Migration and feeding in intertidal whelks, *N. ostrina* and *N. lamellosa*

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Abstract

Our study seeks to gain more information on the migration and feeding patterns of two common intertidal carnivorous snails, *Nucella lamellosa* and *Nucella ostrina.* These whelks are native to the western coast of the United States ranging from California to Alaska and feed primarily on barnacles. The information from our study will be useful in determining some of the effects of global climate change on the intertidal ecosystem. Because of the predatory feeding pattern of these animals they are important in determining what else can live in the region. We gained more clarity on the patterns exhibited by these snails during the period between feeding peaks by observing the counts and densities within a plot on the shoreline as well as the movement of tagged individuals. We found that although there was no feeding peak during our study, and therefore no mass vertical migration, the *N. lamellosa* did appear to be feeding in a higher percentage higher up the shore. We also gained some insight into the effects of radio tagging on snail behavior when we discovered that that radio tagged *N. lamellosa* appeared lower on the shore than those without radio tags. This information will help further studies on whelks.

Introduction

Predatory snails such as the *Nucella lamellosa* and *Nucella ostrina* have a complex pattern of moving up and down the shore to feed (Spight 1982). They feed on barnacles and molluscs farther up shore from their usual habitat (Connell 1961). This consumption can be one of the key factors in determining the population size (Morris et al. 1980) and species distribution of their prey (Connell 1961). *Nucella* use a specialized feeding structure called a radula and drill a hole into the shell of their prey (Morris et al. 1980). This process can take six to eight hours (Spight 1982) and that, combined with the slow speed of *Nucella,* means that they are likely to become trapped high on the shore as the tide goes out.

While they are farther up the shore, the snails have to contend with both increased predation (Spight 1982) and desiccation (Helmuth et al. 2002). Predicting the extent of these stresses is difficult because it depends on the timing and length of the tidal exchange and on air temperatures while the tide is out (Mislan et al. 2009) and the orientation of the shore with respect to the sun (Harley 2008).

Global climate change could have an effect on the extent of these stresses (Kearney et al. 2009). As global temperatures increase there will be more stress on feeding snails caught out of water. These stresses could affect the energy usage of the snails as they have to change their behavior, e.g. moving to find shade to stay cool (Kearney et al. 2009). To fully understand what role climate change could play we need to first understand more about snail migratory patterns. Global climate change could also affect barnacle distribution, which in turn could change the foraging patterns of the snails. Barnacles may have reduced survival farther up the shore because of exposure to hotter temperatures for longer periods of time (Connell 1961). In addition, barnacles from warmer locations to the south, such as California, may start to settle further up the shore, including species with harder, thicker shells that are more resistant to *Nucella* predation (Sanford et. al. 2007). Both of these changes would also lead to changes in the dynamics of competition between the barnacle species, one of the most important factors determining their locations in the intertidal zone (Connell 1961).

We predict that one of the biggest challenges for these snails is the risk of desiccation and overheating while the tide is out. The San Juan Islands experience semidiurnal tides, with two lows and two highs per day, that vary in height over a two week period. When there is a full or new moon, the tidal exchanges are the most extreme (spring tide). When the moon is half full, the exchanges are less extreme (neap tide). We predict that the snails will time their migration so that they spend as little time out of water as possible. To do this, they would migrate at neap tide when the low tide is highest (Spight 1982). Previous work has shown that *Nucella* do migrate in a two week cycle, moving slightly after neap tide (Carrington & Kull 2011). We will track the movement of individual snails up and down the shore and compare the two species present in our location, *Nucella ostrina* and *Nucella lamellosa*. Past field studies on *Nucella* migration has sampled once a week, so our study will gain more precision by sampling everyday during low tide. Because it is not know how long it takes a snail to migrate up and down the intertidal zone, we will also document this behavior in lab.

Methods

Our research had two components. The first was a field study done at Colin's Cove, a rocky shore-line located on the east side of San Juan Island to the north of Friday Harbor, WA. We set three separate sites at Colin's cove. At each site we created a grid that was 1 m across and marked out tidal heights from 0.0 m to 2.0 m above Mean Lower Low Water (MLLW). At each site we tagged approximately half of each whelk species present, *Nucella lamellosa* and *Nucella ostrina.* In our study we used to different types of tags, wire tags and radio tags. Wire tags are small white numbers that were glued to the shell of the snail. The radio tags are glass tags, approximately 1 cm, that we stuck the shells with epoxy. The snails that we tagged were divided equally between each tagging method. During our survey period of 9 days we surveyed each site everyday. We counted the total number of snails found in each tidal zone in our plot, as well as noting the location and behavior of all of the tagged snails we found. We used a radio tracker to search both inside in our plot and a in larger area around the plot for our radio tagged snails.

