The life history of the invasive European green crab (*Carcinus maenus*) in San Francisco Bay

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ABSTRACT

The European green crab, *Carcinus maenus*, was first discovered in 1989 in San Francisco Bay and has since spread northward along the west coast of North America. They are one of the top most successful invasive species in the world due to their tolerance of a wide range of salinities and water temperatures. They are also a voracious predator, often outcompeting native species for food and habitat and overwhelming native populations of prey organisms. This study investigates the current status of the population of *C. maenus* in the S.F. Bay over a five-year period and how their populations and carapace widths have changed over time. The data collected suggested that current populations of green crab are stable and slightly increasing while carapace width remains the same. This indicates that green crabs are not becoming an overwhelming threat in the S.F. Bay area but further research is needed to successfully determine the future of this species.

KEYWORDS

carapace size, life history ecology, European green crab, invasive species, habitat

INTRODUCTION

The invasion of marine and estuarine systems by alien species and the consequent ecological and environmental threats they pose to the natural habitat is a well-studied field of marine biology. Species transportation across global waters has significantly increased with increasing globalization, particularly in costal marine waters through ship ballast water and also by natural ocean currents (Griffen 2011). As a result, most coastal marine habitats are inhabited by non-indigenous species, which affect the native flora and fauna, sometimes in extremely negative ways.

Invasive species that have wide-ranging adaptive characteristics are able to survive well and proliferate throughout the habitat they are invading by outcompeting native species for food and shelter and predating heavily on lower trophic levels (Roudez et al. 2008). They are often able to adapt to a wide range of salinities and water temperatures, giving them an advantage above native species that are limited to certain habitats. Because of their ability to outcompete native populations and rapidly take over an area's food resources, the non-native species often grow larger and faster than those of the same species that live in their own native ranges (Roudez et al. 2008). Once established, non-native populations can spread rapidly and over great distances from the initial point of introduction, thereby expanding their range into most if not all nearby suitable habitats. Documented range expansions are characteristic of most biological invasions, making them ideal systems for ecological and evolutionary studies in natural populations because interactions between native and non-native species (predators, prey, competitors) are uncharacteristically well-defined (Edgell & Hollander 2011). One major goal of invasion ecology is to predict the establishment and spread of non-native populations because predicting where and how much species can invade and spread can help prevent major ecological disasters in certain regions by early detection and eradication efforts.

This study investigates the invasion of *Carcinus maenus*, the European green crab, in San Francisco Bay. *C. maenus* was first documented in San Francisco Bay in 1980 and has since spread north along the west coast of North America to Vancouver Island, where they were discovered in 1998, having travelled over 1300 km in 18 years, significantly faster than the range expansion of *C. maenus* on the east coast (1800 km over 100 years) (Edgell & Hollander 2011) (Fig. 1). There is strong genetic evidence that the invasion of *C. maenus* of the west coast of North America was from a single invasion event in San Francisco Bay, and larvae from this area subsequently spread north (Yamada & Korso 2010). Green crabs are known to be voracious predators and very adaptable crustaceans, with tolerances for large ranges of salinities and water temperatures. These characteristics make *C. maenus* one of the most successful invasive species in the world (Edgell & Hollander 2011). They have successfully invaded many estuaries around the globe, often causing extreme declines in native prey species, like the Asian clam, and other competing crustaceans, like juvenile blue lobsters (See & Feist 2010).

Although green crabs inhabit a variety of habitats in their native range, their predominant habitat on the west coast of North America is currently limited to the high intertidal zone in protected estuaries such as San Francisco Bay, due to the size and circulation of the bay and the entrainment of hatched larvae within the bay (See & Feist 2010). Therefore, San Francisco Bay is likely an ideal environment for *C. maenus* but there is little information about the current population status of *C. maenus* within the bay.

For the purposes of this study, I hypothesized that green crab morphology and population sizes have changed somewhat (if not significantly) since initial collections in 2005, conjecturing that there was a significant increase in carapace width and a significant increase in population size. This study aimed to clarify the current status of *C. maenus* and to predict the future of *C. maenus* in San Francisco Bay based on the past and current morphological and population patterns in comparison to other documented *C. maenus* invasions around the globe.

