Linking Large Scale Ocean-Atmospheric Patterns with Recruitment in Kellet's whelk (*Kelletia kelletii*)

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Katherine Rodriguez

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Katherine N. Rodriguez, *Biological Sciences Department, California Polytechnic State University, San Luis Obispo, CA, USA*

ABSTRACT

Global warming influences the biogeography of many marine and terrestrial species. Understanding species range shifts is ecologically and socioeconomically important when guiding management decisions for ecosystems exposed to a rapidly changing climate. In this natural experiment, I follow Danielle Zacherl's methods (Zacherl et al. 2003) to study the effects of large-scale ocean-atmospheric patterns on recruitment of a marine snail, Kellet's whelk (Kelletia kelletii); these organisms recently expanded their range North past the geographic barrier of Point Conception to Monterey, CA, USA. I use shell length data collected at 32 subtidal rocky reef kelp forest sites in 2015 (before El Niño) and again in 2016 (after El Niño) to test the effect that El Niño has on recruitment of Kellet's whelk in its expanded range. After comparing my results to Danielle Zacherl's findings from the 1997 El Niño event, I found substantial evidence that there is a statistically significant increase in recruitment for Kellet's whelk in its expanded range after an El Niño event. I also found evidence for differences in population structure between the expanded and historic ranges.

Keywords: *Kelletia*, global warming, range expansion, feminist methodology, El Niño

INTRODUCTION

Anthropogenic global warming influences the biogeography of many species (Sorte et al. 2010). Specifically, atmospheric and ocean temperature increases from global warming are linked to poleward range shifts by numerous species in both the terrestrial and marine environments (Sorte et al. 2010). Scientists predict global warming will increase the frequency and intensity of El Niño Southern Oscillation (El Niño), an ocean-atmospheric phenomenon in the Pacific Ocean hypothesized to drive poleward range expansions of marine species (Sorte et al. 2010). There is a record of poleward range shifts in relation to global warming for a variety of eukaryotic groups such as plants, algae, arthropods, molluscs, birds, reptiles, amphibians and mammals (Sorte et al. 2010). Consequently, understanding species range shifts in relation to El Niño is ecologically and socioeconomically important for guiding current and future management decisions in marine ecosystems exposed to a warming climate.

In this natural experiment, I use the 2015 El Niño to study the future of a warming ocean with the goal of understanding ecological effects of warm water anomalies on a species that recently expanded its range along the west coast of North America: Kellet's whelk (*Kelletia kelletii*). Kellet's whelk is an emerging fisheries species (CDFW 2006) and shares many life history traits with other ecologically and socioeconomically important fisheries species such as sheephead, spiny lobster, and kelp bass. These California subtropical species are slow growing, sedentary and demersal as adults, and annually produce pelagic larvae. With many similar life history traits, Kellet's whelk could be used as an indicator species for these other important fisheries species.

It is challenging to test the effects of El Niño events due to the unpredictability of this natural phenomenon; this makes it difficult to obtain data prior to the El Niño year. However, a female marine biologist at Cal State University, Fullerton, Dr. Danielle Zacherl, was able to lead a natural experiment and record Kellet's whelk size frequency data before and after the 1997 El Niño event. Her team found strong recruitment of juvenile Kellet's whelk in the expanded range after the El Niño. The more recent 2015 El Niño provides an opportunity to re-run Zacherl's natural experiment and compare our results. I hypothesize that for the recent 2015 El Niño, there will be significantly more juvenile *Kelletia kelletii* recruitment in the species' expanded range after the El Niño event compared to the previous year. This result would support Danielle Zacherl's findings.

MATERIALS AND METHODS

Feminist Methodology

Feminist Methodology: In my opinion, feminist methodology can be used to accomplish many different things. In my research, I am using these methods to recognize marginalized groups, recognize bias in science and be transparent with my research.

Positivist approaches aim to create scientific descriptions of reality by producing objective generalizations (Collins 2000). Scientific researchers have extremely different values, experiences and emotions, yet the positivist methodological approach requires the researcher to distance her or him self from these inherent biases (Collins 2000). However, objectivity is essentially "a view from nowhere," and is therefore, unattainable for researchers.

