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Implications of Body Size and Habitat Distribution of Carcinus Maenas for Predation on Mytilus Edulis in the Gulf of Maine

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IMPLICATIONS OF BODY SIZE AND HABITAT DISTRIBUTION OF *CARCINUS MAENAS* FOR PREDATION ON *MYTILUS EDULIS* IN THE GULF OF MAINE

by

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ABSTRACT

The blue mussel, *Mytilus edulis*, is a commercially important species along the Gulf of Maine. Its rapid decline in population size over the last forty years has led many researchers to question if the invasive green crab, *Carcinus maenas*, is affecting its distribution. The increase in annual mean water temperature, due to global climate change, has led many to fear an expansion of the green crab's range and an increase in population density among areas they currently inhabit. The Damariscotta River in Walpole, Maine offers a unique thermal gradient to study the effects of temperature on green crab distribution, abundance, and size. I conducted field surveys to measure the abundance and size of both *Carcinus maenas* and *Mytilus edulis* within the intertidal zone of ten sites along the river. Results showed the highest abundance of both species occurred along the outer coast at sites dominated by cobblestone habitat. Sites with the highest abundance of green crab recruits also had the highest sample size and population density. In addition to intertidal surveys, green crabs were caught off the dock at the Darling Marine Center. Size frequency data from these traps suggest larger adult green crabs can be found both within the intertidal zone and in shallow subtidal waters. Green crabs caught within the subtidal and intertidal zone at the Darling Marine Center were used to conduct feeding trials to study the feeding capabilities, rates, and limitations of green crabs on blue mussels. Results showed that mussels 25 mm or greater are immune to green crab predation from crabs with a carapace width <50 mm. Size frequency data collected on the blue mussels show that despite large mussels being relatively immune to green crab predation, they are found in historically low numbers. The increased demand of blue mussels by humans over the last century could offer one explanation for the lack of large adult mussels along the Damariscotta River.

INTRODUCTION

Carcinus maenas "the European green crab," was first introduced to the eastern North Atlantic in the early 1800s. It has been ranked among the 100 'worst alien invasive species' in the world (Lowe et al., 2000) having successfully invaded the Atlantic and Pacific coasts of North and South America, as well as South Africa, Australia, and Asia (Cohen et al., 1995). *Carcinus maenas* was originally introduced to North America in 1817 near Long Island Sound, New York. In the 1980s, its range moved north through the Maritime Provinces of Canada (Roman, 2006; Blakeslee et al., 2010). Genetic analysis showed that the northward expansion was the result of a second introduction of the species from northern Europe (Roman, 2006). This species is of minor commercial importance within the United States; in fact, the major focus of this species is its importance as a potentially lethal predator to invertebrate species along the coasts it invades (Welch, 1968). After spreading throughout the Gulf of Maine, *C. maenas* preyed heavily on native shellfish species, eventually bringing about the decline of *Maya arenaria* populations (Welch, 1968; Donahue et al., 2009). Green crabs have also been blamed for the decline in commercially important shellfish industries including soft shell clams, quahogs, oysters, scallops, and mussels (Fincham, 1996). The green crab's success as a predator stems from its wide tolerance for salinity, temperature, oxygen, and habitat type. It also produces large numbers of planktonic larvae which are dispersed at all life stages (Cohen et al., 1995).

The green crabs native range encompasses a 25°C range of average sea surface temperature. Despite its wide range of thermal tolerance compared with other intertidal species, mass declines in green crab populations have been observed during periods of severe cold (Welch, 1968). Records beginning in 1906 of mean annual water temperature suggest that the last time Maine's water warmed (the 1950s) there was an increase in green crab abundance and a decline in soft shell clams because of increased predation (Welch, 1968).

As water temperature cooled in the 1960's, trapping data showed a rapid decline in green crab populations (Welch, 1968). The increase in annual mean water temperature because of global climate change has led many people to fear an expansion of the green crab's range and an increase in population density among areas it currently inhabits.

The blue mussel, *Mytilus edulis*, is a prey species which has been shown to influence diversity and production within the intertidal communities. Since the 1970's, the blue mussel population in the Gulf of Maine has decreased by more than 60%, leading scientists to question what is causing such a rapid decline in this foundation species (Sorte et al., 2017). If green crab populations are increasing because of climate change, then it is even more important to understand the predator-prey dynamics between the two species.

The focus of this study was to determine if green crab reproduction is linked to warming water temperatures. I propose that as water temperatures increase from the coast to sites upriver, patterns of recruitment and abundance will also increase. The final part of this study focused on the feeding capabilities, rates, and limitations of green crabs on blue mussels. The purpose of this feeding experiment was to determine the size of prey eaten by green crabs, and compare the size of prey eaten in lab experiments with the size of mussels available in the green crab's critical habitat to determine if green crab predation is the cause of decline of mussels along the Damariscotta River.

