



Barnacle (*Balanus balanus*)

Feeding adaptations of the *Balanus balanus* barnacle: How the rates and extensions of cirri change depending upon changes in fluid flow



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Feeding Adaptations of the Balanus balanus barnacle: How the rates and extensions of cirri change depending upon changes in fluid flow

Introduction

Balanus balanus barnacles are members of the crustacean class that typically are found in inter-tidal zones. All barnacles are hermaphrodites that attach themselves to their substrate (usually rocks, pebbles, shells, clams) during their larval stage and stay attached throughout their lives (Beller, 2000). Due to the barnacle's inter-tidal habitat, they are subject to numerous changes in their environment and therefore must adapt. One of these environmental changes that the barnacle has to adapt to is changes in fluid flow. A general adaptation to changes in fluid flow that the *Balanus balanus* barnacle has evolved is evident through the barnacles orientation on a substrate. When they attach themselves to the substrate, the barnacles typically orient themselves in clusters that flow upstream, perpendicular to ambient water flow (Pullen & LaBarbera, 1991). This orientation is optimal for barnacles because studies have shown that upstream clusters capture more food particles and have a larger growth rate than clusters that are orientated downstream (Pullen & LaBarbera, 1991). Due to different orientations within a cluster, the sizes of full grown barnacles vary between 3 and 23 centimeters (Beller, 2000).

Barnacles use filter feeding to obtain their plankton and other food. This filter feeding mechanism includes long cirri (limbs) that are covered in tiny hairs unrolling from the operculum and extending across the water to capture their prey (Dill, Lawrence & Gillett, Jill, 1992). There is no muscle in the six pairs of cirri, so the unrolling and extension of the cirri is due to pressure in the haemocoel rather than muscle contraction (An example of a sessile filter feeder: The Barnacle, 1997). Depending upon different environmental conditions, barnacles have been shown to elicit three general patterns of cirri movement: normal beat, rapid beat, and extension (Pullen & LaBarbera, 1991). Typically during conditions of high flow, the barnacles shift from rapid cirri beating to long cirri extensions or retraction of their cirri and closing of the operculum (Pullen & LaBarbera, 1991). This retraction of cirri is a defense mechanism barnacles have developed to survive in their inter-tidal zone environment. This defense mechanism is primarily used to escape from predators (Mauck & Harkless, 2001). This defense mechanism is lessened during feeding times and is why this experiment compares the rates and extensions of cirri movement under different flow conditions while the barnacle is feeding (Sturdy, 2002).

For this experiment, the *Balanus balanus* barnacle's feeding adaptations to changes in fluid flow were tested. Specifically this experiment compared the extension and rate of cirri movement in high-flow, mid-flow, and no-flow conditions. Three hypotheses were created. Hypothesis one was that the barnacle will have an average rate of cirri movement, and cirri extension (both height and width) in mid-flow than at either high-flow or no-flow situations. This is because mid-flow is not an extreme water flow condition like no-flow or high-flow conditions; therefore, barnacles will not alter their cirri movement or extension as much to accommodate different environmental conditions. Hypothesis two was that at conditions of no-flow and high-flow the rate of cirri will increase from that of mid-flow and both the height and width or cirri extension will increase due to drastic changes in their environment. Hypothesis three was that at a high-flow scenario, the barnacle will retract its cirri and close up completely in order to protect itself from hazardous conditions.

The experiment collaborated with Nicole Schaaf and Lisa Martin. Nicole Schaaf and I both did experiments that looked at the feeding mechanisms of marine organisms. Nicole Schaaf tested chemosensation of starfish and how that impacts their feeding strategies while I looked at barnacles feeding response to different water flow conditions. Lisa Martin and I both did experiments that used marine organisms that have evolved a hard outer covering to live in their ever changing environment. Lisa Martin looked at shell preference in hermit crabs while I looked at barnacles adaptations to changes in fluid flow.

Materials and Methods

For this research project one glass tank, one *Balanus balanus* barnacle, plankton, pipette, a digital video camcorder, aerator, I-Movie, and adobe photoshop were used. This experiment took three days to perform and was conducted in the cool room on the third floor of the Science Center.

Day one began with the rinsing of the plastic aquarium that was previously washed to avoid transferring diseases to the *Balanus balanus*. Next sea water was made with a fellow experimenter Lisa Martin. The creation of sea water took about 20 minutes. We used instant ocean salt and five gallons of pre-cooled deionized water. The deionized water was

obtained from the cool room (3rd floor of the Science Center at Wheaton College) and therefore was at 10 degrees Celsius. The temperature of our salt water was compared with the temperature of the aquarium holding our animals using a thermometer. The salinity of our salt water was compared with the salinity of the aquarium holding our animals using a hydrometer. The salinity of both aquariums sea water was 25 degrees (specific gravity). The salt water was then aerated using an aerator for about 30 minutes. Next, some of the salt water was poured into the new aquarium. While the new aquarium was being aerated, plankton from the cool room was obtained and placed next to the new aquarium.

