). Samples were approximately 120 ml and were taken from the top 5 ml of sediment. Each sample was sieved using a 1mm mesh sieve and any clams found were identified, measured, and saved for other components of the experiment. Beach slope at the heights of interest was measured. Wave energy was estimated and ranked among sites by using a chart to measure the distances waves travel to each site, both perpendicular to the shoreline and maximum distance.

Fig 1. Sites sampled in the San Juan Islands. 1=Wescott Bay, 2=Bell Point, 3= Garrison Bay, 4=Beaverton Cove, 5=Jackson Bay, 6=Argyle Lagoon, 7=Argyle Beach, 8= First Lagoon, 9=4th of July Beach, 10=False Bay, 11= Shoal Bay, 12=Swift Bay, 13=Spencer Spit North, 14=Spencer Spit South.

Growth Rates

Juvenile clams of five species were collected from local beaches to measure growth rates under "ideal conditions". The clams were collected both from quantitative sediment samples and from bulk sieving of surface sediments from numerous tidal levels. *Saxidomus* juvenile were uncommon throughout the San Juans, but were collected from the south end of Whidbey Island. For growth studies, clams were placed in screen-mesh "baskets" of clean sand (collected from False Bay and dried to eliminate any organisms present). "Ideal growth conditions" were achieved in a tide tank with no low tide period, i.e. the clams were constantly submerged in running seawater. Each species had representatives of uniform sizes per species in each of three size classes—small, medium and large (size ranges differed between species). Temperature was recorded every fifteen minutes using a Tidbit data-logger buried in the sediment. I removed the clams from the sediment once weekly to measure increase in shell length along the anterior-posterior axis.

Mortality in Extreme Conditions

To measure the effect of extreme conditions (i.e. heat stress) on juvenile clam mortality, several (2-4) clams of each size class of each species were placed in two tanks where the water could be drained daily to simulate low tide —one tank had a short (one hour, 1-2 pm) daily low tide and one had a long (four hours, 1-5 pm) daily low tide. As in the tank with no low tide, Tidbit data-logging devices were placed in the sediment and temperature was measured every fifteen minutes. Two additional Tidbit loggers recorded air temperature near the tanks—one logger with and one without a plastic boot to reduce heat absorption. I removed the clams from the sediment once weekly to measure increase in shell length along the anterior-posterior axis, and replaced the individuals that had perished with live ones of the same size and species.

Effects of Predation

Two species of *Hemigrapsus* crabs—*H. nudus* and *H. oregonensis*—were collected at beaches nearby Friday Harbor Laboratories to test the effects of predation on juvenile clams. Shore crabs were used because they are extremely abundant on beaches in the San Juan Islands. In addition to *Hemigrapsus* I collected juvenile red rock crabs (*Cancer productus*) to observe the predation behavior of a less common but much more voracious predator. All crabs were measured for carapace width and dactyl length and thickness, and a dactyl length-to-thickness ratio was calculated due to the relatively large claws of *Hemigrapsus oregonensis* in comparison to *H. nudus.* I fed the crabs *Macoma spp.* and *Saxidomus giganteus* because of their difference in shell thickness—*Macoma* having relatively thin shells and *Saxidomus* with robust shells. Half of the crabs received one medium and one large *Macoma*, the other half one medium and one large *Saxidomus*. The crabs were placed in isolation into plastic containers with mesh sides and monitored once daily. After it was determined that the *Hemigrapsus* were not attempting to eat the *Saxidomus* they were given, I presented new shore crabs with the preferred size class of *Macoma* and a piece of *Ulva* that had been cut to a 3x3 cm square. Again, the crabs were isolated in plastic containers, but they were checked every 15 minutes to determine which food was consumed first.

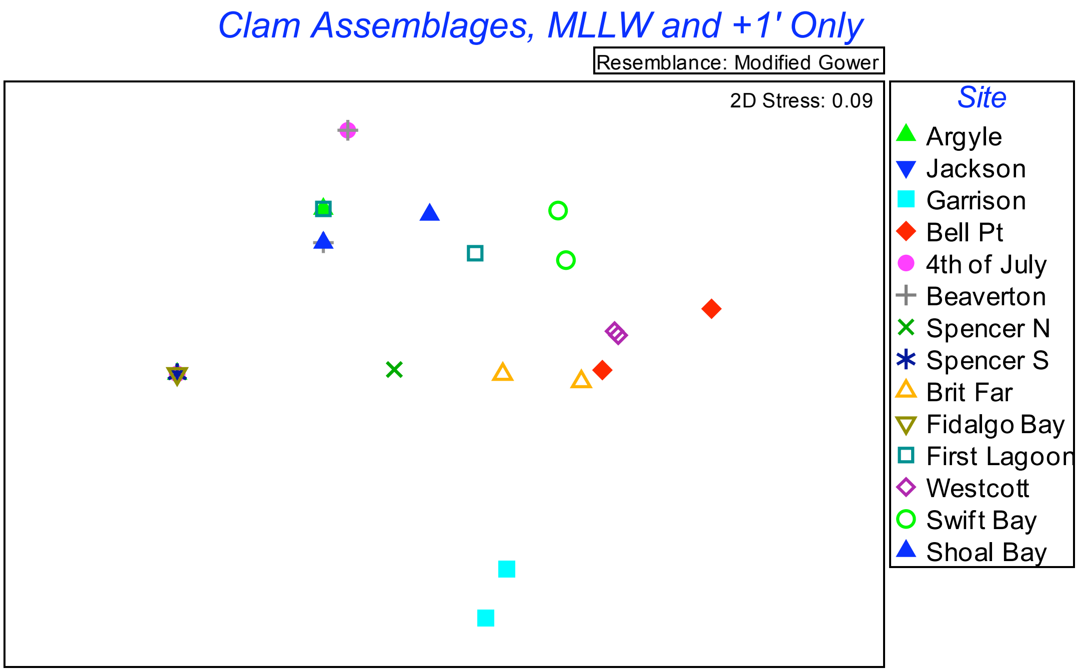
Rather than test feeding preferences of *Cancer productus*, I tested their feeding capabilities. After the crabs were given several *Macoma* it was obvious that the clams were easily consumed. Next, I gave the crabs large juvenile littlenecks (14-17mm shell length) and recorded whether the crab was able to eat the clam over the course of a day to determine a range of shell lengths that juvenile *C. productus* are capable of eating.

