Ocean acidification is causing increased predation on *Mytilus californianus* by specialist and generalist crabs

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Abstract

Ocean acidification is negatively impacting organisms that use calcium carbonate to form their shells. Increasing OA conditions are putting a strain on these calcareous animals by weakening their shells, thus causing them to become more vulnerable to predation. Worsening shell integrity may lead to a decline in hard-shelled prey populations as predators are able to break them open with greater ease. For this study, possible consequences of ocean acidification on predator-prey interactions was tested by comparing the number of normal to thin-shelled mussels eaten by two species of crabs. The time it took each crab to break into both types of mussel was also recorded. It was hypothesized that these crabs would eat a higher proportion of thin-shelled mussels over normal mussels due to their easier accessibility. It was found that crabs preferred thin-shelled mussels over normal mussels, and thus consumed them in higher quantities. Timed trials conducted on the shell-breaking times for each crab showed that thin-shelled mussels took significantly less time to open than normal mussels. These results provide insight into shifting future community structures as a direct product of ocean acidification.

Introduction

Crabs are opportunistic consumers that eat a variety of prey including bivalves, gastropods, barnacles, algae, fish, and even other crabs (Yamada and Boulding 1998). The ability to consume certain prey is dependent on the crab's claw strength, gape, and morphology (Yamada et al. 2010). The variations in crab diets as a result of differences in claw strength and morphology allow for crabs to be divided into two categories: generalists and specialists (Yamada and Boulding 1998). Species that feed on a narrow set of organisms (specialists) will have specialized feeding structures designed to consume their prey with greater efficiency than predators with a broader diet (generalists) (Yamada and Boulding 1998). Generalists have a greater nutritional balance than specialists due to their wider range of food types, but are limited in their body plan due to their need to capture a variety of prey items (Buck et al. 2003). Compromises in their morphology result in generalists being less efficient at consuming any one particular food group. To this end, one can assume that specialists will have a competitive advantage of their target prey over generalists, thus playing a role in species distributions.

The likelihood of a crab abandoning a specific prey is limited by strength, gape, and time (Yamada and Boulding 1998). If the crab is not strong enough to crush a shell or if the gape of the claws is not large enough to grasp the prey, then the item will be rejected for another option. In addition, crabs will preferentially select prey that take less time to crush and consume (Yamada and Boulding 1998). These limitations play a significant role in determining which prey are most important in a crab's diet. In accordance to these limitations, prey that exceed a certain size are able to avoid predation by being too large to be consumed (Paine 1969). However, this size refuge may be shifting as a result of the changing ocean due to ocean acidification.

As global carbon dioxide levels rise, a portion of the CO_2 is absorbed by the ocean (Siegenthaler and Sarmeinto 1993). While this is beneficial for moderating future climate change, it is negatively impacting the ocean, namely by causing ocean acidification (OA). As uptake of CO_2 continues, ocean waters warm and become more acidic due to higher hydrogen ion concentrations present in the water (Orr et al. 2005, Fabry 2008). As aqueous CO_2 concentrations increase, carbonate ions decrease, reducing the organic calcium carbonate used by marine organisms to form their shells (Orr et al. 2005). Lowered calcification rates lead to thinner, weaker shells that are more vulnerable to predation. Predators are able to eat more prey, larger prey, and even expand the species they are able to consume. One such organism affected by OA is the mussel *Mytilus californianus*, whose shell integrity is degraded by the reduced concentrations of calcium carbonate (Gaylord et al. 2011). As a result, mussels affected by OA may be easier for crabs to consume since they are easier to break open. This pattern may lead to a shifting community structure where the mussel population is significantly reduced.

For this study, two crabs, the Red Rock crab (*Cancer productus)* and the Kelp crab *(Pugettia producta)*, were chosen based on their claw morphology and eating habits. Red Rock crab can be classified as specialists based on their larger, crushing claws designed for breaking open hard-shelled prey (Yamada et al. 2010). One of their main food options is *M. californianus*. Kelp crab, alternatively, are generalists that consume brown algae, but will also eat mussels, barnacles, and hydroids if their main food source is not available (Knudsen 1964). We are interested in observing how the feeding behaviors of both species of crab will change when presented with thinner, weaker shelled mussels (like one would see in advanced OA conditions). We hypothesized that when presented with an equal number of normal and thin-shelled mussels, the crabs would eat a higher percentage of the weaker mussels due to their easier accessibility.

