Claw morphology and influence on feeding electivity of four Pacific Northwest crab species

Katie Bigham[1, 2], Stephanie Crofts[1, 3], Katie Dobkowski[1, 3]

FHL 470: Research in Marine Biology
Autumn 2014

[1]Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250
[2]School of Oceanography, University of Washington, Seattle, WA 98105
[3]Department of Biology, University of Washington, Seattle, WA 98195-1800, USA

Contact information:
Katie Bigham
School of Oceanography
University of Washington
1503 N.E. Boat Street
Seattle, WA 98105
bighamkt@uw.edu

Keywords: Glebocarcinus oregonensis, Pygmy Rock Crab, *Chionoecetes bairdi,* Tanner Crab, *Pugettia producta*, Northern Kelp Crab, *Oregonia gracilis,* Graceful Decorator Crab, claw morphology, diet

Abstract

Crabs use their claws for a number of uses including handling and processing of prey items. However claws are not uniform across species, they show a number of variations including those in their denticle patterns. To investigate these variations individuals from the species *Glebocarcinus oregonensis, Chionoecetes bairdi, Pugettia producta*, and *Oregonia gracilis* were collected and the morphology of the crabs' claws were measured. The measurements included the radius of curvature of the denticles and distance of these denticles along the claw. From these measurements we made predictions about potential prey type preference for each species. To test these predictions the crabs were put through choice and no choice feeding trials. Food types tested included kelp, snail, and shrimp species. We found that all the crab species in this study showed difference in their claw morphologies as well as their feeding preferences. *G. oregonensis* showed a preference for snails while the other species consumed more shrimp or kelp. However despite these differences all four species consumed shrimp as a first or second choice.

Introduction

In many species, diet and preferred prey type can be inferred from the animal's feeding structure or habits. Animals that specialize on a particular prey generally have more specialized feeding structures than those with a broader, more general diet. For example the house sparrows that share a commensal relationship with humans exhibit larger, more robust skulls, and larger, more pointed beaks than the non-commensal house sparrows they descend from. These morphologic changes allow them to handle and eat the larger seeds produced by human agriculture than can their non-commensal counterparts (Riyahi et al. 2013).

Studies looking at crab claw biomechanics have shown that crabs also show specialization and generalization (Yamada and Boulding, 1998). The mechanics of claws prevent them from being both fast and strong. Strong claws have greater propal width and height, while fast claws are relatively long compared to their height (Warner and Jones, 1976). Crabs that feed on thick shelled mollusks as a primary food source generally have slow but powerful claws, while crab species that feed on fast moving prey tend to have faster, but weaker claws (Seed and Hughes, 1995). Crabs that favor mollusks as a primary food source also tend to have dimorphic claws. One claw, typically on the right hand side, is larger, more powerful, and is used to crush prey. The left claw is smaller, weaker, and functions as a cutting claw (Seed and Hughes, 1997). While force is important in determining what foods a crab might be able to handle or eat, Schenk and Wainwright (2001) looked at claw dimorphism in six brachyuran crabs and found variation in the force produced that could not be accounted for by size alone. They suggested that occlusions and dentations needed to be assessed to fully draw conclusions between force and diet.

Yamada and Boulding (1998) examined the strength and speed of the claw as well as the denticle (the tooth like protrusions found on both the propus and dactyl) shapes and patterns in five species of Pacific Northwest intertidal crabs, *Hemigrapsus nudus, Hemigrapsus oregonensis, Lophopanopeus bellus, Glebocarcinus oregonensis,* and juvenile *Cancer productus.* They classified the species as specialists or generalists, based on the analyzed morphology of their claws and ability to feed on mollusk prey. Differences in morphology were noted in size, denticle shape, pattern, distribution, as well as size and strength. The specialist crabs had at least one large, strong claw, with broad blunt denticles, and at the tip they had sharp denticles that overlapped in a scissor-like fashion. The generalists had narrower claws with finer denticles and the blunt tips of the claw came together like a scoop.

The goals of this study were threefold: 1) to quantify and analyze denticle morphology in crab species local to the Pacific northwest; 2) use choice/no choice feeding trials to determine feeding preferences for these same crab species; and 3) to determine if denticle morphology is related to food preference. By combining these two approaches, we can test hypotheses generated by the morphological analysis and examine denticle function, beyond the ability to simply handle mollusk prey.

Methods

Local crab species were collected using otter trawls at about 100m depth in San Juan Channel. Crabs were also collected from the Friday Harbor Lab dock pylons with nets. Species captured were *Glebocarcinus oregonensis, Chionoecetes bairdi, Pugettia producta,* and *Oregonia gracilis* (Plate1). Ten individuals of *G. oregonensis* were used for the feeding trials and morphological analysis. Only six *C. bairdi* and five *P. producta* were caught, so all individuals were used for both the feeding and morphological analysis. Thirty *O. gracili* were caught and showed high variation in merus length, which was used to separate the population into three bins (small, medium, and large) of ten individuals each. All crabs were housed in flow through seatables before the feeding trial. Methods and Results for morphological measurements and feeding experiments are described separately below.