METHODS

Field Experiment

All field experiments were conducted between September and December 2016 along the Damariscotta River in Lincoln County, Maine. Ten sites were sampled in total, with the outer coast site being Pemaquid Point, and the Damariscotta Boat Ramp the furthest inland. Ten quadrats were used to randomly survey each site for *C. maenas* and *M. edulis*. Quadrats were randomly thrown above mean low water. In each quadrat substrate, species of algae, mean low water, time, date, and latitude/longitude were recorded. Calipers were used to measure carapace width in *C. maenas* and shell length in *M. edulis*. Data was pooled for sites that were geographically close and that had similar substrate. Sites that were pooled included 29 Water St. and the bank next to the Damariscotta boat ramp and two sites on Pemaquid Point. Despite being geographically close the two sites at the Darling Marine Center were not pooled due to a difference in habitat. One site was dominated by cobblestone while the second location was dominated by *Ascophyllum nodosum*.

Lab Experiment

All lab experiments were conducted in the flowing seawater lab at the Darling Marine Center in Walpole, Maine, during December 2016. *Carcinus maenas* were collected from underneath the outflow of the flowing seawater lab and from a trap set off the Darling Marine Center dock. The carapace width of each crab was measured before being put into individual containers measuring 5 1/8" x 4 7/16" x 2 3/4" (small), 7 1/4" x 4 3/4" x 3 3/32" (medium), and 6 9/10" x 6 9/10" x 4" (large) depending on the size of the crab. A slight variation occurred in the size of the containers because of difference in manufacturing. Small openings on the sides of containers allowed constant water flow through all containers for the duration of the experiment. Crabs were starved for forty-eight hours prior to the start of any feeding trials and any crab with only one claw or which had recently molted was excluded from trials to ensure results represented the feeding capabilities of green crabs. *Mytilus edulis* were scraped from the side of the Marine Center dock and cleaned of all organisms attached to the shell before being measured and sorted according to length into three size classes. The small size class consisted of mussels <15 mm, the medium class 16-25 mm, and the largest size class >26 mm. The size classes of green crabs ranged from small <30 mm, medium 30-50 mm, and large >50 mm. Containers were placed into a larger flowing seawater tank in which water was held at 10°C using Aqueon submersible heaters for the duration of the experiment. During Trial 1, a mussel from the smallest size class was placed into every container with a crab. Once the mussel was consumed, a mussel from the next size class replaced it. If a mussel remained untouched for twenty-four hours it was recorded as not being consumed and the crab was given a mussel from the next size class. Experiments were checked hourly during the day and every four hours at night for three full days. All experiments were terminated after seventy-two hours.

RESULTS

Size frequency distributions of *Carcinus maenas* at 10 intertidal sites on the Damariscotta River showed the highest population densities and greatest abundance of juvenile crabs at the outer coast (Figs. 1-9). *C. maenas* was found in the lowest abundance at sites closest to the head of the river (Fig. 1). Twenty quadrats were sampled across two sites resulting in a sample size < 10 crabs, a population density of < 1m^2, and a mean size of 17 mm. Sample size and population density of *C. maenas* was higher at

Dodge point, while mean size remained at 17 mm carapace width. The largest crab recorded during field surveys was seen at Dodge point and had a carapace width of 65 mm (Fig. 3). Mean carapace width declined to ≤ 10 mm while the number of *C. maenas* sampled increased across the remaining sites (Figs. 4-9). The cobblestone-dominated habitat at the Darling Marine Center had a higher sample size and population density, Cobblestone dominated coastal sites such as Pemaquid Point and the Thread of life had both higher sample size and population densities of *C. maenas* when compared with the sand and boulder dominated Sand Cove (Figs. 7-9).

