FINAL REPORT TO THE UNIVERSITY OF HAWAIʻI AT HILO

# Temporal variation in recruitment & condition of cabezon (*Scorpaenichthys marmoratus*) along the Oregon Coast

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**Abstract**

Research on survivorship of marine fish larvae is challenging due to the small size and rarity of larvae, thus drivers of fluctuations in recruitment magnitude are largely unknown. Plausible causes for fluctuations could be varying sea surface temperatures (SST) and diet. Previous research has suggested that analyzing otoliths (ear stones) can be used to understand fish condition as otoliths are used for motility and stability. The objective for this study was to determine if diet contributed to an increase or decrease of larval fish settlement. Newly settled cabezon juveniles collected weekly from Standard Monitoring Units for the Recruitment of Fishes (SMURFs) were used to examine how recruitment varies relative to the local oceanographic indices like SST, North Copepod Abundance and Copepod Community Index. Furthermore, condition of juveniles was estimated from a comparison of asymmetry by imaging 50 sagittall otoliths using ImagePro software and transcribing images into 12 harmonics (for 98.5% shape accuracy) that generated 45 Normalized Ellipictical Fourier coefficients for all otoliths using shapeR. A significant relationship showed that mean and max recruitment rate was proportional to the annual index of SST. There was no significant relationship between otolith asymmetry shape discriptors and oceanographic indicies, however, analysis of otolith shape using Fast Fourier techniques shows potential for tracing fish condition for underlying ocean conditions. Our non-significant trend suggests cabezon recruit in greater volume in wamer SST, however, fast growth could lead to malnutrition in cabezon resulting in mortalilty after the settling stages. This study was the first to examine the relationship of recruitment magnitude and recruit condition, and determining oceanographic conditions most responsible in affecting larval survival. This research can further help investivigate recruitment sucess for a variety of fish populations and creating sustainable fish stocks as SST rises due to anthropogenic climate change. Furthermore, additional time series and otolith microstructure analysis are planned to disentangle larval growth from condition under variable oceanographic conditions.

*Keywords*: *Recruitment rate, otolith asymmetry, larval fish mortality, developmental success, cabezon*

## Introduction

Research on larval fish is difficult due to many unknowns about survival, diet, dispersal, and recruitment. Early life history stages in fish experience the highest mortality, where any variation in oceanographic conditions can drastically affect recruitment rates and habitat selection, thus affecting population in coastal fisheries (Houde 1987; Halpern & Waren 2002; Cowen & Sponaugle 2009).  Over the past century, a suite of hypotheses have suggested that the primary causes of larval mortality are: starvation, low prey abundance, and unstable, unfavorable oceanographic conditions (Hjort 1914; Cushing 1975; Lasker 1975; 1978). Other hypotheses suggest that increased survival is correlated with higher levels of upwelling, highly turbulent events, and the coincidence of spawning events with suitable oceanographic conditions (Houde 1987). Upwelling occurs when warm surface waters near coasts are displaced offshore via Ekman transport, causing cooler, nutrient-rich subsurface waters to be brought into the near-shore photic zone (Huyer 1983). The influx of nutrients stimulates phytoplankton growth which translates up the food web and increases prey availability for pelagic larvae.

There can be significant variability in an upwelling system with consequences for larval success. For example, particular portions of an upwelling system can sustain high levels of consistent upwelling, while upwelling in other portions of a coast can be highly seasonal, creating differences in larval survival and recruitment rates across the larger system. For decades, researchers have hypothesized that larval distribution patterns can be predicted in areas with intermittent upwelling; however, recent research suggests that this hypothesis is questionable, and that biological indicators of oceanography can be used to predict variability in settlement magnitude (Shanks & Morgan 2017).

Copepod abundance, copepod community structure, and sea surface temperature (SST) all impact larval feeding and growth rates because their short life cycles allow them to reflect event-scale changes in climate or predator-prey distributions (Hooff & Peterson 2006). Copepod abundance can determine whether larval fish survive solely due to the amount of food that is present at that given time. Copepod biodiversity or community structure in a particular water mass can indicate from where the water mass was transported (Peterson 2009). SST also reflects water mass origin and often has a direct effect on larval success due to the relationship between temperature, development, and growth rates (Sponaugle et al. 2006). Assuming access to abundant prey, organisms that experience higher temperatures have faster growth and developmental rates, allowing them to settle sooner than expected. While higher temperatures can increase recruitment rates and population connectivity for some species, such temperatures can also have a negative effect on larvae that are dependent on cold water temperatures (Quinn & Rochette 2015). It is often difficult to examine the oceanographic conditions that have significant impacts on settlement magnitude; however, we can obtain some indications about events occurring during the life of larval fishes through the examination of their otoliths (ear stones) (Sponaugle 2010).