We also predicted that the time it took the crabs to break into the thin-shelled mussels would be faster. This information will provide insight into future predator-prey interactions resulting from OA effects on calcareous organisms.

Materials and Methods

Crabs were collected from the rocky intertidal zone along the Oregon Coast at Tokatee Klootchman, Yachats, and Manipulation Bay. The first two sites are located within Cape Perpetua, which is a spot rich in nutrients and invertebrates (Menge 2000). The latter site is located within Cape Foulweather, an area containing a lower abundance of nutrients but a higher abundance of algae (Menge 2000). Crabs were also collected via crab pots off the Newport Public Fishing Pier. Once in the lab, each crab was given a number and their carapace (shell) and cheliped (claw) length were measured. Gender, weight, and site of collection were also recorded. Any molts that occurred during the experiment were noted so as to explain possible difficulties breaking into mussels due to their softer shells. *Mytilus californianus* were also collected and brought back to the lab where they were measured and separated into three size groups: small (0-3 cm), medium (3-6 cm) and large (6-9 cm). These size classes were associated with the three crab classes, which were also separated into small, medium, and large. The mussels were filed using a dremel tool. The control mussels only had the top layer removed, so as to remove any texture differences between the control and filed mussels. The experimental mussels were filed until spots of white were showing on their shells, indicating we were nearing the last layer of their shells. The filed mussels were thinned to this degree in order to mimic OA conditions. These mussels were marked with a blue dot to distinguish them from the control mussels.

In three consecutive trials the crabs were isolated in separate containers within a flow-through tank, each with a mesh lid to prevent escape. Each crab was starved for two days. Once the starvation period was over, each crab was provided ten mussels, five control and five filed. Mussels of similar size were provided, with large crabs receiving large mussels, medium crabs receiving medium mussels, and small crabs receiving small mussels. We observed the crabs immediately after providing them with food. Any attempts to open a mussel were timed, starting from when the crab made contact with the shell and ending when the shell first broke open. Shell-breaking time and the type of mussel were recorded for that specific crab. Crabs were then left with the food for two days. Upon return, we recorded the number of filed and control mussels eaten for each crab before removing them from their separate containers and placing them in an aquarium to make room for the next batch of crabs. The next trial of crabs were then separated and their starvation period began.

After the third trial was concluded certain crabs were chosen, depending on if we had previous shell-breaking times for them, to be re-starved before being provided with a single mussel, either filed or control, depending on which type of mussel we already had the breaking-time for for that crab. These crabs were only provided this food when we were watching and all shell-breaking times were recorded.

Once the data was collected, analysis could begin. Differences in the proportion of control and filed mussels consumed during each feeding trial were conducted using a two-sided t-test. Shell-breaking time comparisons were conducted using a paired two-sided t-test. Differences in number of mussels eaten for both mussel types were observed between Kelp and Red Rock crab to see if there was a shift in food preferences due to the presence of thin-shelled mussels.

Results

Of the 25 Red Rock crabs collected, 20 were recorded to have eaten at least one of the ten mussels provided during their feeding trial. Additionally, 2 out of the 10 Kelp crab ate during their feeding trial. Both Kelp crab that ate during their trial only consumed filed mussels. The crabs that did not eat were not included in the data analysis. It was observed that the shells of the control mussels remained mostly intact when being pried open whereas the filed mussels were shattered. There was a significant difference between the proportion of filed mussels vs. control mussels eaten by the crab ($p = 0.001$). In general, filed mussels were preferred by the crabs over control mussels, as a higher proportion of filed mussels were consumed during each feeding trial (Figure 1).

The shell-breaking times for each mussel type were also compared for the crabs. There was a significant difference between the time it took crabs to break open a control mussel and the time it took the crabs to break open a filed mussel ($p = 0.016$). Shell-breaking times for filed mussels were, on the whole, faster than shell-breaking times for control mussels (Figure 2).