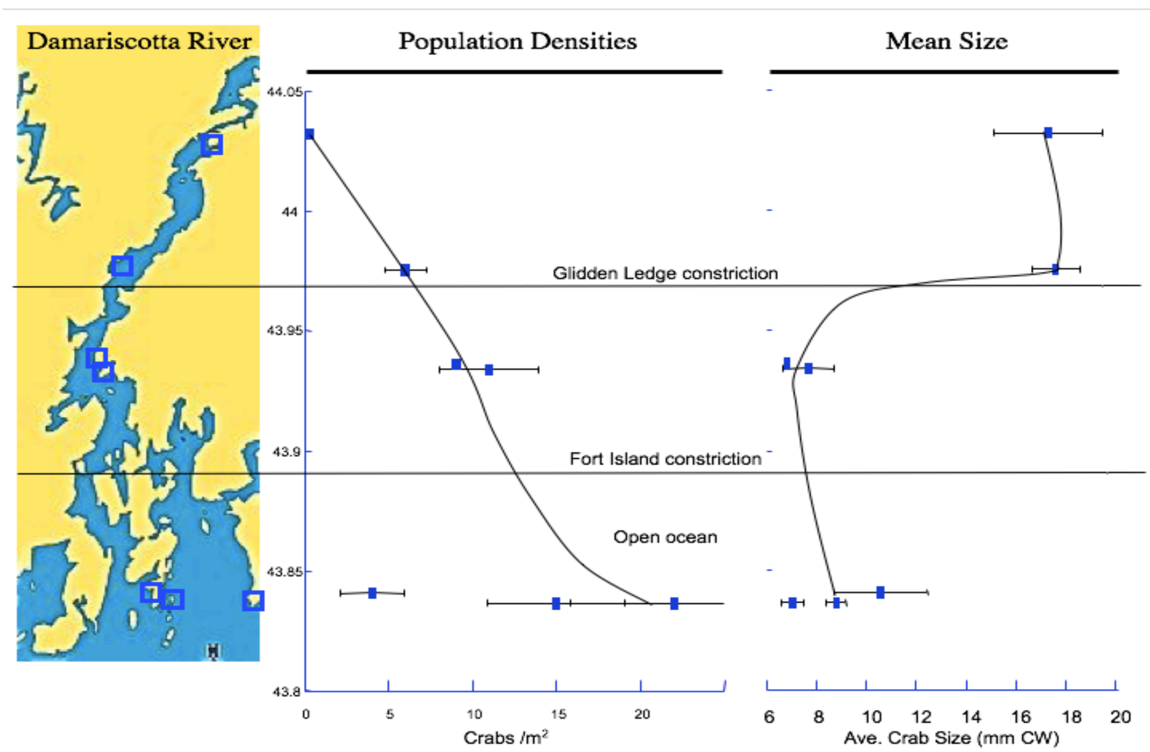

Figure 1. Relationship between *Carcinus maenas* population densities and mean size, shown plotted against the geographic location of sites along the Damariscotta River.

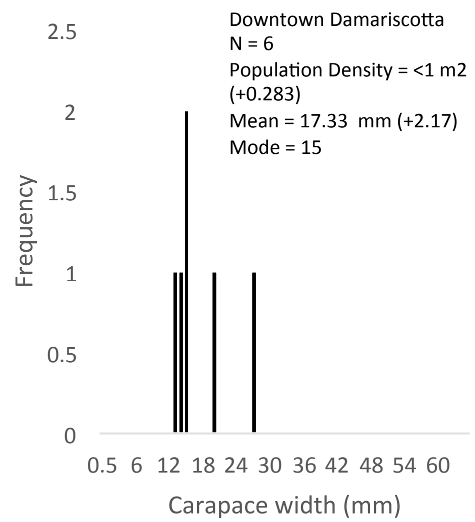

Figure 2. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at the downtown Damariscotta Boat ramp (44.03247, -69.53282) on 22 September, 2016, and 29 Water St, Damariscotta, (44.03123, -69.5338), 23 September, 2016.

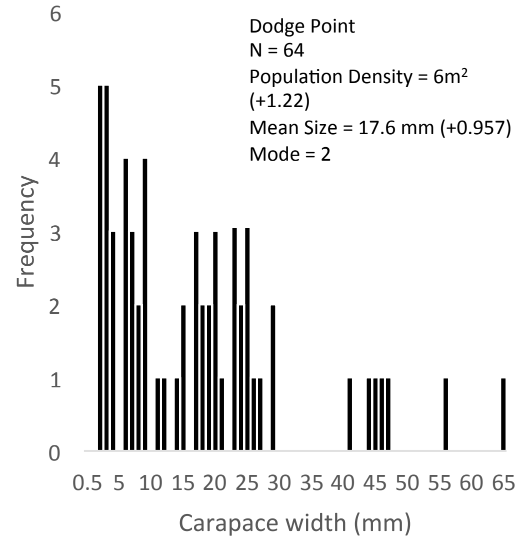

Figure 3. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at Dodge Point Preserve, Newcastle, ME (43.9849, -69.56379) on 7 October, 2016.

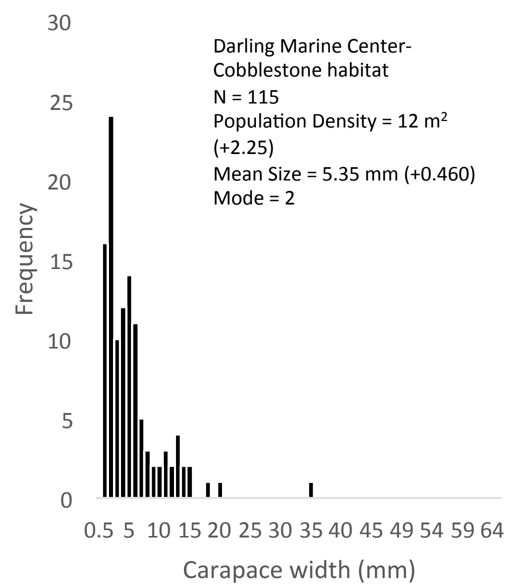

Figure 4. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at the Darling Marine Center, Walpole, ME (43.93597, -69.58067) on 5 September, 2016.

