Assessing the Relationship Between *Anthopleura elegantissima* Body Size Change and Temperature Increase in the Intertidal

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ABSTRACT

Rising temperatures are frequently linked with decreasing body sizes of marine organisms. Smaller body sizes may be indicative of stressful conditions, especially since many organisms cannot reproduce until they reach a certain size. Few studies have been published regarding the effects of temperature increase on non-calcifying intertidal invertebrates. Portions of the study by Sebens (1977) were replicated in order to determine if a relationship existed between temperature increase and body size change of the aggregating anemone *Anthopleura elegantissima*. Basal diameters of *A. elegantissima* were measured at two tidal elevations and population density was measured at two sites at Cattle Point, San Juan Island. The range of body sizes has increased slightly since 1977, but the mean basal diameters of anemones have stayed relatively consistent. Anemones may be denser in smaller tide pools. The range of densities at the Eastern site (high tidal elevation) is larger than the range of densities over two tidal elevations at the Western site. Smaller body sizes of *A. elegantissima* have not been observed, meaning that the anemones either do not match the common trend of smaller body sizes with increasing temperatures, or that temperatures have not increased enough at Cattle Point to detect a meaningful change. If the anemones are in fact unchanged by rising temperatures, then understanding the mechanism for this resilience will lay the groundwork for future intertidal studies.

INTRODUCTION

The relationship between rising global temperatures and the body sizes of marine organisms has been a topic of intense study in the past decade (Daufresne et al., 2009, Kroeker et al., 2010, Gardner et al., 2011, Ohlberger, 2013). These studies have established a “third consequence” of global warming: decreased body size among marine organisms as a result of climate change and ocean acidification. Smaller body sizes may be seen as a “negative” result, since many organisms cannot reproduce until they reach a certain size. Many of these studies have focused on the calcifying invertebrates (i.e. corals, snails, bivalves, etc.)(Daufresne et al., 2009). Global warming and ocean acidification directly impact these organisms because they are not able to calcify (form shells) at low pH values. However, multitudes of non-calcifying invertebrates such as anemones, polyps, etc. are important key players in intertidal ecosystems-- serving as vital nutrient recyclers, as well as hosts for primary producers (Sebens, 1983, Bates et al., 2010, Dimond et al., 2011). The effects of rising temperatures on non-calcifying invertebrates in the intertidal are largely unknown.

The common Pacific Northwest aggregating anemone, *Anthopleura elegantissima*, is a key component to the intertidal ecosystems along the Pacific coast of North America. These anemones are often found in intertidal mussel beds (*Mytilus californianus*), and feed on mussels and barnacles (Sebens, 1982). Aggregations of clones tend to settle in tide pools or surge channels when not in mussel beds, and compete for space with algae and other invertebrates (Sebens, 1983). Members of the genus *Anthopleura* are incredibly prolific, occupying large intertidal areas, and feeding on zooplankton and benthic invertebrates (Secord et al., 2000). These important carnivores keep many components of the rocky intertidal food web constant.

Body size is a major factor influenced by temperature/ aerial exposure of the anemones during a low tide. Generally, warmer temperatures are associated with smaller anemone body size (Chomsky, 2004). Sebens (1983) found that at Cattle Point, San Juan Island, individuals in higher tide pools were smaller than those lower in the intertidal. These findings were attributed to the lower metabolic requirements needed to sustain a smaller individual under high desiccation stress. The implications of smaller anemone body size are significant, as anemones cannot reproduce until they reach a certain diameter (Sebens, 1981). Additionally, body sizes in both high and low intertidal pools tended to increase in the warmer months (maximum body sizes observed in the months of July-August). These periods of increasing body size corresponded to known rises in zooplankton abundance. Therefore, greater nutrient availability will lead to an increase in *A. elegantissima* body size, but maximum body size is limited by temperature and desiccation stress as individuals move higher up in the intertidal.

