Vertical migration patterns of two marine snails: *Nucella lamellosa* and *Nucella ostrina*

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Abstract

Nucella ostrina and *Nucella lamellosa* are two species of predatory marine intertidal snail. They are common along the coast from California to Alaska, US and prey upon barnacles. We studied vertical migration and feeding patterns of each species and the best method for tagging them. We found that there was not much fluctuation in vertical movement, nor any significant peaks in feeding over our study period; however we did verify that *N. lamellosa* move up the shore a bit to feed. We also found that radio tagged *N. lamellosa* were more abundant lower on shore than their typical zone. These studies will help future studies on *Nucella* spp as well as further advance our efforts in predicting effects of climate change of behavior.

Introduction

Over the course of the next century, coastal regions are expected to experience a temperature increase of several degrees (IPCC 2007). Its effect on the natural world is a concern for many. Changes in temperature are likely to modify animal behavior. For example, Kearney (2009) found that lizards generally attempt to stay cool, e.g. by seeking shade when the sun comes out. If climate change decreases vegetation and therefore shade, lizards may have to spend more energy traveling to find food and shade (Kearney 2009). Similarly, climate change may alter organismal behavior along the coasts if warmer temperatures become stressful to marine ectotherms.

The tide cycle plays a major role in ecology of the intertidal zone (Helmuth 2002). Spring tides are characterized by extremely high and extremely low tides while neap tides have little variation in water level. Organisms that live in the intertidal must be able to survive being both fully submerged and fully exposed for prolonged periods of time. Alternating exposure to air and water produces high variation in temperature, which is dependent on how long each low tide lasts (Mislan 2010). Potential time spent out of water substantially influences a marine animal's behavior, which can be measured by its movements. When exposed to air, the animal risks desiccation; therefore, a behavior that takes a while, like feeding, must be precisely timed.

Nucella ostrina and *Nucella lamellosa,* two species of marine snails commonly found in the San Juan Islands, feed on barnacles in the intertidal (Connell 1961, 1970, Morris 1980). They must migrate up the rock face to get to where the barnacles have settled. The optimal time for mobile intertidal organisms to move up shore to feed is driven by many factors; light and shell size (Bertness 1977), risk of predation (Aschaffenburg 2008, Mach 2010), and time exposed (Mislan 2010), which determines the temperatures snails encounter while exposed (Helmuth 2002, Harley 2008). Many of these factors are ultimately controlled by the tide cycle.

If the environmental temperature increases, many factors will change. The barnacles that *Nucella* spp. eat in the upper intertidal zone, *Balanus glandula*, may shift lower on the shore so they are not exposed to the heat as long. If *B. glandula* shifts into the zone of *Chthamalus dalli*, a lower intertidal barnacle, interspecific competition would ensue, leaving less food for *Nucella* spp. (Connell 1970). With decreased food resources, *Nucella* spp. populations may decrease as well. There is also a question of whether there would be intraspecific competition between *N. ostrina* and *N. lamellosa*.

Many studies have been conducted regarding marine animal body temperature, tide cycles, feeding habits and substrate temperature in the intertidal zone (e.g. Barnes 2006, Harley 2008). Very few have been conducted on *Nucella* spp. physiology and behavior related to tides. Competition, temperature stress, migration behavior, and tide cycle may all affect *Nucella* spp. behavior and feeding habits.

My research focuses on how the tide cycle affects the timing, distance, and direction of vertical migration of *Nucella ostrina* and *Nucella lamellosa,* when and where feeding occurs, and evaluating methods for tracking vertical movement. Migration behavior will determine whether the two species live in different niches. Recent work has shown a significant increase in number of snails feeding every two weeks (Carrington & Kull, 2011, Hayford, et. al unpublished data). The increase occurs during neap tides, when low tide occurs in the morning (Hilary Hayford, UW Biology, unpublished data). The snails may be responding to the tide and temperature so that they can feed when out of the water for a short amount of time during a cool part of the day. To test this hypothesis on timing of movement, we conducted two sets of surveys; one in the snails' natural environment where we monitored migration from one day to the next, the second in the lab with controlled conditions where we monitored movement of individual snails within one day. During these studies, we also monitored tagged snails in the field, which then could be compared to distributions from count data. These data will help others decide what the best method of tagging is in the future.