The second half of our experiment took place in an outdoor tank on the University of Washington's Friday Harbor Laboratory campus. We lined the bottom of this tank with gravel and set up a cinder block in the center (Figure 1). On the north side of the brick two mussel shells that barnacles settled on them were bolted to the wall to simulate the vertical migration needed for feeding. The tank had a constant flow of fresh seawater through it.. Twice daily we changed the tide by changing the height of the drain. In order to determine the times at which to change the tide we took the average of of the two zones in which we had seen highest density of both species. The tide height in the middle was .8m above MLLW. From their we looked that the time at which the water would pass that height in field and moved the drains accordingly. At high tide the top of the brick was exposed in a such a way that half the food was under water and half was exposed. We calculated the timing of the tide change to mirror the time the tide changes in the field at a shore height between the natural ranges of *N. lamellosa* and *N. ostrina,* .8 m. We collected 14 *N. lamellosa* and 16 *N. ostrina* from Colin's Cove near our field study, placed in another lab tank for a week for adjustment, then numbered them with wire tags and placed them in the tank. We noted the locations of all the snails in the tank every time we changed the tide.

Results

Distributions. The two species of *Nucella* observed in this study both exhibit a distribution with a bell curve shaped slope between tide heights (Figure 2). The two species differ in their population mean density (defined as $PMD = (\Sigma D_x * X) / \Sigma D_x$) locations (Two-sample t-test, $t = -9.348$, $p < 0.001$). Although there was some fluctuation during our study the average center of density for the *N. ostrina* was located between 1.25 and 1.5 meters above Mean Lower Low Water (MLLW), while the center of density for *N. lamellosa* was lower at 0.75 - 1 meter above MLLW. The same general pattern was seen for just the tagged snail, although the center of density for *N. lamellosa* was slightly lower at 0.5 to 0.75 meters above MLLW (Figure 3).

Based on the earlier work we expected to see a well defined peak of migration at towards the end of our study (Hayford, Unpublished data), however no such peak was present in our data (Figure 4). There was some fluctuation across time as to which zones had the highest density of each species. Both *N. ostrina* and *N. lamellosa* moved both up and down the shore twice during the period of the study (Two-Way ANOVA, F= 0.1890, p = 0.133).

Feeding. One of the assumptions we were testing was that *Nucella* would move up and down the shore based on their feeding patterns. We tested whether there was a higher percentage of the snails present in the higher zones that were feeding, when compared to the lower zones (Figure 5). There were few *N. lamellosa* in the 1.5 – 1.75 m zone and therefore the large percentage of individuals feeding is biased however, the *N. lamellosa* do show a general trend of having a higher percentage feeding in higher zones. There does not seem to be a similar pattern for the *L. ostrina,* which have approximately constant percentages feeding across all of the zones they were found in.

We also looked at the overall percentage of each species feeding across all zones over time (Figure 6). This percentage varied for both species over the study but there was never more than 25% of the individuals of either species feeding at any point during the study. Previous studies have found between 50% and 70% feeding during a peak (Hayford, unpublished data) indicating that this was not a high feeding time for either species.

Radio Tags. When the movements of all of the tagged snails were combined there was no clear movement pattern in any of the sites (Figure 7). Both sites 2 and 3 had very little overall movement of tagged individuals and the net average movement was close to zero. Site 1 had much more movement than the other two sites with a general movement up the shore. When looking the individual snails, rather then the averages of all snails at a particular height, we can see that no net movement is not necessarily the same thing as no movement. There is significant movement of individual snails at site 3 but they do not seem to be particularly co-ordinated (Figure 8). Therefore there are still snails moving their movements are just counter acted by snails moving in the other direction. This could show up in both our count data and these radio tag tracks.

Lab. To gauge the vertical migration patterns of our lab snails we looked at the number of individuals in and out of water before the artificial tide was changed. The numbers of snails feeding was summed over the days and then averaged. The number of *N. lamellosa* under water varied between 67.1% and 54.4% between high and low tides respectfully (Figure 9). This difference isn't significant ($\chi 2 = 0.162$, $p = 0.9834$). There was a larger difference in *N. ostrina* who were exposed between the tide heights who varied between 52.0% and 34.3% (Figure 9). This difference was significant ($\chi 2 = 35.724$, $p = 0.0001$).

Between the two tide heights the numbers of *Nucella* feeding did not differ greatly (Figure 9), indicating that the feeding individuals probably continued to stay on the food through out the tidal exchange. The main difference noted in the feeding data was between the two species. There was a significantly higher percentage of *N. ostrina* feeding at both tidal heights ($\chi 2 = 68.939$, $p = 0.0001$). *N. ostrina* varied between 33.1% and 36.2% which was not a significant change ($\chi 2 = 0.428$, $p = 0.9344$). while the percentages of *N. lamellosa* stayed constant at 3.6% ($\chi 2 = 0.122$, $p = 0.9891$).

