Case Study: Sea Urchins, Ocean Acidification and Adaptation

Background: The ocean is home to countless organisms and provides for humans in many ways. Carbon dioxide generated by humans' use of fossil fuels is making life harder for many of these organisms (and all of us who depend on the ocean) because it reacts with seawater to form carbonic acid—a process known as ocean acidification (OA). Pacific oysters have made the news recently as an important marine resource that is threatened by acidification, but they are not the only species that is sensitive to changing seawater chemistry. Ocean acidification may make it harder for *all* calcifiers (marine organisms that use calcium carbonate to build their shells and skeletons) to grow and survive. Sea urchins, which inhabit the rocky intertidal zone of the North American west coast, from Alaska to Mexico, could also be vulnerable. This Case Study describes how a commercial urchin diver and several California scientists are asking the question "What impact will ocean acidification have on sea urchins, and will they be able to adapt to an increasingly corrosive environment?"
[Hofmann lab webpage: https://labs.eemb.ucsb.edu/hofmann/gretchen/]

Lesson Plan:

Day 1 (50 minutes):

1. Watch this 3 minute Seattle Times video featuring sea urchin diver Bruce Steele and UC Santa Barbara scientists Gretchen Hofmann and Morgan Kelly: http://video.seattletimes.com/2790375299001/
2. Read the associated Seattle Times *Sea Change* article (part 4 in an ongoing series of articles about Ocean Acidification). Best read online, with embedded graphics and video: http://apps.seattletimes.com/reports/sea-change/2013/nov/2/can-sea-life-adapt/
3. Watch the 7 minute Museum of Natural History video showing how Gretchen Hofmann and her grad students investigate the effect of ocean acidification on sea urchin larvae: http://www.youtube.com/watch?v=mFlOgNrfSdo

Day 2 (1-2 hours):

4. Conduct an experiment to see how CO_2 affects sea urchin larvae online at Virtual Urchin: http://virtualurchin.stanford.edu/AcidOcean/AcidOcean.htm

Day 3 (optional; 1-2 hours):

5. (Advanced) Read and discuss the scientific article published by Kelly, Padilla-Gamiño and Hofmann: "Natural variation and the capacity to adapt to ocean acidification in the keystone sea urchin *Strongylocentrotus purpuratus*".

Study Guide:

Seattle Times video and accompanying article

1. What is evolution? **Evolution is the change in the inherited characteristics of biological populations over successive generations**. What must exist in order for evolution to occur? **Genetic differences between individuals in a population. Without genetic variability, natural selection has nothing to act upon.**

2. To what challenge will sea urchins have to adapt, if they are to survive in an increasingly acidic ocean? **They will need to maintain their ability to 'calcify' (form their calcium carbonate skeletons and spines), even though acidification will make the carbonate ions they need for this processes increasingly scarce.**

3. What did Gretchen Hofmann discover when she started analyzing the effects of ocean acidification on sea urchin larvae? **She found that 1) sea urchin larvae raised under high CO_2 conditions were, on average, smaller than larvae raised in normal seawater, but also 2) not *all* the larvae raised under high CO_2 conditions were smaller.** Given what you know about ocean acidification, do you find these results surprising? **Yes, I would have expected that high CO_2 would make it harder for every larvae to grow normally; or No, I know that every individual is slightly different, so I wouldn't expect all of them to respond to high CO_2 conditions in the same way.**

4. What approach did Hofmann and evolutionary biologist Morgan Kelly take try to understand whether sea urchins have the capacity to adapt to ocean acidification? **They asked if the body size variation they observed was due to genetic differences, and whether that variation was heritable.** What did they discover? **They found that urchins did have the ability to pass along 'tolerance' (the ability to grow to normal size under high CO_2 conditions) to their offspring, and therefore must have *some* capacity to adapt to acidification.**

5. What does the term "genetic variation" mean? **Genetic variation refers to differences among individuals in a population. This type of variation is at the level of the gene (or genes) that determine a particular trait, such as body size.** Why is genetic variation important? **Adaptation cannot occur without genetic variation.**

6. What natural process might be providing the selective pressure to maintain genetic variation for size among sea urchin populations on the west coast? **Upwelling, which creates a lot of day-to-day and seasonal variability in seawater chemistry.**

7. Can you conclude from the results of Hofmann, Kelly and the other scientists mentioned in the article that sea urchins will be able to cope with increasingly acidic waters? Why or why not? **Their results suggest that sea urchins have *some* capacity to adapt, but they do not reveal how *great* that capacity is.**

   They may not be able to adapt sufficiently or fast enough to keep pace with the rapid rate of changing conditions.