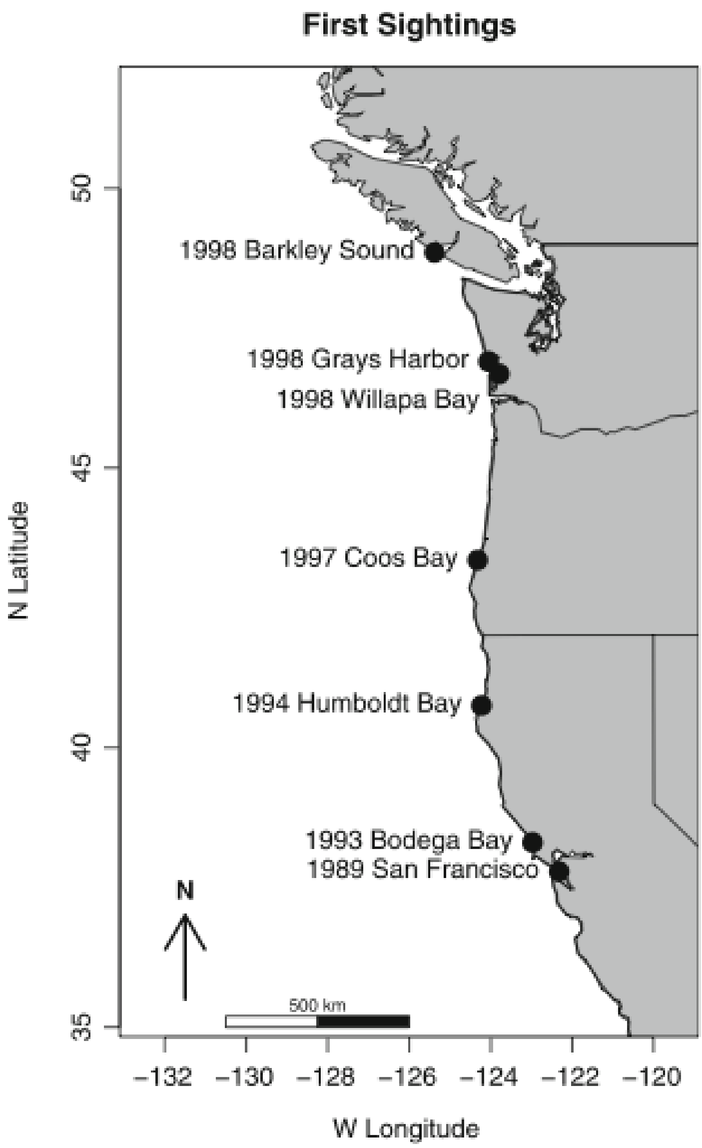

Fig. 1 Dates of first arrival of *C. maenus* in west coast estuaries based on confirmed first sightings.

METHODS

Study Site

China Camp State Park is located along the shore of San Pablo Bay, Marine County, California. It is a part of the San Francisco Bay National Estuarine Research

Reserve. Surrounding habitats include an intertidal salt marsh, meadow, and oak habitats. It has a variety of flora and fauna and is home to several endangered species.

Data Collection

The traps used to capture Green crabs were baited modified minnow traps. Collections were made at the following five transects starting from 23 July 2005 until present, four times per year. The traps were left in for approximately 24 hours before they were collected.

Transect	**Coordinates**	**Description**
A (China Camp Village)	Trap 1: N 38º 00.208', 122º 27.763' Trap 2: N 38º 00.186', W 122º 27.810' Trap 3: N 38º 00.212', W 122º 27.873'	Open mud
B (Bullhead Flat)	Trap 1: N 38º 00.230', W 122º 28.050' Trap 2: N 38º 00.208', W 122º 28.132' Trap 3: N 38º 00.271', W 122º 28.227'	Vegetation
C (Chicken Coop Hill)	Trap 1: N 38º 00.407', W 122º 28.731' Trap 2: N 38º 00.387', W 122º 28.743' Trap 3: N 38º 00.370', W 122º 28.759'	Creek channel
D (Bullet Hill)	Trap 1: N 38º 00.540', W 122º 28.972' Trap 2: N 38º 00.516', W 122º 28.999' Trap 3: N 38º 00.504', W 122º 29.018'	Creek channel
E (Turtle Back Hill)	Trap 1: N 38º 00.615', W 122º 29.054' Trap 2: N 38º 00.600', W 122º 29.079' Trap 3: N 38º 00.584', W 122º 29.102'	Creek channel