Discussion

Overall through this study we gained a higher resolution of data on the migratory habits of the two species of *Nucella*. Our data on the general densities and tidal heights of both species agreed with previous literature (Connell 1970). Although we didn't sample over a period of high feeding we did gather information on their general migration and baseline locations and feeding rates. We also gather valuable information on the effectiveness of radio tags.

Distribution. Our data support prior work showing that *N. ostrina* and *N. lamellosa* occupy different but slightly overlapping tidal heights along the shore . This was shown clearly by both the average densities from within the plot and the average locations of the tagged individuals. There was some variation in zone densities throughout the study, which manifests itself in the error bars on figure 2, which is averaged over all the days.

Feeding. Using predictions from previous data (Hayford, Unpublished data), we expected to see a peak feeding time on the last day of our study, May 27th 2012 because of it's position in the tide cycle. However our data did not show this peak occurring. Previously observed peaks showed feeding percentages up around 60% as compared to our high of 25% (Hayford, Unpublished data). The data gather by Hayford was gathered later in the season so there may be a seasonal difference to tidal feeding patterns, effected by either temperature or breeding patterns. We were sampling during a spring tide with the low tides in the afternoon. As the we were getting later in the spring this tidal situation had the potential to lead to very hot, long periods in which snails caught up high on shore would be exposed to the elements. We also predicted seeing a 14 day cycle in the percentage of snails feeding, but because we only sampled over a 9 day period that fell mostly during spring tide, it is possible that the feeding peak was offset from our sampling period, falling at neap tide, and therefore was missed by our study.

Due to the fact that we didn't see a period of high feeding the fact that there was no clear vertical movements was expected. However we still expected to see a higher percentage of the individuals in the higher zones feeding because those individuals who were feeding would still have to migrate up the shore to the food (Connell 1961). That appears to be the case for *N. lamellosa* but not the *N. ostrina* (Figure 4). Given the assumption that both species share a common food source located in the higher zone, this finding makes sense. The *N. ostrina,* which are already living exclusively higher on the shore, can feed in these zones without migrating. The *N. lamellosa,* which typically live in zones closer to MLLW, would need to migrate up to the higher zones to reach their food source.

Radio Tags. We tracked the vertical migration of individual snails to be able to compare their movements to the population density changes on the whole. This data can help us distinguish between actual vertical migration and as opposed to more snails emerging from cracks. Previous studies have assumed that any changes in densities that was observed between zones was caused by a vertical migration pattern, but this assumption has never been proven. Because there was no large shift in which zones had higher densities during our study, we wouldn't expect to see a pattern of large numbers of individuals moving a great distance up the shore.

This lack of co-ordinated movement is generally what we saw when averaging all three sites (Figure 7). At site 3 there was an overall trend toward upward movement throughout the study, but this trend was not mirrored by coordinated movements of multiple individuals (Figure 8). On the whole there was a significant amount of vertical movement by tagged individuals at site 3 (Figures 8). The fact that it wasn't coordinated into a large vertical migration correlates with the absence of a large feeding peak.

Radio tag data was graphed only for *N. lamellosa* because not enough *N. ostrina* appeared on consecutive days to allow analysis. Because *N. ostrina* are smaller, they are more effective at crawling into smaller cracks where they couldn't be found. They might also be more susceptible to having increased mortality form the addition of a radio tag, but many of the snails were seen at different intervals throughout the study (personal observation). Although this means that they were unavailable for movement analysis it does indicate that they probably did not have decrease survival due to their radio tags.

The radio tag data was also useful in its comparison with the data form the counts. Comparing these two methods of sampling allowed us to compare the effects of using radio tags on the behavior of the snail. When comparing the overall densities of the count data with the numbers of radio tagged *Nucella* found in each zone, you see that the center of density is .25m lower on the shore for the *N. lamellosa* but not the *N. ostrina*. This could be the effect of the radio tags limiting the mobility of the *N. lamellosa,* however because the *N. ostrina* are the smaller species we would expect that they would be the ones affected. One possible explanation for this disparity could be the difference seen in the zonation of feeding we observed. The *N. lamellosa* have a greater need to move up the shore to feed, while the *N. ostrina* feed in all of the zones in which there are found. Therefore the lack of ability for the *N. ostrina* to migrate up to the food because of the radio tags may have gone unnoticed because they simply stayed where they were. The *N. lamellosa* however, would have had their migration patterns thrown off if they were unable to complete this migration.

