Crabby Consequences of an Invasive Seaweed Cuisine: the scoop on Poop, Mass, and Molting in *Pugettia gracilis*

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Introduction

Along the western coast of North America, kelp forests contribute greatly to the productivity of marine ecosystems and are essential to maintain biodiversity (Springer et al., 2010). Throughout their geographic range, bull kelp forests house a variety of fish and invertebrates, and provide nursing and nesting grounds for shorebirds and sea otters (Springer et al., 2010). However, deleterious abiotic and biotic forces are threatening these bull kelp forest dynamics.

Among those threats, climate change continues to cause increasing shifts in the density and distribution of bull kelp (Beas‑Luna et al., 2020). Frequent marine heatwaves, ocean acidification, and the reduction of trophic regulators such as sunflower stars, are threatening bull kelp numbers (Arafeh-Dalmau et al., 2023). In Northern California, more than 90% of kelp forests have been lost due to these marine heatwaves and overgrazing by sea urchins (Arafeh-Dalmau et al., 2025). Heatwaves in particular, as a result of climate change, are compromising kelp forests' capacity to provide coastal protection, nutrient cycling, and carbon sequestration, all costing billions of dollars to humanity (Smale, 2019). The combined effects of these stressors has reduced the ability for kelp forests to bounce back and recover, and as foundation species, their loss can profoundly impact hundreds to thousands of species that rely on them (Arafeh-Dalmau et al., 2025; Rogers-Bennett, 2019).

Pugettia gracilis, also known as the graceful kelp crab, is an intertidal and subtidal species that resides in the kelp beds of the Salish Sea. As common residents of the brown seaweed, *Nereocystis luetkeana* (bull kelp), they cling to its blades and graze on the macroalgae, mediating its overall growth and survival. For kelp crab species in the

Salish Sea of the eastern Pacific Ocean, bull kelp beds offer both a nutrient-rich food source and a three-dimensional home where they can mate and protect themselves from predators (Smale et al., 2013). However, their homes are being threatened by abiotic and biotic pressures from climate change and invasive seaweed species.

Invasive seaweed species also substantially impact native kelp in the Salish Sea (Britton-Simmons, 2004). The invasive seaweed *Sargassum muticum,* also known as Japanese wireweed, is a ubiquitous brown seaweed initially introduced to North America's Pacific coast in the early 1900s via Pacific oyster harvesting (O'Clair & Lindstrom, 2000). Its highly effective reproductive and dispersal strategies have expanded its presence from Alaska to Mexico, and *Sargassum* is directly competing with native seaweeds (Britton-Simmons, 2004). In the Salish Sea, *Sargassum* has contributed to a 75% reduction in native canopy cover by limiting light availability and nutrient concentrations, all essential for native species such as bull kelp (Britton-Simmons, 2004; Johnson et al., 2023). The ecological and developmental impacts of *Sargassum* on kelp crabs is not entirely understood, but previous studies suggest that while it is not a preferred food of kelp crabs, they can and do eat it (Dobkowski, 2017).

In a world where the effects of climate change and other abiotic pressures could potentially eradicate or diminish native bull kelp populations, understanding the developmental consequences of a less preferred brown seaweed diet on kelp crabs could offer unique insights into dietary consequences for herbivorous consumers. We used molting rate, change in fecal output, and change in body mass to quantify the potential developmental consequences of an invasive *Sargassum* seaweed diet on graceful kelp crabs. A more nuanced picture of trophic relationships will also contribute to our comprehension of the broader ecological consequences of invasive seaweed species on kelp forest food web dynamics in a changing ocean.

This study uses laboratory feeding experiments to quantify *P. gracilis* growth and molting patterns based on two diets: native bull kelp and invasive *Sargassum*. Our first objective was to understand if kelp crab growth is influenced by a diet of different seaweed species. We asked: Are kelp crabs developmentally influenced by their diets if they feed on invasive seaweed? If so, can time to molt vary based on these different diets? Our hypothesis is that kelp crab molting rate is influenced by the food in which they eat. Nguyen et al. (2014), demonstrated that dietary protein and fluctuations in essential amino acids based on different diets in *S. serrata,* mud crab, influences molt frequency. Therefore, we believe kelp crabs have the potential to exhibit the same behaviors.