The data set analyzed in this study was provided by graduate students at the Romberg Tiburon Center, who did all the data collection and recording. The data set included carapace size, sex, water temperature, salinity, state of the bait at the time of collection, amount of soak time, and weather observations.

Statistical Analysis

The main goal of this study was to examine patterns and discrepancies in the morphological data (carapace size and sex) and population data over the time span of five years and also across seasons in order to see if current *C. maenus* populations are exhibiting significantly negative invasive characteristics since their initial establishment. I looked at a linear regression of the number of crabs over time and also by separate seasons, Fall and Summer, the seasons when *C. maenus* was most proliferate in the S.F. Bay to determine their seasonal abundance.

I also looked at a plot of the means of carapace size over five years and also by separate seasons to determine the general size variances of *C. maenus* since initial collections. I then ran an Tukey multiple-comparisons test to determine if any differences in size between seasons were significant or not. Finally, I ran a nested ANOVA test on the variance of size across seasons between male and female crabs to determine if there were differences in size between males and females during each season.

RESULTS

Population Size

Over the five-year time period, 215 green crabs were found in the traps. I was able to plot the number of crabs over the five-year span and found that there was an overall increase in population size with an R^2 value of 0.3389 (Fig. 2). There were fluctuations approximately each year but a general increase in number of crabs. I was only able to plot Summer and Fall data points due to the fact that other seasons had only one or two recorded crabs or none at all.

