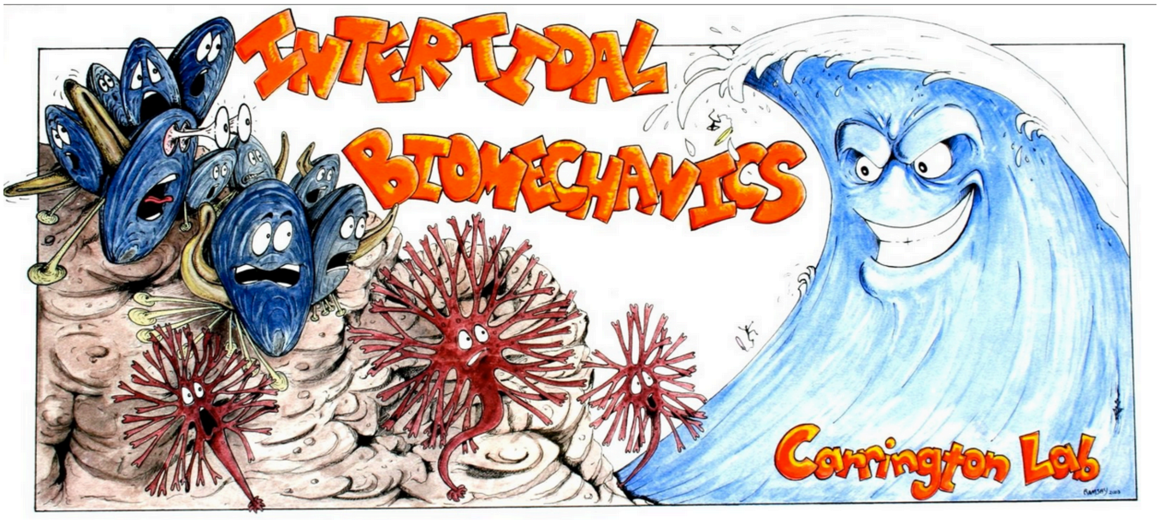


Case Study
A Tale of Two Stressors—Ocean Acidification in a Warming World

Background: Biologists who study ocean acidification (OA) in the laboratory often focus on the effects of pH change in isolation from other environmental variables. This can be a useful approach, because it allows researchers to definitively link cause (lower pH) and effect (for example, smaller urchin larvae). This is not the way marine organisms experience acidification in their natural environment, however. It is much more typical for an organism to experience multiple stressors simultaneously. This Case Study describes how the Carrington lab at the University of Washington (http://depts.washington.edu/ecarring) is trying to understand the combined effects of acidification *and* increased seawater temperature on mussels, a type of bivalve. It also considers the findings of another group of researchers (http://pfisterlab.uchicago.edu/ and http://woottonlab.uchicago.edu/) who are studying how ocean change is affecting the intertidal community on remote Tatoosh Island, off the northwest corner of Washington State.

Lesson Plan (1-2 days):

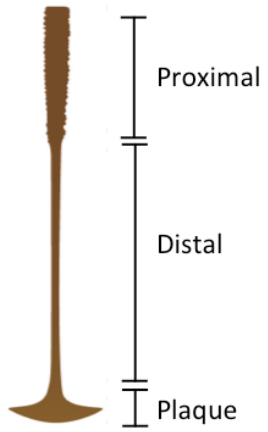
Review the following resources about how mussels are able to survive in the stressful intertidal environment, and how ocean acidification may be making it harder for them to maintain their grip (literally):

- BBC video (4.5-minutes) about the coastal intertidal zone: http://www.bbc.co.uk/nature/habitats/Intertidal_zone#p00l2t0n
- *UW Daily* article: http://www.dailyuw.com/science/article_cbf0d545-3e7e-55ce-a58c-58d5142ec2a4.html
- UW press release: www.eurekalert.org/pub_releases/2013-02/uow-mcb020813.php