Methods

We observed and measured vertical migration in natural populations of two species of marine snail; *Nucella lamellosa* and *Nucella ostrina*. We chose three sites at Colin's Cove located at Friday Harbor Laboratories Marine Preserve based on angle and accessibility of the rock face, and whether *Nucella* spp. were seen at that location. We set up one plot at each site 1m wide, that stretched from the top of the rock to Mean lower low water (MLLW, 0m). The plots were broken into 0.25m intervals for counting purposes. All snails found in each plot were collected and about half (150 snails) were tagged with either a wire tag or radio tag. Wire tags are number stickers super glued to the snail shell. The radio tags give off signals that can later be read and identified by a specific number. These were attached to the shells with epoxy. Surveying took place over nine days at low tide each day. Surveys included counts of each species found in each plot, and records of habitat of found tagged snails: sun and air exposure, orientation, shading by algae or crevices, and height. Snails were tracked in a larger plot that completely encompassed the counts plot.

We conducted a second survey in the lab: 16 *N. ostrina* and 14 *N. lamellosa* were collected from the field, placed in a tank with wire tags glued to their shells, and starved for one week. This experiment measured snail migration within one day. The tank had a gravel floor, two drains (one high, one low) a running sea water source, and a cinder block with barnacle bait attached at the top (Figure 1). The tide was changed twice every day for nine days. Times at which we changed the tide were calculated by looking at the height each species generally were found and taking the average between the two. This turned out to be 0.8m. We then found what time the natural tide crossed below or above 0.8m each day. The tank roughly simulated what the snails would experience if they were in the wild. Each time we changed the tide, we also took notes on where all of the snails were in the tank. Notes included sun and air exposure and location in the tank (north, east, south, west side of brick/ wall, on the rocks, under block).

Extrapolating from Hilary Hayford's previous research, and assuming the snails move up shore for the sole purpose of feeding, we predicted high numbers of snails May 27th-

29th. Numbers would not be nearly as high for the rest of data collection. These days reflected optimal conditions for snail feeding; early morning tides with a somewhat shallow low tide.

Results

Distribution

Both *N. lamellosa* and *N. ostrina* looked like they had normal distributions across their respective zones. *N. lamellosa* were mostly found 0.75-1.0m above MLLW and *N. ostrina* was found 1.25-1.5m above MLLW across sites and days (see Figure 2). The population mean density (PMD = $\Sigma Dx * X / \Sigma Dx$) is different for each species (two-sample t-test, $t = -9.348$, $p < 0.001$). There was slight variation in zone over time throughout the survey period (Two-Way ANOVA, $F = 0.1890$, $p = 0.133$). *N. lamellosa* moved upward about 0.5m from the 22nd to the 26th and *N. ostrina* moved down and back up during our survey period, May 22nd to the 26th. Total movement over our survey period is about 1.0m in all (Figure 3).

Feeding

A high proportion of *N. lamellosa* were found feeding 1.5-1.75m with a gradual decrease in percentage getting closer to MLLW (Figure 4). The large proportion seen from 1.5-1.75m is likely inflated because very few snails were found in that zone. *N. ostrina* fed proportionally in each of the zones in which they are usually found (Figure 4). There were higher percentages of both species feeding May 21st-24th. The proportion of N. ostrina was about 18% while N. lamellosa was about 10% (Figure 5).

Tagged Individuals

Density of tagged snails across sites show a generally normal distribution over their typical zones. Tagged *N. ostrina* are most dense 1.25-1.5m and *N. lamellosa* peak 0.5-0.75m (Figure 6). Figure 7 shows movements of three tagged individuals over days. Surprisingly, each is doing something different from the other. One moves a lot and one moces very little relative to the others. There is not much of a universal trend across sites. Tagged snails as a whole show different migration patterns at each site: in general, snails at site 3 moved much more than those at the other two sites (Figure 8).

LAB

During high tide, 67.1% of *N. ostrina* and 54.4% of *N. lamellosa* were found below the water level. At low tide, 34.3% of *N. ostrina* and 52.0% of *N. lamellosa* were found below the water level (see Figure 9). Whether *N. ostrina* were under water at high or low tide is not signifincant, nor is it significant whether *N. lamellosa* were found under water in either tide ($\chi 2 = 35.724$, $p = 0.000$, $\chi 2 = 0.162$, $p = 0.9834$, respectively. During high tide, 33.1% of *N. ostrina* and 3.6% of *N. lamellosa* were feeding (found on a barnacle). During low tide, 36.2% of *N. ostrina* and 3.6% of *N. lamellosa* were feeding (Figure 10). The difference between *N. ostrina* feeding at high or low tide was not significant, nor was this comparison with *N. lamellosa* ($\chi 2 = 0.428$, $p = 0.9344$, $\chi 2 = 0.122$, $p = 0.9891$, respectively). However the difference between species feeding is significant ($\chi 2 = 68.939$, $p = 0.0001$). The tank was sampled twice per day: once at high tide before we let the tide out and once at low tide before we let the tide back in. Percentages were calculated by the number of snails feeding summed over days.