Results

Juvenile Clam Distribution

Using multidimensional scaling analyses, clam assemblages and physical features (surface and subsurface sediment types, beach slope, wave heights) were compared at MLLW and +1' tidal heights across all sites sampled in this study and in Krauszer's (2011). Both clam assemblages and physical features were more similar within a site across tidal heights than within a tidal height across sites (Fig. 2).

Analyses of the extent to which the patterns seen among sites in clam assemblages match the patterns seen among sites in physical parameters were done using the BEST analysis in PRIMER. For the data from 0 and +1' (the levels surveyed at all 14 sites), the BEST analysis showed that a combination of 4 physical parameters give a rank correlation coefficient (rho) value of 0.59; these parameters were beach slope, and amounts of subsurface pebble, subsurface shell material, and surface mud. The amounts of surface and subsurface granules appeared as important in other parameters affecting clam assemblages in different combinations of variables. Percent cover of surface granules and increasing beach slope had negative correlations with clam richness, and percent cover of surface mud had a positive correlation with clam abundance (Figs. 3, 4 and 5)



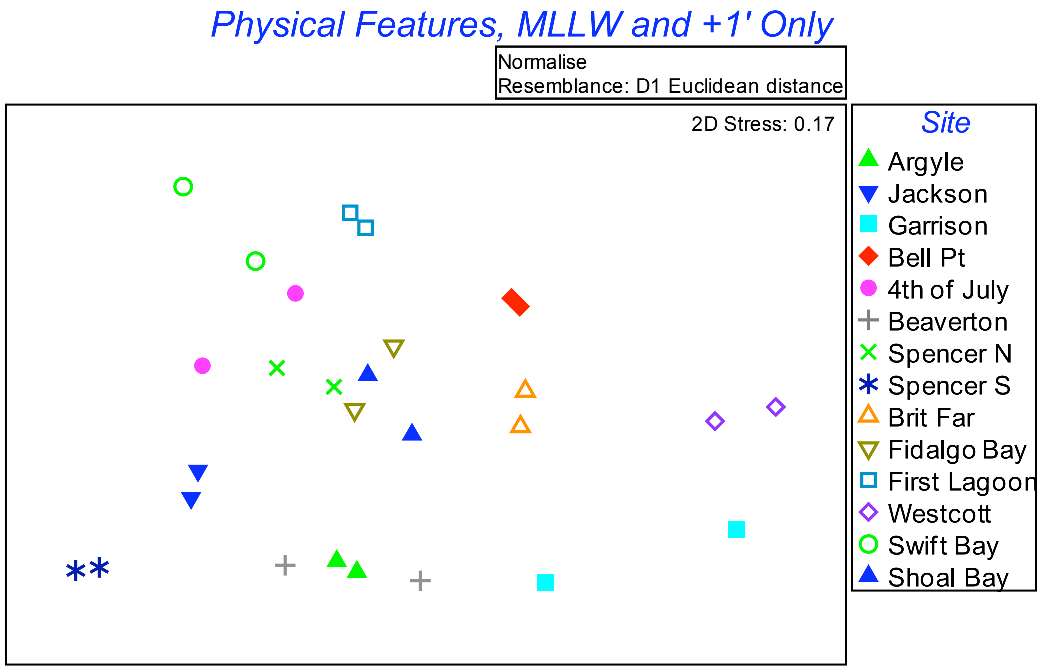


Figure 2. Multidimensional scaling plots of clam assemblages and physical communities at all the sites surveyed. Each point represents the average value for the replicate samples (5 for clams, 3 for physical parameters) for each site and tidal level. Points closer together in each plot indicate greater similarity in the suite of measured parameters.

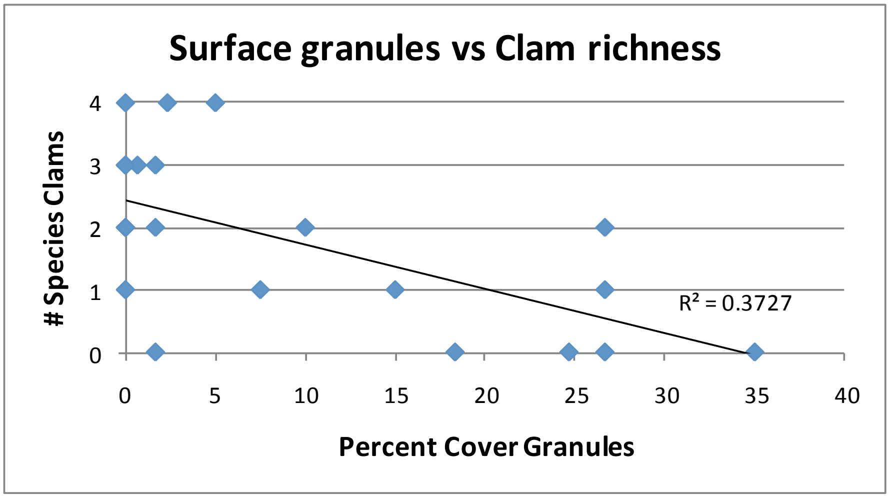


Figure 3. Relationship between percent cover of surface granules and clam richness