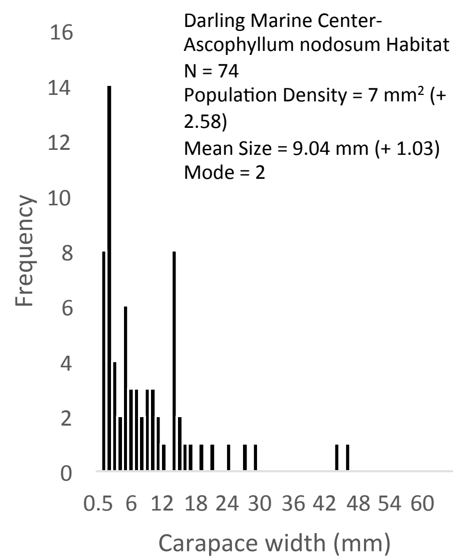

Figure 5. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at the Darling Marine Center, Walpole, ME (43.93622, -

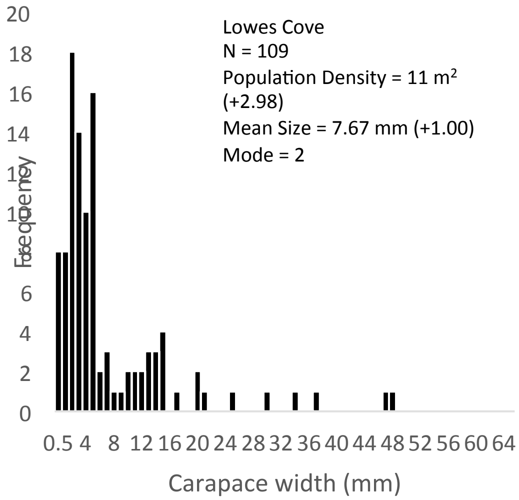

Figure 6. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at Lowes Cove, Walpole, ME (43.93827, -69.58233) on 15 September, 2016.

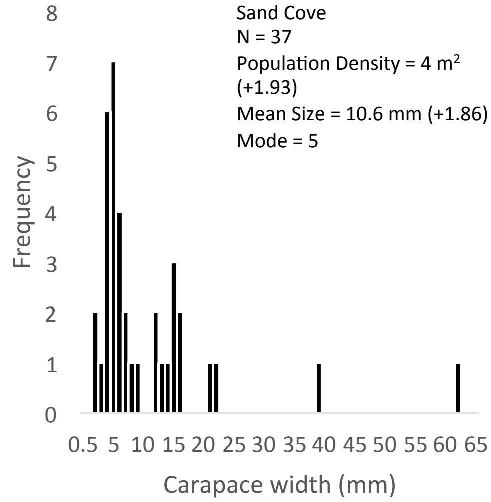

Figure 7. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at Sand Cove, Winter Harbor, ME (43.8409, -69.55565) on 30 September, 2016.

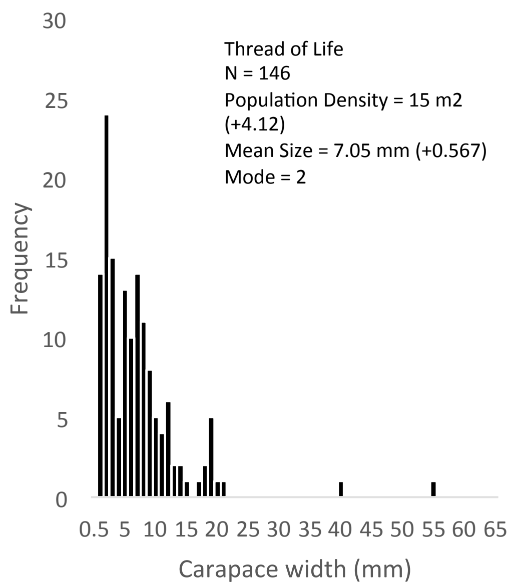

Figure 8. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at the Thread of Life, South Bristol, ME (43.83679, -69.5514) on 2 October, 2016.

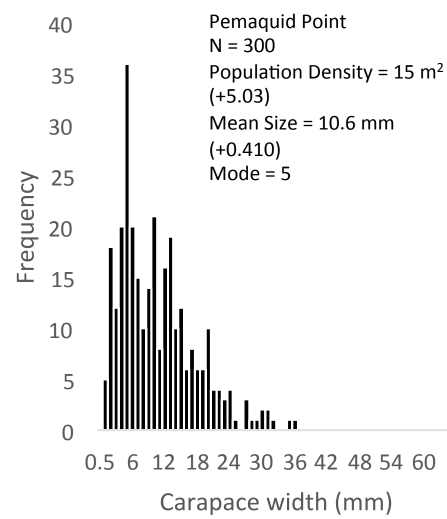

Figure 9. Size distribution of carapace width (*Carcinus maenas*) of samples collected from the intertidal zone at Site 1 on Pemaquid Point, Pemaquid, ME (43.83526, -69.51427) on 25 September, 2016, and Site 2 on Pemaquid Point, Pemaquid, ME (43.836481, -69.515559), on 8 October, 2016.

Carcinus maenas caught for the lab-experiment using a trap off the Darling Marine Center dock had a minimum size of 65 mm carapace width, which was the largest size seen during intertidal surveys. Sample size remained low with only 11 crabs caught that could be used in feeding trials (Fig. 10). Originally, 15 crabs were collected, however, four crabs were returned before measurements could be taken because they were missing claws.