Here, I attempted to replicate part of a study in which the basal diameters of *A. elegantissima* were measured at both high and low intertidal elevations at Cattle Point, San Juan Island, between June 1974 and May 1976 (Sebens, 1977). Utilizing historical data is valuable because it is easier to see change over a longer period of time. I used historical weather data to determine the change in temperature over the past 41 years, and then compared to my measurements of anemone body size to determine if a correlation exists between temperature and *A. elegantissima* body size. Based on previous observations of marine organisms, I predicted that anemone basal diameters would become smaller, since smaller organisms have lower metabolic requirements and are thus better adapted to conditions of temperature stress.

METHODS

Choosing a Historical Study

Specific criteria were taken into consideration when choosing a study to repeat. First, the study must be ecological. I was interested in finding how *A. elegantissima* has been affected by increasing temperature since the 1970's. Additionally, the study must involve an intertidal invertebrate or algae, and be at least 30 years old. This is so that a reasonable amount of time has passed before determining change in an organism over time. Most importantly, the study must be replicable. The presence of maps, lat/long information, and clear methods were all factors in choosing a suitable historical study.

Dr. Ken Sebens' 1977 Doctoral Dissertation aimed to determine the size-frequency distribution of *A. elegantissima* across multiple study sites in Western Washington. One of the sites was Cattle Point, San Juan Island. To determine whether changes in mean individual size were due to changes in the distribution of individuals over size classes, multiple individuals were measured at each site bimonthly over the course of two years. (March 1974 to May 1976). The anemones were sampled monthly during the time period of March to September 1975. Blind throws of a 10 cm X 10 cm quadrat were taken in each of high and low intertidal areas. Basal diameters of each anemone within the quadrat were measured. This process was repeated until 150 anemones had been encountered. (Sebens, 1983)

Study Sites

As I had a limited amount of time for data collection, only one location from the original study was chosen to repeat. Cattle Point, San Juan Island (48.4501 N, -122.9641 W) is a rocky intertidal area with pools that are semi-exposed to wave action. There is a wide rocky bench on the Southwest-facing shore, and multiple cracks and indentations that serve as prime habitat for *A. elegantissima* (Sebens, 1983). The study site is just west of the Cattle Point lighthouse. (Fig. 1a) The "low" intertidal height was defined as -0.17 m to +1.16 m below/above MLLW; the "high" intertidal height was defined as +1.45 m to +2.04 m. The lower channels were just above the water line at a zero tide, and contained the majority of the anemones. The high pools and surge channels contained tightly aggregated clones, tucked deep into the rock to avoid desiccation.

Fig. 1a. Western Site at Cattle Point, San Juan Island. Transect boundaries are marked on the map by "Western boundary" and "Eastern boundary".

Body Sizes of A. elegantissima

Basal diameters were measured for "low" and "high" elevations over two days (May 4th and May 5th, 2018). For each elevation, 3 transects were positioned 5-10 m apart, parallel to the waterline at the specified height above MLLW. The "low" elevation boundaries were 48.4501 N, -122.9641 W (Western) and 48.4500 N, -122.9637 W (Eastern). The "high" elevation boundaries were 48.4502 N, -122.9642 W (Western) and 48.4501 N, -122.9638 W (Eastern). Wire quadrats (10 cm x 10 cm) were positioned randomly along each transect line (10 quadrats per transect for "low", and 5 quadrats per transect for "high"). This was done rather than simply performing blind throws, in order to make the study more objective. Each anemone within the quadrat was measured with calipers across the center for length and width, and then the average of the two measurements was later taken to acquire "Mean Basal Diameter" of each individual. Nearly 200 anemones were measured for both low and high elevations (rather than 150 total), to increase the power of the study.

Population Density

Eastern site:

A map of the area just East of the lighthouse at Cattle Point (including tide pools and their dimensions, major landmarks, etc.) was drawn as the area was sampled (Figs. 1b, 2a). Eight tide pools were counted in the flat region ~ +1.5m above MLLW, 5 of which were sampled. This area was closer to the upper range of anemone habitat. An additional five pools were counted and sampled from a high bench near the water line. Each tide pool was photographed with transect tape across the center, dimensions were measured, and between 3 and 5 quadrats were randomly placed within each pool along the transect. Each anemone was counted within the quadrat, and the counts were later averaged to produce mean population density for each tide pool. Taking the total number of anemones counted, and dividing by the sum of the quadrat areas calculated the total population density. The Eastern site was sampled on May 15th, 2018.