Instead of using objectivity, I attempt to use feminist methodology throughout this paper in an effort to be as transparent as possible with my research. I use standpoint theory to recover dimensions of the social world that are typically eclipsed from western science writing (e.g. significant roles of female researchers) (Wylie 2012). I include phrases like, "our data" throughout this paper because many people together made this data collection and research possible. I aim to give credit to the many volunteers and collaborators who supported me on this project because this research process is a collective effort. I also want to honor the female biologist, Danielle Zacherl, for her novel research on Kellet's whelk. I use her findings throughout this paper, and use her research as a template for my research. My research is biased as I am a female minority, and I am passionate about conservation and sustainability. I hope to challenge the traditional conventions of Western scientific writing by practicing feminist methodology in my work.

Study Organism

Kellet's whelk (*Kelletia kelletii*) (Forbes, 1852) are marine neogastropods currently found in rocky reef kelp forest habitats from Monterey, California, USA to Isla Asuncion, Baja California, Mexico (Herrlinger 1981). Adults reproduce annually and females lay egg capsules in broods at the rock sand interface from May to August (Zacherl et al. 2003). Veliger larvae hatch after ~30 days and remain in the water column for approximately 5 weeks (Rosenthal 1970, Romero et al. 2012); veligers are transported by the ocean currents and can settle on distant reefs. Within the past few decades, Kellet's whelk expanded its range northward past Point Conception, California, a major oceanographic barrier, to Monterey, CA (Zacherl et al. 2003, Fig.1).

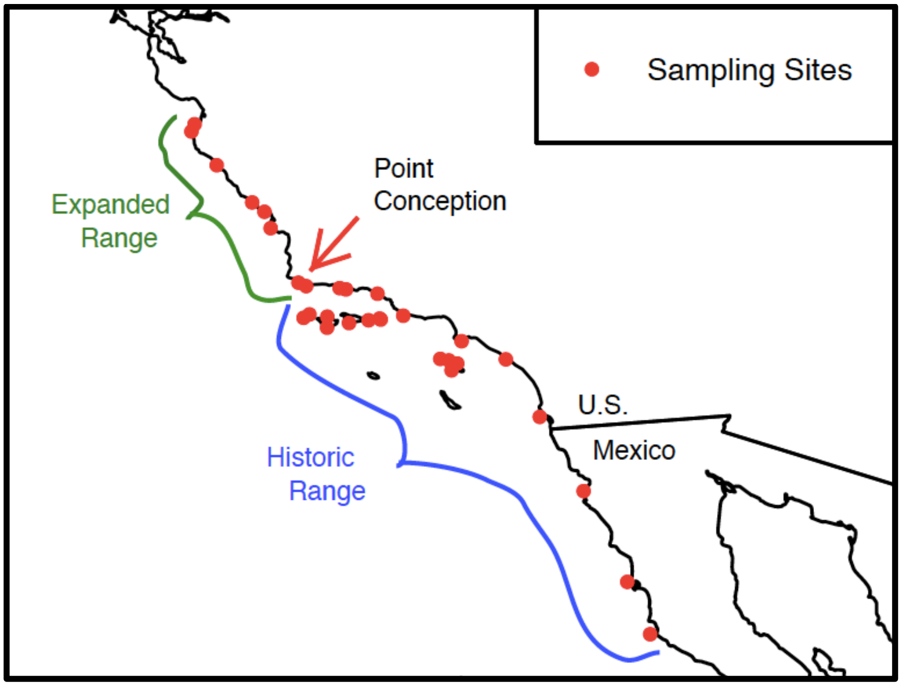

Figure 1. Map of sampling sites for both 2015 and 2016. The expanded range indicated in green north of Point Conception and the historic range indicated in blue.

Natural Experiment Design and Sampling Protocol

I used Danielle Zacherl's research to form a natural experiment and observe the effects of El Niño conditions on recruitment of Kellet's whelk in its expanded range, north of Point Conception. The control group consisted of 32 sites sampled in 2015 (prior to the El Niño) and the treatment group exposed to El Niño conditions consisted of the same sites sampled in 2016 (Fig. 1).