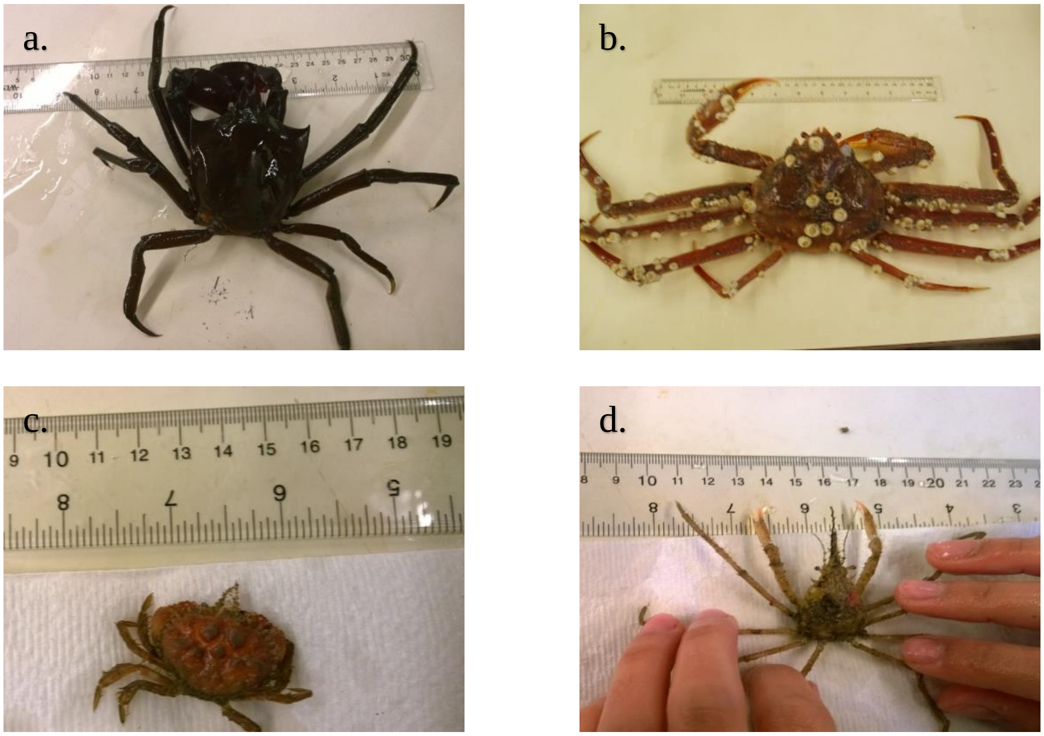

Plate. 1 Dorsal view of all four species. a) *P. producta* – Northern Kelp Crab, b) *C. bairdi* – Tanner Crab, c) *G. oregonensis* – Pygmy Rock Crab, d) *O. gracilis* – Graceful Decorator Crab

Morphology Method

Individual crabs were photographed to obtain morphologic data. ImageJ software was used to measure the following morphologic traits relevant to feeding methods. To take the total size of each organism into account, we measured carapace length and propus length, as well as merus length in the *O. gracilis* (Plate 2). To quantify denticle morphology we counted the total number of denticles, and measured the fulcrum to denticle length, and the radius of curvature of each denticle on one claw. (Plate 3). The radius of curvature is calculated from the area of a circle fitted to the denticle tip. Blunter denticles have a larger radius of curvature than pointed denticles.

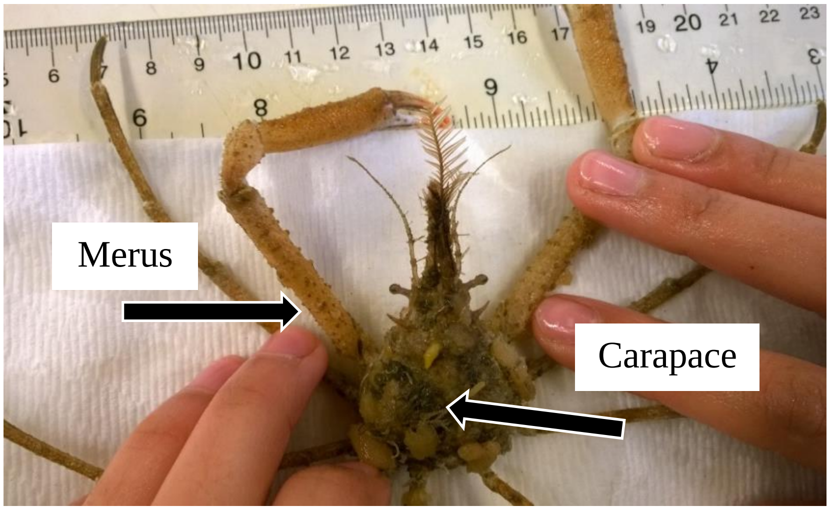

Plate 2. *O. gracilis* body parts measured in morphology analysis.