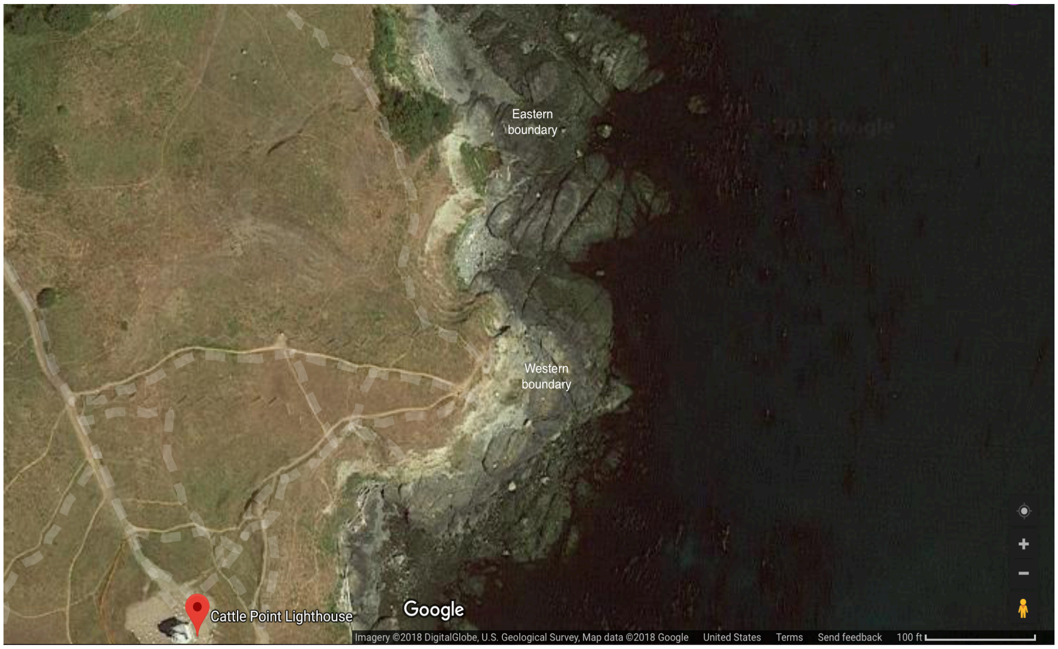

Fig. 1b. Eastern site at Cattle Point, San Juan Island. Site boundaries are noted on the map as “Western boundary” and “Eastern boundary”.