Our second objective was to understand if kelp crab mass changes over time when fed *Sargassum*. Previous studies with *P. camtschaticus,* red king crabs, have determined that diet has a direct correlation with crab mass, carapace width, and survival (Daly, B., Swingle, J. S., & Eckert, G. L. 2009). We hypothesize that graceful kelp crabs fed a preferred diet of bull kelp will exhibit greater changes in mass than those that are only fed *Sargassum.*

Our third objective was to see if poop mass can serve as a metric to quantify growth and developmental changes in the graceful kelp crab. We asked, does poop mass change for crabs fed different seaweed diets? If so, does *Sargassum* have an effect on average poop mass in the graceful kelp crab? We predict that kelp crab poop mass will be influenced by different diets.

Methods

Crab Collection

We collected *P. gracilis* from three different intertidal sites on the San Juan Islands in Washington State in June of 2025: Friday Harbor Laboratories, Deadman Bay, and Cattlepoint (*Fig 1*). We chose to use smaller (juvenile) crabs to increase our chances of observing multiple molting events during feeding experiments, and had no bias towards sex during collection. We divided crabs into two size groups: small crabs (min arm span = 1.4cm, max = 4.3cm) and medium crabs (min arm span = 4.5cm, max =7.2cm).

Fig 1: Map of three collection sites on the San Juan island of Washington State.

Experimental Set-up

We housed the 15 medium crabs in 709 ml (7.5cm x 16cm) miniature plastic storage boxes with 3 puncture holes, a mesh lid, and a single clear vinyl tube with flowing seawater (hereafter “crabitats”). We used 2 flow-through seawater tanks for this, crabitat tanks 1 and 2 *(Fig. 2)*.

We housed the 13 small crabs in 280 ml (5.2cm x 9.5cm) miniature plastic storage boxes with 3 punctured holes and a mesh lid (hereafter “mini crabitats”). These crabs floated in 1 flow-through seawater tank (2ft x 4.5ft), mini crabitat tank 3. All tanks were located at Friday Harbor Laboratories (FHL), Washington State, USA, with ambient seawater temperatures ranging from 11 to 16 °C.

Prior to starting the experiment, crabs were photographed, assigned an ID based on the location in which they were found, and weighed. We also collected a fecal sample from each crab. Before the official start of the experiment, crabs freely consumed a range of seaweeds other than our species of interest (bull kelp and *Sargassum).* This included a mixture of Sea Lettuce (*Ulva ssp.*), Brown Rockweed (*Fucus distichus)*, Green Tuft (Genus *Cladophora*), and Red Ribbon *(Palmaria palmata)*.

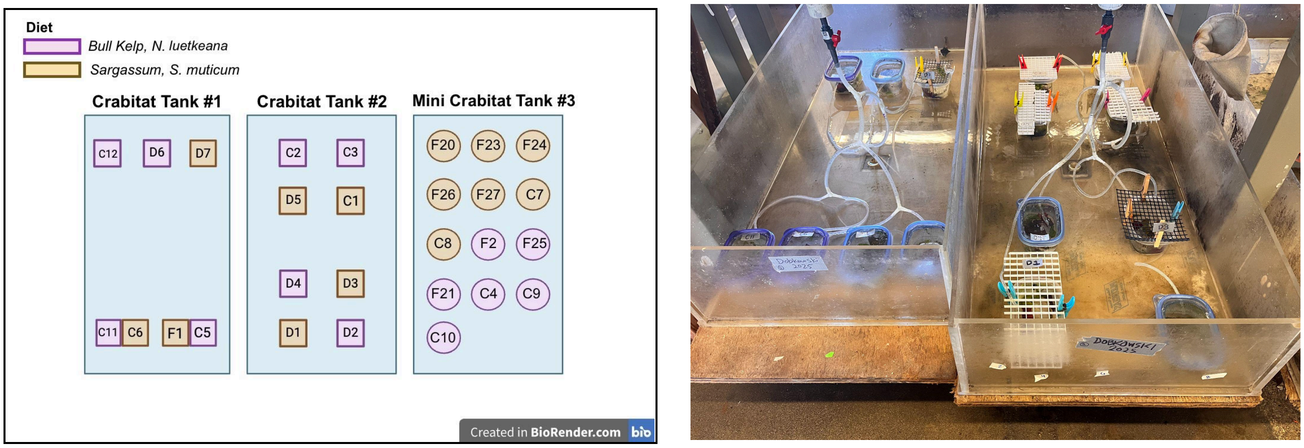

Fig 2 - Diagram showing laboratory feeding setup for small (mini crabitats) and medium-sized kelp crabs (crabitats)

Feeding Experiment

During the experiment, 15 medium crabs were randomly assigned a diet of bull kelp or *Sargassum* (bull kelp diet n=8, *Sargassum* diet n=7). For the small crab size group, 13 small crabs were randomly assigned a diet of bull kelp or *Sargassum* (bull kelp diet n=6, *Sargassum* diet n=7). To prepare food for this experiment,we harvested drift pieces of *Sargassum* and floating blades of bull kelp along the docks of FHL. We used a single blade of fresh bull kelp (non-deteriorated pieces) and a single frond of *Sargassum* cut up into various pieces to feed all 28 crabs.