Colleagues (names and affiliations listed in the acknowledgments) and I conducted fixed width transect surveys (30x2m) via boat-supported SCUBA at depths of 8 to 22m in rocky reef kelp forests to standardize sampling habitat. Teams of two divers each completed multiple transect surveys at each site. Two divers each covered the entire transect area to ensure detection of all Kellet's whelk in the sample habitat. Ideal Kellet's whelk habitat consisted of rocky reef kelp forest with many rock-sand interfaces (Danielle Zacherl pers. obs.). Project leaders trained divers to locate ideal Kellet's whelk habitat, lay a 30m transect, and identify and collect all Kellet's whelk within the sampling area. On the surface, our team measured and recorded the maximum shell length (mm) from the tip of the spire to the siphonal canal with calipers (precision ±0.1mm) for all collected Kellet's whelk at each site with an average sample size of 147 whelks/site/year. Seven of the sites in each year were located in the organism's expanded range. We sampled 32 sites initially in 2015 and again in 2016 during the months of June, July and August following sampling procedures described in Zacherl et al. 2003 and Simmonds et al. 2014.

Analyses

I used two-way Analysis of Variance (ANOVA) tests to investigate the main effects of year and site, and the interaction between year and site on shell length for our two datasets: historic range and expanded range. I included year in the model to account for differences in oceanic and atmospheric weather conditions such as El Niño presence or absence. I included site in the model because it was important in explaining the variability of shell length between populations. The interaction between site and year on shell length was included to fix the lack of fit in the model. A Student's t-test gave me the confidence intervals for my estimates that accounted for variability in site and the site by year interaction. Program R, ggplot2 package and JMP (R Core Team 2017, Wickham 2009, JMP® Pro 2015) helped me organize, analyze, and visualize these data and results.

RESULTS

Evidence for Recruitment Pulse in Expanded Range after 2015 El Niño Event

The ANOVA for our historic dataset showed all effects were significant at the 0.05 significance level. The site variable included 25 sampling sites south of point conception, and the year variable included 2 years: 2015(n=3904) and 2016(n=3626). The main effect for site yielded an F ratio of $F(24,7480)=236.9$, $p<0.0001$, indicating a significant difference between sites. The main effect for year yielded an F ratio of $F(1,7480)=71.6$, $p<0.0001$, indicating a significant difference between years, 2015 (M=72.9mm, SD=27.6mm) and 2016 (M=74.3mm, SD=31.8mm). The interaction effect was significant, $F(24,7480)=29.4$, $p<0.0001$, indicating that year effects shell length differently depending on the site. I am 95% confident that average shell length in 2016 is between 4.5 and 7.2mm smaller than the average shell length in 2015. However, the magnitude of the historic range shell length difference between years seems small when compared to the shell length difference between years in the expanded range (Fig.2, Fig.3).

For our expanded range dataset, I conducted an ANOVA that showed all effects were significant at the 0.05 significance level. The site variable included 7 sampling sites north of point conception, and the year variable included 2 years: 2015 (n=566) and 2016 (n=1281). The main effect for site yielded an F ratio of $F(6, 1833)=78.7$, $p<0.0001$, indicating a significant difference between sites. The main effect for year yielded an F ratio of $F(1,1833)=188.4$, $p<0.0001$, indicating a significant difference between years, 2015(M=63.4mm, SD=26.3mm) and 2016(M=39.0mm, SD= 24.6mm) (Fig.3). The interaction effect was significant $F(6,1833)=26.6$, $p< 0.0001$, indicating year effects shell length differently depending on the site. I am 95% confident that the average shell length in 2016 is between 23.8 and 31.8mm smaller than the average shell length in 2015. This provides evidence for a larger proportion of juvenile whelks in

2016 in the expanded range. In other words, there is strong evidence for increased recruitment in the expanded range after the 2015 El Niño (Fig. 4).