Discussion

Distribution

The normal curves for each species in their respective zones shown in Figure 2 support our predictions and previous research (Connell, 1970). Overall, *N. lamellosa* and *N. ostrina* zones overlap, but the two species inhabit different areas above MLLW. *N. lamellosa* are most dense 0.75-1.0m and *N. ostrina* live a little higher; 1.25-1.5m above MLLW. Over the course of our study, there was some fluctuation in each species' location (Figure 3). *N. ostrina* were always found higher on shore, yet there seems to be an inverse relationship between their movements. When *N. ostrina* move up, *N. lamellosa* move down on shore; they are moving away from each other. When *N. ostrina* move down, *N. lamellosa* move up; moving toward the other species. However, these are small variations. Overall, both species moved up shore approximately 0.5m, or 2 zones over the whole sampling period.

Feeding. The discrepancy between the peaks in density of *N. lamellosa* in feeding snails versus the whole sample population (Figures 2 and 4) suggests that *N. lamellosa* move up the shore to feed. The difference in feeding *N. ostrina* and the peaks in density of the count data suggests that *N. ostrina* feed in any of the zones in which they are generally found. When studied across days, feeding peaks of about 10% and 18% were seen in *N. lamellosa* and *N. ostrina* respectively May 21st to May 24th. Though these were peaks in our small sample size, feeding peaks of approximately 60% are typical in *N. ostrina* during summer (Hayford, unpublished data). Our findings may represent a lack of peak feeding during our sampling period or may be typical for this season. According to her data, we should have seen *N. ostrina* feeding starting to peak at the end of sampling, May 27th.

Tagged Individuals. Densities of counted snails and tagged snails both show normal curves over their respective zones, however there is some variation between the two groups (Figures 2 and 6). While both graphs show peaks 1.25-1.5m for *N. ostrina*, peaks for *N. lamellosa* are at different zones. Counts were found one zone higher (0.75-1.0) than tagged individuals. These findings may be caused by an adverse effect of the tags on the snails: the radio tags must be attached to the shells by epoxy, possibly making them relatively heavy backpacks for the small snails. What is interesting is that the effects are seen in the bigger of the two species. If the tags were to affect either of the species, *N. ostrina* would be more likely to feel the effects because of its smaller size. These data may be skewed because there were very few *N. ostrina* to tag and sample throughout the survey period.

As a whole, there was much more movement in sites 3 of tagged snails (Figure 8). Site 3 showed both extremes of snails moving a lot and not moving much at all. This site has a few shallow cracks, a little algae, and a big pool in the shelf. Some snails may have found one of the cracks and stayed there for days, while others kept searching for protection. Sites 2 and 3, in contrast, had big cracks that provided protection from waves, predation, and desiccation, which may help to explain the lack of movement.

In our lab study, there were approximately equal percentages of each species found under water in each of the tidal conditions. Surprisingly though, the percentage of snails found under water in the high tide is approximately equal to the percentage of snails found under water at low tide. We had predicted, and one would think in general, that there would be more snails under water at high tide because there is less space to be out of water at these times. This behavior is odd for an intertidal organism, whose movements are driven by attempts to avoid desiccation. Additionally, at low tide, we would often find snails not only out of the water, but located high enough in the tank that they would be out of water if it were high tide as well. The individuals found in this location were often in that same spot before we let the tide out; they did not move from their spot after the water started draining. In other words, they did not migrate in either direction when out of water. Finding these snails so high is odd and does not reflect the idea that these snails are always trying to minimize immersion (Harley 2008).

In the field, we found a decreased trend of feeding *N. lamellosa* at lower tidal elevations and approximately equal *N. ostrina* feeding in the zones where they are usually found (Figure 4) and each species show similar feeding patterns across days. There was a slightly larger proportion of *N. ostrina* feeding than *N. lamellosa* May 21st to the 24th (Figure 5). Interestingly, the *Nucella* spp. in our lab tank showed very different patterns. Most of the snails feeding at any given time were *N. ostrina*. Not a single *N. lamellosa* was seen feeding until May 27th, eight days into the experiment. Many factors could play into these very different findings; different sample size, disorientation and/or maladaptation to a new and very different environment with vaguely similar tides.

Further study is needed to solidify and expand our findings. I would be content to conduct the field work similarly, however, I would make major changes to the lab study. I would use multiple tanks, put food on both sides of the cinderblock, not just the shaded side, and take more detailed notes of the snails. For example, marking zones in the tank and recording where they are. Additionally, I would try to brainstorm better ways to figure out who was under the cinderblock. As it was, there was not a good method, and often there would be missing snails. The time lapse camera was a good addition to the project, but if there was a way to capture the whole tank, I think the data would be more useful.