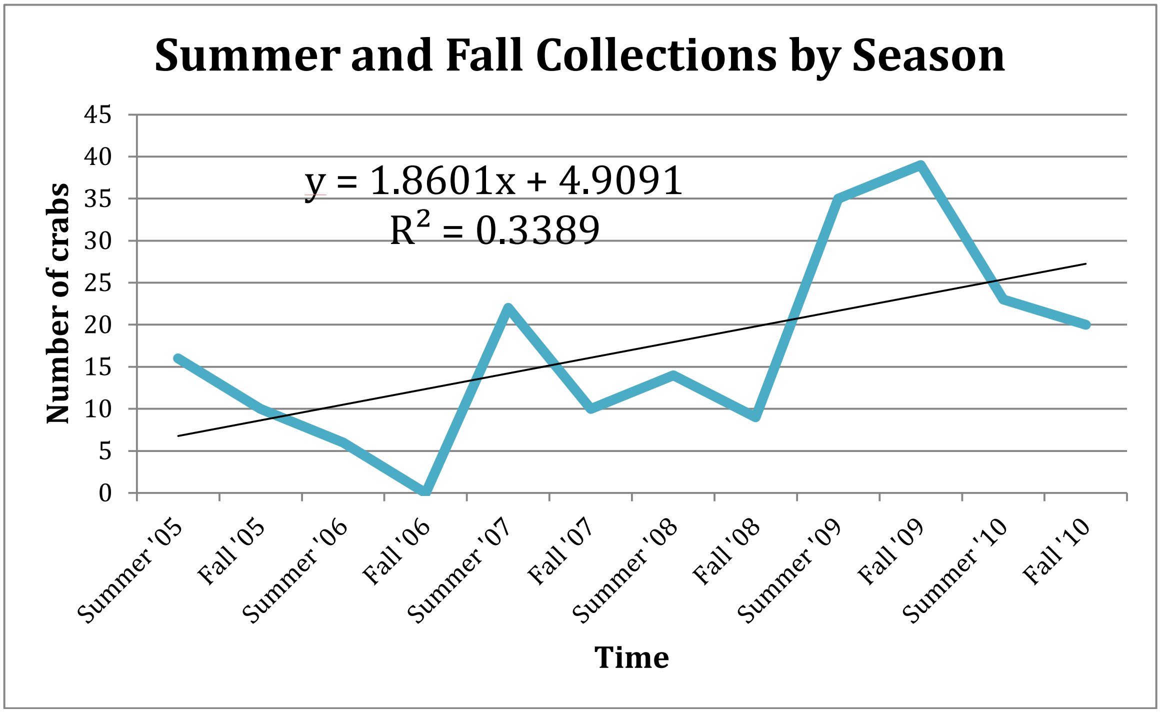

Fig. 2 Number of *C. maenus* over 5-year time span by Fall and Summer collections and only. There was an increase of crabs with yearly fluctuations (R^2 = 0.3389).

Separating the number of crabs by Fall and Summer seasons also showed an even more convincing increase in *C. maenus* populations within each season each year (Fig. 3 & Fig. 4). Separating by season allowed me to exclude seasonal fluctuations that are normal in crustacean populations due to their drifting larval stage and inconstant recruitment numbers, and to focus on their peaks in crab numbers during their yearly cycles. There also seemed to be annual fluctuations with each season, alternating high and low number of crabs every fall and summer of each year respectively.

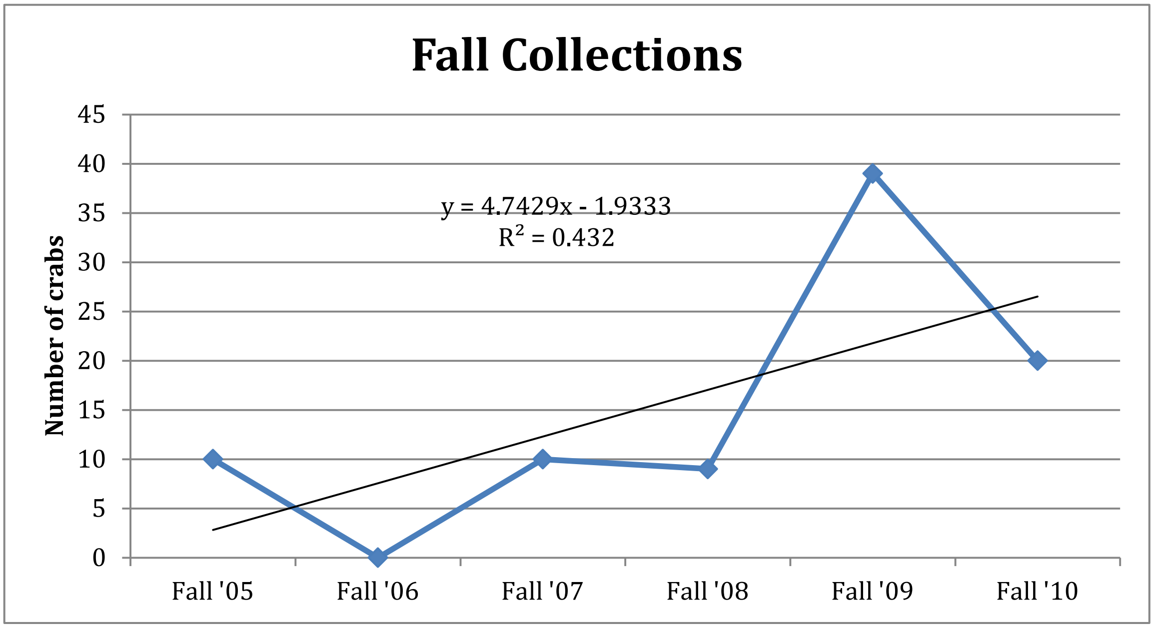

Fig. 3 Number of crabs each Fall each year. There was a significant increase over the five-year span (R^2 = 0.4319).