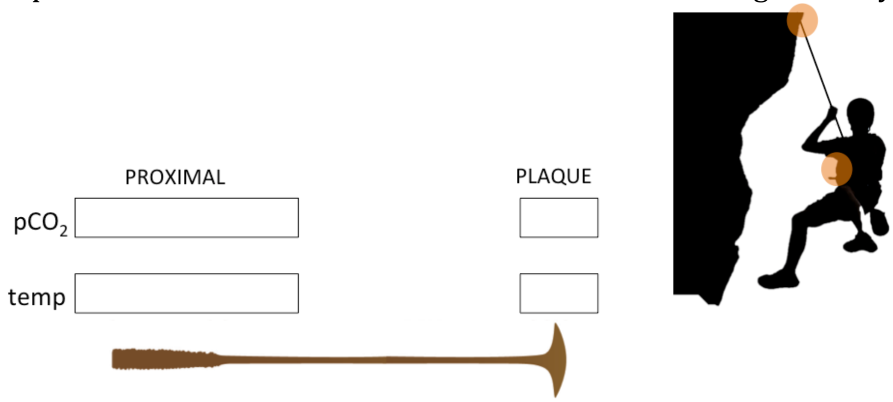
- Carrington lab webpage on OA and Mussel Byssal Attachment: http://depts.washington.edu/nucella/mussel-byssal-threads/
- Carrington lab graduate student Laura Newcomb's presentation on the combined effect of acidification and temperature on mussel byssal thread strength (15 minute video: https://youtu.be/vkHyrL4_nU8). *Note to instructors: you may want to review the connection between dissolved CO_2 (pCO_2) and pH: in seawater, a molecule of CO_2 combines with a molecule of H_2O to form carbonic acid (H_2CO_3), which lowers the pH.*

Use the following questions and exercises as a basis for in-class discussion or group work (possible answers in bold):

1. How would you describe mussels' habitat? **Intertidal, rocky, strong waves and currents, extremely changeable due to tidal cycle…** What adaptation(s) allow mussels to withstand the mechanical stress (i.e. wave action) typical of that environment? **Glue themselves to rocks, hard shells, …** How do mussels attach themselves to a surface? **The mussel's foot secretes byssal threads—strong, stretchy fibers with which it attaches itself to the substrate.**
2. What *other* types of stress do intertidal organisms experience? **Predation, competition for space, competition for food, water temperature changes related to season and tides, unable to feed or breathe when exposed at low tide, desiccation, freezing, log damage, parasites …** What *new* stresses are occurring as a result of anthropogenic (human-generated) CO_2? **Increased seawater temperatures *and* ocean acidification.** What is the connection between CO_2, seawater temperature and pH? **Excess atmospheric CO_2 traps heat, warming the ocean surface; excess dissolved CO_2 (pCO_2) lowers seawater pH.**
3. You already know that marine calcifiers like oysters, urchins (and mussels!) have to work harder to obtain the carbonate they need for their calcium carbonate shells and skeletons from acidified seawater. The Carrington lab has found evidence that mussels could also be vulnerable to another type of direct impact from ocean acidification. Describe. **In laboratory experiments, high pCO_2/low pH conditions weaken byssal threads. Specifically, the weakening seems to occur in the plaque region where the thread adheres to rocky surfaces.** What others environmental stress affects the ability of mussels to maintain their hold on a substrate? **Byssal threads formed at temperatures above 65 F (18 C) are significantly weaker.**
4. Using the byssal thread diagram below, indicate how both elevated temperature and higher pCO_2/low pH conditions affected byssal thread strength in Laura Newcomb's laboratory experiments.



5. Use the diagram below to summarize how temperature and pCO_2 independently affect byssal thread strength. Use the rock climber analogy to explain how these two stressors affect the overall strength of a byssal thread.