One measure of organism condition is via the study of symmetry. Symmetry is viewed as an ideal form while asymmetry is seen as impurities to the ideal form (Somarakis et al. 1997). Comparison of the paired otoliths of a fish enables the calculation of the degree of asymmetry, which can reveal discrepancies in bilateral symmetry. In fish, environmental stress can affect larvae as they are dispersed offshore, influencing their ability to settle. Previous studies have found a direct relationship between environmental stress and biological change, e.g., food availability, temperature, and predator-prey distributions, as reflected in higher levels of asymmetry (Escós et al. 1995; Somarakis et al. 1997). Lemberget & McCormick (2009) found that asymmetry in the Caribbean lizardfish, *Saurida suspicio* (family Synodontidae), was strongly correlated with recruitment fluctuations. While previous research has shown that stress can induce asymmetry, it remains unclear which oceanographic processes induce higher degrees of asymmetry, and whether such asymmetry influences recruitment magnitude.

In the present study we explored the relationship between recruitment magnitude, asymmetry, and oceanographic indices. We hypothesized that annual mean cabezon recruitment and condition will be higher during years with higher proportions of high quality copepods. Lipid-rich copepods are usually found in cooler upwelled waters, thus providing a higher nutritional source for the pelagic food web that includes cabezon, whereas warmer waters support copepods with lower lipid reserves (Peterson et al. 2012). Thus, we expected recruitment of cabezon to be higher during low SSTs and to have higher condition.

## Methods

### *Study Species*: *Scorpaenichthys marmoratus*

We selected cabezon, *Scorpaenichthy marmoratus*, for this study because it recruits regularly to the coast of Oregon each spring-summer recruitment season, providing a robust time-series for analysis. Cabezon spawn throughout the year; spawning commences in October, peaks in January, and continues until April (Lauth 1988). Currents can displace the larvae in pelagic waters roughly 200 miles offshore while downwelling conditions can cause post-larvae to appear in near-shore habitats such as tidepools and kelp beds. Larvae prey upon barnacle larvae, nauplii, amphipods, decapods, euphusiids, and larval fish prior to settlement

(Barraclough 1967). Cabezon recruit back to settlement areas annually from April to September (Lauth 1988).

*Study Sites*

The California Current System (CCS) is an eastern boundary current system that spans coastal waters beginning from southern Alaska (~50°N) and flowing toward Baja California (~15-25°N). The CCS is characterized by seasonal productivity driven by wind-driven (Ekman transport) upwelling in spring and summer periods, and is limited to narrow coastal bands ranging from 10-25 km wide. In the Northern CCS, upwelling is more variable than the southern parts of the CCS; instead of occurring strongly for an entire season like in the southern CCS, upwelling occurs for a short period of time (a few days) followed by a relaxation event throughout the upwelling season (Huyer 1983; Checkley & Barth 2009).

Fish recruitment was monitored along the Oregon coast in two central locations (Fig. 1): Otter Rock (44°42'34.73" N, 124°04'53.74" W) and Cape Foulweather (44°46'21.00" N, 124°04'33.57" W) over 6 years (2012-2017) via access to the R/V *Gracie Lynn* . Both Otter Rock and Cape Foulweather have rocky intertidal habitats, emergent rocks, have patches of kelp, and are subject to relatively low pressures from fisheries. Due to their central location, they experience more variable upwelling conditions.

*Patterns of recruitment*

Four Standard Monitoring Units for the Recruitment of Fishes (SMURFs) were placed at each location to measure recruitment of all benthic fishes including cabezon from April to September of each year (Fig. 2). SMURFs imitate areas of suitable settlement habitats (e.g. kelp fronds), thereby attracting young fish during the transition from their pelagic to benthic life stages. Methodology and construction were based on established SMURF design (Ammann 2004).