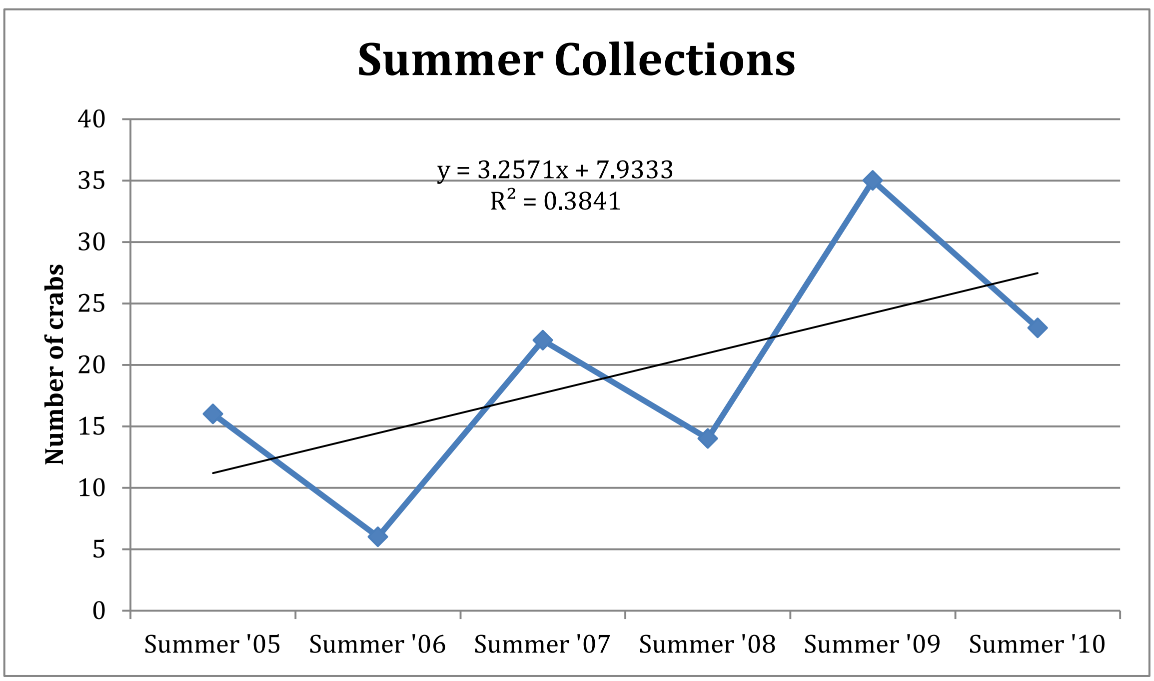

Fig. 4 Number of crabs each Summer each year. There was a significant increase over the five-year span (R^2 = 0.38412).

Carapace Size

The average carapace size of the green crabs found was 48.2 mm, the smallest at 13mm and the largest at 72 mm. There was no significant difference in size between males and females ($p>0.05$) though *C. maenus* usually exhibit reverse sexual dimorphism, with the females larger than the males. I created a plot of the means of carapace size over the five-year time span and saw that there were no discernable pattern over the years due to seasonal fluctuations (Fig 5).