Discussion

Previous studies have shown that crabs will use their chelae to determine the size of a mussel before deciding to accept or reject it (Elner and Hughes 1978). This behavior is concordant with the knowledge that a given sized crab has an optimal mussel size that contains the maximum prey value (Elner and Hughes 1978). This implies that a choice is made to consume prey that have the best energy content to handling time ratio. All mussels provided during the feeding trials were scaled accordingly to the size of the crab, with some trial and error required when determining the appropriate claw to mussel size ratio. On average, the crabs consumed more filed mussels than control mussels, thus demonstrating a clear choice was made for the thinner prey option. This likely occurred because the filed mussels took less effort to open and thus allowed the crab to extract the same amount of nourishment while expending a smaller amount of energy. Mussels that were found to be tougher to crack would be rejected for easier prey (Yamada and Boulding 1998), thus leading the crabs to consume a larger portion of the filed mussels.

Weakened shell integrity of calcareous organisms as a result of ocean acidification has the potential to lead to a decline in prey populations as predators are able to consume them with greater ease (Orr et al. 2005). This ease was demonstrated in our timed trials, since the time it took to break the filed mussels was much faster than that of the control mussels. This difference in shell-breaking time was due to the thinner shells of the filed mussels, which were easier to crush than the control mussels. The decreased integrity of the filed mussels was also demonstrated by the state of the shells after the crab broke them open. Control shells, which were stronger, generally remained in one piece. In contrast, the filed mussels were broken into pieces, demonstrating their weakened state. Faster shell-breaking times as a result of OA will likely lead to crabs eating a greater number of mussels at a time, a notion that does not look kindly on future mussel populations.

In addition to specialist crabs eating a greater amount of mussels as their shells begin to thin, generalist crabs may also begin to depend on mussels as a more prominent food source than they previously had. Kelp crab, which are omnivores that generally consume brown algae, only eat mussels when they are presented with no other option (Knudsen 1964). This correlates to their claw strength, which is not as strong or efficient at breaking open hard-shelled prey (Yamada and Boulding 1998). In our study only 2 of the 10 Kelp crab ate during their feeding trials. Although this is not enough data to conclude any definite trends, it is important to note that both consumed only filed mussels. Further studies must be conducted to determine if this is due to the filed mussels being easier to open and what that means for mussels as a viable food source for Kelp crab and other generalist species in the future.

In regards to the three limitations dictating a crab's ability to consume a specific prey item (strength, time, and gape) this study showed that the first two are altered by ocean acidification. The strength required to break into a mussel decreased in response to the thinness of the shell, thus allowing the crab to expend less energy to consume its prey. Additionally, the time it took to crush the mussel was shortened due to the weaker integrity of the shell. This allowed the crabs to eat a greater amount of prey in a shorter amount of time. The third limitation, gape, was demonstrated to also change in response to ocean acidification in a previous study by Gaylord et al. (2011). This study found that not only are mussels weaker due to OA conditions, but they are also smaller (Gaylord et al. 2011). Smaller mussels will enable a wider range of crabs to consume them since the gape of their chelae will be wide enough to handle the mussel. To this end, we can conclude that each of the three factors that limit which prey items can be consumed by crabs are altered by ocean acidification, thus implying a changing community structure as future generations of mussels become weaker, thinner, and smaller. Fewer prey will be able to reach a size refuge. Predators will have the ability to consume prey in larger quantities and of larger sizes. Species that once did not consume hard-shelled prey may become better equipped to do so. These factors are leading toward a severe decline in mussel populations, all of which are occurring as a result of ocean acidification.