Lab. The difference between the number of *N. lamellosa* in the tank found under and out of water at both high and low tides was not significantly different (Figure 9). This could indicate one of two things. It is possible that the snails were either above the high water line or below the low water line, in which case there was no vertical movement. However there was likely a fair amount of vertical migration for the entire purpose of being above or below the water line. The *N. ostrina* had a much larger change between high and low tides (Figure 9). This may indicate that they spent most of their time between the high and low water lines and became exposed when the water went out and covered when the water went up. Because of the way the tides were changed, resulting in a sudden change between high and low tide rather than a gradual change much farther up and down the shore, this could have effected the migration of the snails. Additionally because there were only two tide height, high and low, rather than a gradual gradient, the distance between sub-tidal and the high water line was reduced down a much smaller distance to travel. Under natural conditions a snail would have to travel much farther to reach a zone where it would never end up under water. Therefore this tank design could be very useful for looking at the feeding habits of the species but much less helpful for looking at migration.

During our lab experiment we occasionally had difficulty finding all of our snail. More often then not the missing snails were *N. ostrina* and the were more often missing when we were sampling before changing the tide from the low to high. We believe that many of these missing snails may have been taking refuge under the cinder block while the tide was low. This was one of the few places the snails could hide within our tank.

Throughout the lab experiment there was many more *N. ostrina* feeding than *N. lamellosa.* This could have been due to the two species having different feeding schedules. However, all experimental snails were collected and kept in another tank in the lab for a week without food before the study was started. Therefore we predicted that all of the tank snails would need to eat at some point in the study. Because the *N. lamellosa* are bigger I would have expected them to get to the food if there had been competition.

In conclusion our data was consistent with previous data on the habitat and tidal zones of the two species of *Nucella*. We set out to further examine the migration of these snails during their feeding, however we did not observe a peak during the period we expected one. We did observe that the for *N. lamellosa* there was a tendency for the zones farther up the shore to have a higher percentage of feeding individuals lower on the shore. That is what we would expect and is consistent with the idea that they need to make a vertical migration in order to feed. We also learned about the movement of individual tagged snails which seemed to be consistent with the movements of the group of tagged snails as whole, if not with the count data.

In order to further test our hypotheses a study could be done with a longer duration that encompasses a period of high feeding. More data on the effects of the radio tags on the behavior and migration of the *Nucella* would also be helpful in directed further studies.

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Figures

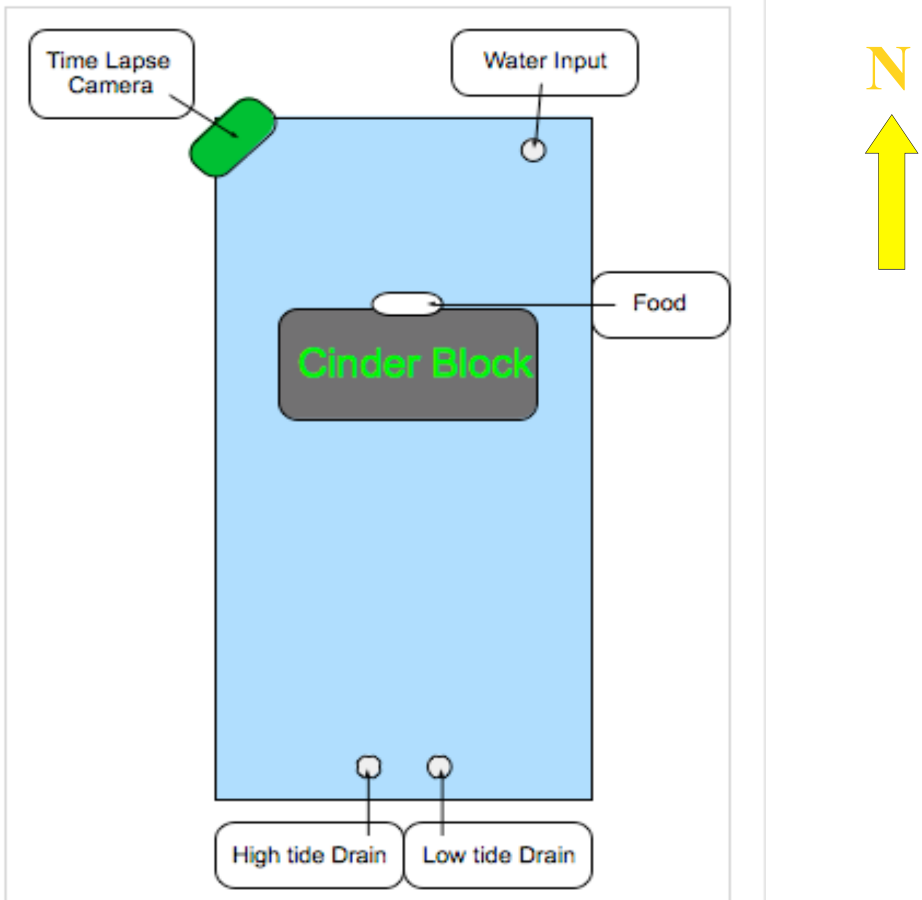


Figure 1 Diagram of laboratory tank set up.