The SMURFs, retrieved by snorkeling, were sampled approximately every two weeks throughout the sampling season. Removal involved encasing the SMURF with a Benthic Ichthyofauna Net for Coral/Kelp Environments (BINCKE) and then the SMURF was detached where it was brought on board and water was poured onto the SMURF while shaking to release any trapped fish or invertebrates and into the BINCKE. All fish species were collected and were humainly euthanized using MS-222, an anesthetic used for muscle relaxation in fish . Later, fish were identified to species or species complex using the methods described by Matarese (1989), and their standard lengths were measured to the nearest hundredth of a millimeter. SMURF collections were made from 2012-2018, however 2018 collections were not used in the analysis because the recruitment season was not completed.

*Recruitment Analysis*

Recruitment rate (fish/SMURF/day) was calculated and annual oceanographic indices obtained (Peterson et al. 2017; www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Annual_Report_2017.pdf) for each of the 6 years. For the purposes of this study, we used three primary indices: northern copepod abundance, copepod community index, and SST. The relationships between annual mean and max rates of recruitment and these three oceanographic indices (Table 1) were modeled using linear regression.

*Otolith Asymmetry Analysis*

Given time constraints, otolith asymmetry was examined for individuals from both central sites combined. Otoliths from 10 individuals were analyzed from each of 6 years spanning variable oceanographic conditions. Otolith dissection involved an incision made ~5 mm above their eyes to near the beginning of the dorsal fin. Otoliths were extracted and placed in a Petri dish where they were cleaned using a dissecting microscope and placed in a labeled vial with 1 mL of 95% ethanol solution. The right and left sagittal otoliths of each individual were imaged using a dissecting microscope and Image Pro Plus 10.

The package shapeR, written in the programming language R, was used to outline otolith images and measure otolith shape descriptors including perimeter, area, length, width. Fast Fourier harmonics were used to describe the shape of the otolith (Libungan & Pálsson 2015). Fourier analysis is a complex waveform expressed as a series of sinusoidal functions where the frequencies form a harmonic series. The addition of harmonics increases detail of the description of the shape; however, it is best to describe the shape best as possible with the fewest number of terms (Campana & Casselman, 1999). Each otolith shape descriptor was recorded for the right and left otolith (Fig. 3a). Twelve harmonics generated 48 Elliptic Fourier coefficients in shapeR (Fig. 3d), where the first three were omitted due to standardization of size, rotation, and starting point, leaving 45 Normalized Elliptic Fourier coefficients (Libungan & Pálsson 2015). In shapeR, the Fourier analysis contoured the otolith (Fig. 3b), and the outline was extracted. The values for the first 12 harmonics were then summed for each descriptor, and the degree of asymmetry calculated by finding the absolute value of the difference between the right and left descriptors. Otoliths that the shape analysis program failed to accurately outline were removed from our analysis resulting in a total sample size of 50 otoliths. Finally, an ANOVA was used to model the relationship between degree of asymmetry (as perimeter, area, length, width), and 12 Fourier harmonics were used to describe the shape comparing degrees of asymmetry to SST, north copepod abundance, and copepod community index.

## Results

Cabezon recruitment rate varied across the six years of the study (Fig. 4) and appeared to generally track the oceanographic indices (Fig. 5); however, there was no significant relationship between recruitment rate and two of the indices: northern copepod abundance and copepod community index (Table 1). Recruitment rate increased significantly with SST (Fig. 6; $P = 0.0382$; $R^2 = 0.699$, respectively).

Twelve Fourier harmonics were used to obtain a 98.5% confidence interval (Fig. 3d). None of the four otolith descriptors were significantly related to any of the oceanographic indices (Table 2). Otolith shape as described by the 12 Fourier harmonics performed the most consistently across the three oceanographic indices (Fig. 7).

## Discussion

Cabezon recruitment rate varied over the 6-year period, and was highest in 2015 and 2016. Compared to previous years (Ottmann et al. 2018), recruitment of cabezon in 2017 was very low. High recruitment corresponded to years of high SST and this was evident in significant relationships between both mean and maximum recruitment and SST. High water temperatures may increase reproductive output of spawning cabezon as has been shown for other species (Laurel et al. 2008) Alternatively, survival of larvae may be enhanced in warm waters. High temperatures are known to increase growth rates in poikilothermic organisms such as fish. Assuming larvae have access to sufficient food, these high growth rates would result in larger sizes as a given age and shorter pelagic larval durations, both of which generally reduce predation mortality (Anderson 1988, Houde 1989), and would lead to higher recruitment. We do not have access to data on daily growth to test this hypothesis, but used otolith asymmetry as a proxy for condition.