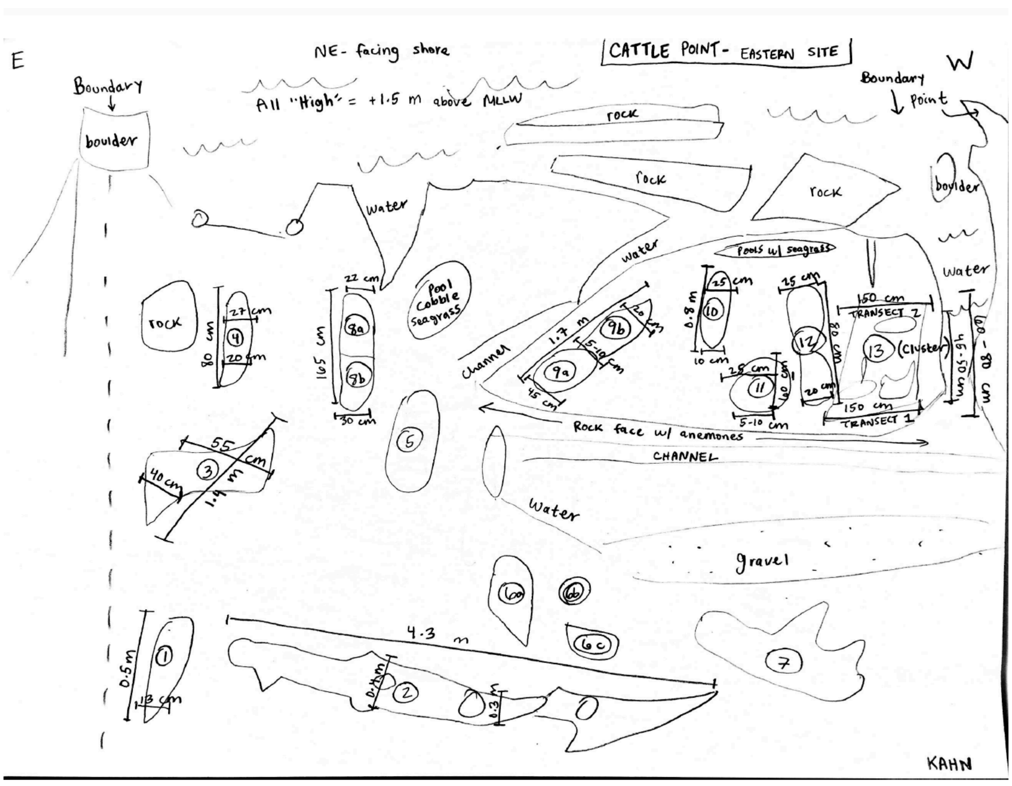

Fig. 2a. Map of Cattle Point, San Juan Island, “Eastern Site”.

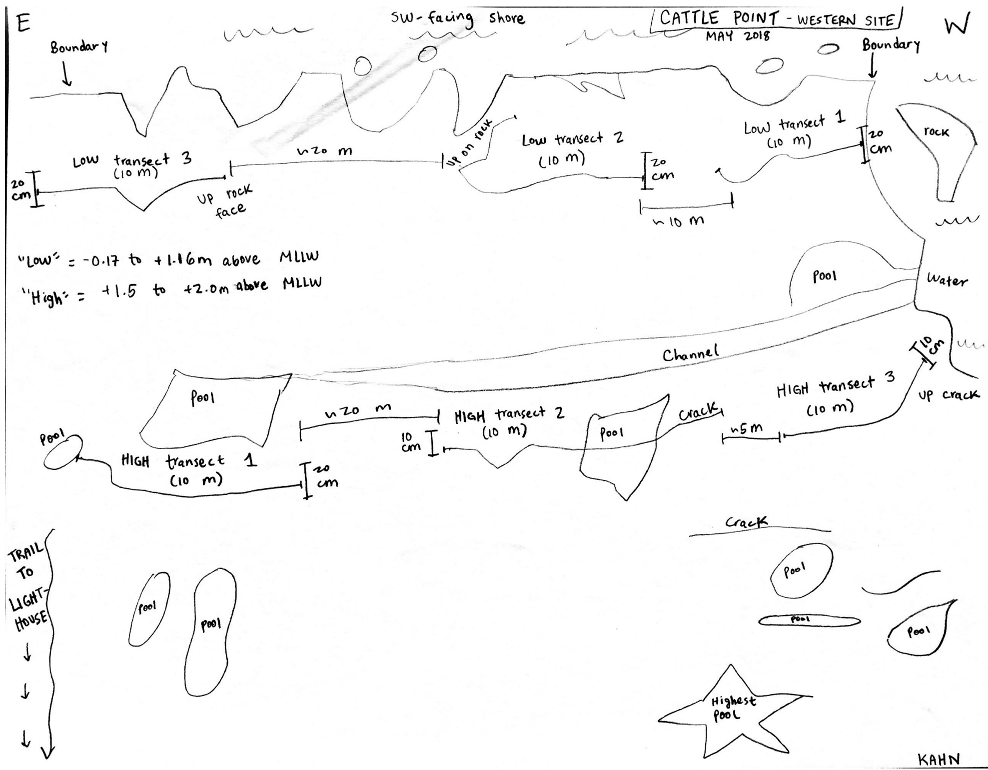

Fig. 2b. Map of Cattle Point, San Juan Island, “Western” site.

