Ocean Acidification Leads to Broadening of Crab Predators and Faster Predation Rate on Mussels

By Katherine Corliss[1], Miranda Toner[1], and Melissa Britsch[1]

[1]Department of Integrative Biology, Oregon State University, Corvallis, OR 97331, USA

Abstract

Ocean acidification is caused by the dissolved carbon dioxide in the oceans lowering the amount of free carbonate ions. This is turn, affects the ability of calcifying organisms like mussels to build thick shells to protect against predation. Mussels are often preyed upon by both specialist crabs, like Red Rock crab (*Cancer productus*), and generalist crabs, like Kelp crab (*Pugettia producta*), but with limitations. This study considers the alterations to the limitations that are caused by thinning of mussel shells by ocean acidification. Crab preference to regular or thinned mussels was recorded during feeding trials. Times were taken for the time it took crabs to break the shells of both regular and thinned mussels. Kelp crab only ate the thinned mussels, meaning they could become a more frequent predator for mussels during ocean acidification conditions. Red Rock crab also preferred thinned mussels and it took them less time to break into them. The differences in feeding preference and breaking time for thinned and regular mussels were significant. This significance could help predict a shift in number of predators and feeding rate of crabs on mussels and other calcareous organisms caused by ocean acidification.

Introduction

Crabs are often generalists and opportunistic feeders, eating whatever they can find, but some species are specialists with certain morphologies to eat a specific type of prey (Yamada and Boulding 1998). The Red Rock crab (*Cancer productus*) is known as a specialist, most often found feeding on molluscs (Smith and Palmer 1994). The Kelp crab (*Pugettia producta*) is more often found feeding on algae but has been known to also feed on mussels and barnacles when algae is hard to find (Knudsen 1964). Being that Red Rock crab eat more mussels than Kelp crab, they are able to eat a wider variety of sizes of mussels due to specialization. This specialization also helps their claws to be stronger so as to break through the mussel shells and consume prey at a faster rate than generalists with weaker claws (Yamada et al. 2010). Since Kelp crab are more inclined to eat algae than mussels, they aren't as specialized for it, meaning it requires more effort and time to break into the mussel shells and are more likely to go for the smaller ones.

Within their diet, though, both species are limited by the size of the prey (their claw gape), their strength (can they crush the shell), and the time it takes to do so (is the energy expended worth the energy gained) (Yamada and Boulding 1998). These are normally correlated together with bigger mussels having harder shells and taking longer to open. If a crab is unable to overcome these limitations, it will give up on that individual and move on to a smaller/weaker target (Yamada and Boulding 1996). Once a prey reaches a certain size, it's typically safe from predation, which is called a size refuge (Paine 1976). After a mussel grows to this point, it's shell is either too big or too strong for a crab to get into within a reasonable amount of time. With our changing environment, however, getting to this refuge may be getting harder.

One problem occurring in our oceans today is ocean acidification (OA). OA is caused by an increase of carbon dioxide in our environment which is being dissolved into our oceans, leading to a lower carbonate to bicarbonate ratio (Fabry et al. 2008). This ratio is important since carbonate is what's used to create strong shells in calcareous species (Orr et al. 2005). Without enough carbonate, species like mussels will have weaker, thinner shells. These weakened shells could lead to an increase in the predation rate and number of predators that mussels have. Weakened mussel shells also help species like crabs to be able to break into bigger shells at a faster rate.

In this experiment, we looked at the effect that thinner shells due to OA will have on mussel predation by crabs. This experiment focused on the Red Rock crab as a specialist and Kelp crab as a generalist and their prey selection and ability to predate on mussels. We hypothesized that 1) crabs will eat a higher proportion of mussels with thinner shells (those mimicking OA) than those with regular shells, and 2) it will take less time for the crabs to break into the thinner shelled mussels. Because of the different diets of these crabs in their natural environments, and the Kelp crab's preference to algae, we expect the Kelp crabs to mostly eat the thinned mussels and eat less in general than the specialized Red Rock crabs. These results can help predict the shifts in mussel predation by generalists and specialists in the future due to worsening OA conditions.

Materials and Methods

Ten Kelp crabs and twenty-five Red Rock crabs were collected either by hand or using crab pots. The crab pots were deployed off the Newport Public Fishing Pier in Newport, Oregon and left overnight (approximately 12 hours) with chicken as bait. The rest of the crabs were collected from rocky tidepools at Yachats Bay and Tokatee Klootchman located at Cape Perpetua and Manipulation Bay at Cape Foulweather on the central Oregon coast. Cape Perpetua sites have a wider shelf and upwelling zone than Cape Foulweather (Menge 2000) allowing more nutrients to stay nearshore and promote settlement and survival of invertebrate larvae. *Mytilus californianus* of sizes ranging from 0 to 10 cm was also collected at these sites.