Evidence for Bimodal Size Frequency Distribution in Expanded Range

The historic range size frequency distribution for both 2015 and 2016 had a normal distribution, whereas the expanded range size frequency distribution for both 2015 and 2016 had a bimodal size frequency distribution (Fig. 4). A bimodal distribution in the expanded range indicates a major difference in population structure between the historic and expanded ranges.

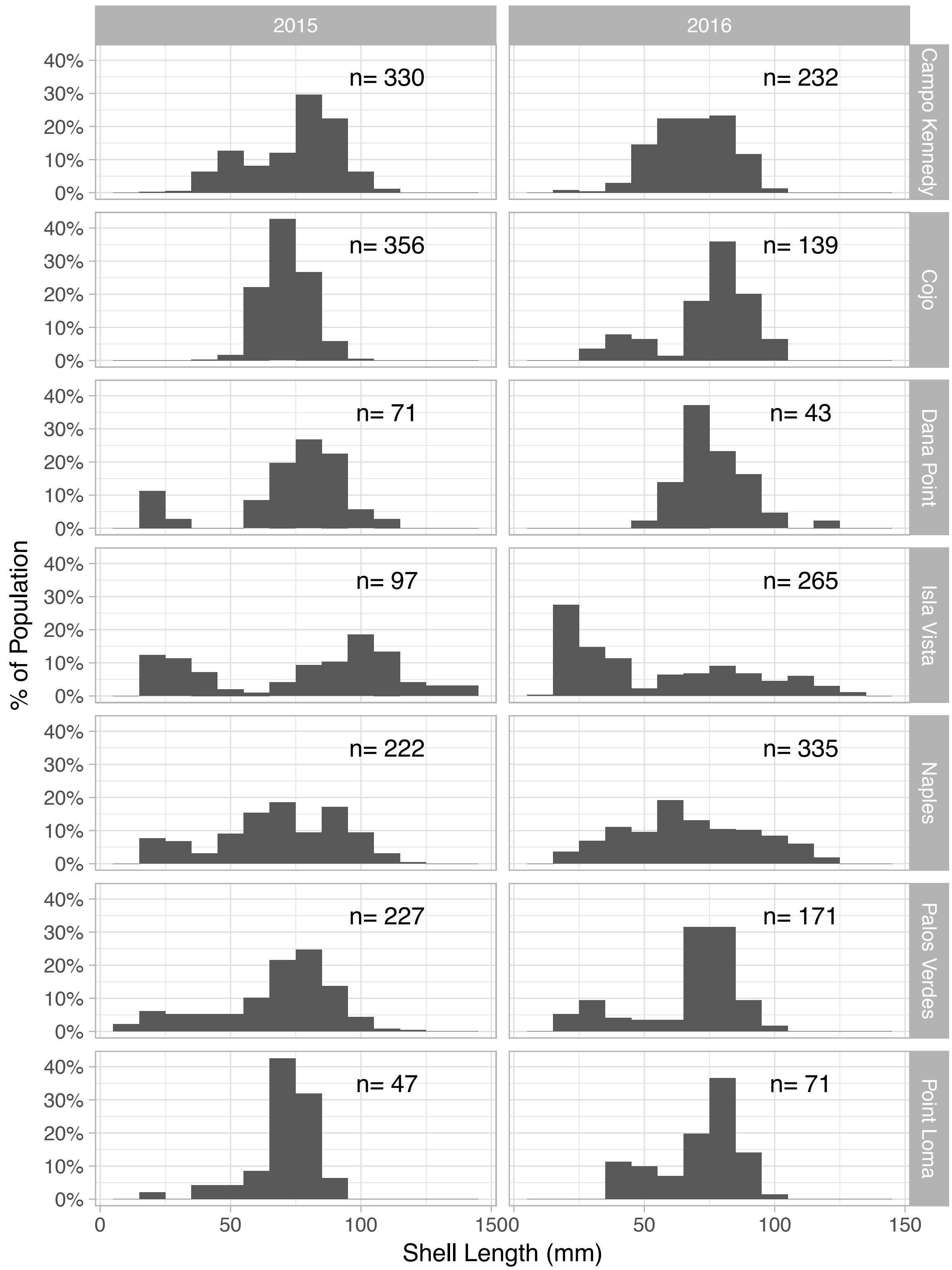

Figure 2. Size frequency distributions by year for 7 historic range mainland sites. No clear recruitment pattern (10-30mm pulse) after the El Niño in 2016.