Western site:

Three, 10m transects were placed in each of the “low” and “high” elevations, using the heights specified in the “Body Sizes” portion of the study. Photographs were taken showing the location of each transect. Within each of the transects, 6 quadrats were randomly placed, and anemones within each quadrat were counted. Population densities for “low” and “high” elevations were calculated as in the Eastern site. The Western site was sampled on May 16th, 2018.

Data Analysis

Body Sizes of A. elegantissima

Size-frequency histograms for *Anthopleura elegantissima* at Cattle Point were created in R (Version 1.1.383 – © 2009-2017 RStudio, Inc.). Data from Fig. 7 in Sebens (1982) was extracted using Web Plot Digitizer, and then transformed into a bar plot in R. The two plots from 1982 and 2018 are compared in Fig. 3. Additionally, a plot of means with standard deviations at both “high” and “low” elevations for 1974-1976, and 2018 was created in R. (Fig. 4). The historical data was extracted from Fig. 5 of Sebens (1983) using Web Plot Digitizer.

Population Density

Population density for *A. elegantissima* was calculated at two sites: Eastern and Western at Cattle Point. At the Eastern site, primarily tide pools were measured, so density was visualized as a function of tide pool area (m^2)(Fig. 5). Mean population density at both sites and elevations was calculated and plotted in R (Fig. 6). Densities are reported as number of anemones per m^2.

Temperature Data

I integrated historical and modern air temperature data from the NOAA station on Olga, Orcas Island, WA (Station OLGA 2 SE, WA US, 48.6116 N, -122.8063 W, https://www.ncdc.noaa.gov) and historical seawater temperatures from the Race Rocks, Canada database (http://www.racerocks.com) to determine the change in air and sea surface temperatures since 1974. Modern sea surface temperatures were obtained from the NOAA buoy on the Friday Harbor laboratories dock (Buoy FRDW, 9449880 - Friday Harbor, San Juan Island, WA, 48.545 N, -123.012 W, http://www.ndbc.noaa.gov). Locations are approximately 70 miles apart, and temperatures are relatively consistent along the Pacific Northwest coast.

RESULTS

Body Sizes of A. elegantissima

The distributions of size classes observed in 1982 and in 2018 are roughly equivalent (Fig. 3). The smallest anemones observed are 0.2 cm in diameter, while the largest outliers are 4.3 cm.

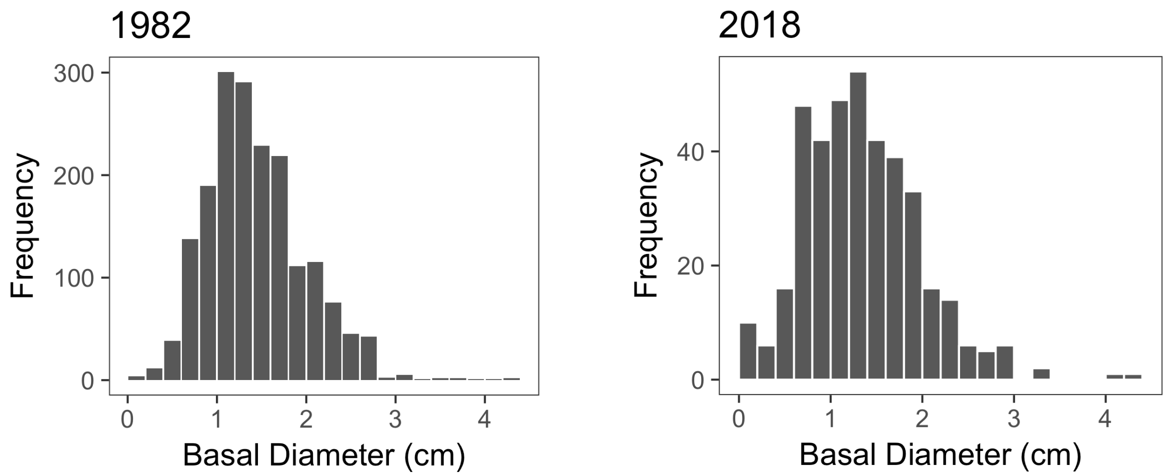

Fig. 3. Size-frequency histograms of *A. elegantissima* at Cattle Point: 1982 and 2018. Frequency is equal to the number of anemones observed at each size class.