In conclusion, we verified that *N. lamellosa* and *N. ostrina* do indeed reside in the intertidal zones that the literature states, however, we did not see significant fluctuation in density over the nine days of our survey. This may be because we did not sample when either species were supposed to have feeding peaks. The majority of the tides were very low and in the late afternoon, neither of which are ideal for a behavior that takes a long time to complete like feeding. Additionally, we barely touched the surface of determining what the best tag is for surveying snails. We saw results for radio tagged *N. lamellosa*, but *N. ostrina* did not seem to be affected by them. These results could mean that radio tags are a heavy burden on the snails and are limiting their ability to climb to higher zones in the area, the lack of difference in *N. ostrina* could be a symptom of a small sample size. Lab results were quite clear; *N. ostrina* ate much more often than *N. lamellosa*. Oddly, this was inconsistent with our field data, which showed that both of the species had about the same percentage of feeding. The next step would be to do this study again over a longer period of time and have a better controlled lab survey as described above.

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FIGURES

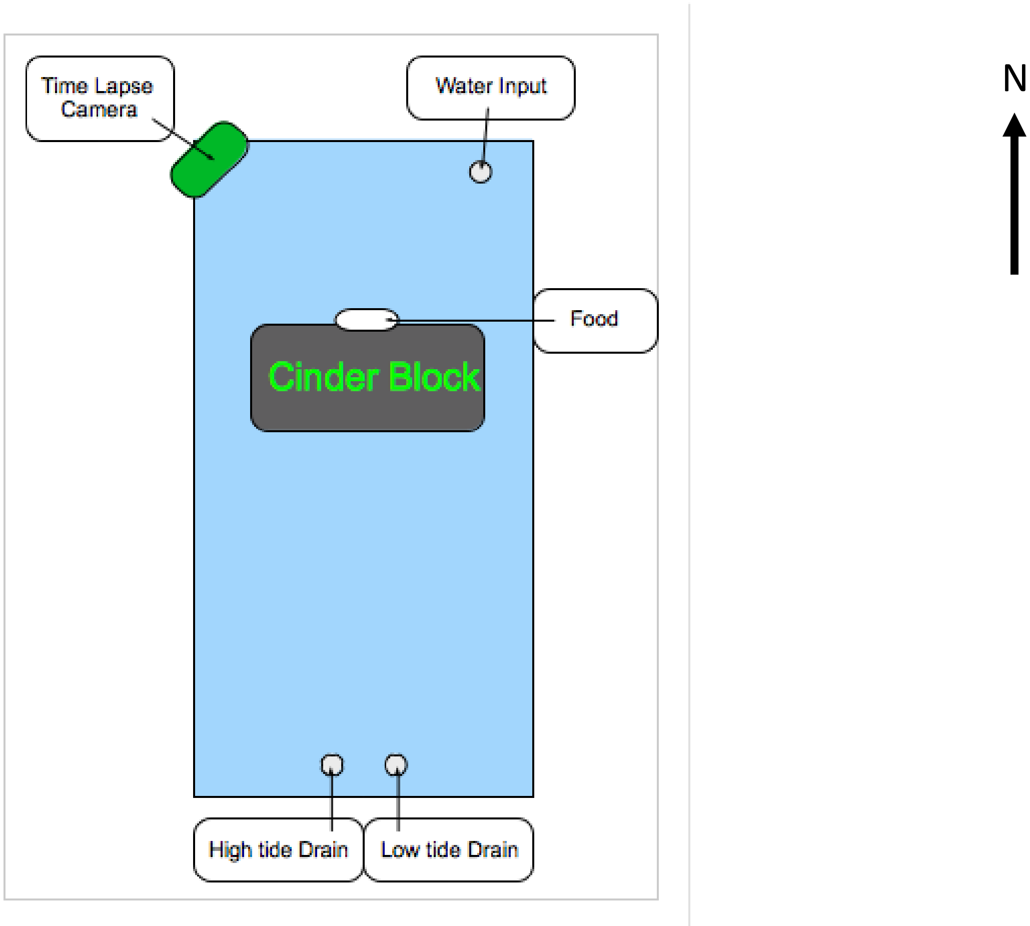

Figure 1: Diagram of tank study. Camera took pictures every 5 minutes, tide was changed twice every day during the study.