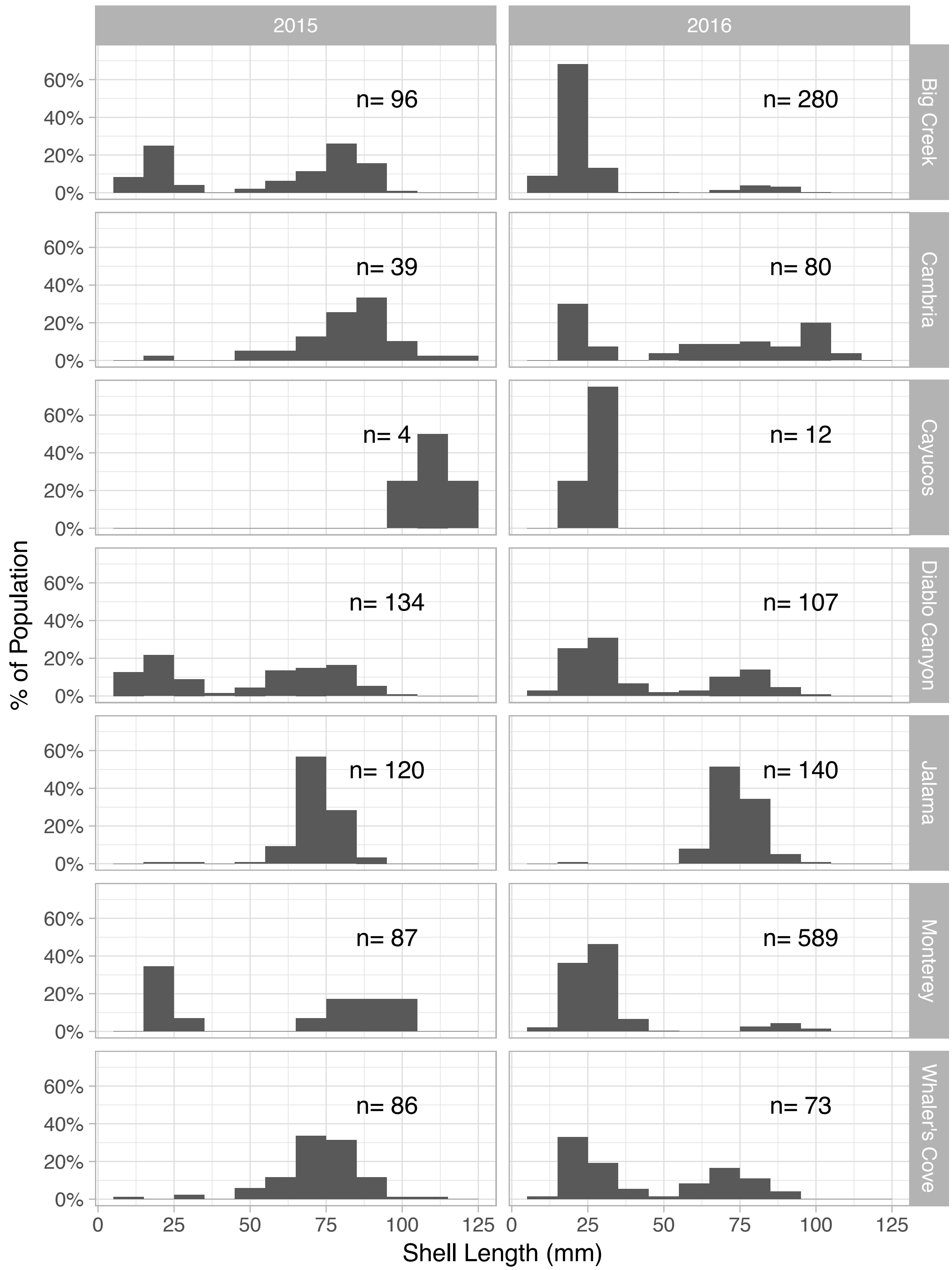

Figure 3. Size frequency distributions by year for 7 expanded range mainland sites. Clear recruitment pattern (10-30mm pulse) after the El Niño in 2016.