Although the relationships between otolith asymmetry (via each shape descriptor) and oceanographic conditions were not significant, each descriptor showed a trend with one of the oceanographic indices; however, the models including Fourier descriptors consistently performed better than models with other shape descriptors. That is, the degree of asymmetry calculated with Fourier descriptors more closely aligned with all three of the oceanographic indices. If more data confirmed this non-significant trend, the data would suggest that years with high cabezon recruitment and higher SST correspond to years with a higher degree of asymmetry for cabezon (and thus poorer condition individuals). This is somewhat contradictory to what fast growth might suggest, but it is possible that fast growth during these warm years is only barely sustained and that the supply or quality of prey items may be insufficient to produce high-condition individuals. Under this hypothesis, in years of high SST, individuals sacrifice better condition for faster growth. Indeed, previous studies have confirmed this phenomenon for other species (Leggett & Debloise 1994). For cabezon in our system, more sampling years and higher resolution oceanographic indices are required to fully test this hypothesis.

If this trend is found to be significant, these data could be used to improve our understanding of the factors that are conductive to successful recruitment and condition, and ultimately, to better predict population dynamics. High pulses of recruitment may not contribute as much to sustaining the population if recruits are of low condition and do not survive early benthic life. Thus, measuring recruitment and recruit condition together with oceanographic conditions should provide a more robust measurement of population replenishment. Inclusion of otolith microstructure analysis to examine growth simultaneously with condition would also greatly improve our ability to distinguish the processes occurring during the early life of cabezon.

In summary, cabezon appear to recruit in greater numbers during years of warmer water temperatures, but the mechanism behind this observation is unclear. Otolith asymmetry data are suggestive that while recruits are more abundant, their condition may be lower. More sampling years and otolith microstructure analysis are required to further test this concept. This study was the first attempt to examine recruitment magnitude *together with* individual recruit condition and shows promise for revealing the oceanographic conditions most important in influencing recruitment success.

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**Tables**

Table 1: Data rank score derived from Peterson et al. (2012) based on long-term time-series of oceanographic and plankton sampling. Data rank scores of Sea Surface Temperature, North Copepod Abundance, and Copepod Community Index where values 1-10 reflect good conditions, 11-15 reflect intermediate conditions, and 16-20 reflect poor oceanographic conditions. Cabezon abundance shows the yield of juvenile cabezon caught in SMURFs for each year.

| *Year* | *SST* | *N. Copepod Abundance* | *Copepod Community Index* | *Cabezon Abundance* |
|---|---|---|---|---|
| 2012 | 12 | 2 | 8 | 24 |
| 2013 | 13 | 4 | 4 | 127 |
| 2014 | 14 | 5 | 11 | 65 |
| 2015 | 19 | 16 | 18 | 241 |
| 2016 | 18 | 20 | 20 | 268 |
| 2017 | 6 | 17 | 16 | 46 |

Table 2: Results for otolith asymmetry analysis depicting the P and $R^2$ for North Copepod Abundance, Copepod Community Index, and Sea Surface Temperature. The bolded values indicate a significant difference.

| | *North Copepod Abundance* | | *Copepod Community Index* | | *SST* | |
|---|---|---|---|---|---|---|
| | P | $R^2$ | P | $R^2$ | P | $R^2$ |
| *Recruitment Rate* | 0.18 | 0.074 | 0.118 | 0.074 | **0.034** | **0.174** |
| *Otolith Perimeter* | 0.76 | 0.026 | 0.882 | 0.006 | 0.255 | 0.306 |
| *Otolith Width* | 0.15 | 0.446 | 0.334 | 0.232 | 0.82 | 0.17 |
| *Otolith Length* | 0.39 | 0.188 | 0.135 | 0.466 | 0.927 | 0.002 |
| *Otolith Area* | 0.84 | 0.012 | 0.464 | 0.141 | 0.61 | 0.071 |
| *Otolith Fourier* | 0.12 | 0.494 | 0.127 | 0.479 | 0.186 | 0.388 |