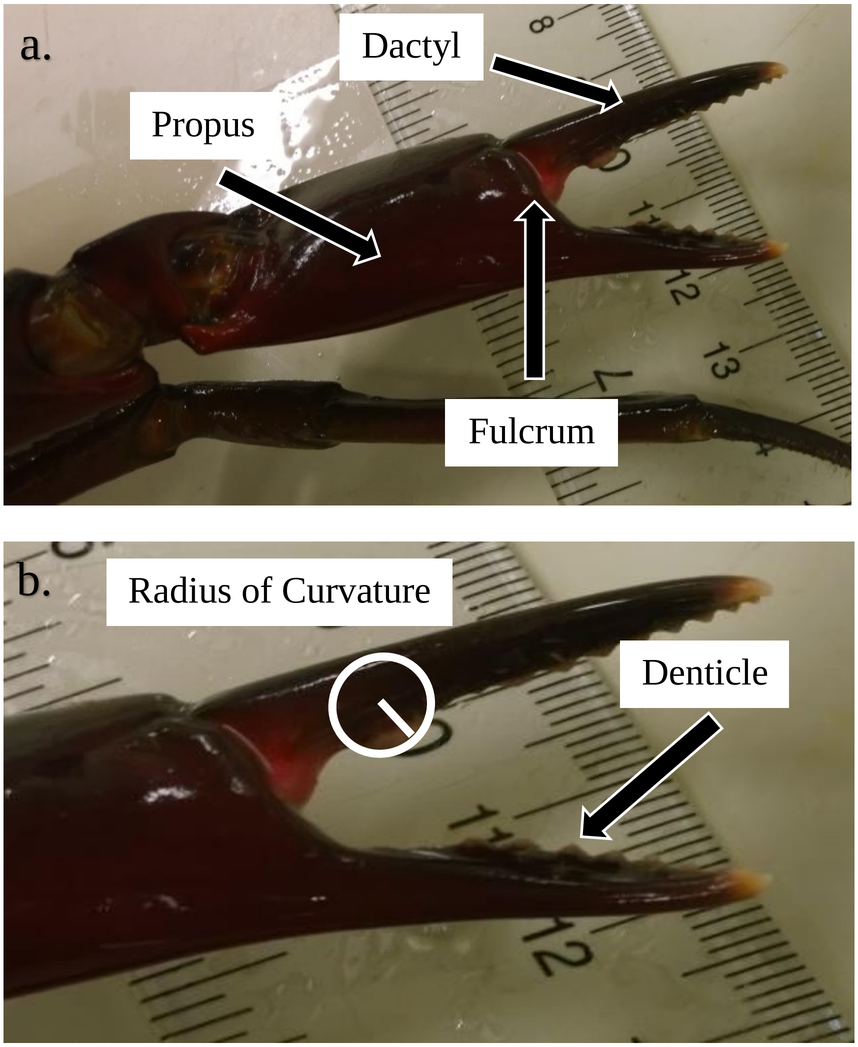

Plate 3. Components of *P. producta* claw relevant to morphology analysis.

Morphology Results

Morphology measurements showed unusual patterns in scaling in the *O. gracilis* claw size to body size (Fig. 1). Comparing merus length to carapace width (Fig. 2) shows two distinct groups of crabs both with different allometric scaling (Fig. 3). Breaking the smaller group into two provides a third allometric group, and better R^2 values for each group (Fig. 4). A summary of average carapace widths and merus lengths used to create the groups can be seen in Table 1. These three bins of *O. gracilis* were treated as three different taxa for the rest of the experiment.

The three groups also showed differences in denticle morphology. Only the medium and large groups had a single denticle on their claws, with larger individuals being more likely to have the denticle. Forty seven percent of large individuals showed a denticle, while only thirty five percent of medium individuals did (Table 1). The denticles on the larger crabs were bigger than those of the medium crabs (Table 2).

All species showed variation in number of denticles, the denticle's distance along the claw, and the denticle's radius of curvature. *P. producta* had five denticles with the second largest mean radius of curvature (Table 2). This large radius of curvature is due to a single large denticle close to the intersection of dactyl and propus, with subsequent denticles being much smaller and decreasing in size towards the tip of the claw (Fig. 5a). The correlation between radius of curvature and distance from the fulcrum is highly significant (Linear Regression (1, 19 df) $f < 0.0001$). *C. bairdi* had six denticles, all with a smaller mean radius of curvature than *P. producta* (Table 2). These crabs also showed a larger denticle close to the intersection with smaller subsequent denticles (Fig. 5b). The correlation between radius of curvature and distance from the fulcrum was also significant (Linear Regression (1, 29 df) f = 0.035). *G. oregonensis* had four denticles, and the smallest radius of curvature (Table 2). The crab's denticles were also the most localized all of them only 0–4% away from the intersection of the propus and dactyl (Fig. 5c). There was no relationship between radius of curvature and distance from the intersection (Linear Regression (1, 35 df) f = 0.332).