To maximize freshness and food availability, we switched out the food every four days, using an Ohaus Navigator XT scale to weigh the old food and new food. We fed the crabitat crabs 4 grams of their designated diet and fed the mini crabitat crabs 2 grams. The experimental feeding period began on July 1st and ran until July 30th 2025.

Fecal Collection

Each feeding day, we extracted a single fecal sample with a disposable pipette tube from the container in which they were held (*Figure 3*). Subsequently, we placed fecal samples in a drying oven at 12 ° F for 10 minutes, to remove excess water. We then weighed the pellets with a Mettler AE 100 scale and noted their mass.

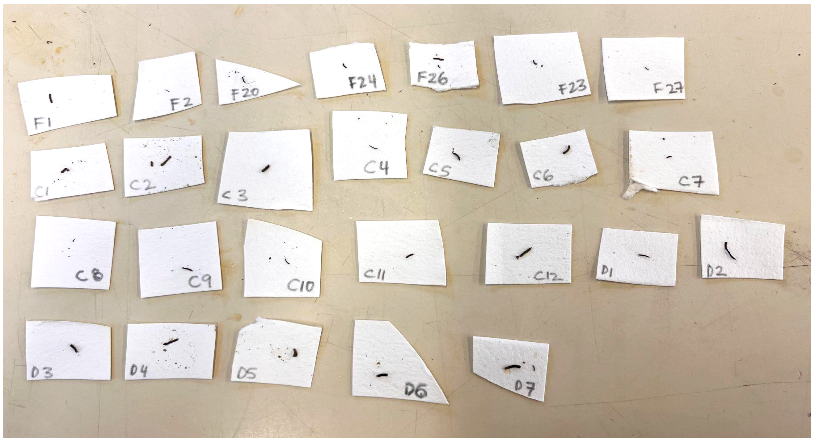

Fig 3 - Pellets of feces collected and weighed.

Molting Data Collection

We noted the dates on which crabs molted, measured their new carapace, and noted their new carapace color. We took photos of molted crabs in a clear container with a ruler, their ID, and their molt *(Figure 4)*.

Fig 4 - Molting Picture set-up.

Results

Change in Crab Mass

In our feeding experiment, the graceful kelp crabs demonstrated no significant changes in crab mass over the 4 week period (t = 0.806, *df* = 21.789, *p*-value = 0.429), when fed a diet of *Sargassum* or bull kelp. Median and interquartile ranges are displayed (*Figure 5*, n = 24). Medium-sized crabs showed more changes in crab mass difference than smaller crabs. (t = 2.349, *df* = 15.837, *p*-value = 0.03214).