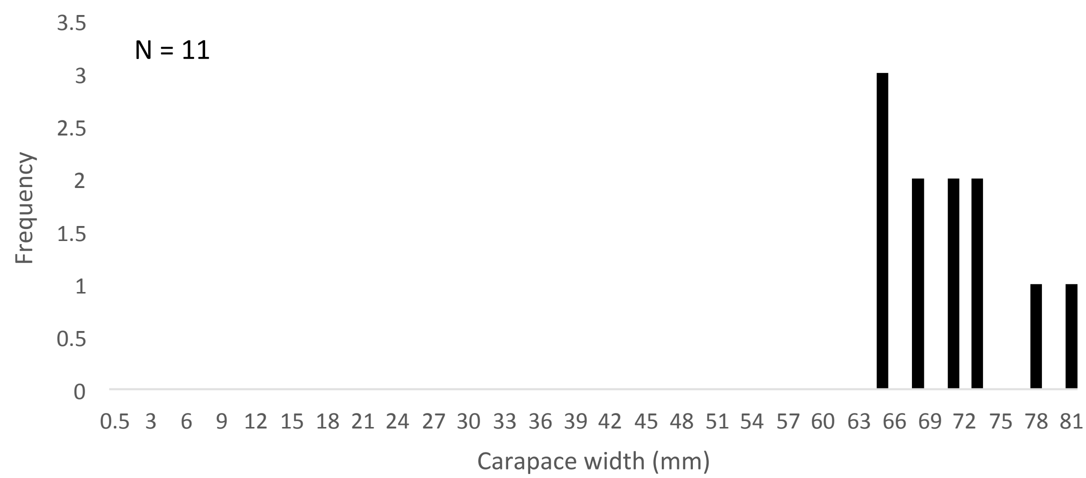

Figure 10. Size distribution of carapace width (*Carcinus maenas*) on samples collected from a wired trap set off the dock at the Darling Marine Center, Walpole, ME.

The mussel, *Mytilus edulis*, was only found at two out of ten sites. The two sites they were found at were both on Pemaquid Point. Mussels were found 1 m or higher on both boulders and flat rock at both sites. Mean size was 23.8 mm with the largest mussel being recorded at 50 mm. Fragments and broken mussel shells were found at Sand Cove and Lowes Cove, however, no live mussels were found at any sites other than Pemaquid Point (Fig. 11).

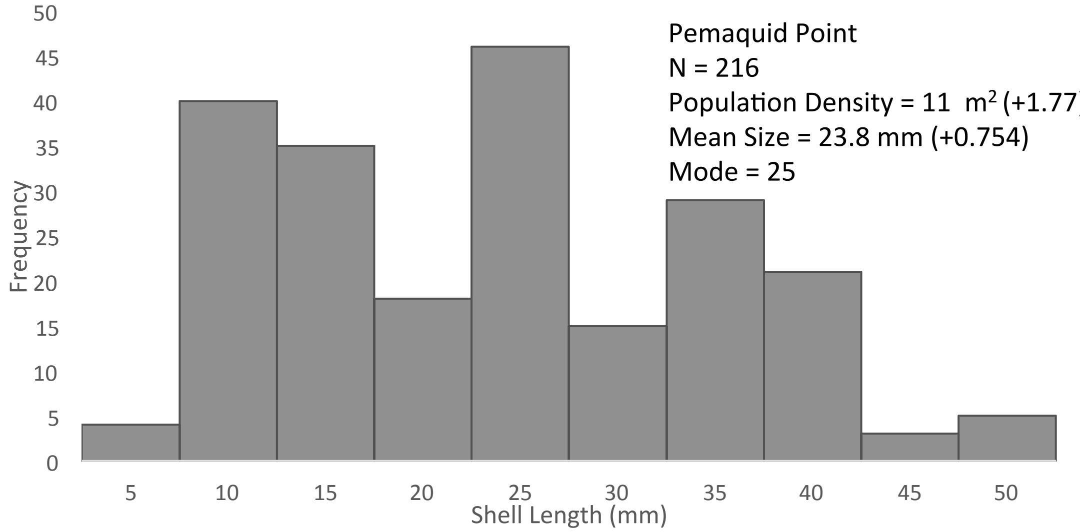

Figure 11. Size distribution of shell length (*Mytilus edulis*) of samples collected from the intertidal zone at Site 1 on Pemaquid Point, Pemaquid, ME (43.83526, -69.51427) on 11 December 2016, and Site 2 on Pemaquid Point, Pemaquid, ME (43.836481, -69.515559), on 11 December 2016.

Laboratory studies to determine the feeding capabilities and limitations of green crabs involved placing crabs from one of three size classes together with mussels from one of three size classes. Almost all (91%) of mussels <15 mm were consumed within the first 24 hours. The percentage eaten dropped to 51% for mussel's size 16-25 mm and only 11% for mussels' size >26 mm. The large chi-square statistic with 2 degrees of freedom has an associated p-value of <0.000001 which is highly significant meaning there is clear statistical evidence for a difference in the number of mussels eaten among the three size classes (Fig. 12). Crabs with a carapace width less than 40 mm took between 1-24 hours to consume both small and medium sized mussels. Crabs greater than 40 mm consumed small and medium mussels within the first five hours of introduction (Figs. 13 & 14). A chi-square of 0.708 with a p-value of 0.702 is well above the threshold of 0.05 meaning the null hypothesis that the proportions of small mussels eaten are different among the three size classes of crabs cannot be rejected (Fig. 13). A chi-square of 8.602 with a p-value of 0.014 means that there is a statistical difference between the number of mussels eaten in the medium size class by each of the three size classes of crabs (Fig. 14). Crabs with a carapace width under 50 mm were unable to eat mussels in the largest size class, whereas crabs in the largest size class of >50 mm could consume this size class of mussels within 1-15 hours following introduction. A large chi-square and an associated p-value of <0.00001 means that there is also a statistical difference between the number of the largest size class of mussels by each of the three size classes of crabs (Fig. 15).