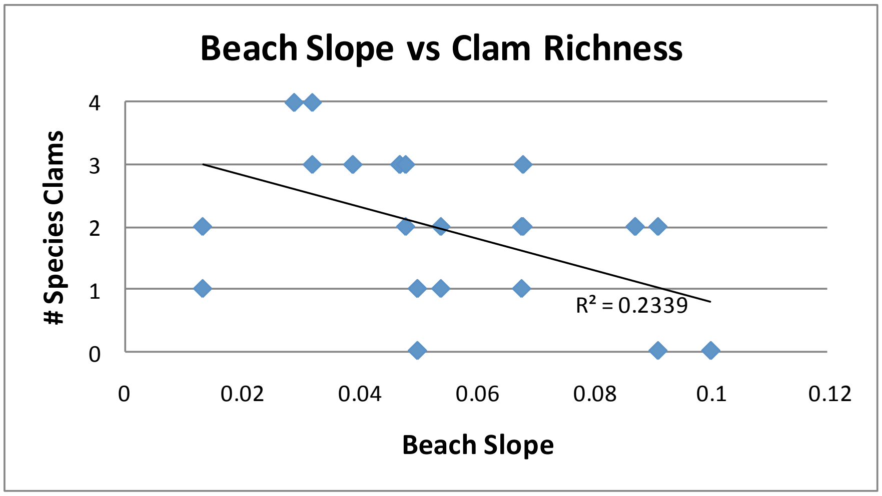


Figure 4. Relationship between beach slope and clam richness.

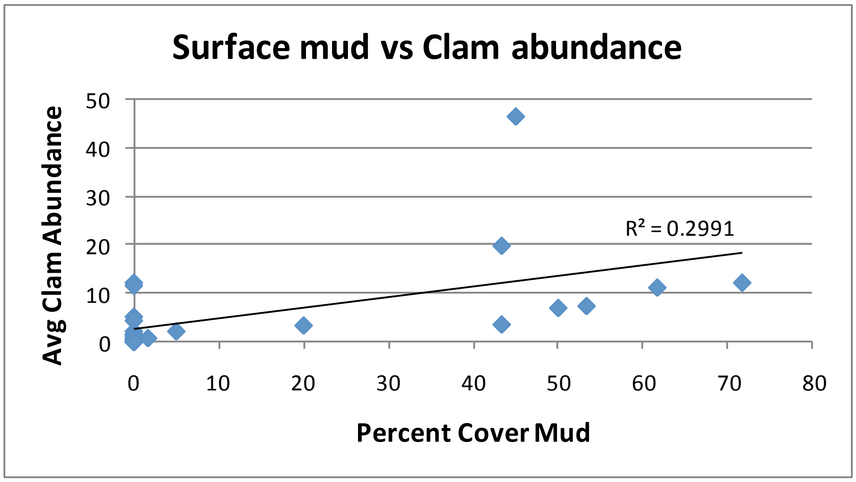


Figure 5. Relationship between percent cover of surface mud and clam abundance.

Growth Rates

In the tank with no low tide (hereafter referred to as tank 1), growth rates were highest in *Mya arenaria* and lowest in *Saxidomus giganteus* (Fig. 6). Within each species, small, medium and large clams had similar growth rates (Fig. 7)

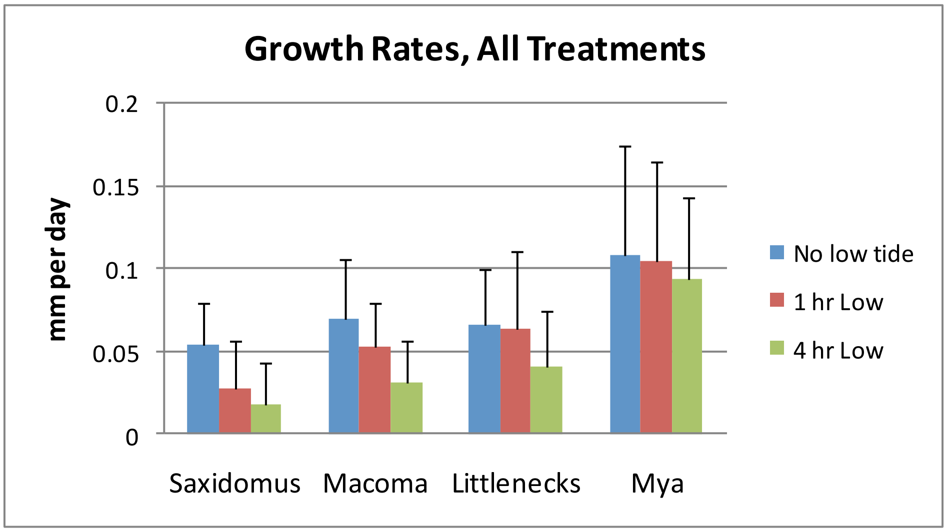


Figure 6. Growth rates of each species, averaged across size classes, in each treatment