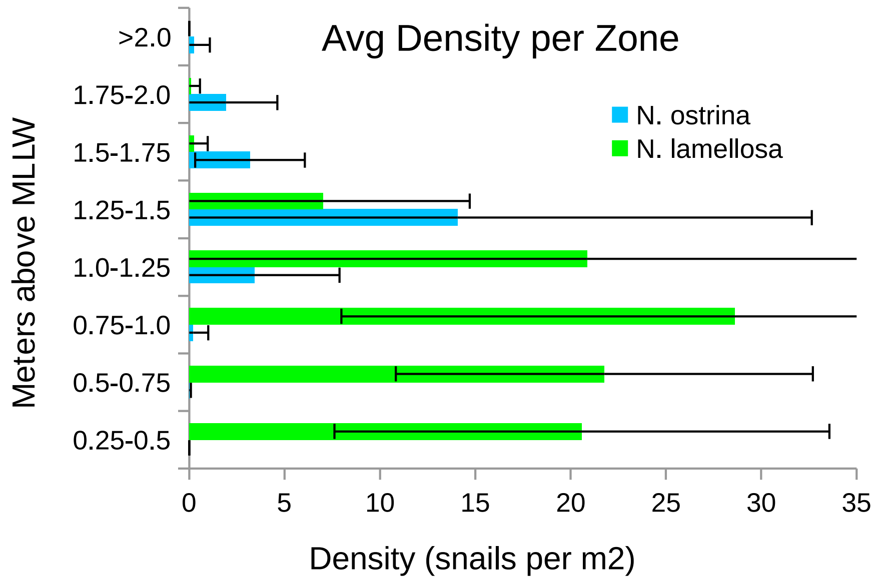
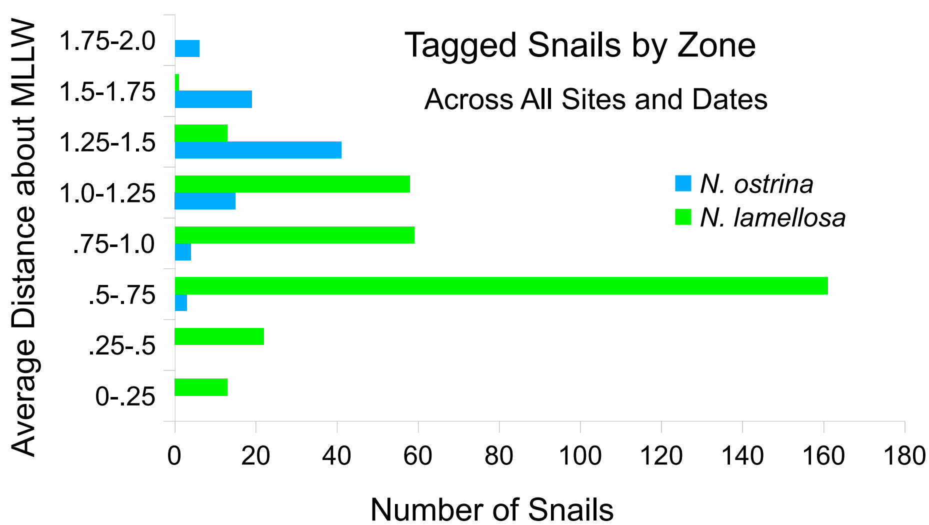


Figure 2 Average density of each species by zone, averaged across all zones and days. Error bars show



standard deviation.

Figure 3 Total number of tagged snails of each species found throughout the study by zone. All date and Zones combined.