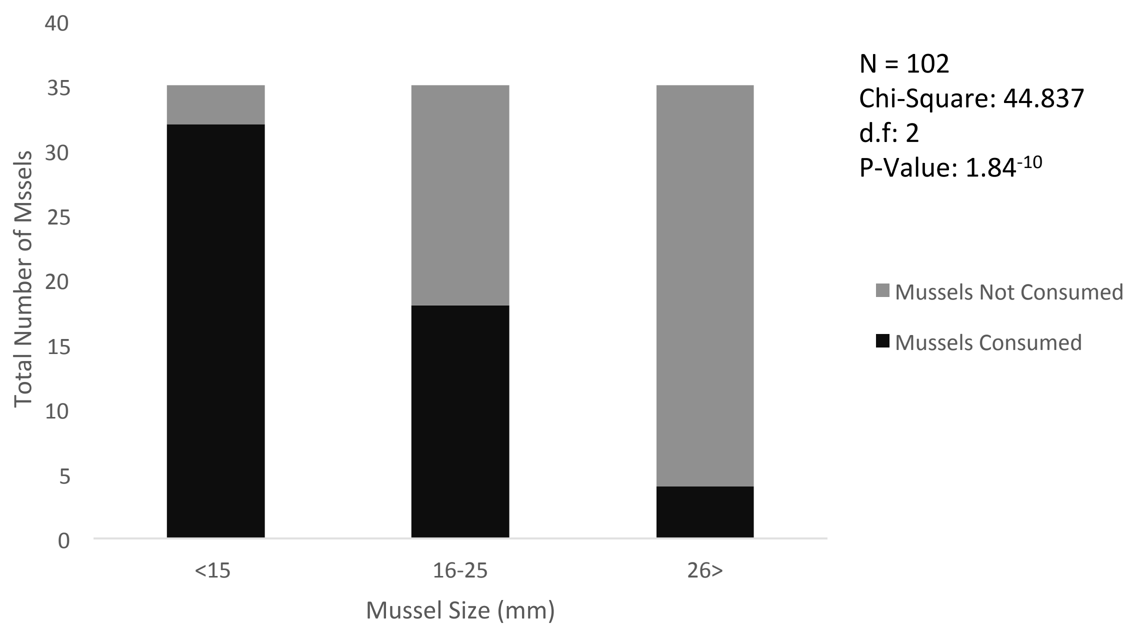

Figure 12. Frequency of mussels (*Mytilus edulis*) consumed by *Carcinus maenas* based on length of shell. Crabs used in this study ranged from 22 mm to 81 mm. The average carapace width of crabs used in this study was 36 mm.

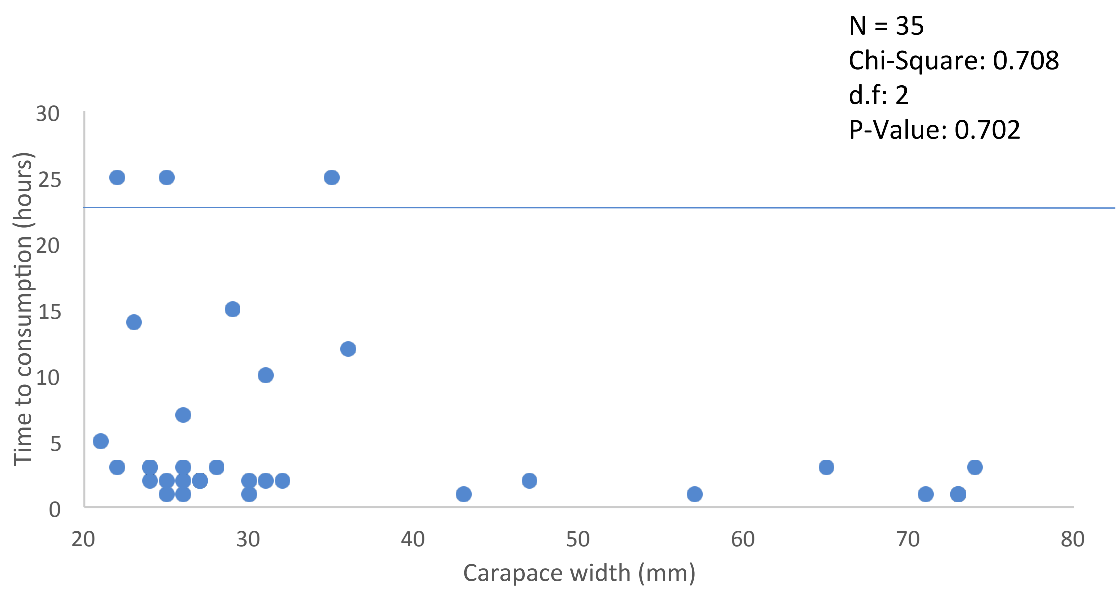

Figure 13. Relationship between carapace width of *Carcinus maenas* and time to consumption of *Mytilus edulis* <15 mm length. Mussels not consumed after 24 hours (indicated by the blue line) are represented at the 25-hour mark. Each point represents data from a different individual. Water was kept at 10°C for the duration of feeding.