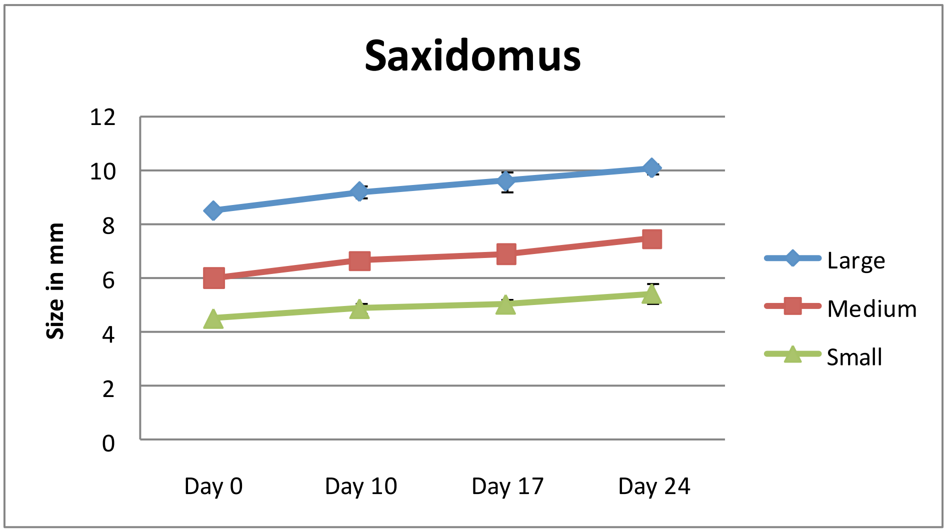


Figure 7. Small, medium and large growth rates of S. giganteus *in tank 1. All other species showed similar results of little variation between size classes.*

Between tanks, clams of all species had the highest growth rates in the tank with a one-hour low tide (hereafter referred to as tank 2) and the lowest growth rate in the tank with a four-hour low tide (hereafter referred to as tank3) (Fig. 6). The difference between growth rates in tank 1 and tank 2 decreased from largest to smallest as such: *Saxidomus giganteus, Macoma* sp., littlenecks, *Mya arenaria* (Fig.6). High variances and small sample sizes prevented the use of statistical tests on these data.

Mortality in Extreme Conditions

Mortality in tank 1 was virtually nonexistent. Only two clams (a medium *M. arenaria* and a large *Macoma* sp.) died of natural causes—i.e. a gaping shell at the surface of the sediment—out of 60 total clams (a few additional clams were crushed in the retrieval from sediment and measurement process).

In tanks 2 and 3, however, mortality was observed. Mortality was moderate in tank 2, with the highest mortality in small and medium *Tresus capax* at 50% death of all individuals used over the entire 24 day period. Medium *S. giganteus* experienced a 20% death rate, and medium *Macoma* sp. and small *M. arenaria* showed a 33% death rate. The remaining individuals in other size classes and species experienced 100% survival (Fig. 8).

Tank 3 showed high mortality. Each size class across all species experienced mortality except for medium and large *M. arenaria.* The highest mortality was observed in *T. capax* and *S. giganteus* with 100% morality in all size classes of *S. giganteus* and small and medium *T. capax*. Mortality decreased steadily from that of *T. capax* and *S. giganteus* to *Macoma* sp., to littlenecks and to *M. arenaria. Nutricola* had the lowest mortality (size classes were not used due to their small adult size and my inability to determine whether the individuals were juveniles or adults) (Fig. 9).