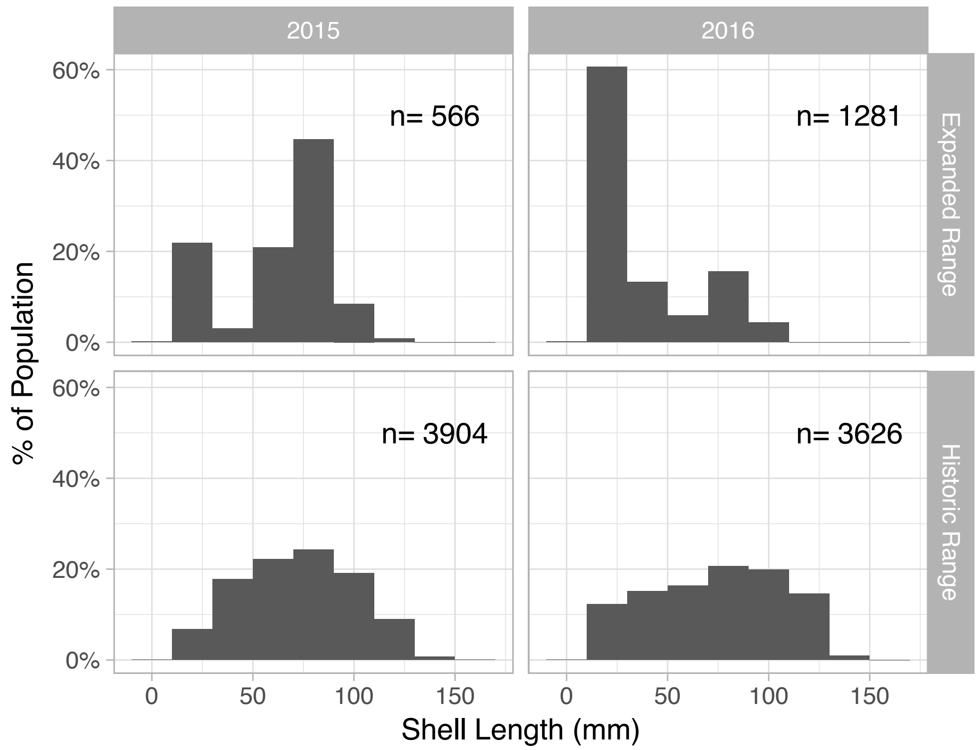

Figure 4. Size frequency distributions by year for expanded and historic range. Small recruitment pulse (10-30mm) in expanded range before El Niño in 2015. Large recruitment pulse in expanded range after El Niño in 2016. Bimodal distribution in expanded range and normal distribution in historic range.

DISCUSSION

El Niño Drives Recruitment: Decoupling of Warming and Poleward Flow

Our dive team observed two recruitment pulses in the expanded range: one relatively small pulse in 2015 and one large pulse in 2016 (Fig.4). I compared these pulses to Zacherl's surveys in 1997 and 1999 (Zacherl et al. 2003). Two years after the 1997 El Niño, Zacherl's team detected recruits at Monterey and Diablo Canyon; similarly, we observed recruits one year after the 2015 El Niño at Monterey and Diablo Canyon. These pulses and my significant statistical results supported Zacherl's findings, indicating increased Kellet's whelk recruitment in the expanded range after El Niño events.

However, data comparisons prior to these El Niño events did not match like the post-El Niño recruitment data did. Zacherl's team did not detect any recruits before the 1997 El Niño for any of their expanded range sites (Monterey, Diablo Canyon, and Jalama). Whereas, our team detected a small recruitment pulse for Monterey and Diablo Canyon before the 2015 El Niño and detected a few recruits at Jalama. It is interesting that we observed recruitment prior to an El Niño event, yet Zacherl's team did not observe a single recruit.