The range of anemone body sizes from "low" to "high" elevations has trended towards a slight increase since 1974. (Fig. 4) Mean basal diameters in 1974 were 1.22 cm +/- 0.50 cm for low, and 1.26 cm +/- 0.70 cm for high tidal elevations. In 2018, mean basal diameters for low were 1.46 cm +/- 0.67 cm, and 1.27 cm +/- 0.59 cm for high. Thus, the average difference in mean basal diameters between low and high elevations has increased by 0.17 cm.

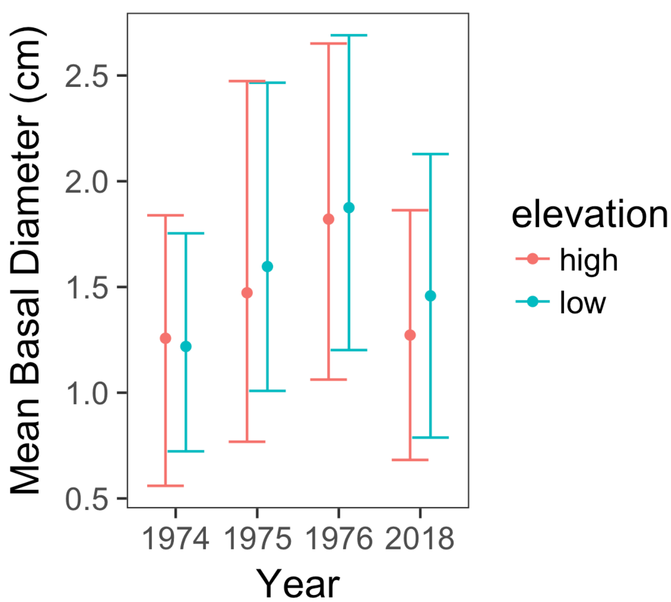

Fig. 4.

Mean Basal Diameters at Cattle Point by year, with standard deviation. "High" elevation means are depicted in red; "Low" elevation means are depicted in blue.

Population Density

A. elegantissima may be denser in smaller tide pools at the Eastern Cattle Point site. Most anemones are observed in smaller pools (on the order of 1e+04 m^2 or less). (Fig. 5).

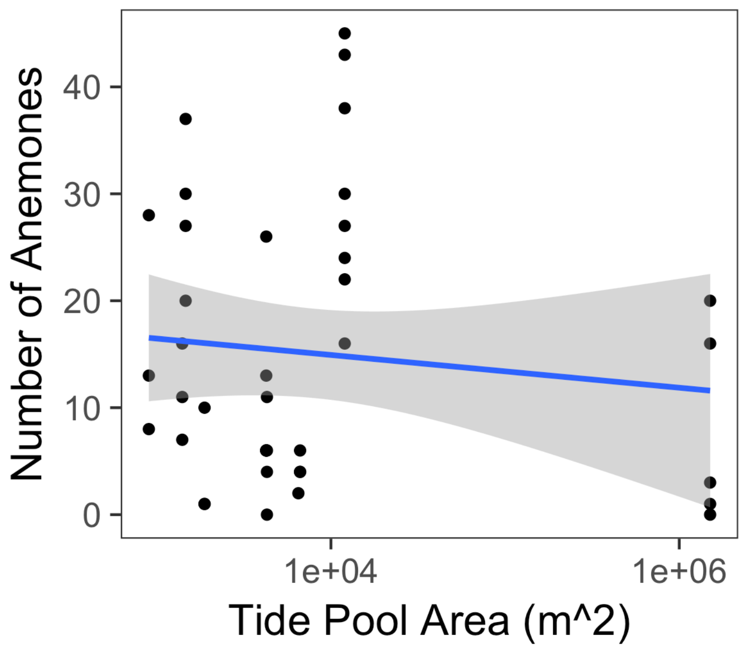

Fig. 5

Average population density as a function of tide pool size (m^2). The blue line represents the linear trend of mean number of anemones per tide pool area, with grey shading representing standard deviation.