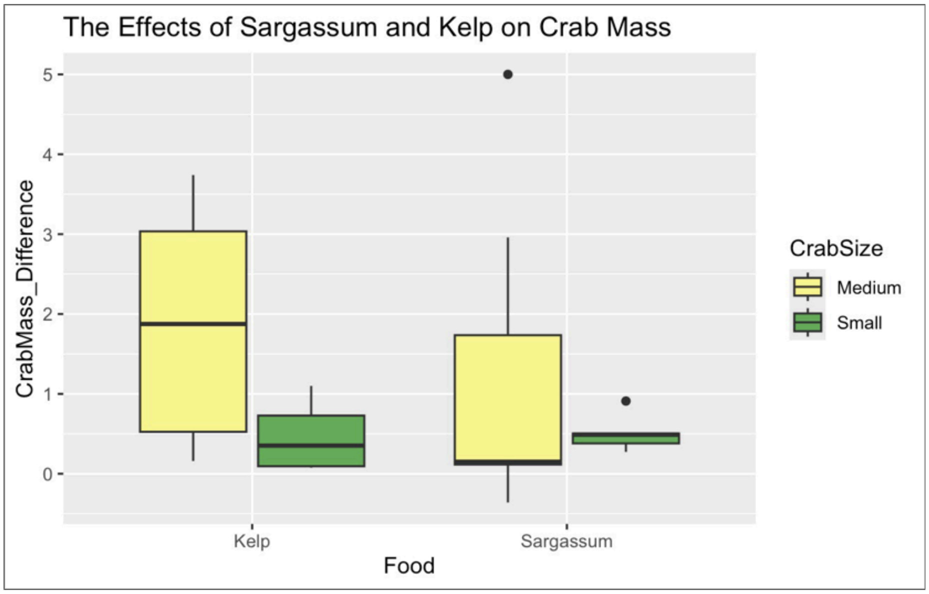

Fig 5 - Boxplot showing the effects of Sargassum and bull kelp on crab mass. Horizontal bands indicate median crab mass difference values, and black dots indicate outliers.

Change in Poop Mass

Average poop masses calculated from our fecal extractions showed no statistically significant correlation with diet (t = -1.0108, *df* = 13.541, *p*-value = 0.3298). Medium-sized crabs fed ~4g of their assigned diet, on average, produced heavier and larger fecal pellets than our smaller crabs, 0.001 ± 0.001 g (*Fig. 6,* medium crab poop mass: $\bar{x}_{\text{medium}}$= 0.00107, $\bar{x}_{\text{small}}$= 0.000204). Crab size had a significant correlation with average poop mass (t = 3.8132, *df* = 15.414, *p*-value = 0.001624).

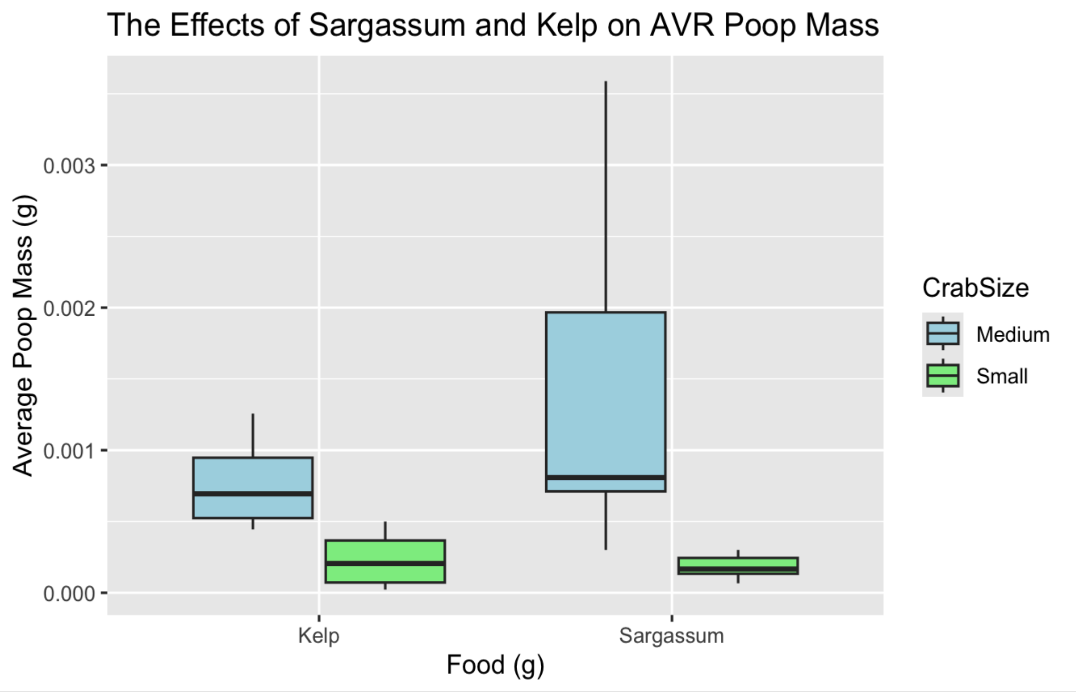

Fig 6 - Boxplot showing the effects of Sargassum and bull kelp on average poop mass. Horizontal bands indicate median poop mass values, and outliers are indicated by black dots.

Using a linear model, we tested the interaction between final crab mass difference, average poop mass, and diet (*Fig. 7).* We found a significant positive relationship between end crab mass and average poop mass (r_{kelp}= 0.750, p_{kelp}= 0.00497, $r_{\text{sargassum}}$= 0.637, p_{kelp}= 0.00497). Crabs eating *Sargassum* produced more poop per gram of crab mass than those with the bull kelp diet ($\text{slope}_{\text{sargassum}}$= 0.00025, $p_{\text{sargassum}}$=0.0259, $\text{slope}_{\text{kelp}}$= 0.000103, p_{kelp}=0.00497).