After collection, crabs were weighed, length of carapace and dactyl (moveable) part of the cheliped (claw) was measured, and they were placed in separate, numbered containers. Containers were then covered with mesh (to prevent escape) and stored in flow-through tanks in a wet-lab at Hatfield Marine Science Center, Newport, Oregon, to be starved for two days. During this time, mussels were separated into three size classes: small being from 0 to 3 cm long, medium between 3 and 6 cm, and large from 6 to 10 cm. Each crab was assigned a size of mussel based on its size with the smaller crabs getting smaller mussels. At the end of the starvation period, each crab was given ten mussels. Five of these mussels were filed down (using a Dremel or hand file) until white spots of the lower layer were seen to ensure the shell was thinned, mimicking OA conditions. The other five mussels were just slightly filed without changing the thickness of the shell to be used as a control. Once fed, the crab had two days to eat the mussels, at which point the number of filed and control mussels eaten were recorded. The proportions of filed and control eaten were calculated against the total number eaten and analyzed using a t-test in RStudio.

While these crabs were being fed, we did time trials to compare the time it took them to break into the filed and control mussels. Time started when the crab grabbed the mussel and ended as soon as the crab had broken through the mussel enough to get food out of it. These times were recorded separately for filed and control mussels and were averaged for each crab individually. The average filed and control shell breaking time for each crab was used in a paired t-test in RStudio.

Results

Comparing the proportion eaten of control and filed mussels showed that almost half as many control mussels were eaten on average than filed mussels (Fig. 1) (Control: 0.35, Filed: 0.65 (+/- 0.284 SE)). Looking at the distribution of proportions eaten, the range for both filed and control is the same with some crabs eating none and some eating all the mussels. This difference in proportions between the groups is highly significant (p-value: 0.0015). Of the ten Kelp crab in this study, only two of them ate mussels and they only ate the filed mussels.

For the time trials, the time it took the crabs to break into the control mussels ranged from 2.4 min. to 75.8 min. while the filed took between 1.4 min. and 21.0 min. (Fig. 2). The average time it took the Red Rock crabs to break into the controlled mussels was 22.7 min (+/- 24.6 SE) while to average for the filed time was merely 7.7 min (+/- 6.8 SE). The average of the differences between the two types of mussels is 15.0 min. The difference between the times is significant (p-value: 0.0157). Of the crabs apart of the time trials, they were all Red Rock crab of varying sizes and we got comparative times for 14 of them.

Discussion

Based on the proportions eaten during the feeding trials, more of the filed mussels were eaten on average than the control. Previously mentioned research showed that the limiting factor of crab feeding is the size of the prey, the crab's strength, and the time it takes to open the shell (Yamada and Boulding 1998). Because our data showed that crabs ate more of the filed mussels, we can conclude that the thinning of the shells alters these limitations. The limitations are most likely altered by the fact that the filing weakens the shell, requiring less effort for the crab to break it. In order for our first hypothesis to be supported, there needs to be a difference in the number of filed and control mussels eaten with a greater number of filed mussels being eaten. The significance of the feeding trials (p-value: 0.0015) supports this hypothesis.

Kelp crabs ate the weakened mussels during the feeding trials suggesting that this food source could become more available to them under OA conditions. As of now, they simply eat it when algae is infrequent, mostly in winter (Knudsen 1964), but this has potential to expand to year round. With mussels being a viable option in OA conditions, they could start preying on them as well as their regular algae diet, adding to the list of predators for these mussels. With only two out of the ten Kelp crab feeding, however, this aspect of the findings needs further research that focuses more on Kelp crab and other generalist feeders of mussel.

The significance of the time trials alters another limiting factor of crab feeding. With weaker shells, they are easier to break and thus take less time and energy to open the shell. Our second hypothesis is therefore supported because of this significant time difference. With regards to OA, this could lead to more crabs feeding on larger mussels. Because it's easier for the crab to get into these mussels, they are able to crack open larger mussels with the same amount of energy it previously took for smaller mussels, and get more nutritional value out of it.