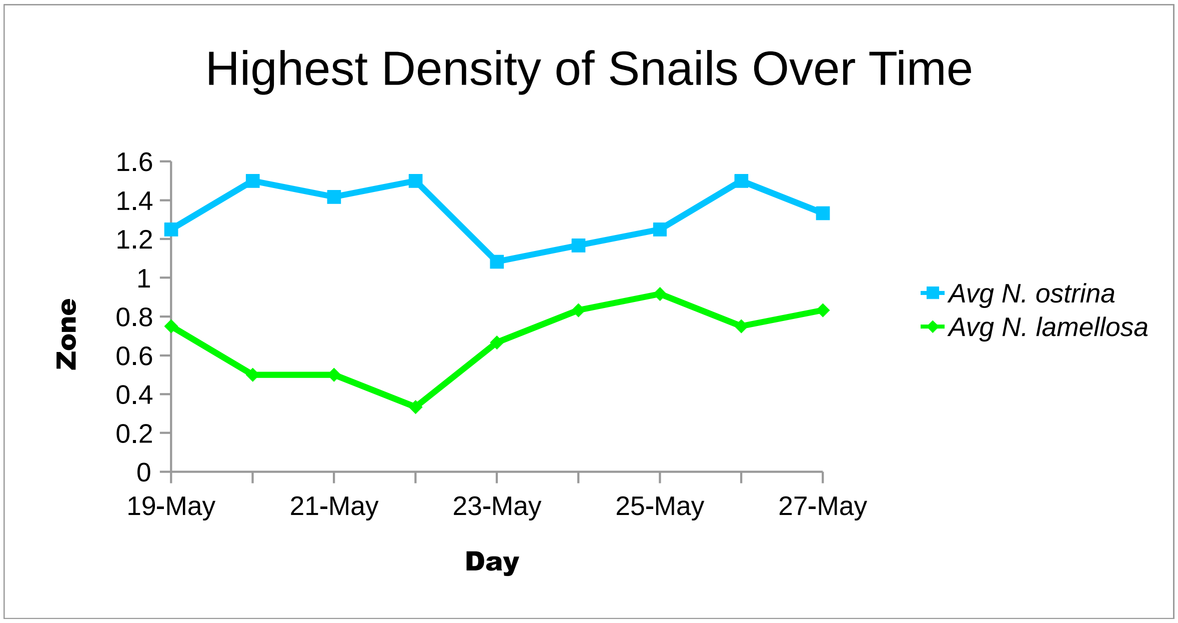


Figure 4 The changes in density of each species of snail across all sites per day.

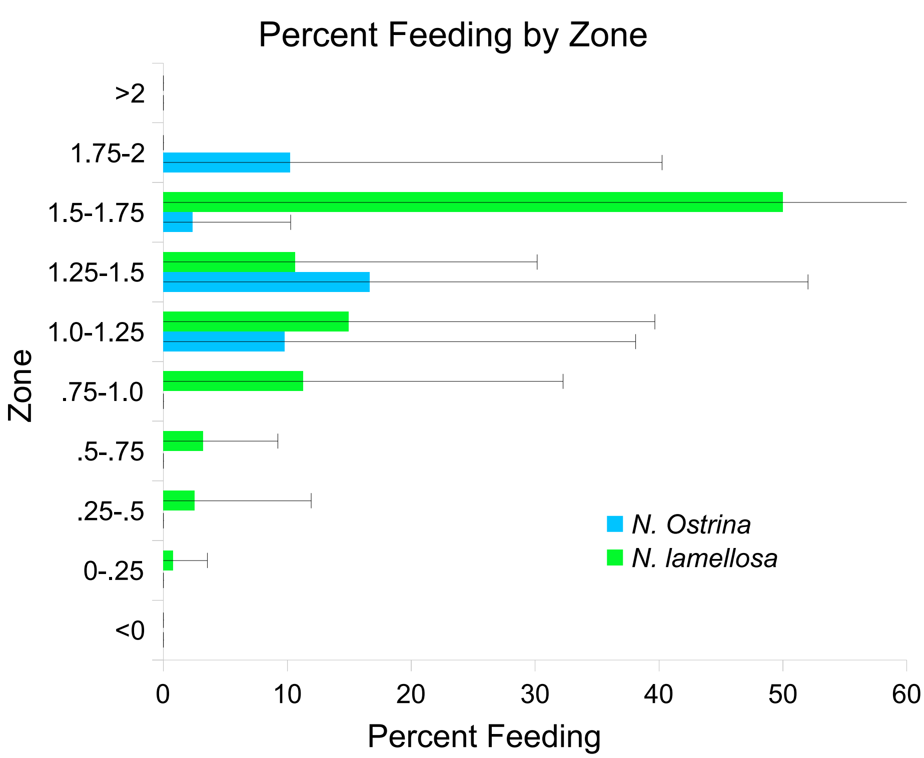


Figure 5 The percentage of snails per zone found eating, calculated across all days and sites. Error bars were calculated from the standard deviation.