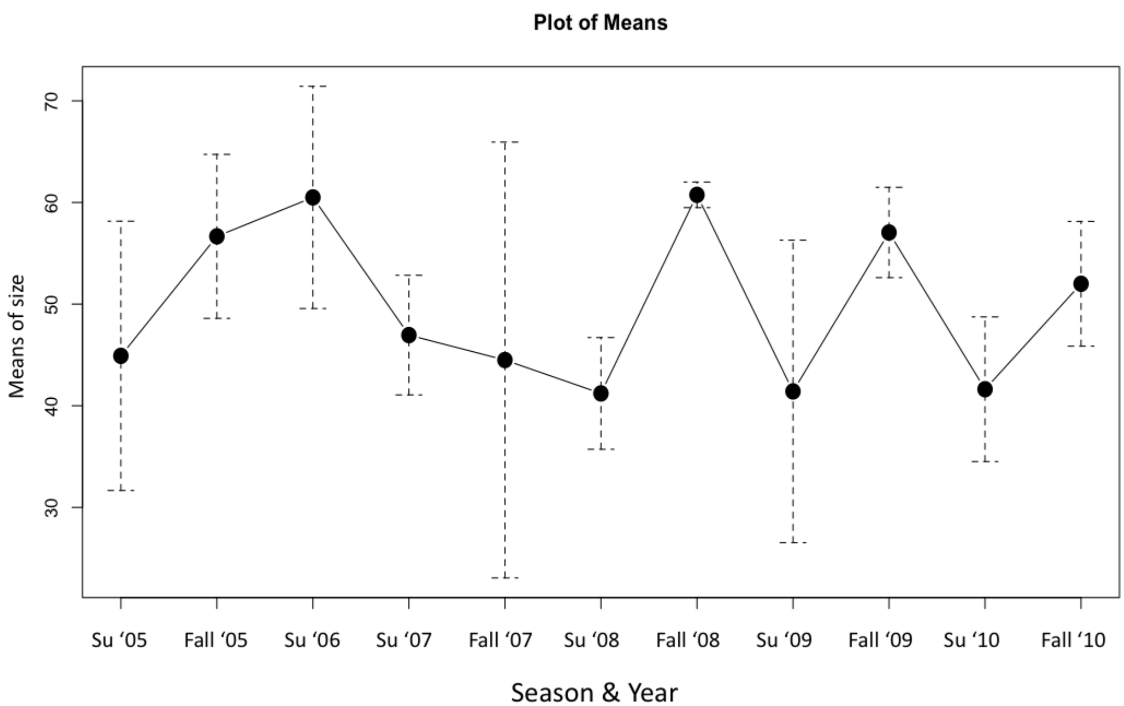

Fig. 5 Plot of means of carapace size over five-year time span. No discernable significance due to seasonal fluctuations.

However, by plotting just Summer populations (the season when they are at their highest numbers but smallest sizes) and through a Tukey multiple-comparisons test, I saw that there was a statistically significant peak in average size in the summer of 2006 ($p<0.05$) and then a drop back down to what looks to be constant carapace size at around 40 mm in the last three most recent summers (Fig. 6). However, there was no statistical difference between the other four summers besides the summer of 2006 ($p>0.05$).