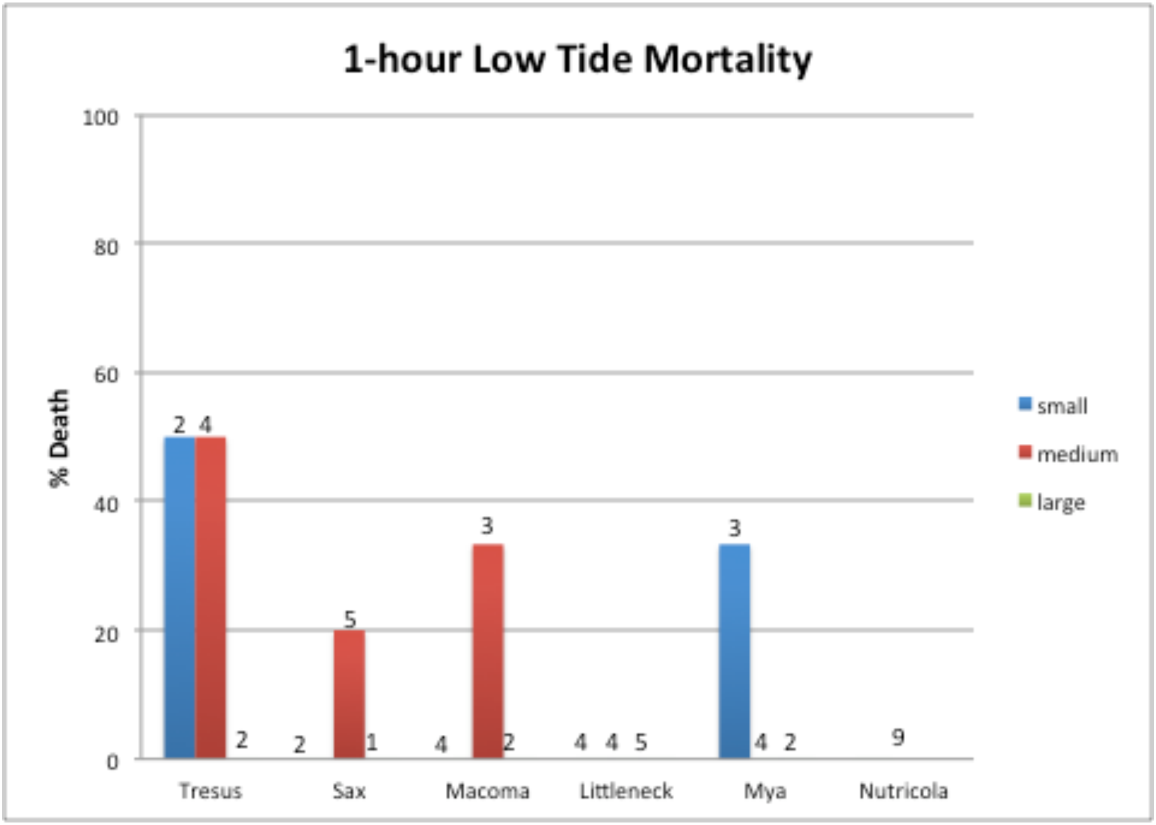


Figure 8. Mortality in tank 2, measured in percent of total clams that perished. The values at the top of each column are n, the total number of clams of that size class-species used.

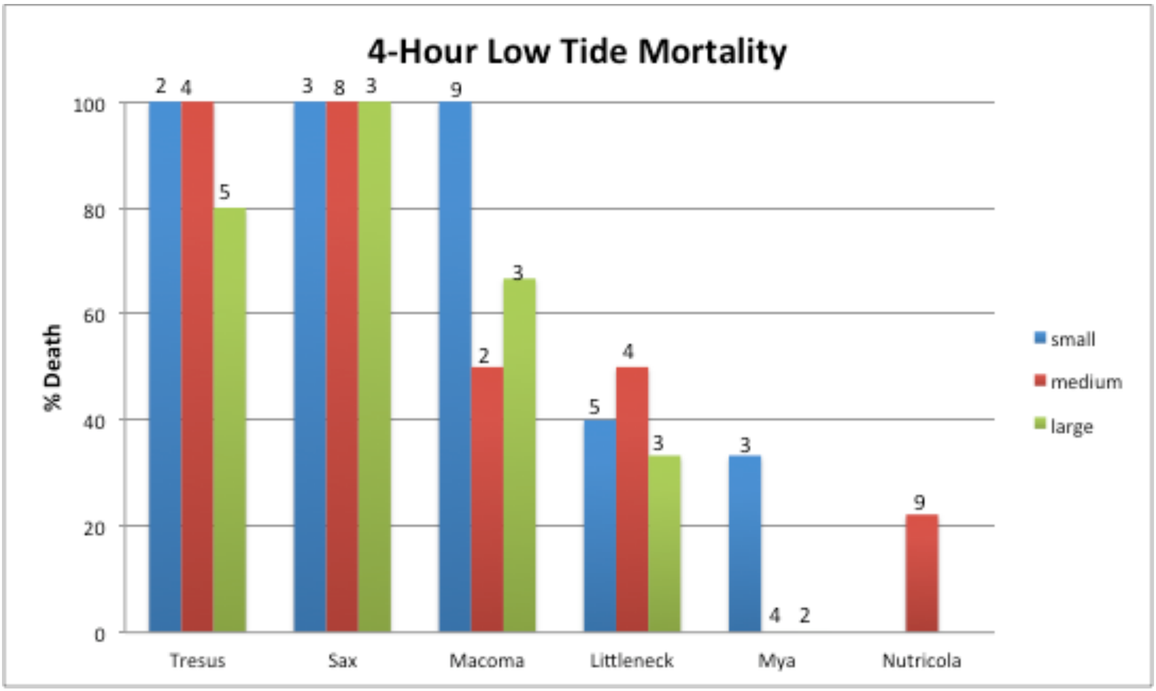


Figure 9. Mortality in tank 3, measured in percent of total clams that perished. The values at the top of each column are n, the total number of clams of that size class-species used.

The sediment temperatures experienced by clams in each tank varied as well. Tank 1 clams were always submerged and were thus experiencing ambient seawater temperature. Maximum sediment temperatures observed in tanks 2 and 3 did not vary drastically (Fig. 10), but the cumulative heat added to the sediment over the course of the low tide in comparison to seawater temperature was dramatically higher in tank 3 than in tank 2. Heat added from low tide in tank 3 ranged from 109-232 degree-hours higher than the heat added to tank 2 from low tide (Fig. 11).