8. Food for thought: Gretchen Hofmann seemed surprised to hear from Bruce Steele, but because he wasn't afraid to pick up the phone, and she was open to talking to him, her research headed in a whole new direction. What are some barriers to

him, her research headed in a whole new direction. What are some barriers to better communication between the public and scientists? What would make it easier for scientists and interested citizens to work together?

Natural History Museum video

9. What experimental design does Hofmann's lab use to study the effect of ocean acidification on sea urchins? **They bubble CO_2 into the seawater tanks where they're raising urchin larvae to create artificial acidification conditions. Then they observe the effect elevated CO_2 has on larval development by measuring their skeletons.**

10. What do they observe under high CO_2 conditions? **The larvae are "shorter & stumpier"; most metrics are shrinking by 10-15%**

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11. Dr. Hofmann is concerned that even though larvae do seem to be capable of forming their skeletons under high-CO_2 conditions, they may still fare poorly. What is she worried about? **An embryo has a limited amount of energy; if it has to work harder to build its skeleton, will it still be able to cope with the other stressors, like increase ocean temperature, that are also caused by human CO_2 emissions?**

Virtual Urchin

This online tutorial comes with its own exercises and study questions.

Kelly, Padilla-Gamiño and Hofmann (2013)

Article: Natural variation and the capacity to adapt to ocean acidification in the keystone sea urchin *Strongylocentrotus purpuratus*

Reference: Global Change Biology; Volume 19; pages 2536–2546

What they were studying: These researchers compared the size of larvae* resulting from crosses between two distinct populations of purple urchin *Strongylocentrotus purpuratus*. Parents were collected from two locations along the CA coast that experience different "upwelling regimes" (i.e. the two environments differ in the degree and duration of acidification). They chose to look at larval size because it is an important determinant of overall fitness. Ultimately, they are interested in the capacity of *S. purpuratus* to evolve increased tolerance to ocean acidification.

Hypothesis: Different upwelling regimes act to maintain genetic variation among urchins for tolerance to high CO_2/low-pH conditions. [In other words, the researchers hypothesize that 1) there is a genetic component to tolerance of high CO_2/low-pH conditions, and 2) urchin populations exposed to these conditions have a different collection of alleles than urchins from a less corrosive environment.] They predict that if urchins from the high CO_2 environment are better adapted to those conditions, they will be able to pass those genes along to their offspring.

Key questions:

1. *Does* genetic variation for pH tolerance exist within natural populations?
2. If there *is* variation, *how much* variation is maintained by natural differences in pH conditions among populations from the two test sites?

Prediction #1: If there is genetic variation for size under low-pH conditions, the researchers expected to see a difference in the size of larval offspring, *attributable to the sires* (fathers)*.

* Sires (fathers) contribute only genetic material, whereas dams (mothers) contribute both genetic material and "maternal effects" (such as the yolk quantity), which can also influence larval size. Focusing on the relationship between offspring size and sires allowed the researchers to exclude non-genetic factors.

Prediction #2: If there is local adaptation to carbonate chemistry, the researchers expect

Prediction #2: If there is local adaptation to carbonate chemistry, the researchers expect the offspring of sires from the northern site (with greater upwelling, longer low-pH events) *to be larger under high* pCO_2 than the offspring of sires from the southern site.

What they measured: Body size (total skeletal length) of pluteus-stage larvae (116 hours after fertilization, just past the end of the non-feeding stage, during which larvae subsist on maternally provided yolk).

Re: Figure 1:

1. What are the sensors measuring at the two sites?
2. What is the relationship between pCO2 and pH?
3. How do the two sites differ in terms of pH? (see Fig 1b)?

Re: Methods:

4. How did the researchers set up their crosses?
5. Why did they set up so many crosses?

Re: Results:

6. Under what two pCO_2/pH conditions did they rear the larvae?
7. Why did they choose 1210 µatm (microatmospheres) as their "high pCO_2" treatment, when the average sea surface pCO_2 level is only predicted to reach 450 µatm by mid-century?
8. Did they see a difference in the size of larvae reared under high pCO_2 vs. low pCO_2 conditions (see text and Fig. 4)? Given what you know about the effect of ocean acidification on calcifying species like sea urchins, is this what you would expect?

9. Did it seem to make a difference whether the sires (fathers) came from the northern (higher pCO_2) site vs. the southern (lower pCO_2)?
10. What would *you* conclude from the larval size data?

Re: Discussion:

11. What do you think is the most significant conclusion Gretchen and her team were able to draw from this study, and how did they reach this conclusion?