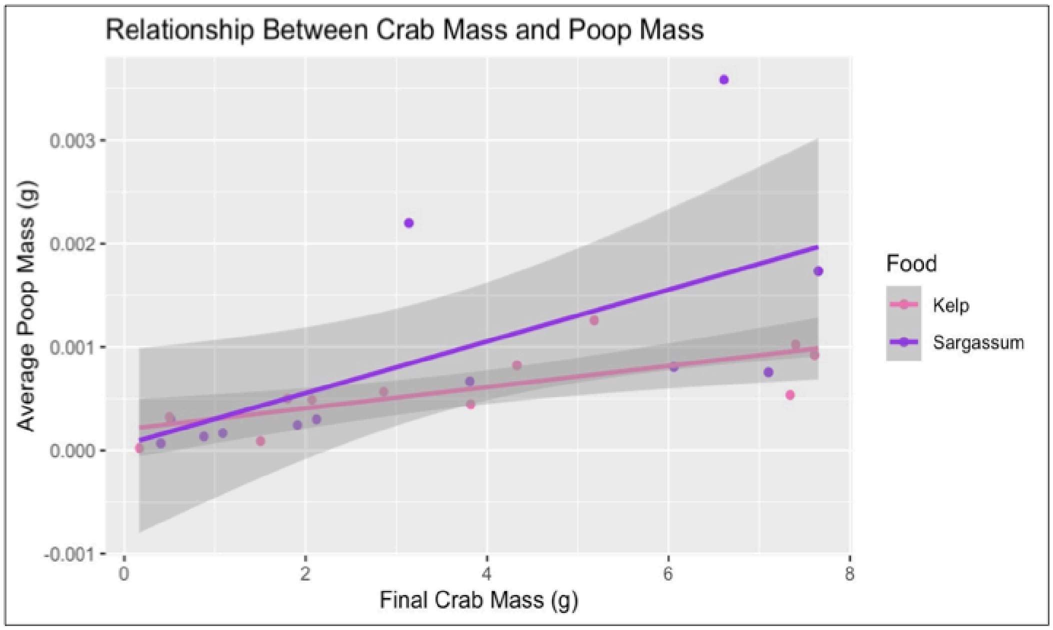

Fig 7 - Linear model showing the relationship of final crab mass and average poop mass, separated by diet (Sargassum diet: slope$_{sargassum}$*= 0.00025* R^2*=0.40; kelp diet: slope*$_{kelp}$*= 0.000103* R^2*=0.56).*

Molting Rate

We analyzed the impacts of food on molting rate, indicated by the number of days it took for crabs to molt and their crab size (*Fig. 8)*. Diet alone did not significantly impact the amount of time it took for crabs to molt (t = -0.31254, *df* = 14.385, *p*-value = 0.759). However, crab size did influence molting rate (t = 2.3609, *df* = 13.639, *p*-value = 0.0337). On average, smaller crabs molted sooner (after few days) than medium-sized crabs ($\bar{x}_{medium}$= 18.714, $\bar{x}_{small}$=10).