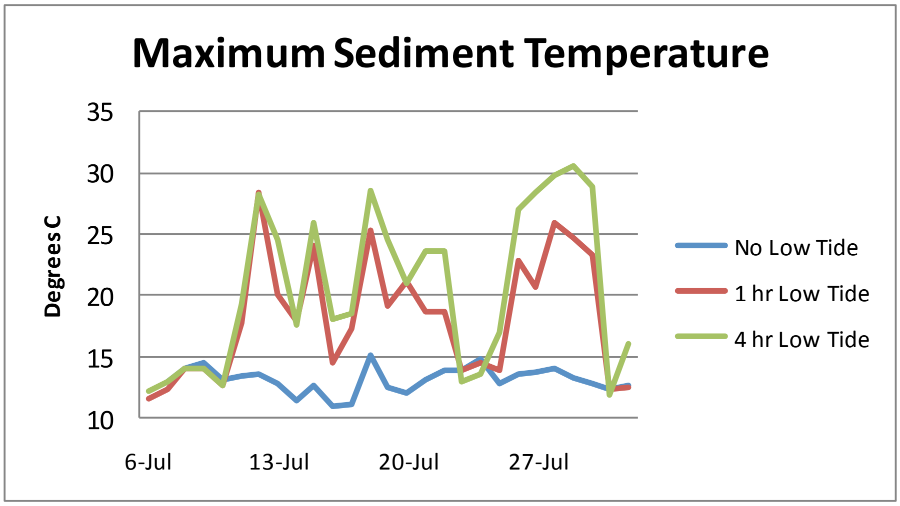


Figure 10. Maximum sediment temperature reached in each tank in degrees C. The large drop between July 20 and July 27 is a result of two days during which low tide was not simulated.

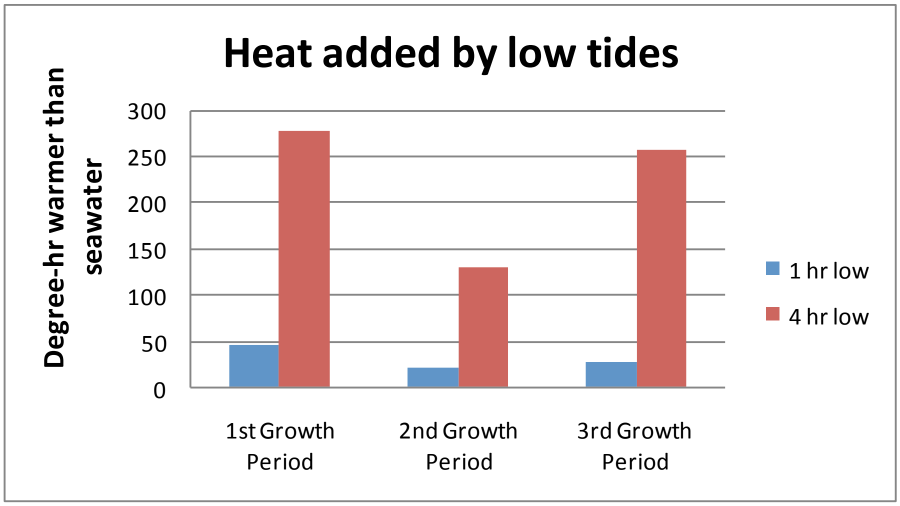


Figure 11. Cumulative heat added to the sediment relative to the temperature of seawater in tanks 2 and 3, measures in degree-hours.

Effects of Predation

In feeding trial one, where five *Hemigrapsus* spp. were given a medium and a large *Macoma* spp., four of the five crabs ate both clams, and one crab ate neither. The carapace widths of these crabs ranged from 1.8-2.2 cm and the dactyl lengths from 6-8 mm. Of the five *Hemigrapsus* spp. that received a medium and a large *Saxidomus giganteus,* none consumed either of the clams. Carapace widths in this group ranged from 1.9-2.2 cm and dactyl lengths from 5-7 mm. The medium clams of both varieties measured 7-8 mm in shell length and the large clams measured 10-11mm in shell length.

The ten crabs used in feeding trial two received two *Macoma* spp.—a medium and a large. Medium clams measured 5mm in shell length and large clams 9mm. Carapace width ranged from 2.1-2.6 cm and dactyl length ranged from 6-9 mm. Only five crabs consumed any clams—four of the five chose the medium *Macoma* spp. first and one chose the large clam first. Two of the five crabs ate both clams; the crab that chose the large clam first ate the medium clam soon after, and a crab that chose the medium clam first did the opposite. The crabs opened the clams by crushing their shells in feeding trials one and two, indicated by the crushed shells left behind in the container.

The same crabs were used for the subsequent feeding trial comparing feeding preference between a medium *Macoma* sp. and *Ulva*. Over two days, 80% of the crabs that had eaten a clam in the previous feeding trial made a feeding decision—that is, visibly consumed either the *Ulva* or *Macoma* sp. 100% of those crabs chose the clam over *Ulva.* Of the crabs that did not consume a clam the previous week, 60% made a feeding decision—100% of those crabs chose *Ulva* over the clam. Three crabs did not make a choice—two had molted after they were collected and one died during the experiment.

Juvenile *Cancer productus* easily consumed both the medium and the large *Macoma* spp. presented to them, leaving only crushed shells behind in the enclosure. The three crabs had carapaces ranging from 4.1-4.3 cm in width and dactyl lengths that ranged from 8-10mm. Each of them consumed a large juvenile littleneck clam (14-17mm) in two consecutive trials, and a large juvenile *Saxidomus giganteus* (12-14mm) in a third feeding trial. Rather than crushed shell, half-shells with chipped edges remained as evidence that the clam had been eaten.

Discussion

Juvenile Clam Distribution

The multidimensional scaling analysis results show that clam assemblages and physical features are more similar within a site across tidal heights than at a particular tidal height across sites. This suggests that clam assemblages are more tightly coupled to physical features than to any tidal height, and perhaps that a particular environment's physical features are more influential in the growth and survival of a juvenile clam than the different aerial exposures and sediment temperatures a clam might experience at different tidal heights.