There is more variation in average population density between sites (Eastern and Western) than there is among tidal elevations (high or low)(Fig. 6). Mean population density for the Eastern site (high) is 1508 +/- 1278 anemones per m^2. The mean density for the Western site (high) is 700 +/- 508 individuals per m^2, and (low) is 1367 +/- 971 individuals per m^2.

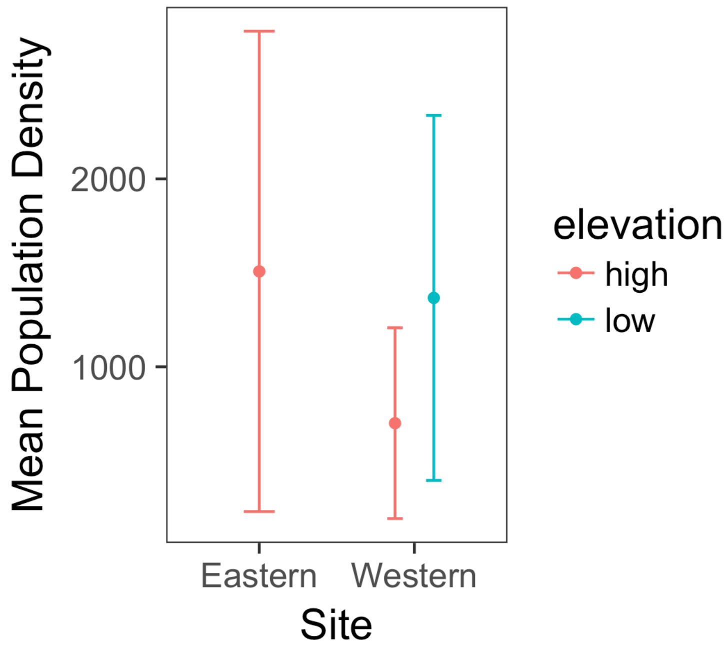

Fig. 6

Mean population densities plus standard deviation of *A. elegantissima* at two sites on Cattle Point. "High" tidal elevation is depicted in red; "Low" elevation is depicted in blue. The Eastern site was considered "high" elevation only.

Temperature Data

Air temperature between the years of 1970 and 2015 has increased by an average of 2.56 ˚C. The average temperature in 1970 was reported as 9.50˚C, and in 2015 the average temperature was 12.06˚C (NOAA Station at Olga, Orcas Island, WA). The NOAA buoy at Friday Harbor laboratories, San Juan Island, WA reported air temperatures of 11.0˚C (May 1st, 2018) to 17.1˚C (May 22nd, 2018).

Sea surface temperature between 1974 and 2015 has increased by an average of 2.0 ˚ C. In 1974, the average sea surface temperature was reported as 8.5˚C, which increased to 9.9˚C by 1982. In 2015, the average sea surface temperature was reported as 9.5 to 10.8˚C (Race Rocks Canada seawater temperature database). The NOAA buoy at Friday Harbor laboratories reported sea surface temperatures of 9.3˚C (May 1st, 2018) to 10.5˚C (May 22, 2018). Note that averages for air and sea temperatures were taken by comparing two years, rather than the entire time period, and may not be reflective of the true variability and net increase over the years.

DISCUSSION

The *Anthopleura elegantissima* individuals at Cattle Point have not decreased in basal diameter since 1974; if anything, body size has increased slightly (see Fig. 4). This is in contrast to my prediction that anemone body size would decrease in response to rising air and sea surface temperatures, since that has been an observed trend amongst intertidal organisms (Daufresne et al., 2009, Kroeker et al., 2010, Gardner et al., 2011). In essence, global warming on the scale of an aggregating intertidal anemone at Northern latitude may have little effect on the body size of each individual.