Once the new aquarium's temperature and salinity was equal to the old aquarium, the *Balanus balanus* was obtained from its original aquarium and placed in the center of the new aquarium. About 2 millimeters of plankton was placed from the top into the new aquarium. The barnacle was observed for approximately 3 minutes before it began to open their operculum and extend their cirri (retractable appendages).

A digital video camcorder was obtained and set up on a tripod as close to the aquarium as was possible. About 2 millimeters of plankton was placed into the aquarium. The digital video camera was focused and 5 minutes of the barnacle feeding was recorded to obtain a constant. After recording, the barnacle was placed back into its original aquarium and the work bench was cleaned up.

Day 2 began by setting up the aquarium with pre-made 12 degree aerated salt water. The barnacle was then placed in the center of the aquarium and was able to adjust to its new surroundings for about five minutes. Meanwhile, the digital video camera was set up on a tripod as close to the aquarium as possible. Once the 5 minutes were up, about 2 millimeters of plankton was placed into the aquarium from the surface. The digital video camera then recorded the cirri movement for 5 minutes. Once the 5 minutes passed, the digital video camera was paused. The aerator was plugged in and placed on the bottom of the aquarium. The digital video camera was set to record and a sample size of about 2 millimeters of plankton was obtained and dropped on the surface of the water. The cirri movement and extension was recorded for 5 minutes. After 5 minutes, the digital video camera was paused and the aerator was removed from the aquarium. The barnacles were given 5 minutes at a no-flow condition in order to return the water flow to a constant and allow the barnacles to adjust. Next, the aerator was re-plugged in and placed on the surface of the aquarium. The digital video camera was set to record and a sample size of about 2 millimeters of plankton was obtained and dropped on the surface of the water. The cirri movement and extension was recorded for 5 minutes. After 5 minutes, the digital video camera was shut off and the aerator was removed from the aquarium. The barnacles were given 5 minutes at a no-flow condition in order to return the water flow to a constant and allow the barnacles to adjust.

Once the barnacles adjusted and the water flow was no-flow a second trial at each of the three different flow conditions was done. The first recording was done at the no-flow condition. Two millimeters of plankton was placed into the aquarium from the surface. The digital video camera then recorded the cirri movement for 5 minutes. Once the 5 minutes passed, the digital video camera was paused. The aerator was plugged in and placed on the bottom of the aquarium. The digital video camera was set to record and a sample size of about 2 millimeters of plankton was obtained and dropped on the surface of the water. The cirri movement and extension was recorded for 5 minutes. After 5 minutes, the digital video camera was paused and the aerator was removed from the aquarium. The barnacles were given 5 minutes at a no-flow condition in order to return the water flow to a constant and allow the barnacles to adjust.

Next, the aerator was re-plugged in and placed on the surface of the aquarium. The digital video camera was set to record and a sample size of about 2 millimeters of plankton was obtained and dropped on the surface of the water. The cirri movement and extension was recorded for 5 minutes. After 5 minutes, the digital video camera was shut off and the aerator was removed from the aquarium. The barnacles were given 5 minutes at a no-flow condition in order to return the water flow to a constant and allow the barnacles to adjust. Once the water flow settled to a no-flow situation, 2 millimeters of plankton was placed on the waters surface and the rate and extension of cirri were recorded for 5 minutes.

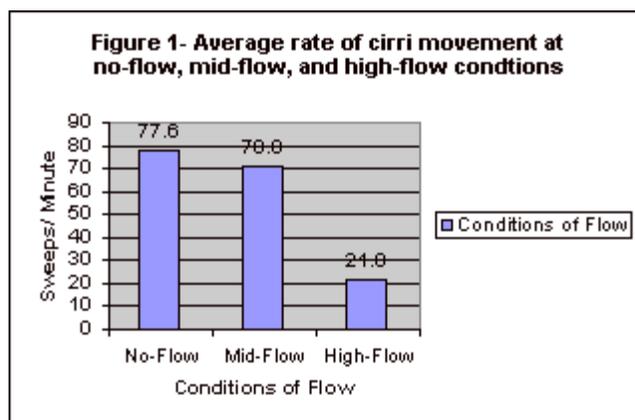
Day 3 consisted of quantifying and analyzing the data that was collected. This behavioral experiment was quantified in two steps. First, the rate of cirri movement was measured in sweeps/ minute. This was done using I-movie and counting the number of sweeps in one minute from various barnacles in mid-flow, no-flow, and high-flow conditions. The number of sweeps/min was recorded. A total of five separate barnacle cirri movement were recorded for each of the three water flow conditions, no-flow, mid-flow, and high-flow. Once all the data was collected, an average rate of cirri movement/ minute was obtained from each of the three flow conditions. These averages were then placed into a bar

graph that depicts the average number of cirri beats/minute for each of the three water flow conditions.