In the data from the sites I surveyed, in addition to Krauszer's 2011 data, several physical features emerged as indicators of clam presence. From the high r^2 values observed when comparing surface granules and beach slope to clam richness and surface mud to clam abundance, it appears that beaches with low percent cover of granules, low beach slope and high percent cover of surface mud are ideal environments for juvenile clams. Subsurface shell material, combined with beach slope, subsurface pebbles and surface mud, were physical features whose patterns matched those seen in clam assemblages among sites well.

From informal field observations, I have noted that beaches with high cover of shell hash are host to a high abundance of juvenile clams. Many of these clams were found through repeated, unrecorded bulk sieving and are not necessarily reflected in the data. In a recent study, Green (2009) found that juvenile clams living in acidic mud common to sheltered coastal bays had high rates of mortality due to dissolution of their shells. The addition of crushed *M. arenaria* shells to the sediment increased survival of the juvenile clams by buffering and raising the pH of the sediment (Green *et al.*, 2009). In 1990, Sponaugle and Lawton found that portunid crabs such as *Callinectes sapidus* were less efficient foragers in sediment composed partially of shell hash than in just sand or mud. These studies' results give possible reasons for the statistical and observational support I've shown for shell hash as an indicator of juvenile clam presence—protection from dissolution and reduced foraging by predators.

The overwhelming impression that I've come away with after conducting this study is that juvenile clams are scarce in the San Juan Islands. It was very difficult to collect clams at even the beaches with the highest clam abundances. Contrary to what might be assumed, presence of adults is not a reliable indicator of juvenile presence—there were many beaches surveyed with an obvious cohort of adult clams. This begs the question, where did all these adults come from? Where are the juveniles that will eventually become the adults that are so prevalent? To answer these questions further research into the post-settlement biology of clams is required.

Growth Rates

The growth rates in the tank with no low tide were assumed to be growth rates in “ideal conditions”—the clams were never subjected to elevated temperatures, and they had a constant supply of food and minerals for shell growth. The lack of difference in growth rates between size classes was contrary to what has been found in other studies—Teixiera de Sousa *et al.* (2011) found that large size classes of juvenile *Ruditapes decussatus*, the carpet shell, grew faster than medium sized juveniles, which in turn grew faster than small individuals. Zettler (2007) found that *M. arenaria* has fastest growth rates in small individuals and slowest rates in large individuals. However, Zettler found that *M. arenaria* growth can be modeled by a sigmoidal curve, so it’s possible that there wasn’t large enough age diversity in my individuals to show significant differences in rates. Depending on where the age range of all the individuals in a study fall on the greater sigmoidal growth curve, relative growth rates could differ between sizes/ages.

There were obvious differences in tank 1 growth rates between species. *M. arenaria* had higher growth rates in all size classes than the other species. These clams have very thin shells, so the higher growth rates could reflect a decrease in energy required to increase shell thickness, and a complete allocation of energy to increase in shell length. *S. giganteus* and littlenecks, on the contrary, have thick shells and therefore devote a greater proportion of their energy to shell thickness than do *M. arenaria. Macoma* sp., although they have thin shells, are not purely filter feeders like the other study species. They use their long siphons to vacuum organic matter off the surface of the surface of the sediment, and the sediment that I collected was relatively clean and free of organic matter—it's possible that they were limited nutritionally.

Across treatments, it appeared that growth rates decreased along an intertidal gradient. From observations in the field, the intertidal distribution of my study organisms is as follows: *T. capax* living lowest in the intertidal, followed by *S. giganteus, Macoma* spp., littlenecks and *M. arenaria* living highest in the intertidal (pers. comm. Megan Dethier). Growth rates in all tanks were lowest in *S. giganteus* (growth rates weren't measured in *T. capax* due to insufficient sample size) and increased with increasing range in elevation in the intertidal. It's possible that species that are usually limited in their growth by long low tide aerial exposures were able to grow faster in perpetual high tide.

Another trend observed in Figure x is a marked decrease in difference between growth rates in tank 1 and tank 2 along an intertidal gradient. There is a large difference between those growth rates in *S. giganteus,* but almost no difference between the two rates in littlenecks and *M. arenaria*. This suggests that the species existing highest in the intertidal are conditioned to living with periods of time with elevated temperatures without access to food, and that a one-hour low tide had a negligible effect on their growth. Species living lowest in the intertidal are rarely exposed to low tides of moderate length, and even one hour out of the water appears to hinder their growth significantly (Fig. x). A study by Laing *et al.* (1987) showed that growth rates of juvenile clams decrease with increased water temperature, and while the clams in this study were exposed to increased sediment temperatures, their findings seem to support ours in that an increase of the temperature of any medium will negatively affect juvenile growth rates.

Mortality in Extreme Conditions

Mortality was virtually nonexistent in tank 1, presumably because with a constant supply of food, consistent low temperatures and a lack of other organisms there is no reason that a juvenile clam would die, except for perhaps a disease or parasite. In tank 2, there was some mortality, mostly in the species living in the low intertidal. This is explained in a similar way to the pattern observed in growth rates—even the elevated sediment temperatures experienced for one hour subject these clams to excessive heat stress and they perished.

Mortality was high in tank 3. Species that experienced mortality in tank 2 had a much higher percent death in tank 3 and species that did not experience mortality in tank 2 did in tank 3. Again, as observed in growth rates, mortality appeared to be connected to intertidal distribution. Mortality was highest in tank 3 in *T. capax* and *S. giganteus* and decreased with *M. arenaria* showing the lowest death rate. The large amount of heat relative to seawater added to the sediment in tank 3 in comparison to tank 2 is likely responsible for the much higher mortality in tank 3. Species living lowest in the intertidal could not cope with the prolonged high temperatures as well as the high intertidal organisms and thus experienced much higher mortality.