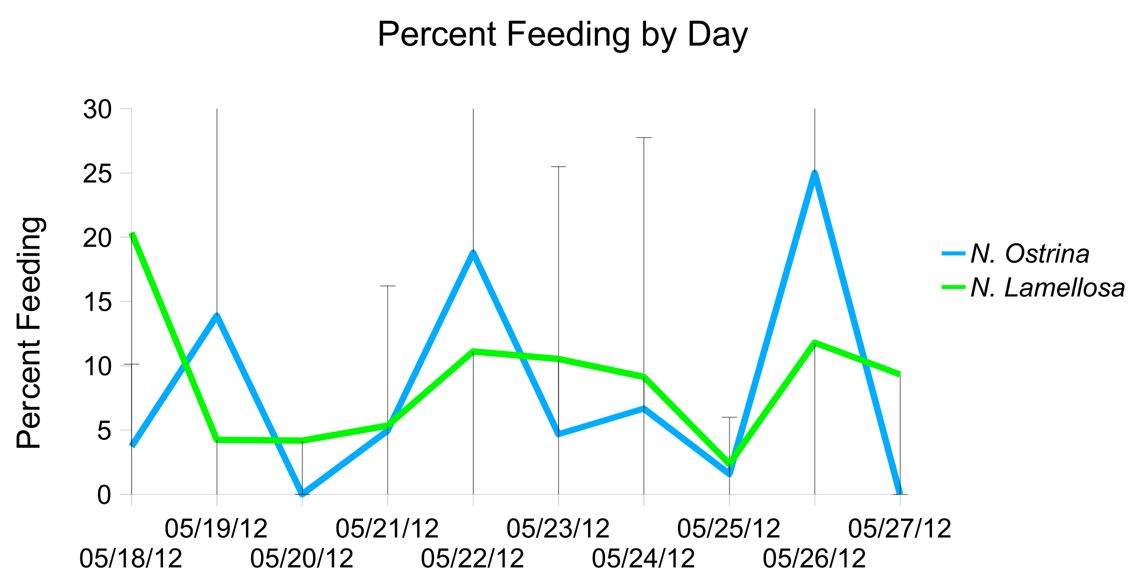


Figure 6 Percentage of snails feeding each day, calculated across all zones and sites. Error bars are calculated from standard deviation, positive error bars are on *N. ostrina,* negative error bars are on *N. lamellosa.*

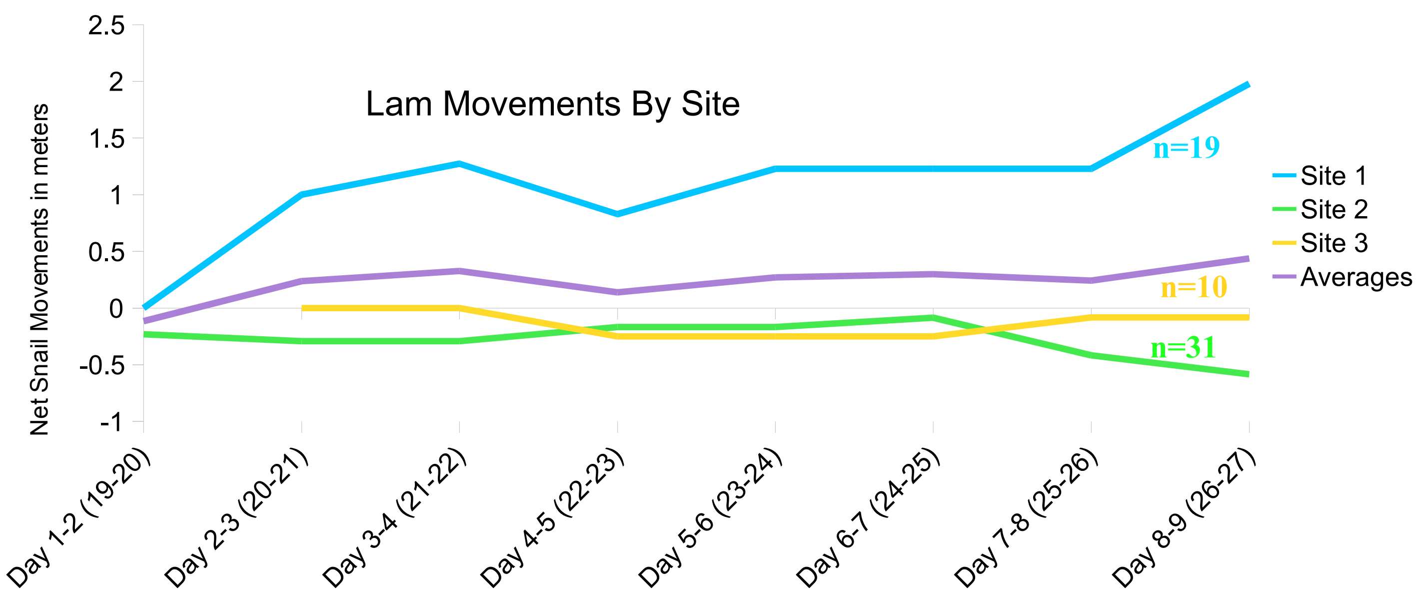
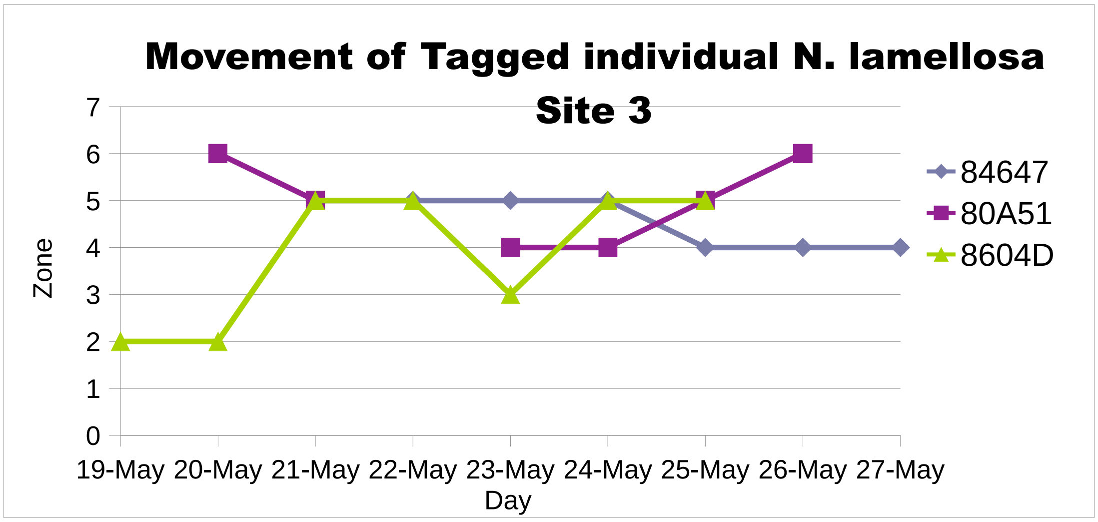