6. Laura concluded that pCO_2 and temperature do not act 'synergistically' to weaken byssal threads (in other words, the combined effect of these two stressors is *not* greater than the effect of either one by itself). However, these two climate change-related stressors may still combine to reduce the overall ability of mussels to colonize a surface, whether they're growing on a rocky shore or a culture rope. What is one possible mechanism, and how would you test your idea? **If the timing of high pCO_2 episodes and warmer temperatures do not coincide, then these two stressors could combine to lengthen the period of time when mussel byssal threads are weaker, leading to a longer window where detachment is a problem.**
7. How did Laura apply what she learned in her lab experiments to her field work at Penn Cove mussel farm? **After concluding that temperature was a more important determinant of byssal thread strength than pH, she tested the byssal thread strength of mussels growing at different depths along the culture ropes, to see if tenacity correlated with seasonal temperature patterns.**
8. If you were a mussel grower, would you change anything about your culture practices based on Laura's findings?

- **Optional (advanced): As a group, read and discuss the Carrington lab publication *Mussel Byssus Attachment Weakened by Ocean Acidification*; Nature Climate Change; March 2013; doi:10.1038/nclimate1846.** Direct link: http://rdcu.be/F9G0 (subscription required); also available from the Carrington lab website: https://depts.washington.edu/nucella/mussel-byssal-threads/. *Note to instructors: Reading and interpreting a scientific article will be challenging for most high school students, but it's possible to gain something from the experience without getting bogged down by technical language or complex figures. There are several ways to approach this manuscript:*

- *Use the paper as an opportunity to see how scientists share their findings with their peers;*
- *Explore the structure of a scientific paper (framing the research question in the introduction; presenting the results; sharing the methods; backing up statements with references);*
- *Simply to try to summarize the authors' hypothesis, major results and conclusions;*
- *Carefully analyze a figure and discuss whether the data support the authors' conclusions;*
- *Focus on the Methods section. How were the experiments carried out? Discuss why the authors might have chosen to conduct the experiments as they did* [Note: reference #26 (Moeser and Carrington, 2006; *Seasonal variation in mussel byssal thread mechanics*; Journal of Experimental Biology vo. 209) provides a more thorough explanation of the methods used in this study]

Review the following resources about scientists Tim Wooton's and Cathy Pfister's ocean acidification field work on Tatoosh Island, off the coast of Washington:

- New York Times article (Oct. 2012): http://www.nytimes.com/2012/10/07/us/scientists-in-washington-state-adopt-tiny-island-as-climate-change-bellwether.html
- Oregon Public Broadcasting 9-minute video (Feb 2010): http://www.opb.org/television/programs/ofg/segment/ocean-acidification/

Use the following questions and exercises as a basis for in-class discussion or group work (possible answers in bold):

- Scientists have been monitoring the intertidal habitat on Tatoosh Island for over 40 years. Recently, they've observed some startling trends. What are they? **Declines in seabird and calcifier (barnacles, mussels and coralline algae) populations; mussels—thinner shells & weaker attachment to substrate;**

- What do the scientists believe is behind these changes? **Human's use of fossil fuels is increasing the level of CO_2 in seawater. In seawater, CO_2 combines with water molecules form carbonic acid, which is making seawater more acidic (i.e. lowing the pH). Declining pH is directly impacting some species, and indirectly affecting others (through food web interactions and changes in habitat).**
- What is the "Keystone Species Hypothesis", and how does it apply to what scientists are seeing on Tatoosh Island? **The keystone species concept has been a mainstay of the ecological and conservation biology literature since its introduction by University of Washington zoology professor Robert T. Paine in 1969. A keystone species is one whose impacts on its community or ecosystem are large and greater than would be expected from its relative abundance or total biomass. Keystone species are usually noticed when they are removed or they disappear from an ecosystem, resulting in dramatic changes to the rest of the community. The phenomenon has been observed in a wide range of ecosystems and for a wide range of organisms. On Tatoosh, mussels and barnacles are keystone species; they dominate the intertidal zone, and influence many other Tatoosh species through food web interactions, and as architects of the intertidal habitat.**