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**Figures**

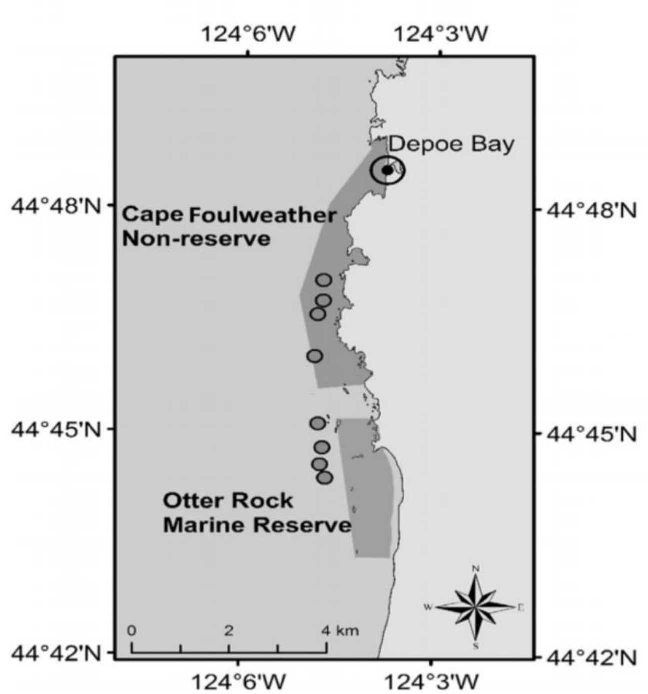


Figure 1: Two central sites along the Oregon coast are monitored May-September each year (2012-2018) for recruitment of benthic fishes using SMURFs. The shaded grey blocks signifies the areas enclosing Cape Foulweather (non-reserve) and Otter Rock (marine reserve). Each SMURF in the area is denoted by a dark grey circle with a black outline. The black circle with a bolded outline marks the closest cit, Depoe Bay, to SMURF collections (Ottmann et al. 2018).

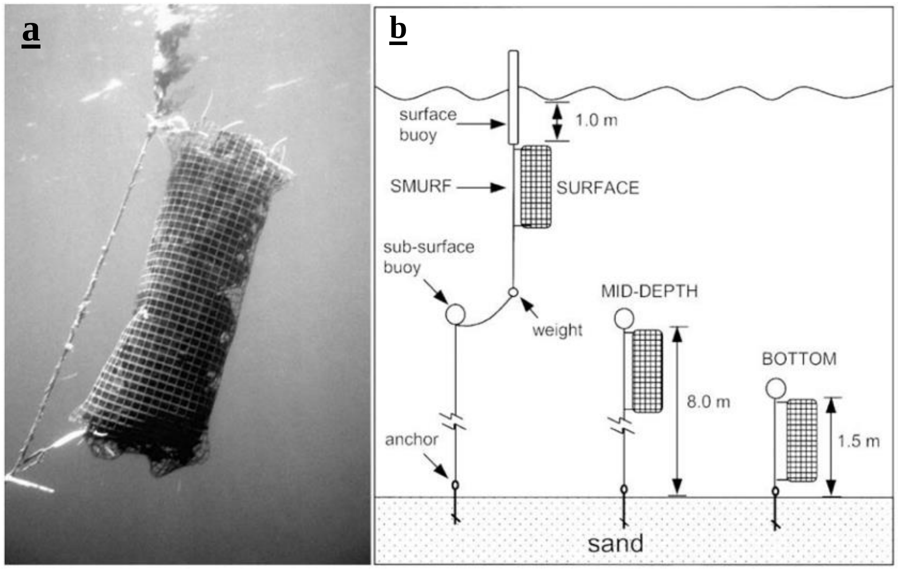


Figure 2: (a) A SMURF resembling an artificial kelp bed used for measuring recruitment in Cape Foulweather and Otter Rock. (b) Diagram of SMURF deployment in the water column (Ammann 2004).