In the ideal situation, half of the mussels used in this study would have naturally been thinner shelled. Since that wasn't a possibility, filing them down by hand was the next best option. This method, however, could have caused some discrepancies. If one mussel has thinner outer layers than another, it could have not been thinned as much as the others or if each person thinning the mussels thinned to different amounts of white spots visible. Since there is variation in thickness in nature, this shouldn't have caused too much interference with our overall results. The size classes of mussels were assigned to crabs based solely on visual appearance. This could have been the reason that some crab ate none of the mussels (the mussels were too big) and some crab ate all of them (the mussels were too small). In future studies, more research should be done on the proper correlation between mussel and crab sizes.

By the year 2100, CO_2 concentrations could potentially rise to be anywhere from 540 to 970 ppm (Houghton et al. 2001). These levels have been shown to cause weaker, thinner, and smaller shells in this foundation species of mussels, *Mytilus californianus* (Gaylord et al. 2011). From this finding and our own, we have shown that OA could potentially cause a shift in all three of the current feeding limitations of crabs on mussels. Due to the significance of both the feeding preference and timed trials, thinning out of these mussels by OA has the potential to cause a shift in their predation. Red Rock crab will be able to eat a wider range of sizes of them as well as eat them at a much faster rate. Kelp crab, who were only tested for the feeding preference, will also be able to eat mussels that are affected by OA. As OA worsens, the predation rate and the time and effort required to get to a size refuge will grow, leading to more predators and more predation on this foundation species of mussels, *Mytilus californianus*.

References

Fabry, V. J., B. A. Seibel, R. A. Feely, and J. C. Orr. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science **65**:414–432.

Gaylord, B., T. M. Hill, E. Sanford, E. A. Lenz, L. A. Jacobs, K. N. Sato, A. D. Russell, and A. Hettinger. 2011. Functional impacts of ocean acidification in an ecologically critical foundation species. Journal of Experimental Biology **214**:2586–2594.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, editors. 2001. Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, New York.

Knudsen, J. W. 1964. Observations of the reproductive cycles and ecology of the common Brachyura and crablike Anomura of Puget Sound, Washington. Pacific Science **18**:3–33.

Menge, B. A. 2000. Top-down and bottom-up community regulation in marine rocky intertidal habitats. Journal of Experimental Marine Biology and Ecology **250**:257–289.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, G.-K. Plattner, K. B. Rodgers, C. L. Sabine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature **437**:681–686.

Paine, R. T. 1976. Size-Limited Predation: An observational and experimental approach with the *Mytilus-Pisaster* interaction. Ecology **57**:858–873.

Smith, L. D., and A. R. Palmer. 1994. Effects of manipulated diet on size and performance of Brachyuran crab claws. Science **264**:710–712.

Yamada, S. B., and E. G. Boulding. 1996. The role of highly mobile crab predators in the intertidal zonation of their gastropod prey. Journal of Experimental Marine Biology and Ecology **204**:59–83.

Yamada, S. B., and E. G. Boulding. 1998. Claw morphology, prey size selection and foraging efficiency in generalist and specialist shell-breaking crabs. Journal of Experimental Marine Biology and Ecology **220**:191–211.

Yamada, S. B., T. M. Davidson, and S. Fisher. 2010. Claw morphology and feeding rates of introduced European Green Crabs (*Carcinus maenas* L, 1758) and native Dungeness Crabs (*Cancer magister* Dana, 1852). Journal of Shellfish Research **29**:471–477.