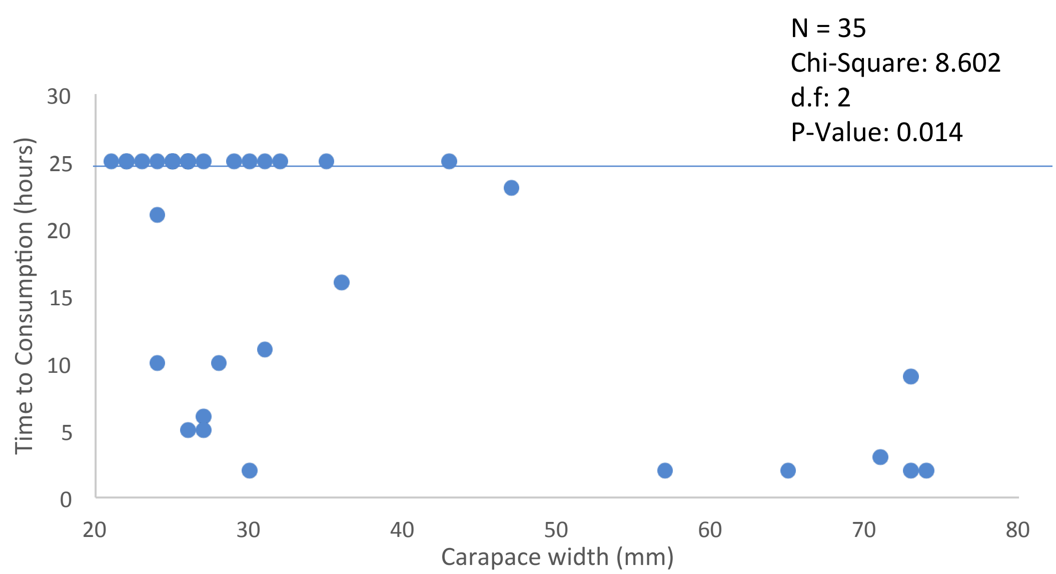

Figure 14. Relationship between carapace width of *Carcinus maenas* and time to consumption of *Mytilus edulis* with a length of 16-25 mm. Mussels not consumed after 24 hours (indicated by the blue line) are represented at the 25-hour mark. Each point represents data from a different individual. Water was kept at 10°C for the duration of feeding.

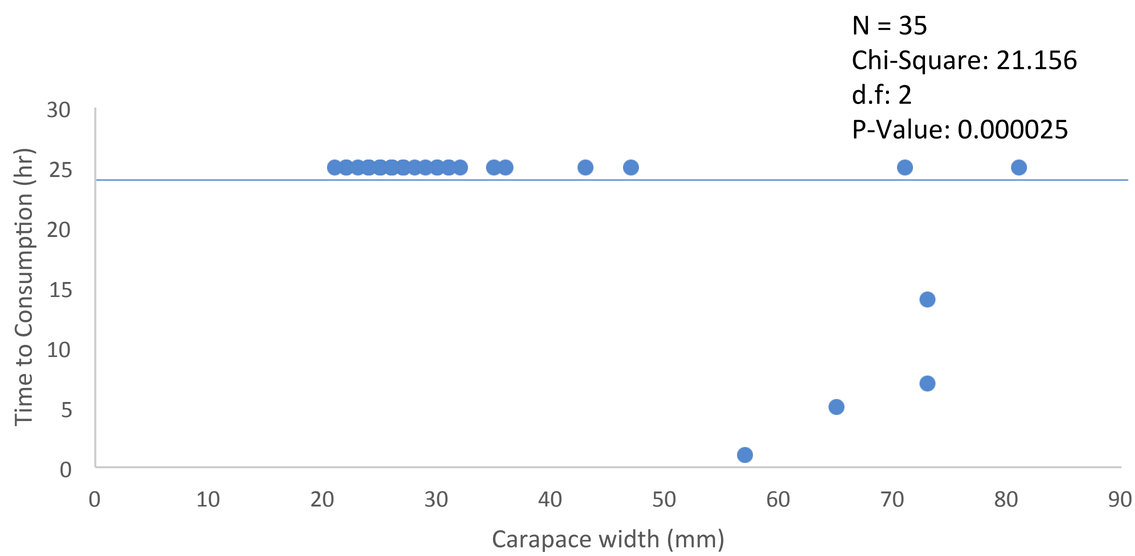

Figure 15. Relationship between carapace width of *Carcinus maenas* and time to consumption of *Mytilus edulis* with a length of 26 mm or greater. Mussels not consumed after 24 hours (indicated by the blue line) are represented at the 25-hour mark. Each point represents data from a different individual. Water was kept at 10°C for the duration of feeding.