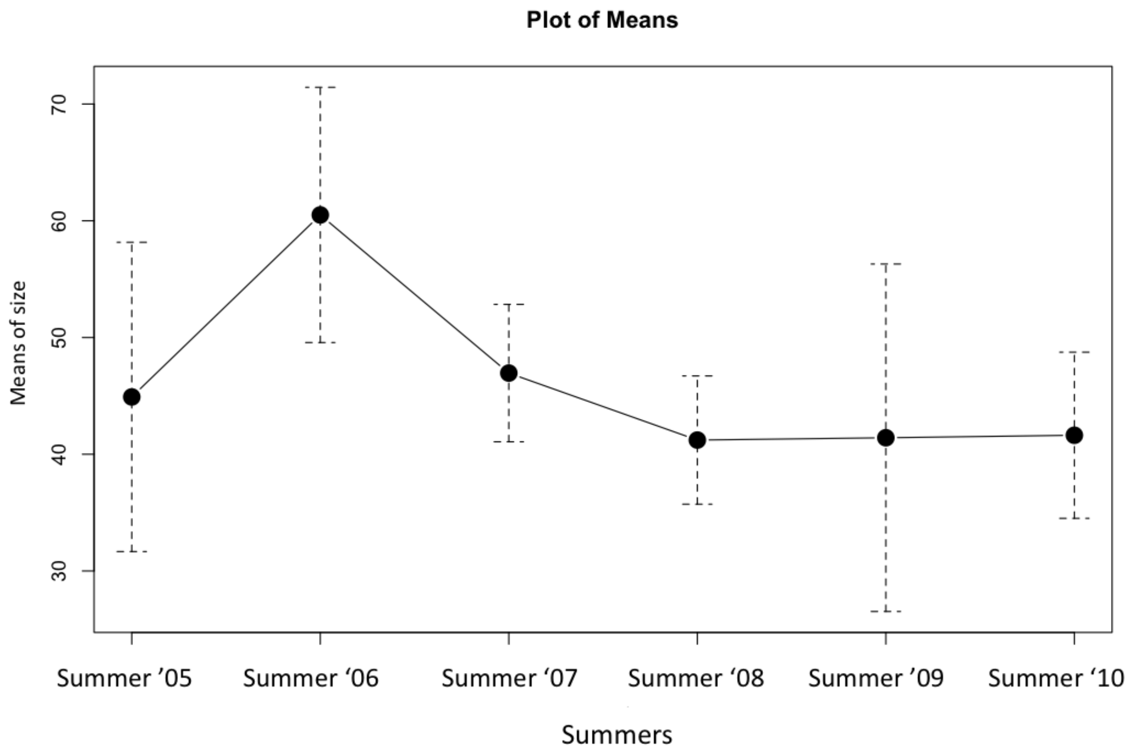

Fig. 6 Plot of means of carapace sizes per summer per year. There was a peak in Summer '06 but overall constant size thereafter.

I also compared mean sizes between sexes within each season. Through a nested ANOVA, I found that there was no statistical differences between the sizes of the two sexes ($p>0.05$) and only a statistical difference between the summers of each sex and the rest of the seasons ($p<0.05$). This indicates that the crabs were the smallest during the summer and varied in size for the rest of the year; there also was no significant difference in size between the two sexes (Fig.7).

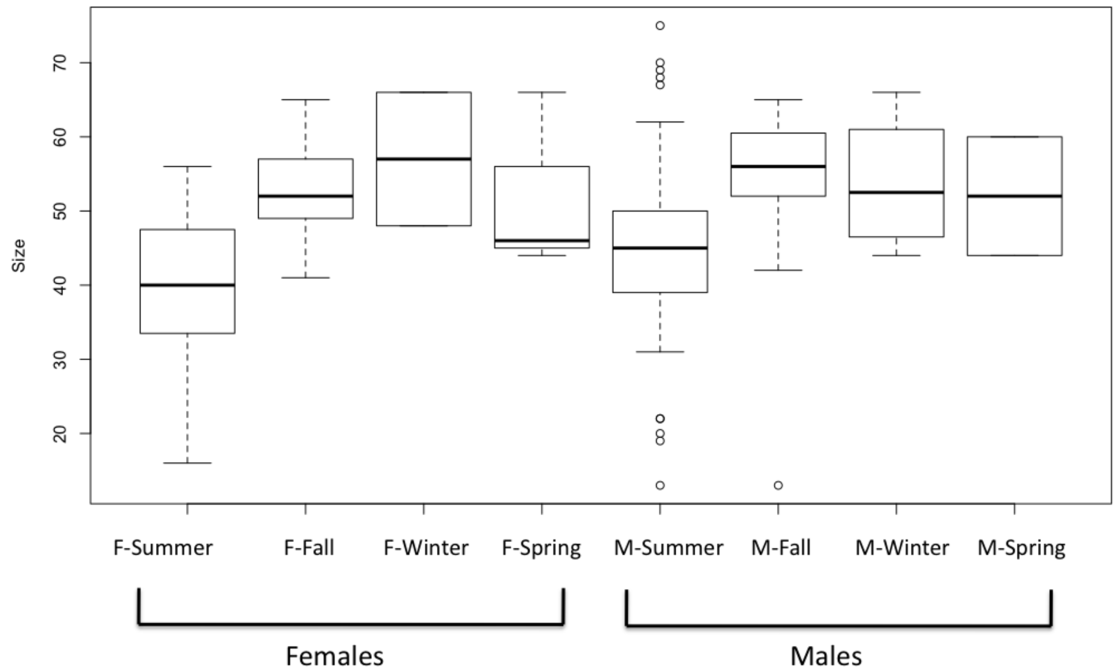

Fig. 7 Boxplots showing the mean size variances per season per gender. Summer sizes are significantly smaller than the other sizes in both genders but there is no statistical difference between the two sexes in terms of size.

DISCUSSION

Population Size

There was an observable increase in population size of *C. maenus* within each season over the years. This may indicate that the population of green crabs is increasing but this conclusion is limited by the fact that the data collected only spanned over five years and that there are visible fluctuations in the data. There are many factors that affect population growth including food availability, water temperature effects on larval growth, currents that affect larval recruitment, and competition with native species, and so an observation of an increase in five years may just be the high of a fluctuation that occurs in ten-year or fifteen-year increments (Yamada et al. 2005). However, if what I observed is in fact a significant increase in terms of population size, then this might be an indication that *C. maenus* populations may continue to grow and take over San Francisco

Bay and potentially cause significant harm to the surrounding habitat and native species as they have in other parts of the world's estuaries.