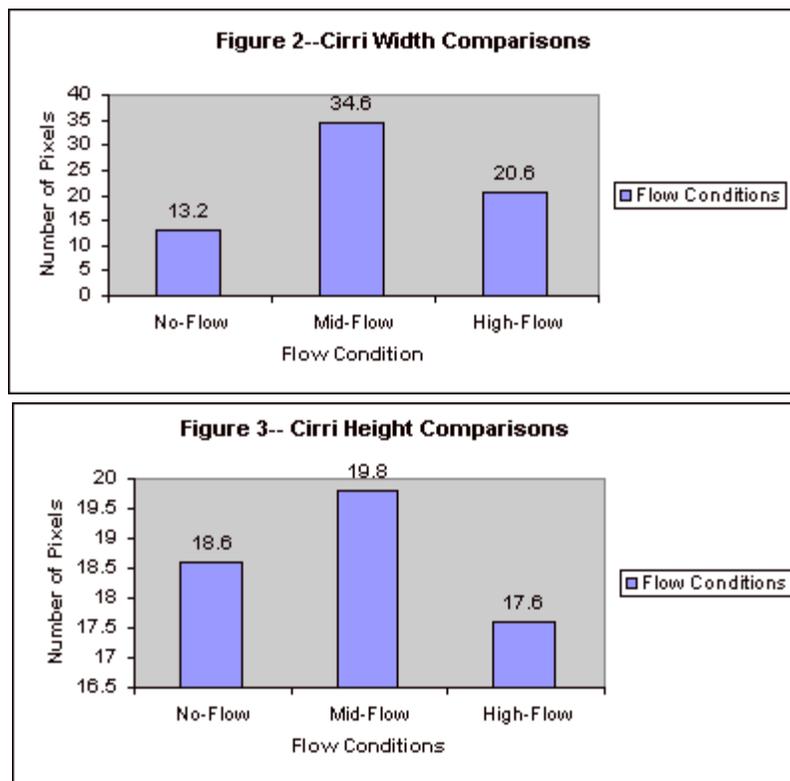
The second step in quantifying the data was to record cirri extension using adobe photoshop. Cirri extension was quantified by determining the height and width of each cirri extension. This was done by recording the number of pixels in Table 1. Recording of pixels was done for each of five samples within each of the three flow conditions. Bar graphs were made depicting the average width and height cirri extension for no-flow, mid-flow, and high-flow conditions (See Figure 2 & 3).

Results

For this experiment, the cirri rate was measured in sweeps/minute. A total of 5 random samples were recorded for each of the 3 different water flow conditions (n=15). For conditions of no-flow the 5 random samples yielded cirri movements of 72, 84, 89, 73, and 70 beats per minute. Averaged together this yielded 77.6 beats per minute. For conditions of mid-flow the 5 random samples yielded cirri movements of 65, 68, 80, 78, and 63 beats per minute. Averaged together this yielded 70.8 beats per minute. For conditions of high-flow 5 random samples yielded cirri movements of 30, 3, 28, 25, and 23 beats per minute. Averaged together this yielded 21.8 beats/ minute. The average beats/ minute for no-flow, mid-flow, and high-flow were placed into a bar graph (See Figure 1). In general the cirri beat at a slower rate, measured in sweeps/minute, during mid-flow circumstances than during no-flow circumstances; however, at high-flow circumstances the cirri movement was significantly lower than at either mid-flow or no-flow conditions.



The height and width for 5 cirri extensions for each of the three water flow conditions was recorded (n=15). Cirri extension was measured by counting the number of pixels to determine the height and width of each cirri extension. The height and width of each cirri extension for all samples were recorded. Average numbers were obtained for height and width pixel numbers. For conditions of no-flow the 5 random samples yielded cirri width of 13, 15, 12, 14, and 12 pixels. Averaged together this yielded 13.2 pixels. For the same no-flow water condition, the 5 random samples yielded cirri height of 20, 18, 18, 19, and 18 pixels. Averaged together this yielded 18.6 pixels. For conditions of mid-flow the 5 random samples yielded cirri width of 33, 35, 38, 34, and 33 pixels. Averaged together this yielded 34.6 pixels. For the same mid-flow water condition, the 5 random samples yielded cirri height of 19, 19, 21, 21, and 19 pixels. Averaged together, this yielded 19.8 pixels. For conditions of high-flow the 5 random samples yielded cirri width of 33, 35, 38, and 34 pixels. Averaged together this yielded 20.6 pixels. For the same high-flow water condition, the 5 random samples yielded cirri height of 16, 17, 18, 18, and 19 pixels. Averaged together this yielded 17.6 pixels. Bar graphs were constructed so that comparisons between no-flow, mid-flow, and high-flow conditions could be made (See Figure 2 & 3).