Anemones at Cattle Point may be denser in smaller tide pools than larger tide pools. This is interesting, because it shows that the anemones may be aware of the size of their habitat. They appear to spread out when more space is available, and will pack together tightly when needed. At the Western site, anemones appear to be denser at low tidal elevations, where body sizes are larger. Perhaps this is because lower tidal elevations are the more optimal habitat for *A. elegantissima*, so individuals will have a higher rate of asexual reproduction at this elevation than they would at a higher tidal elevation. Additionally, the range of population densities varies wildly between the two sites at Cattle Point. This shows that population density estimates at one site cannot be compared with those at another site. Spatial differences in densities may be caused by a variety of factors, including wave exposure, amount of shading, potential differences in algal coverage, competition with invertebrates, etc.

Since *A. elegantissima* is spread over a wide range of habitat-- from California all the way up to Canada-- individuals on San Juan Island may be experiencing cooler than optimal temperatures for premium growth (Ohlberger, 2013). The warmer temperatures may even contribute to the attainment of optimal body size for the anemones, up to a point. This would explain the slight increase in body size observed between 1974 and 2018. However, the optimal temperature of the anemone itself is not the only factor in this intertidal drama.

A. elegantissima hosts photosynthetic green and brown algal symbionts, which are quite productive during peak seasonal conditions, and contribute to the photosynthetic primary productivity as much as intertidal seaweeds in Southern California (Dimond et al., 2011, Bingham et al., 2011). As these symbionts absorb light from the environment, they may offer a protective "shading" effect that shields anemones from excessive light (Bates, 2010). This may be one mechanism by which the anemones' body sizes have remained relatively constant since 1974. However, the algal symbionts vary in their abilities to adapt to rising temperatures. If temperatures rise beyond a certain threshold, anemones may lose their symbiont communities. We could then expect to see an increase in body size, if temperatures are indeed lower than optimal for this organism.

Another aspect that may contribute to the effect (or lack thereof) of increasing temperatures on these anemones is their physiology. Increased atmospheric CO_2 results in at least two consequences: climate change and ocean acidification. Since anemones are not calcified, they are not as susceptible to the negative effects of ocean acidification (Kroeker et al., 2010). While other intertidal invertebrates such as snails and mussels are decreasing in body size, anemones do not require calcium carbonate to make a vital exoskeleton, and are thus less affected by the increased CO_2 in the oceans (Doney et al., 2009). However, the lack of protective shell in these anemones requires a novel response to desiccation stress.

Sebens (1982) describes the general trend of larger *A. elegantissima* body sizes at lower intertidal heights (lower temperatures, and less exposure during low tides). This trend continues as shown in Fig. 4. However, the scope of this study did not cover shifts in the distribution of these anemones with regard to intertidal height (MLLW). An interesting future point of research would be to compare historical and modern distributions of *A. elegantissima* to see if there has been a shift towards the subtidal. Perhaps these organisms have adapted to the rising temperatures high in the intertidal, and are gradually moving down in the intertidal to avoid desiccation. More work must be done to understand why these anemones, and perhaps other non-calcifying invertebrates, seem to be defying the pattern of smaller body sizes with increasing global temperatures. Generally, larger body sizes are considered to be signs of health, since larger anemones are better able to reproduce. By learning how these invertebrates seem to thrive in the modern-day climate, we may be able to better focus conservation efforts to those at risk.

CONCLUSIONS

Body sizes of *A. elegantissima* in 2018 are roughly equivalent to those recorded in 1974, suggesting that temperature increase on San Juan Island has not been enough to noticeably influence body size. The range of body sizes has slightly increased, with smaller anemones at high intertidal elevations, and larger anemones at low elevations. These findings suggest that *A. elegantissima* may have shifted their distribution to lower in the intertidal. Anemones are denser in smaller tide pools, suggesting that they may be able to sense the magnitude of the habitat that they occupy. The range of densities between sites is greater than that between tidal elevations, showing that population density measurements cannot be accurately compared across sites.

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SUPPLEMENTARY MATERIALS

See attached .csv files for raw data and R scripts.