It is significant to note that *C. maenus* populations were at their highest during summer months, in contrast to invasive *C. maneus* populations in Oregon/Washington, whose populations were at their highest during the winter and spring months (Yamada et al. 2005). Since the summers are also when they are at their smallest sizes, this may indicate that *C. maenus* of the S.F. Bay area depend more on the warmer coastal waters of S.F. Bay during the summer to grow from their juvenile stage to their adult stages and have trouble growing and reproducing in the more extreme cold waters of S.F. Bay than in Oregon and Washington estuaries.

Carapace Size

Contrary to my hypothesis, carapace size did not increase over the five-year span, instead remaining relatively the same, with an outlying increase in larger crabs in the summer of 2006. None of my data indicated that this was due to a methodical mistake; it may have been due to higher than average water temperatures that summer, higher than normal amount of food resources, or unusually low competition from native species. However, the data for the other summers indicate a constant average carapace width over time. Again, this conclusion is limited by the short time span of this study and this observation of a constant carapace width may just be part of a fluctuation.

However, if it is true that carapace width has remained relatively the same over the years, this indicates that green crabs in S.F. Bay, though increasing in number, are growing at normal rates individually and not at hyper-accelerated rates that other studies have found in other invasive green crabs (Yamada et al. 2005). The range of sizes is similar to that of native *C. maenus* and so there is no indication that current green crabs are larger in carapace width than their native standard. This means that the *C. maenus* in S.F. Bay have either adjusted to the environment and other species of the bay and are being readily controlled by the other species and temporal factors, or that they are experiencing a low in a 10 to 15 year cycle of usually large carapace size.

Also, though green crabs exhibit reverse sexual dimorphism, this was not so in the study's data, as there was no significant difference in size between males and females and even within the seasons. This may indicate that the larger and older females are not completely outcompeting native species for food and so may not be reproducing as often or as long as they potentially could if they were taking over the area's resources.

Limitations

There were an unfortunate amount of limitations to this study, the biggest being that the study was not long enough and that collections were not made frequently enough to determine very convincing statistical conclusions. The average life span of a green crab is about 4 years, which is one year less than the length of the study, and so the study could have been a look at a majority of just one year class of crabs, and in comparison to the other 22 years the green crab has been in S.F. Bay, the data of this study may have only been a window of a time of a longer fluctuation.

Another limitation to this study was the very small amount of crabs collected in spring and winter seasons of all five years. No crabs were collected in the majority of the winters and springs and so data could not be accurately represented in graphical or statistical form. This may have been due to the misplacement of traps in the different sites, but most likely due to the fact that winter S.F. Bay waters are too cold for the crabs to flourish in; when temperature drop below 10°C , crabs stop molting and feeding and rather find shelter until temperatures reach durable levels again. Even though they are very adaptable organisms, their initial fall and summer numbers are not large enough to sustain viable populations during the winter and spring. This further indicates that green crab populations are not becoming threateningly large in the S.F. Bay area and so may not be of a great future concern.

It is important to note also that the other data collected during this study such as water temperature, weather, and salinity, were not able to be thoroughly analyzed due to the inconsistency in record among the different researchers that collected data. Some of the external data was not recorded by researchers while others took care to note these other factors in detail.

Future implications

This study suggests overall that *C. maenus* populations are approaching a sustained and not overwhelmingly large abundance and size, unlike the populations of invasive green crabs found elsewhere globally. This may be due to several environmental factors specific to S.F. Bay, such as the water temperature and salinity and also because green crabs are potentially being biologically controlled by native species that are competing for the same food and shelter resources. However, because of the limitations of this study, more research must be done of the China Camp area, and more data must be gathered of the same type over a longer period of time. Perhaps then, it may be possible to determine the future of *C. maenus* in S.F. Bay and if they could potentially have a devastating impact on the S.F. Bay flora and fauna.

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