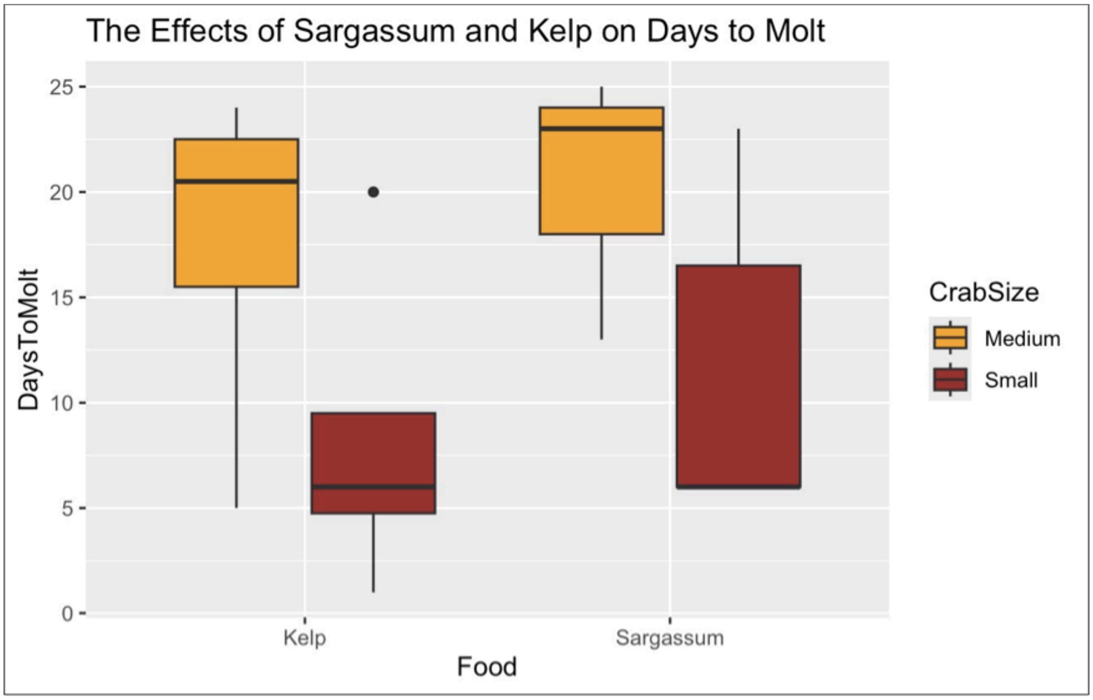

Fig 8 - Boxplot showing the impacts of food on days to molt. Horizontal bands indicate median days to molt values, and outliers are indicated by black dots.

Discussion

Effects of diet on fecal output, molting rate, and crab mass

Our results demonstrated that diet alone does not significantly impact *P. gracilis* across the three metrics: average poop mass, molting rate, and crab mass. This suggests that *Sargassum* may become a more generalist diet in *P.gracilis* beyond the kelp that it prefers, and that this less preferred food likely does not significantly impact the crab's overall growth and development, at least in the short term. *P. gracilis* has been identified as a generalist species, meaning it can adjust to varying environmental conditions and can expand its diet to consume invasive food sources (Johnson et al., 2023). Our study revealed that the expansion of this diet to invasive food sources, such as *Sargassum*, does not inhibit their growth and development.

While diet alone did not influence our three metrics, crab size did. Medium-sized crabs on average produced larger poop masses, had more differences in their mass from the start of the experiment to the end, and took a longer time to molt. This may indicate that as *P. gracilis* ages, individuals experience a transitional stage where the demand to molt decreases but their metabolic demands increase.

Physiological changes based on diet

Interestingly, we noted that crabs fed *Sargassum* experienced a shift in carapace color from dark brown to orange/amber (*Fig. 9)*. Closely related crabs in the family Epialtidae have been found to change carapace colors based on sequestration of dietary pigments into the crab's developing cuticle from the algae that they live on and consume (Hultgren & Stachowicz, 2008). Color change assays performed by Hultgren and Stachowicz on red *Pugettia producta*, the northern kelp crab, demonstrated that red juvenile kelp crabs fed a diet of amber-colored giant kelp, changed colors after molting to match the kelp in which they consumed. This indicated that diet has a strong influence on carapace color (Hultgren & Stachowicz, 2008). Similarly, we saw that our *Sargassum* fed crabs experienced this color shift after molting, which confirms that *P. gracilis* also displays this form of plastic camouflaging as a type of anti-predator defense. Background matching via diet-derived pigments can serve as a non-invasive bioindicator of diet in kelp crabs and become a useful tool to study food web dynamics. Additionally, this bioindicator can tell us the conditions of our oceans and inform us what food is becoming more/less abundant as our oceans continue to experience the effects of climate change.

Fig 9 - Table showing Sargassum-fed crabs before and after the experiment. Top row: crabs pre-molt, Bottom row: crabs post-molt.

Findings from this study highlight the impacts of invasive brown seaweed species on the graceful kelp crab, *P. gracilis*: how less preferred seaweed diets in *P. gracilis* don't have significant implications for their growth and development in the short-term. Rather, *P. gracilis* can modify its carapace color to adjust to the environmental conditions it faces. Ecological implications of this background matching must be further studied to assess the potential disruptions of *Sargassum* on predator–prey interactions, camouflaging efficiency, and overall ecosystem stability in our oceans. As the effects of climate change manifest in our oceans and invasive species such as *Sargassum* continue to flourish, understanding these responses in native species will be crucial for predicting resilience and quantifying their vulnerability for conservation efforts. In an era of rapid ocean change, protecting the ecological relationships that sustain marine life and human communities is vital for the survival of life on Earth and begins with resistance, awareness, and acknowledgment.

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