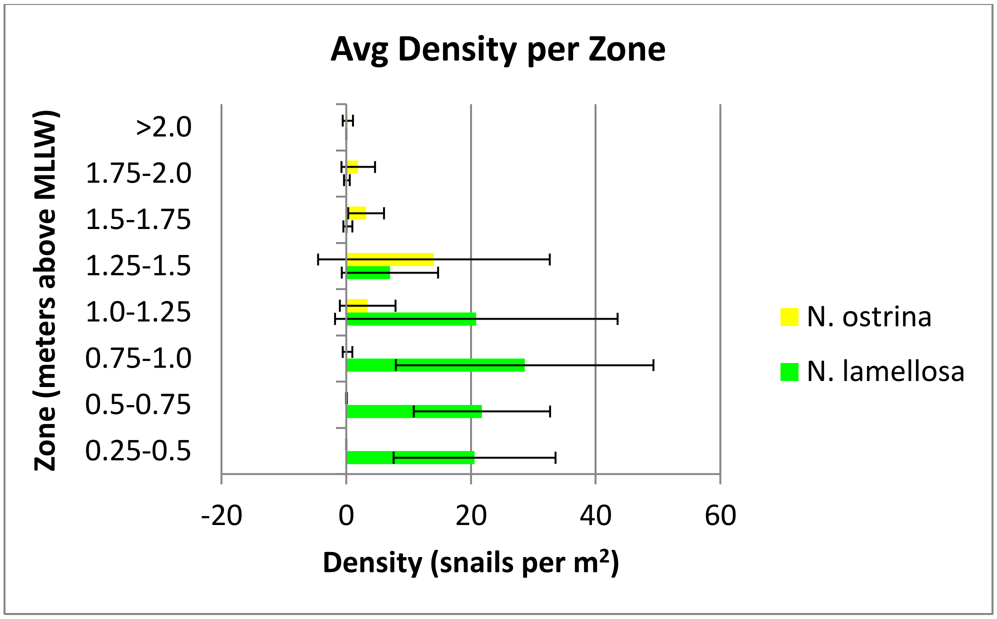

Figure 2: Average density of each species of snails per zone above the water across sites and days. Error bars are standard deviations of the mean density across sites and days

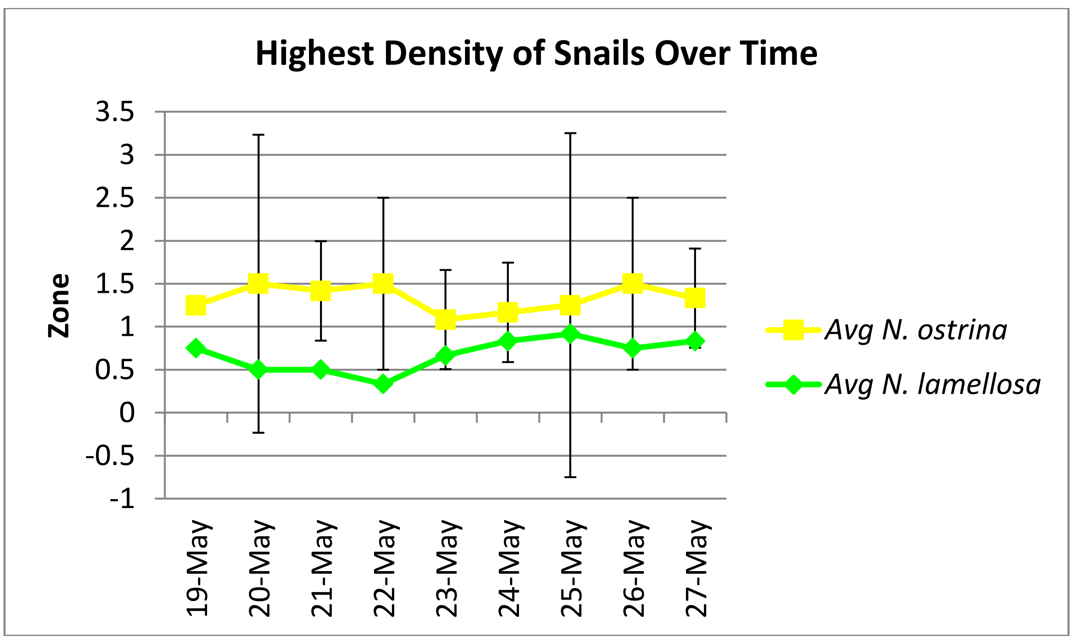

Figure 3: Highest density of each species found in each zone per day averaged across sites. Error bars derived from these calculated averages.