Many factors could contribute to recruitment seen prior to the 2015 El Niño, yet not seen prior to the 1997 El Niño. Both our team and Zacherl's team followed the same collection protocol; therefore, I assumed that the difference was not due to sampling error. I decided to investigate major atmospheric and oceanographic differences surrounding each El Niño event. "The Blob" was the greatest anomaly observed in the North Eastern Pacific since the 1980s, and the warm sea surface temperature (SST) anomalies subsequently expanded and reached coastal waters in spring and summer 2014 (Bond 2015). Therefore, the recruitment pulse that we observed in 2015 was exposed to "The Blob" and increased SST. Increased SST in 2014 could be one possible explanation for the recruitment pulse seen in 2015. The lack of increased SST in 1996 could explain why Zacherl's team did not observe recruits in 1997.

The El Niño is correlated with both increased SST as well as change in ocean current direction from equatorward flow to poleward flow. Therefore, it is rare to observe events with only one of these mechanisms. Zacherl expressed the importance of determining the relative effects of SST and poleward flow on Kellet's whelk recruitment in her 2003 paper. Our data collected after “The Blob,” yet prior to the El Niño with corresponding poleward flow conditions could be used as a tool to help future research decouple these often confounded mechanisms.

Source of Recruitment for the Expanded Range

The expanded range had a bimodal population shell length distribution, indicating a bimodal age structure in the expanded range. The expanded age structure was not consistent with the normally distributed historic range age structure. This could indicate population differences such as recruitment, and could be evidence for the expanded range population’s dependence on the historic range for larval supply. Aging Kellet’s whelk will be crucial for connecting ocean-atmospheric events such as El Niño to the peak sizes in the expanded range population distribution.

CONCLUSION

I found our data to be in support of Danielle Zacherl’s previous findings: Kellet’s whelk recruitment increases in its expanded range, North of Point Conception, after an El Niño event. I also found evidence for population structure differences between the historic and expanded ranges. Kellet’s whelk’s response to major ocean-atmospheric patterns could be important for understanding the biogeography of other ecologically and socioeconomically important fishery species. Anthropogenic global warming increases the quantity and severity of rare weather events, and studying the effects of these events is important for guiding current and future management decisions.

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Data Collection and Dive Team

Danielle Zacherl, Lead Scientific Diver, CSU Fullerton Professor

Crow White, Lead Scientific Diver, Cal Poly Assistant Professor

Jenny Palo, Lead Scientific Diver, St. Raymond K-8 School Teacher & Cal Poly Alumni

Katie Grady, Lead Scientific Diver, National Park Service Kelp Forest Monitoring Research Assistant & Cal Poly Alumni

Justin Palmer, Lead Scientific Diver, Cal Poly Undergraduate Student

Emily Spurgeon, Lead Scientific Diver, Cal Poly Alumni

Gabriela Montaño Moctezuma, Lead Scientific Diver, University Automata Baja California Professor

Amanda Bird, Scientific Diver, CSU Fullerton Graduate Student

Megan Wilson, Scientific Diver, Cal Poly Undergraduate Student

Parker Kalan, Scientific Diver, Tenera Environmental Research Assistant

Nicci Hack, Scientific Diver, Cal Poly Graduate Student

Rodrigo Beas, Scientific Diver, Scientific Diver, University Automata Baja California Professor

Jason Felton, Scientific Diver, Cal Poly Diving Safety Officer

Grant Waltz, Scientific Diver, Cal Poly Senior Research Scientist

Ian Robbins, Scientific Diver, Cal Poly Senior Research Scientist

Tom Moylan, Vessel Captain, R/V Richards, Cal Poly Boating Safety Officer

Rob Brewster, Technical Equipment Support, Cal Poly Equipment and Electromechanical Technician

Doug Brewster, Technical Equipment Support, Cal Poly Equipment and Electromechanical Technician

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Charles Lara, Crew Member, NOAA R/V *Shearwater*

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