O.gracili **s Size**	**Mean Carapace Width (cm) ± Standard Error**	**Mean Merus Length (cm) ± SE**	**Mean Propus Length (cm) ± SE**	**Percentage of Individuals with Denticles**
Small	2.54 ± 0.15	1.35 ± 0.08	1.48 ± 0.04	0%
Medium	2.51 ± 0.09	1.97 ± 0.08	2.00 ± 0.02	35%
Large	3.09 ± 0.15	4.09 ± 0.32	3.60 ± 0.09	47%

Table 1. Summary of *O. gracilis* claw morphology for all three groups.

Crab Species	**Mean Carapace (cm) ± Standard Error**	**Mean Propus Length (cm) ± SE**	**Number of Denticles**	**Mean Radius of Curvature of Denticles (cm) ± SE**
P. producta	8.28 ± 0.14	5.03 ± 0.36	5	0.07 ± 0.03
C. bairdi	12.10 ± 0.81	7.53 ± 0.96	6	0.05 ± 0.01
G. orgonensis	3.23 ± 0.19	1.62 ± 0.15	4	0.02 ± 0.00
O. gracilis - Small	2.54 ± 0.15	1.48 ± 0.04	0	0 ± 0.00
O. gracilis - Medium	2.51 ± 0.09	2.00 ± 0.02	1	0.04 ± 0.01
O. gracilis - Large	3.09 ± 0.15	3.60 ± 0.09	1	0.08 ± 0.01

Table 2. Summary of claw morphology data for all species.