Figure 7 Net movements of all tagged snail seen at least two days in a row. Separated by site as well as with an average. The positive direction on the y-axis indicates movement up the shore, while the negative indicates movement down the shore. No Snails were seen at site 3 on both days 1 and 2.



Figures 8 Vertical movement of individual tagged *N. lamellosa* at site 3.

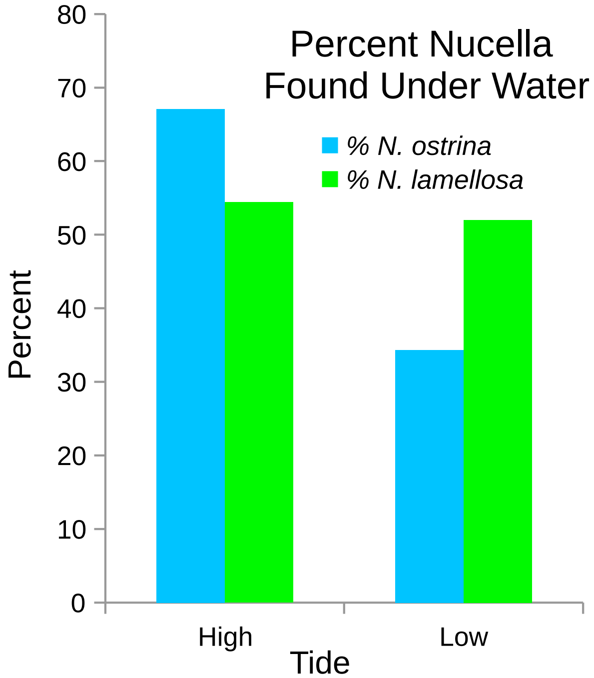


Figure 9 Percentage of each species found under water in the tank study during the two artificial tides.

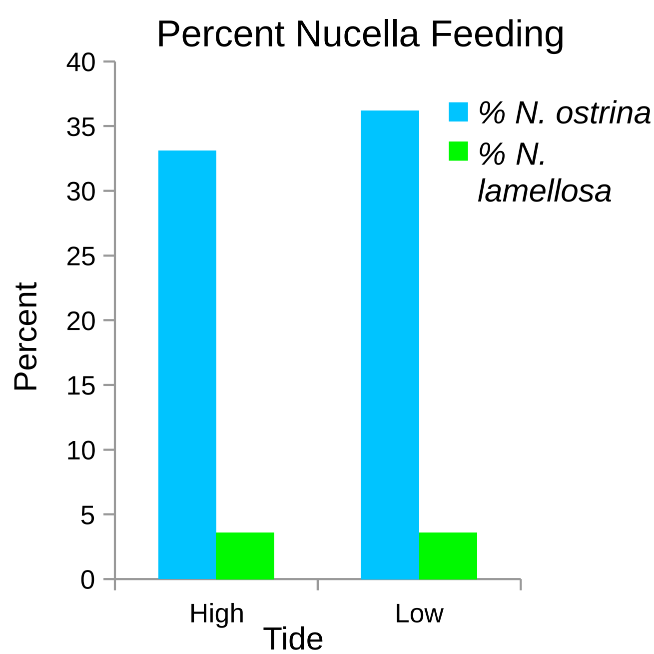


Figure 10 Percentage of each species located on the food during the two artificial tides in the the tank.