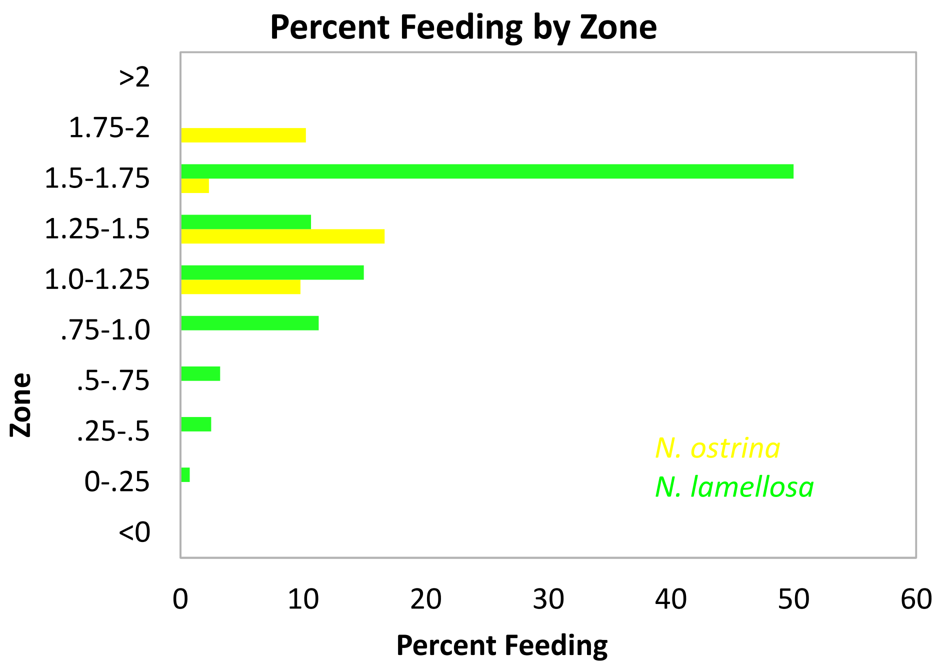

Figure 4: Percent of each species found feeding in each zone averaged across sites and days. Error bars calculated from these averages.

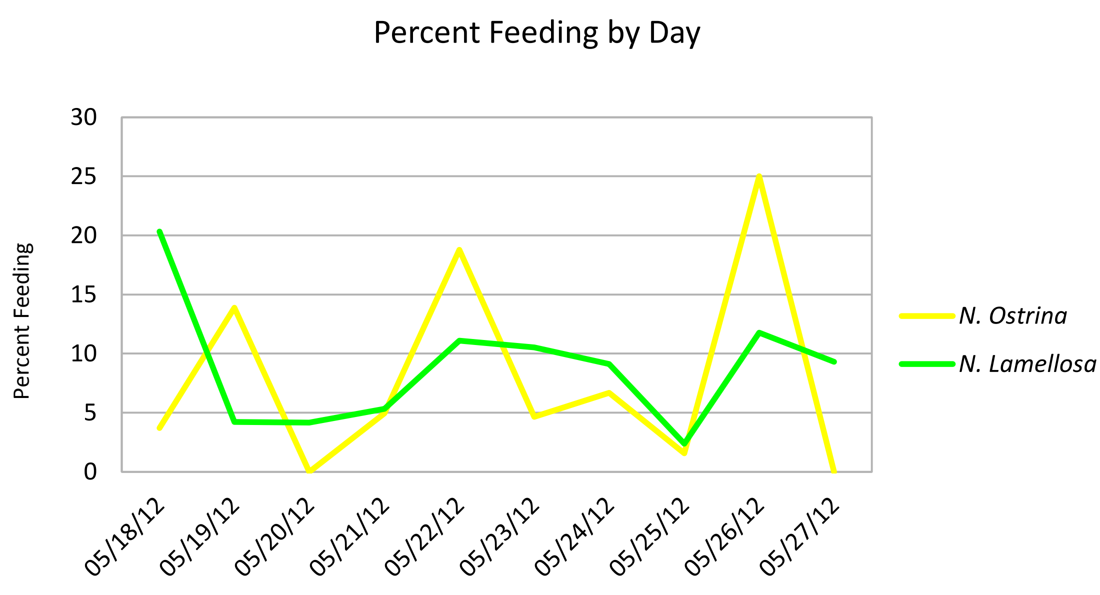

Figure 5: Percent of each species feeding each day across sites and zones.