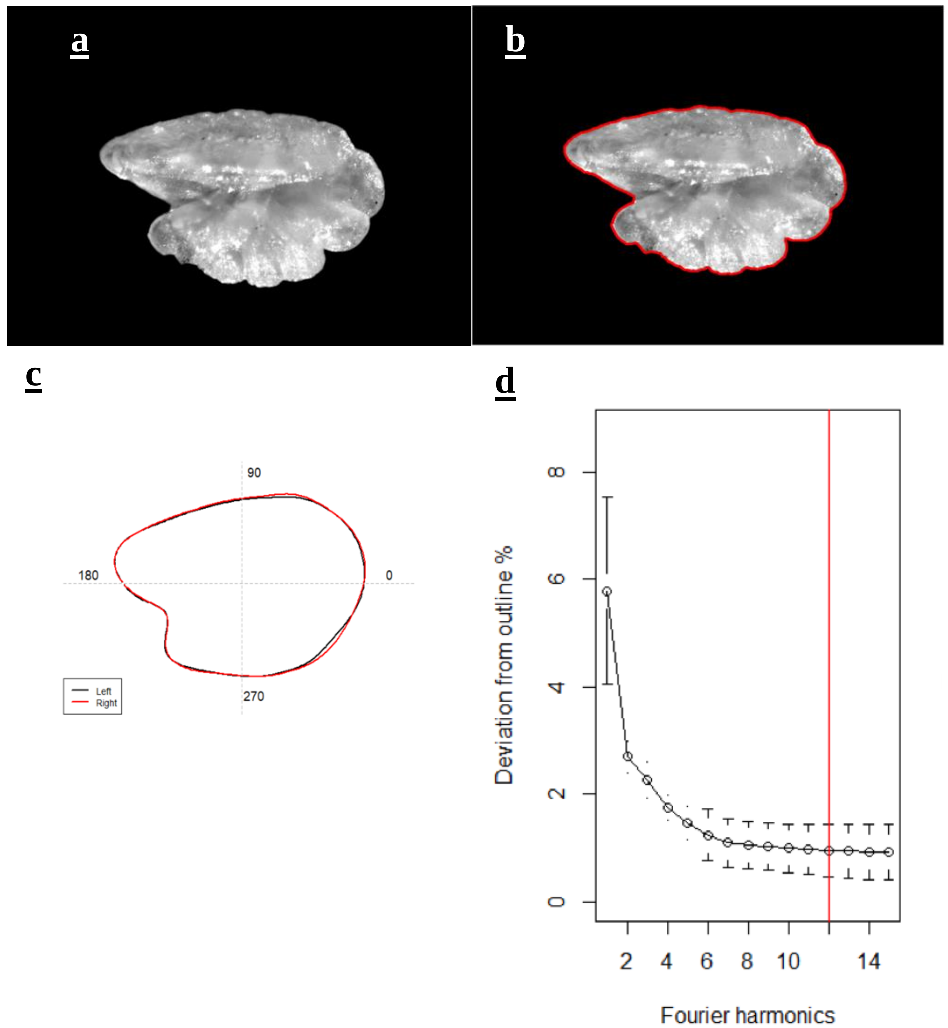


Figure 3: (a) An example sagittal otolith projected using ImagePro. (b) The red outline marks the shape of the otolith which is extracted and described in shapeR for degree of asymmetry. (c) Mean otolith shape reconstruction using Fourier harmonics. Numbers are angles in degrees (°) based on polar coordinates. The centroid of the otolith (center of the cross) is the center point of the polar coordinates. (d) Fourier outline reconstruction. The red line symbolizes the number of harmonics needed for a 98.5% accuracy of the reconstruction.