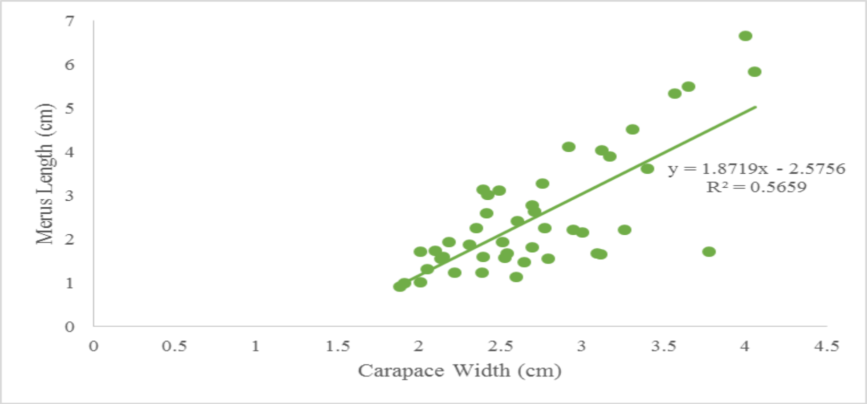

Figure 1. Merus Length to Carapace Width for all *O. gracilis*

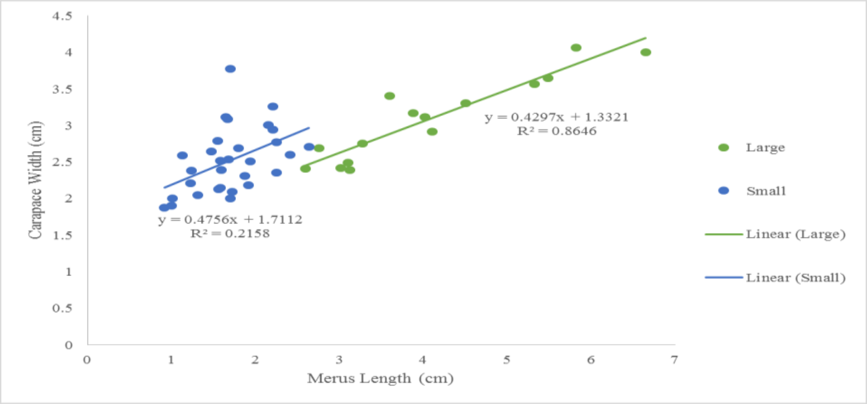

Figure 2. Carapace Width to Merus Length for Two Groups of *O. gracilis*

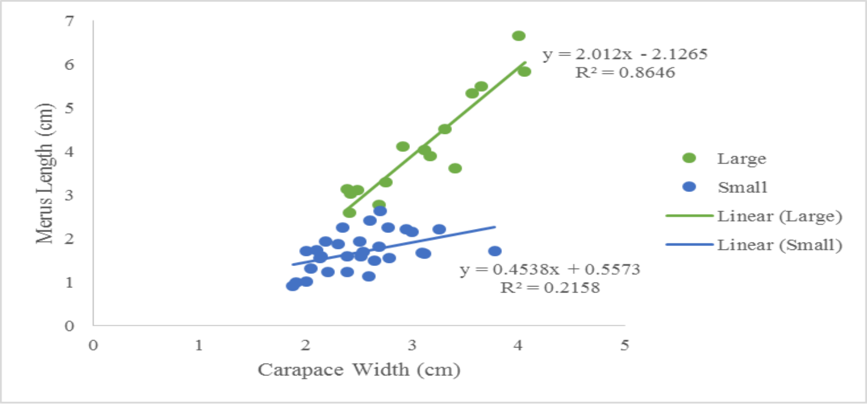

Figure 3. Merus Length to Carapace Width for Two Groups of *O. gracilis*

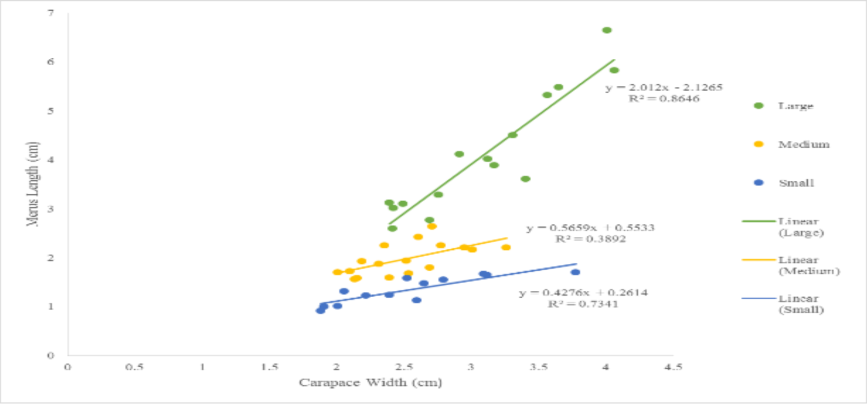

Figure 4. Merus Length to Carapace Width for Three Groups of *O. gracilis*

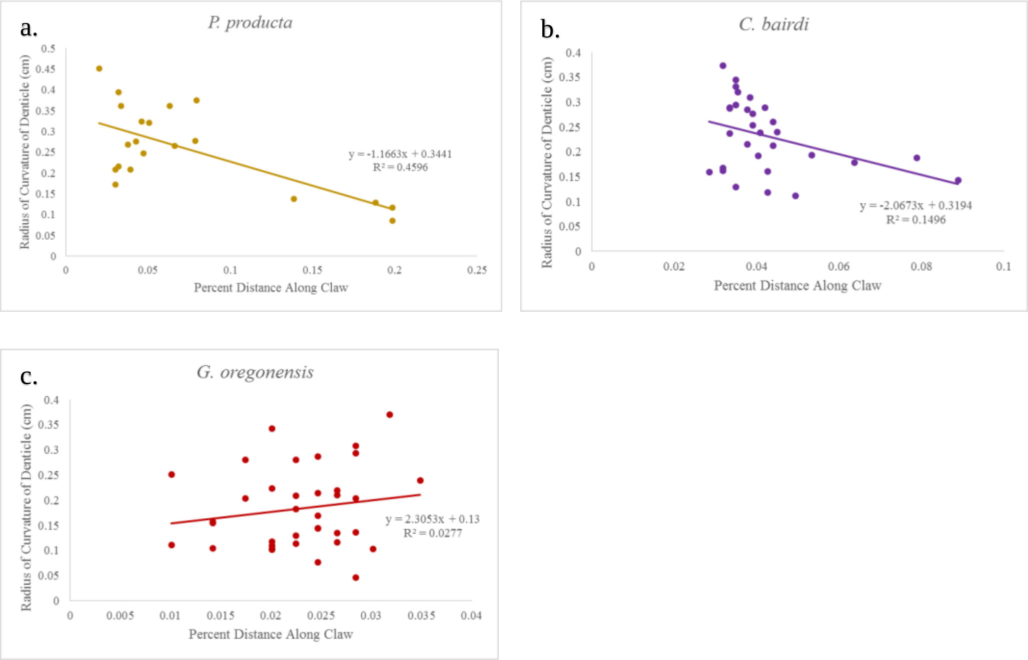

Figure 5. Distance of Denticles Along Claw - Radius of curvature of each denticle graphed against its percent distance from the intersection of the dactyl and propus of the claw.