In general the height of cirri extension was around the same number of pixels in all three water flow conditions; however, the width of cirri extension changed dramatically. Mid-flow had the largest average width of cirri ($x=34.6$ pixels) followed by the average high flow width of cirri ($x=20.6$ pixels). Low flow conditions yielding the smallest width measurements ($x=13.2$ pixels) of any of the three flow conditions (no-flow, mid-flow, high-flow).

Discussion and Conclusions

The general findings of these experiments indicated that for a five minute interval, the barnacles response to either water extreme, no-flow or high-flow, caused reduction in cirri height and width extension. Reduction of cirri width and height was seen through comparing pixel numbers at each of the three water flow conditions. The reduction in width of cirri was more significant than the rate of height of cirri. This is noted by more drastic changes between the three water flow conditions. However, the barnacles rate of cirri movement (number of sweeps/ minute) was largest at a no-flow scenario rather than at a mid-flow or high-flow scenario. Therefore, no-flow conditions, according to my experiments, yielded to the smallest cirri width extension, average cirri height extension, and the largest cirri rate of movement. Mid-flow conditions yielded large cirri width extension, large height cirri extension, and average rate of cirri movement. At high-flow conditions there was average cirri width extension, small cirri height extension, and the smallest cirri rate of movement.

Based upon these results, these experiments seemed to support two of the three hypotheses. Hypothesis one was that the barnacle will have an average rate of cirri movement, and cirri extension (both height and width) in mid-flow than at either high-flow or no-flow situations. This is because mid-flow is not an extreme water flow condition like no-flow or high-flow conditions; therefore, barnacles will not alter their cirri movement or extension as much to accommodate different environmental conditions. This experiment supported this hypothesis because the average rate of cirri movement and average rate of extension (for both height and width) for mid-flow conditions was less than the rate of cirri movement at no-flow conditions, but more than during conditions of high-flow.

Hypothesis two was that at conditions of no-flow and high-flow the rate of cirri will increase from that of mid-flow and both the height and width or cirri extension will increase due to drastic changes in their environment. This experiment showed that the rate of cirri movement during high-flow conditions was the least, followed by conditions of mid-flow,

and conditions of no-flow had the least cirri movement. For cirri width extension, conditions of mid-flow had the largest cirri extension followed by high-flow and no-flow had the least cirri width extension. For cirri height extension, mid-flow had the largest average cirri height, then no-flow, and high-flow had the least cirri height extension.

Hypothesis three was that at a high-flow scenario, the barnacle will retract its cirri and close up completely in order to protect itself from hazardous conditions. Through these experiments, this hypothesis was proven accurate and a cause for possibly some error in this experiment.

In addition to the environmental adaptation of closing up to escape harm, which caused difficulty in obtaining data for certain flow conditions, other possibilities could have caused results to be skewed. Results could have been skewed because the same exact barnacle's cirri were unable to be used for the cirri movement and extension analysis. Results could also have been skewed because at conditions of high flow, the aerator created bubbles which yielded to hard conditions to count cirri movement and extension 100% accurately. If this experiment were to be done again, taking these possibilities for error into account would be helpful in obtaining more accurate results.

The results of my study and the results of both of my collaborators studies, Lisa Martin and Nicole Schaaf, were unable to be correlated. Lisa Martin and I both studied marine organisms that have a hard outer covering, but our experiments were quite different and thus yielded different results. She studied shell preference of the hermit crab while I studied the response of the *Balanus balanus* to different water flow conditions. My results were unable to be correlated with my other collaborator Nicole Schaaf due because she measured her results in terms of food preference and the ability to use chemosensation in that process while i tested my experiment using a constant food source of plankton. Due to these difficulties my results were unable to be correlated to my collaborators.

To continue with this experiment in the future, one could study the cirri response to various food sources in response to changes in water flow. Perhaps feeding on one type of prey causes more or less cirri movement/ extension? Another possibility for continuation would be to observe the barnacle's response to the change in water flow over longer periods of time. Perhaps barnacles adjust to different rates of flow and in the end, once they realize that little harm will be placed on them, will adjust and continue with their normal rate of movement and extension.

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Credits

Barnacle image #1 downloaded from <http://www.maritimstart.com/images/skipsrurbalanuscrenatus.jpg>

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Balanus balanus barnacle downloaded from google on 3/25/2003 at

<http://www.marinbi.com/b-balanu.jpg>