DISCUSSION

Green crab recruits (< 10 mm CW) were found in the highest abundance along the outer coast. Sites with the highest number of recruits also had the highest population densities. A small percentage of large adult green crabs were found further up river. Historical records indicate blue mussels have been found at all ten field sites. Mussels were only found along outer coast sites with almost half of the mussels found being larger than those consumed by the largest green crabs studied in the lab.

Carcinus maenas was found in the highest abundance on wave exposed coastal sites with predominantly cobblestone (ranging from 10-50 cm) habitat (Figs. 8 & 9). The highest number of recruits were found at Pemaquid Point and the Thread of Life; however, recruitment was high as shown by a mean carapace width ≤ 10 mm for all sites except the town of Damariscotta and Dodge point (Figs. 1-9). This suggests that the original hypothesis that warm water would drive an upriver population explosion was unsupported. A study done by Palma et al. (1999) newly settled lobsters and rock crabs were most abundant on exposed coastal sites, with abundance decreasing at sites upriver. They suggest that the increase in distance from potential offshore larval sources combined with factors such as larval mobility and physiological tolerance could explain the pattern of decreasing recruits further up the estuary (Palma et al., 1999). Other studies suggest onshore wind-driven currents and tidal amplitude influence the ability of larvae of other decapods to enter estuaries (Eggleston and Armstrong, 1995; Mense et al., 1995; Morgan et al., 1996). For the Damariscotta River, strong flood tides allow for adequate larval transport out of the estuary toward the open coast, however weaker ebb tides and constrictions such as Fort Island and Glidden Ledge make it more difficult for juveniles to reenter the estuary (Fig. 1).

No green crab recruits were found during intertidal surveys at 29 Water St or on the bank of the boat ramp in Damariscotta, ME (Fig. 2). Mean size and population density increased at Dodge Point which is slightly downriver from the town of Damariscotta (Fig. 1). The largest crab found during intertidal surveys was recorded at Dodge Point and evidence of recruitment there was low (Fig. 3). The tendency of older adult crabs to migrate into sheltered environments has been shown for various crab species including *Cancer irroratus* (Palma et al., 1999), *Cancer magister* (Smith and Jamieson, 1991), and *Carcinus maenas* (Abelló et al., 1997). Alternatively, Lohrer and Whitlatch (1997) found almost no green crabs along the eastern US at high-energy sites where the substrate consisted mostly of gravel or rock. Similarly, in western North America, green crabs have colonized protected embayment’s but were found in low abundance in rocky habitats, a habitat where they are found on the European coast and where they were found in the highest abundance during this study .The factors affecting adult green crab distribution remain unclear as habitat and distribution of green crabs vary greatly depending on the geographic location they inhabit (Groshloz and Ruiz, 1996). They can be found in rocky intertidal, unvegetated intertidal, subtidal mud and sand, as well as saltmarsh and seagrass habitats (Ray, 2005).

Subtidal green crabs, sampled with traps, were significantly larger than those recorded in the intertidal zone (Figure 11). This suggests that bigger adults are present at the Darling Marine Center, but remain subtidal during low tide. It is possible that larger crabs move subtidal during low tide to avoid predation by gulls before moving up the shore as the tide comes back in (Ellis et al. 2005).

Blue mussels, a common prey species of the green crab, were only found at two out of the ten sites sampled (Fig. 12). Despite mussel shells being found at two of the other sites, their condition made it impossible to confidently determine what caused the shell to break in half or where the shells came from. It is possible that empty shells were dumped after being harvested by humans, meaning the mussels found might not be from the Damariscotta River. The average size of live mussels seen at Pemaquid Point was much smaller than the broken shells found at both Sand Cove and Lowes Cove. Mussels at Pemaquid Point had an average size of 23.8 mm, which is within the middle size class of mussels used in feeding trials (Fig. 13). Roughly 51% of mussels this size was consumed during the laboratory experiment, with that percent dropping to only 11% as mussel size increased past 26 mm (Fig. 13). Only crabs with a carapace width of 50 mm or higher could consume mussels past 26 mm (Fig. 16). Historical records on blue mussel size suggest that mussels on Rutherford Island (the location of the Thread of Life and Sand Cove) measured 110 mm in length and were up to 25 years old (Voorhees, 1994). This suggests that something other than green crab predation is preventing the growth of mussels along the Damariscotta. Harvesting of blue mussels is one explanation for the lack of adult blue mussels along the Damariscotta. Most of the commercial landings of the blue mussel on the East Coast of the United States comes from Maine and Massachusetts. Little information is available on the size of the blue mussel fishery in Maine because most of its harvest comes from unmanaged wild mussel beds that are subject to much less control than other commercial shellfisheries (Newell 1989). If larger mussels could grow in the intertidal zone, then it is possible that they could coexist with predators such as the European green crab since results from this study indicate they are only able to prey upon small mussels. The continued foraging of natural blue mussel beds along the coast of Maine, could result in the complete loss of the blue mussel from the intertidal zone.

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