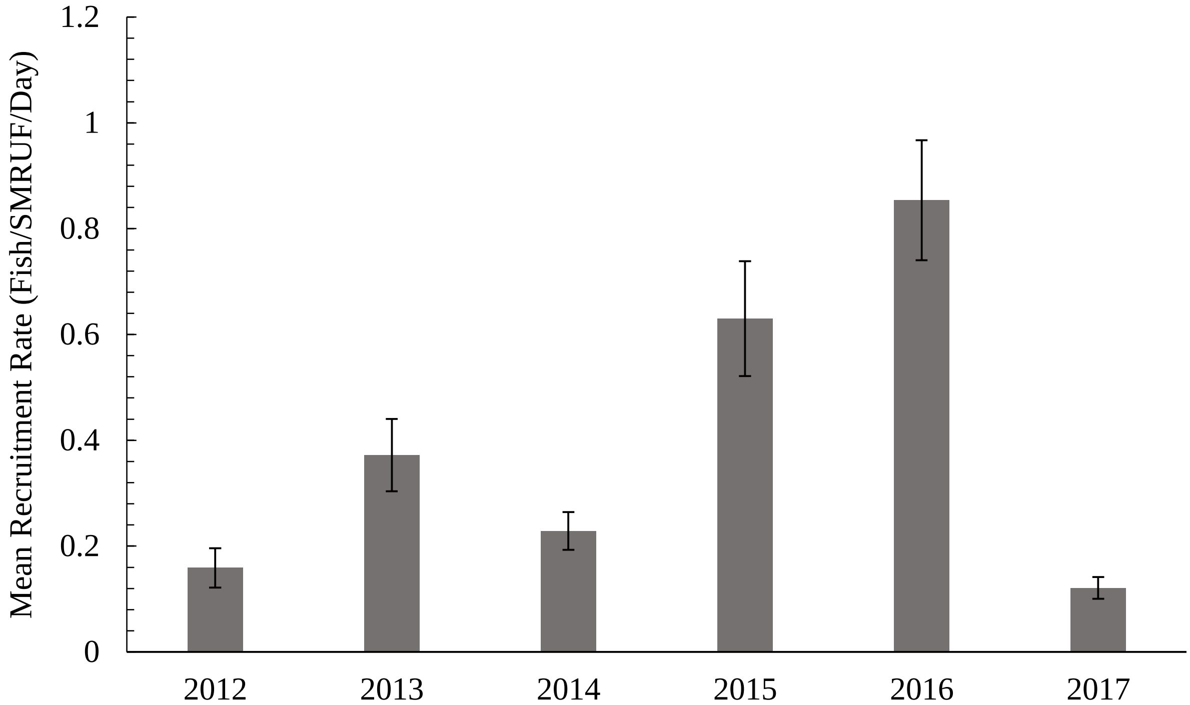


Figure 4: Time-series of mean annual recruitment of cabezon over the period 2012-2017 as measured by the number of individuals arriving to replicate SMURFs deployed along the central Oregon coast.