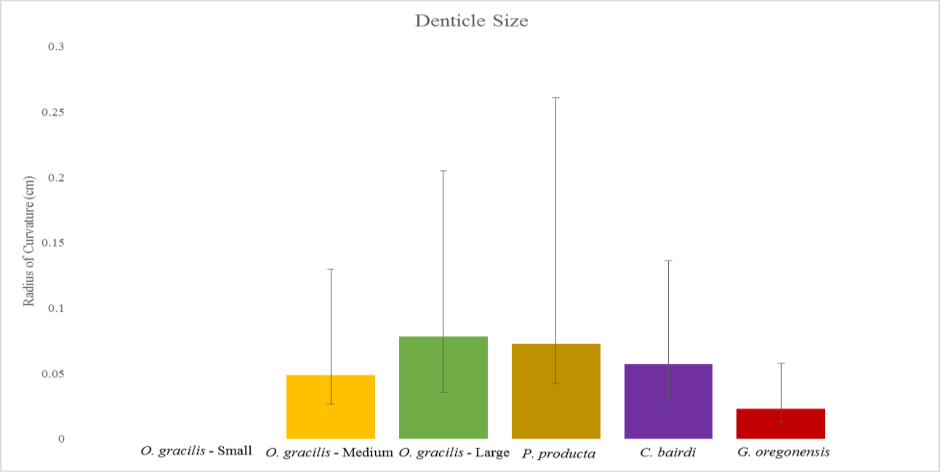

Figure 6. The columns represent the average radius of curvature of each group or species. The bars represent the range of denticle size observed in all individuals, with the top being the larges denticle and the bottom the smallest.

Feeding Experiment Methods

The crabs went through a series of choice and no choice feeding trials. Individuals were housed in a six quart plastic box with holes drilled in the side to allow water to flow through. The offered foods were the kelp species *Nereocystis luetkeana,* live *Littorina* sp. snails, and dead *Pandalus* sp. shrimp to represent non-algal detritus. Each individual crab was used in four separate trials, three “no choice”: kelp only, snails only, and shrimp only; and one “choice” experiment where all three foods were available. The kelp and shrimp were both collected from the Friday Harbor Lab dock, and the snails were collected from nearby beaches. The kelp was wiped with a paper towel to reduce bacteria and epiphytes, and cut into segments and weighed. Twenty snails were used for each trial and weighed beforehand. The shrimp were killed, shelled, and weighed. The number and mass of snails, and the mass of kelp and shrimp remaining at the end of 12 hour feeding period was recorded. Consumption was quantified as mass eaten in grams, and calculated by subtracting the final weight of food choices from their initial weights. To control for any change in mass not due to crab consumption, each of the four trials were also run with no crabs.

Feeding Experiment Results

Different species and sizes of crabs showed differences in preferred food and quantity of food eaten. Two factor ANOVAs were run on food preferences of the three size groups of *O. gracilis* for both choice and no choice feeding trials. Both the choice (2 factor ANOVA (4, 89), $p<0.0001$) and no choice (2 factor ANOVA (4, 89), $p<0.0001$) results showed significant interactions between food choice and size. For all three sizes classes in both experiments, however, *Pandalus* sp. was clearly the preferred food; the significant interaction is probably attributable to much larger consumption rates by larger specimens (Fig. 7a, Fig. 7b).

Different species and sizes of crabs showed differences in preferred food and quantity of food eaten. One factor ANOVAs were run on foods eaten by *P. producta*, *C. bairdi*, and *G. oregonensis* and results are summarized in Table 3. *P. producta* showed a highly significant difference in consumption rate of different foods in both the choice and no choice experiments. For both types of experiment, *Littorina* sp. was hardly ever consumed while both *N. luetkeana* and *Pandalus* sp. were (Fig. 7c, Fig.7d). *C. bairdi* also showed a highly significant difference in food consumption for both experiments. In the choice experiments, *Pandalus* sp. was consistently eaten regardless of the other options (Fig. 7e). For the no choice experiment with *C. bairdi*, *Pandalus* sp. was again favored, but two crabs did consume small amounts of *N. luetkeana* and *Littorina* sp. (Fig. 7f). *G. oregonensis* consumed the greatest variety of food types, but in the no choice experiments it still showed a significant difference in consumption rate, with *Littorina* sp. being consumed at the highest amounts, and *N. luetkeana* not being consumed at all (Fig. 7g). The choice experiments did not show a significant difference in consumption, though *Littorina* sp. was still consumed at the highest amount and *N. luetkeana* at the lowest (Fig. 7h). Only one specimen of *G. oregonensis* consumed any *N. luetkeana*, and that one crab consumed an unusually high amount of kelp compared to all other trials.