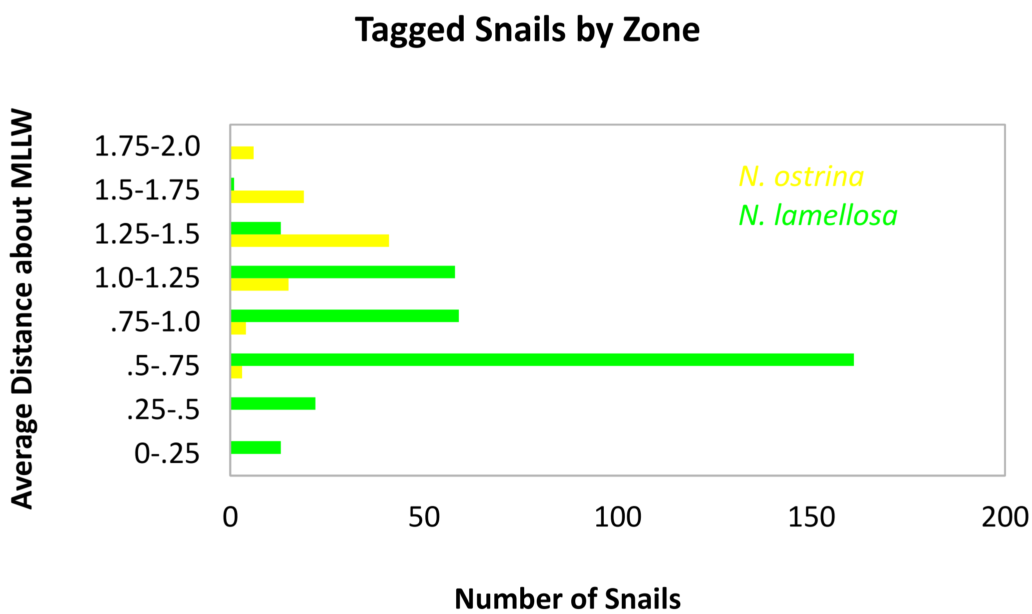

Figure 6: Distribution of tagged *N. lamellosa* across sites and days.

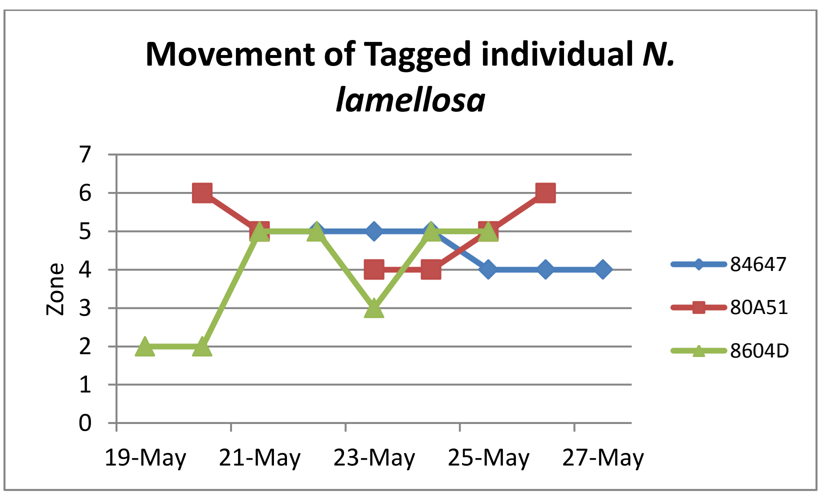

Figure 7: Depicts 3 tagged individual *N. lamellosa* moving from one zone to the next each day in site 3. Individuals to graph were chosen based on number of times sighted (amount of data we had for each).

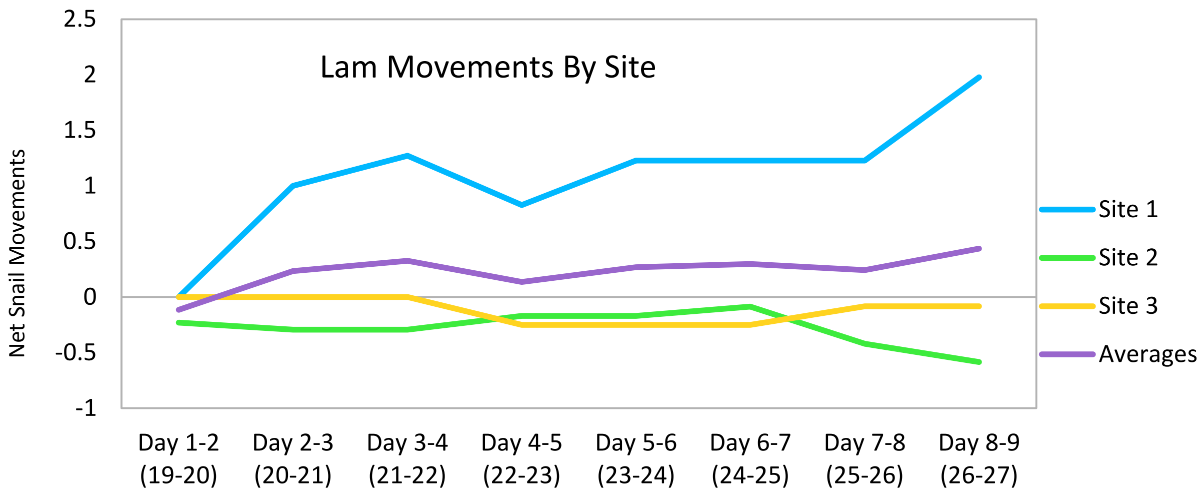

Figure 8: Distance and direction (moving up and down the plot depicted by positive and negative numbers) of tagged snails from one day to the next. Individuals and species averaged for each site.