Tables and Figures

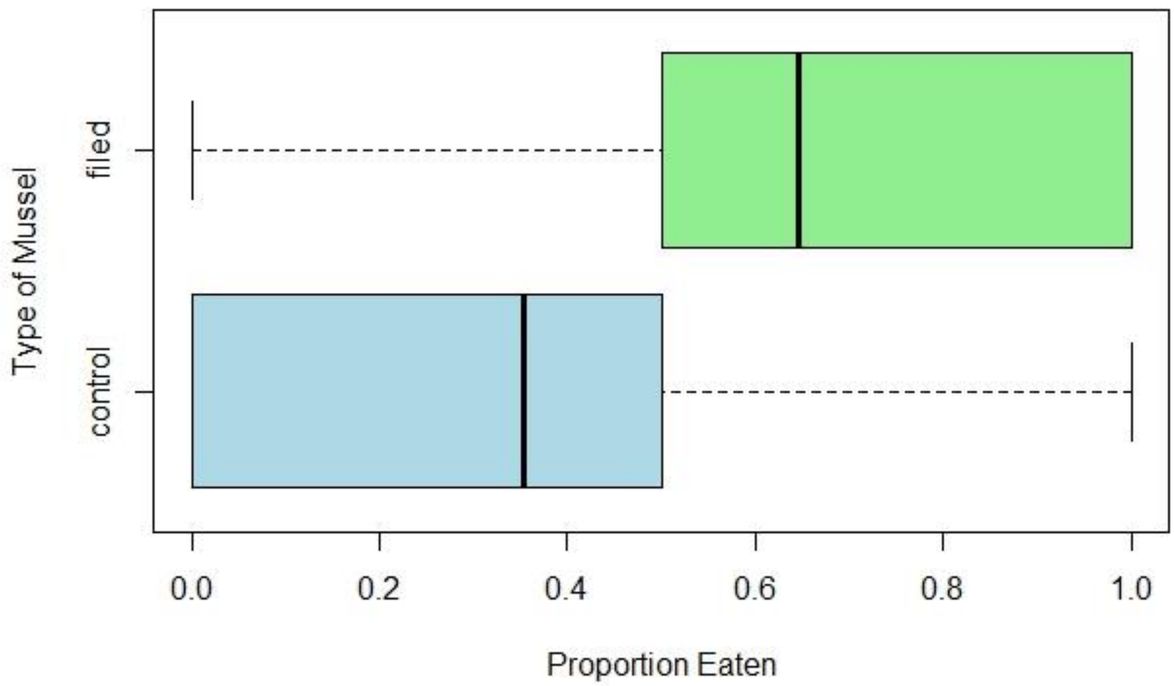

Figure 1. The proportions of control and filed *Mytilus californianus* eaten compared to the total number of mussels eaten for 25 *Cancer productus* and 10 *Pugettia producta*. This difference is significant (p-value: 0.0015).

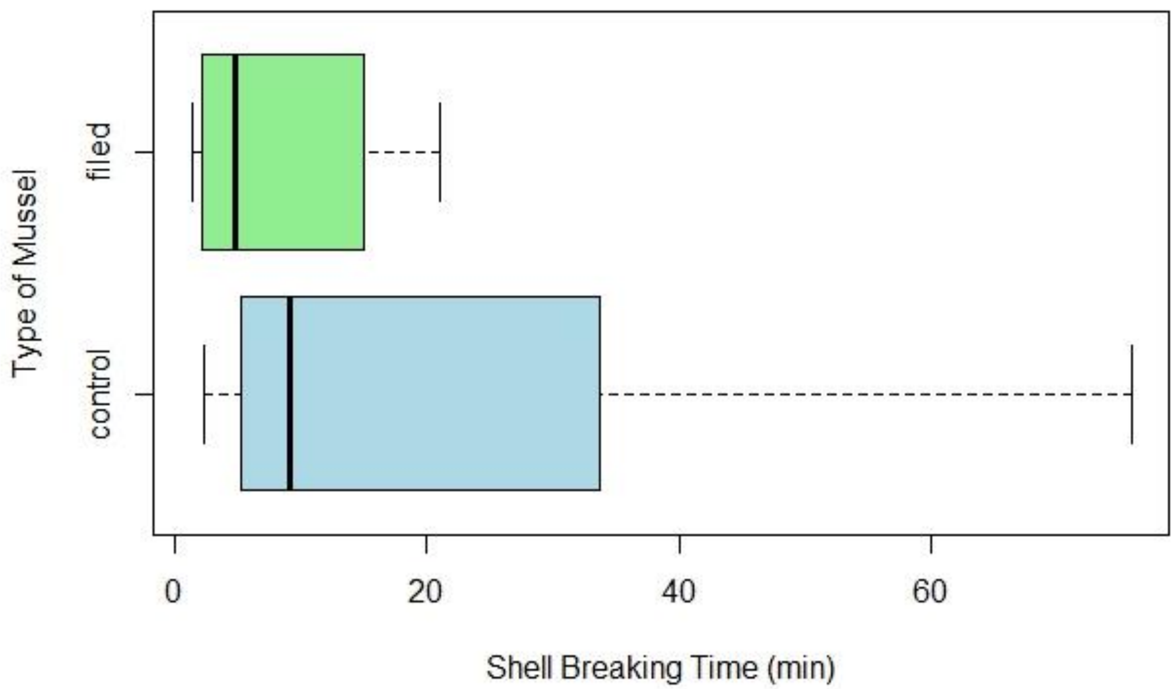

Figure 2. The shell breaking time in minutes of *Cancer productus* for control and filed *Mytilus californianus* measured from the time the crab grabs the mussel to the time it breaks the mussel enough to get food out of it. This difference is significant (p-value: 0.0157).