		Choice			No Choice	
Crab Species	N	Df	P	N	Df	P
P. producta	5	2, 14	< 0.00001	5	2, 14	0.0032
C. bairdi	6	2, 17	0.0032	6	2, 17	0.0179
G. oregonensis	10	2, 29	0.0962	10	2, 29	0.0053

Table 3. Results of One-way ANOVAs Testing Feeding Trials

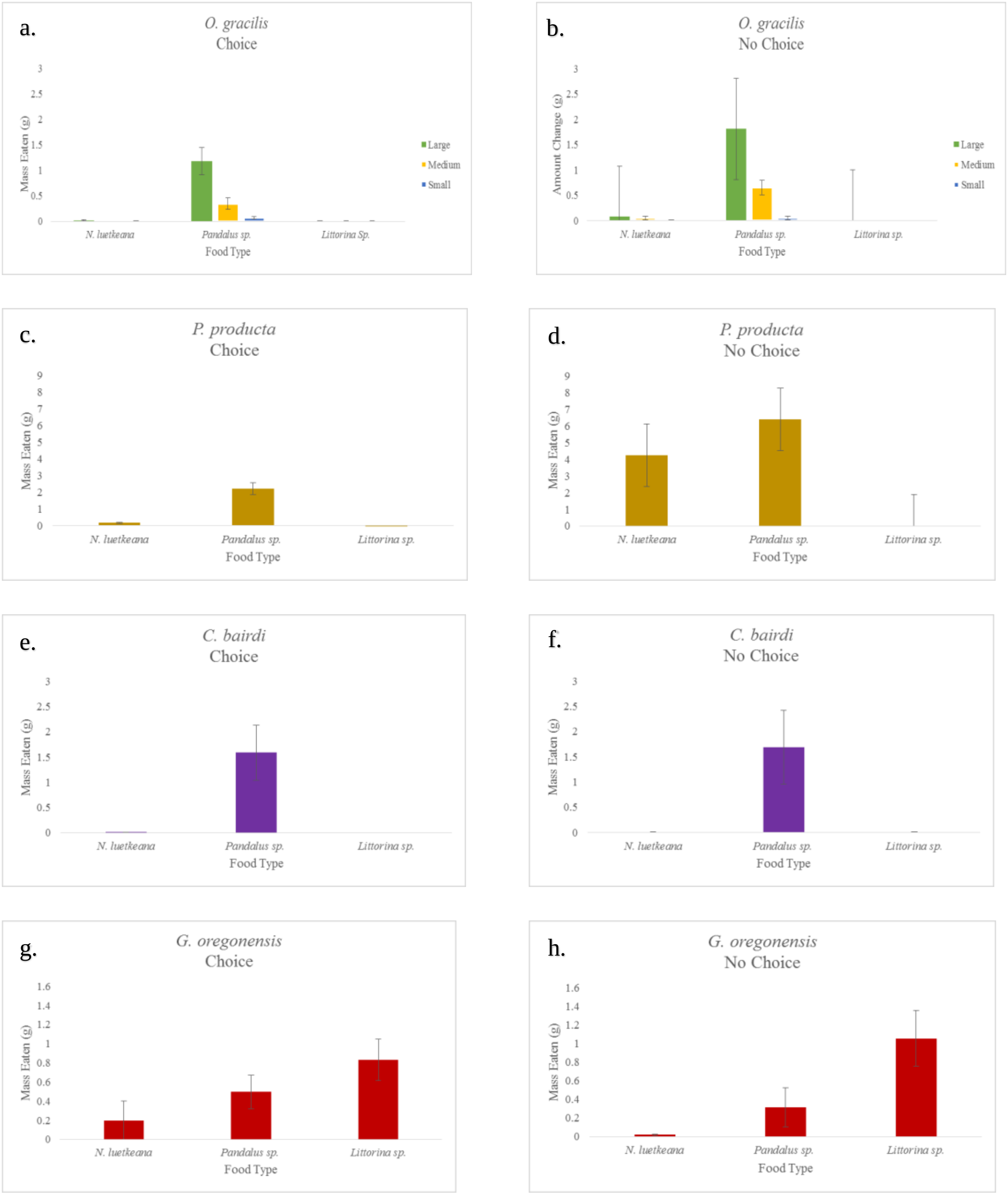

Figure 7. Average mass eaten for three food types in Choice and No Choice experiments. Standard error is reported by error bars. The y-axis within each species is the same for the two types of experiments but is not the same across species; the scale for *P. producta* is much larger than for the other species.

Discussion

The crab species studied varied greatly in both claw morphology and food preferences. This variation was noticeable between species as well as between individuals. The most striking morphologic difference seen was in *O. gracilis*, the Decorator Crabs; the crabs were able to be divided into three separate groups based on merus length to carapace width. Each group showed a different and distinct allometric scaling, with large crabs having proportionally much larger claws. There were also different likelihoods of having denticles within the groups. As a species the Decorator Crabs never displayed more than one large denticle, which was found close to the intersection of dactyl and propus. But size does seem to matter in whether or not a crab had this denticle. No crab from the small group had a denticle, while the crabs from the large group were most likely to have it. It's unclear what causes these differences in morphology; some possible explanations may be differences in growth rate when claws are being regenerated, or the claw being adapted for a non-feeding behavior such as decorating. The morphologic differences did appear to allow at least one large crab to consume snails, which no other crabs from the other groups did. Either the large crab simply had large enough claws to handle the snails or the large denticle may have made the claw a better tool for crushing shells. Despite these differences in morphology, all three groups showed a preference for shrimp.