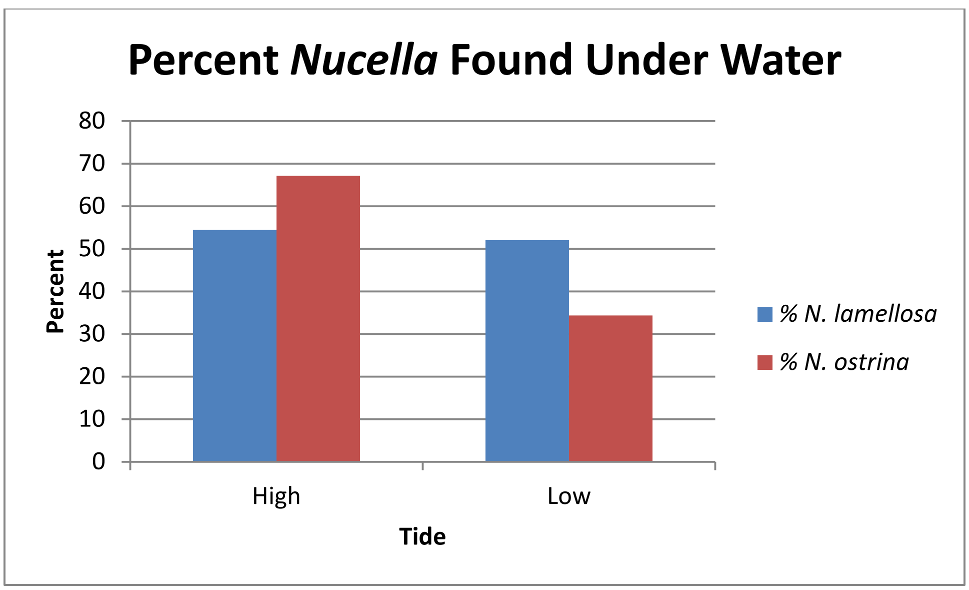

Figure 9: Percent of each species found under water across days. Snails that could not be found were eliminated from the data set. Calculated for high and low tides.

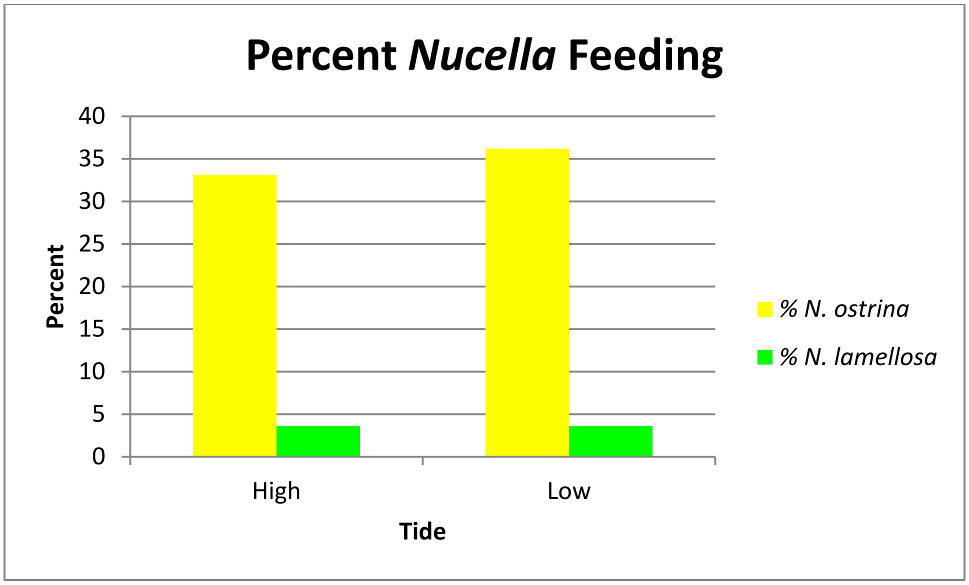

Figure 10: Percent of each species feeding (found on barnacle) across days. Calculated for high and low tide.