Effects of Predation

Hemigrapsus nudus was able to crush and eat *Macoma* sp., but not *S. giganteus*, presumably because of the difference in shell thickness—*H. nudus* might not have been strong enough to open *S. giganteus*. The majority of *H. nudus* preferred medium *Macoma* sp. to large individuals. This is consistent with previous findings—Seed and Hughes (1995) found that crabs will forage preferentially on clams below the critical size they are capable of handling to maximize their feeding efficiency.

An interesting trend was observed when testing the feeding preferences of *H. nudus* to a medium *Macoma* sp. or *Ulva*. The ten crabs used had been used in the previous week for the size preference feeding trial, and five of them had eaten a clam. Of those five crabs, 80% of them made a foraging choice—each of them chose *Macoma* sp. over *Ulva.* Of the five crabs that did not consume a clam the week before, 60% of them made a foraging choice—each of these crabs chose *Ulva* over *Macoma* sp. This is contrary to what I expected might happen. I predicted that perhaps the crabs that had eaten recently would be less hungry and thus more likely to choose *Ulva*—less nutritious but far easier to handle.

The crabs were collected on a rocky, cobble-covered beach that likely has a low density of juvenile clams. These results lead me to believe that crabs with previous experience handling clams will choose them over a less nutritious but more easily handled food. Crabs that don't have experience handling clams are less likely to risk the time and energy necessary to open a clam and will choose the more easily consumed food, such as *Ulva*, instead.

Cancer productus easily consumed all sizes of *Macoma* sp. it was given. Rather than test its feeding preferences, since it would unlikely eat *Ulva* in the field, I investigated the size extreme that it could feed on. All the individuals tested were capable of opening large (14-17mm) juvenile *S. giganteus* and littlenecks. The larger range of sizes and species that *C. productus* is capable of preying on could make it a more effective predator on juvenile clams than *H. nudus*, but this cannot be said for sure. The relative effect of predation by these two crab species on juvenile clams remains unknown because, although *C. productus* is more capable of causing mortality, they are far less common than *H. nudus* in the intertidal which decreases the pressure they are capable of exerting on clams.

Due to the scarcity of juvenile clams on the beaches of the San Juan Islands, data gathered were insufficient to get a good idea of where juvenile clams live in this region, but this study, combined with Krauszer's, are a starting point for predicting what types of environments one might find juvenile clams.

My results, while sample sizes were not large enough to show statistical significance, show important patterns in the way different species' growth and mortality are affected by temperature. Species are affected differentially depending on where they live in the intertidal and this is an important pattern to know. Clams are sessile creatures, and can't shift their zonation according to a changing environment. Knowing how increased temperature affects them will be important given the possibility of rising sea levels and warming oceans.

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References

Beukema, J. J., R. Dekker, et al. (2010). "Long-term variability in bivalve recruitment, mortality, and growth and their contribution to fluctuations in food stocks of shellfish-eating birds." Marine Ecology Progress Series 414: 117-130.

El-Wazzan, E. and J. Scarpa (2009). "Comparative growth of triploid and diploid juvenile hard clams Mercenaria mercenaria notata under controlled laboratory conditions." Aquaculture 289: 236-243

Goong, S.A. and Chew K.K. (2001). "Growth of butter clams, Saxidomus giganteus Deshayes, on selected beaches in the state of Washington." Journal of Shellfish Research 20: 143-147

Gosselin, L. A., P. Quain (1998). "Juvenile mortality in benthic marine invertebrates." Marine Ecology Progress Series 146: 265-282.

Green, M. A., G. G. Waldbusser et al. (2009). "Death by dissolution: Sediment saturation state as a mortality factor for juvenile bivalves." Limnol. Oceanagr. 54: 1037-1047.

Krauszer, M. (2011). "Distribution and abundance of juvenile intertidal bivalves in the San Juan Islands, WA." Unpublished.

Laing, I., S.D. Utting et al. (1987). "Interactive effect of diet and temperature on the growth of juvenile clams." Journal of Experimental Marine Biology and Ecology 113: 23-38

Masu, T., S. Watanabe et al. (2008). "Establishment of shell growth analysis technique of juvenile Manila clam Ruditapes philippinarum: semidiurnal shell increment formation." Fisheries Science 74: 41–47.

Peterson, C (1982). "The importance of predation and intra- and interspecific competition in the population biology of two infaunal suspension-feeding bivalves, Protothaca staminea and Chione undatella." Ecological Monographs 32: 437-475.

Seed, R. and R.N. Hughes (1995). "Criteria for prey size-selection in molluscivorous crabs with contrasting claw morphologies." Journal of Experimental Marine Biology and Ecology 193: 177-195.

Sponaugle, S. and P. Lawton (1990). "Portunid crab predation on juvenile hard clams: effects of substrate type and prey density." Marine Ecology Progress Series 67: 43-53

Teixeira de Sousa, J., D. Matias et al. (2011). "Growth variation in bivalves: New I nsights into growth, physiology and somatic aneuploidy in the carpet shell

Ruditapes decussatus." Journal of Experimental Marine Biology and Ecology 406: 46-53

Zettler, M. L. and F. Schaffer (2007). "The clam siphon as indicator for growth indices in the soft-shell clam Mya arenaria ." Helgol Mar Res 61: 9-16.