P. producta, Kelp Crabs, had a similar morphology to the Decorator Crabs, with a large denticle close to the claw intersection, but differed in having subsequent smaller denticles, giving their claws a serrated nature. A similar pattern was seen in *C. bairdi*. *G. oregonensis*, Pygmy Rock Crabs, had a very different morphology from the other three species. They had four small denticles, all very close to the intersection of the claw on a raised portion of the claw. These four small denticles may act as a single larger structure. The Pygmy Rock Crabs' preference for and ease at eating snails (Fig. 7e) would support this theory of the denticles use; Yamada and Boulding (1998) found that crabs with larger denticle structures were better at crushing mollusk prey.

Kelp Crabs and Pygmy Rock Crabs both consumed all three of the food types, but showed different preferences. Kelp Crabs consumed mostly shrimp, some kelp, and one snail (Fig. 7a). Pygmy Rock Crabs consumed mostly snails, some shrimp, and occasionally kelp (Fig. 7e). These two species fit well into the generalist and specialist groups described by Yamada and Boulding (1998). They described generalists, such as the Kelp Crab, having finer claws with serration patterns, and generally consuming detritus or macroalgae along with the occasional mollusk prey. And specialists, such as the Pygmy Rock Crab, as having stronger claws better adapted for crushing mollusk prey.

It looks like the large, blunt denticle close to the claw's intersection is necessary for predation on snails. This is supported by small and medium Decorator Crabs being the only crabs that generally didn't have this denticle (Table 1) and the only crabs to not consume snails (Fig. 8). Further the Pygmy Rock Crab's with their four small denticles forming one larger pseudo denticle showed the greatest preference for snails. These four small protrusions may actually be acting as serration on a larger denticle structure. Which may give the crabs a more secure grip, similar to what Abler (1992) found with his work on serrated tooth structures. Anderson and Labarbera (2008) that blade shaped teeth, especially those with serrations, were better able to cut into shrimp and smelt bodies. The smooth or serrated scissor-like claws seen in all Decorator Crabs, Kelp Crabs, and *C.*

bairdi, similarly appear to be better for tearing kelp and particularly shrimp detritus, as all of these crabs preferred shrimp and kelp over snails.

The most consistent result from the feeding trials is that all of the crabs consumed shrimp. This is most likely because that prey was the easiest to handle, by all claw types. This may have been because the shrimp was dead, unlike the snails which were alive and could possibly escape predation. Further avenues of study raised by this finding would be to look at the nutritional content of the food types to see if this could account for the crabs' choices. It is known that kelp is deficient in some important nutrients, such as nitrogen, the shrimp has these nutrients and this could explain the preference of shrimp detritus over kelp detritus. In addition, comparisons of feeding preference of crabs between dead shrimp, live shrimp, dead snails, and live snails would be able to determine what effect the potential escape responses of the snails may have had.

Acknowledgments

I would like to thank Katie Dobkowski and Stephanie Crofts for being my mentors on this project, and Megan Dethier for her comments, suggestions on the paper and just generally keeping the quarter on track. Special thanks to Myesa Fixx with all her help on everything from catching shrimp, to crabsitting while I was off island. I am also grateful to the Friday Harbor Laboratories faculty and staff for all their advice, support, and use of their facilities.

References

Abler, W.J. 1992 The serrated teeth of tyrannosaurid dinosaurs, and biting structures in other animals. Paleobiology

Anderson P.S.L., M. Labarbera. 2008 Functional consequences of tooth design: effects of blade shape on energetics of cutting. J. Exp. Biol. 211, 3619–3626.

Levinton, J.S. 2014 Marine Biology: Function, Biodiversity, Ecology. Vol. 4

Riyahi, S., O. Hammer, T. Arbabi, A. Sanchez, C. S. Roselaar, M. Aliabadian, and G. P. Saetre. 2013. Beak and skull shapes of human commensal and non-commensal house sparrows *Passer domesticus*. Bmc Evolutionary Biology 13:8.

Schenk, S. C., and P. C. Wainwright. 2001. Dimorphism and the functional basis of claw strength in six brachyuran crabs. Journal of Zoology 255:105-119.

Seed, R., and R. N. Hughes. 1995. Criteria for prey size-selection in molluscivorous crabs with contrasting claw morphologies. Journal of Experimental Marine Biology and Ecology 193:177-195.

Seed, R., and R. N. Hughes. 1997. Chelal characteristics and foraging behaviour of the blue crab *Callinectes sapidus* Rathbun. Estuarine Coastal and Shelf Science 44:221-229.

Warner, G. F., and A. R. Jones. 1976. Leverage and muscle type in crab chelae (Crustacea-Brachyura). Journal of Zoology 180:57-68.

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.