Figures and Tables

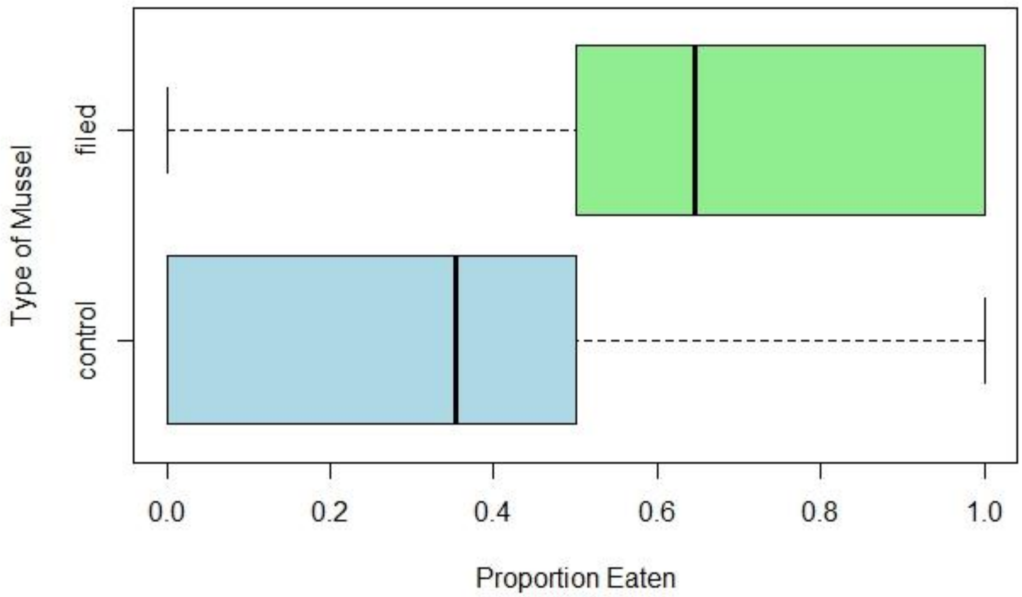

Figure 1: Comparison of proportion of filed and control *M. californianus* eaten by Kelp and Red Rock crabs during their feeding trials. A significantly higher proportion of filed mussels were consumed by the crabs over control mussels (p = 0.001)

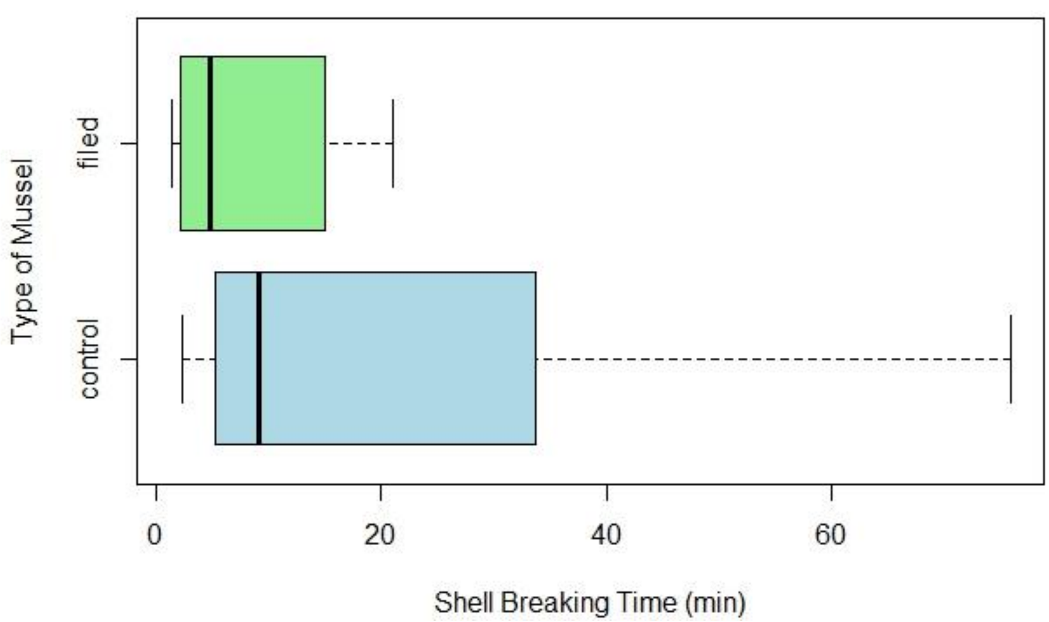

Figure 2: The time it took (in minutes) to break open control and filed mussels by Red Rock crabs. There was a significant difference in the shell-breaking times between the two types of mussel, with filed mussels being the quicker type to open (p = 0.016).

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