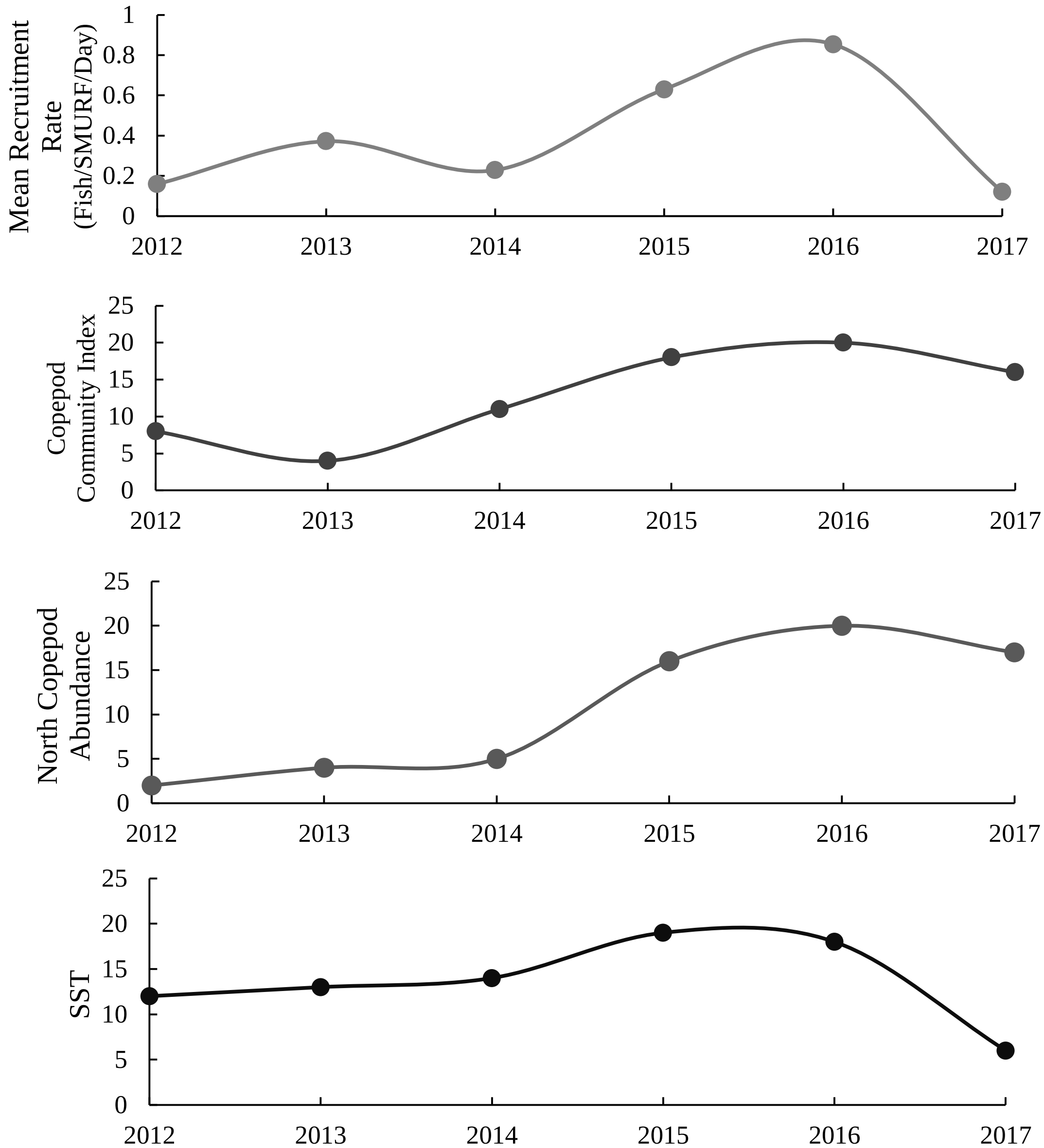


Figure 5: Time-series of annual mean and maximum cabezon recruitment rate together with annual variations in oceanographic indices (Peterson et al. 2017; from NOAA; www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Annual_Report_2017.pdf).

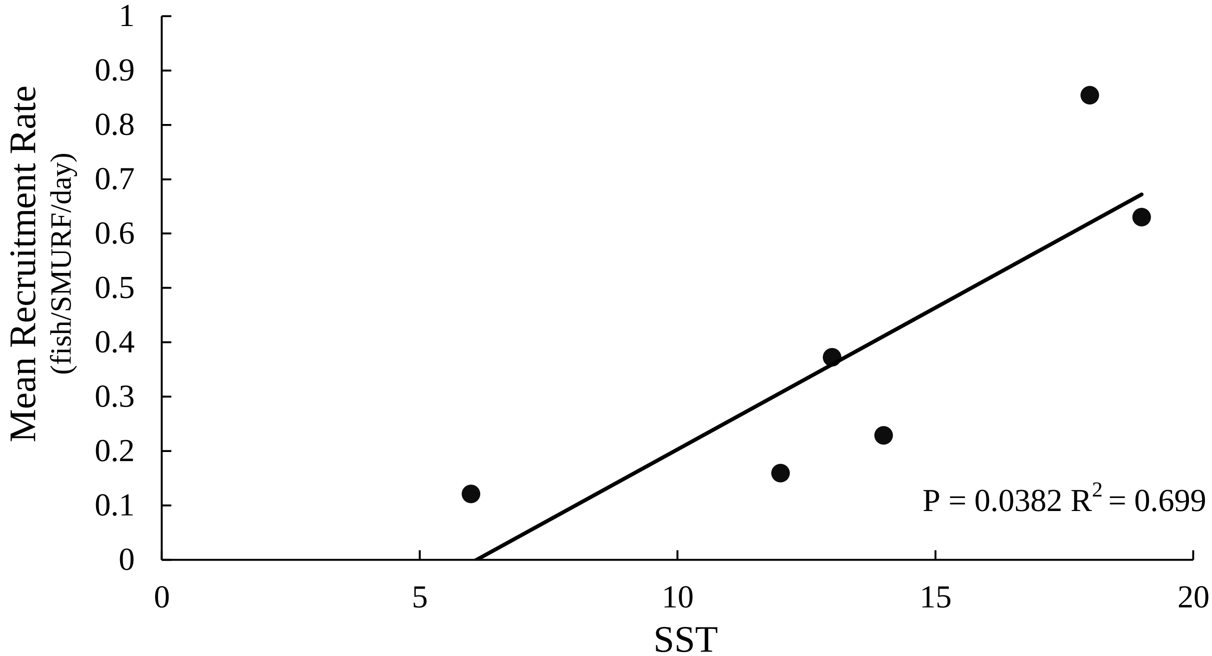


Figure 6: Mean annual cabezon recruitment rate to the central Oregon coast as a function of SST index. (Peterson et al. 2017; from NOAA; www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Annual_Report_2017.pdf).

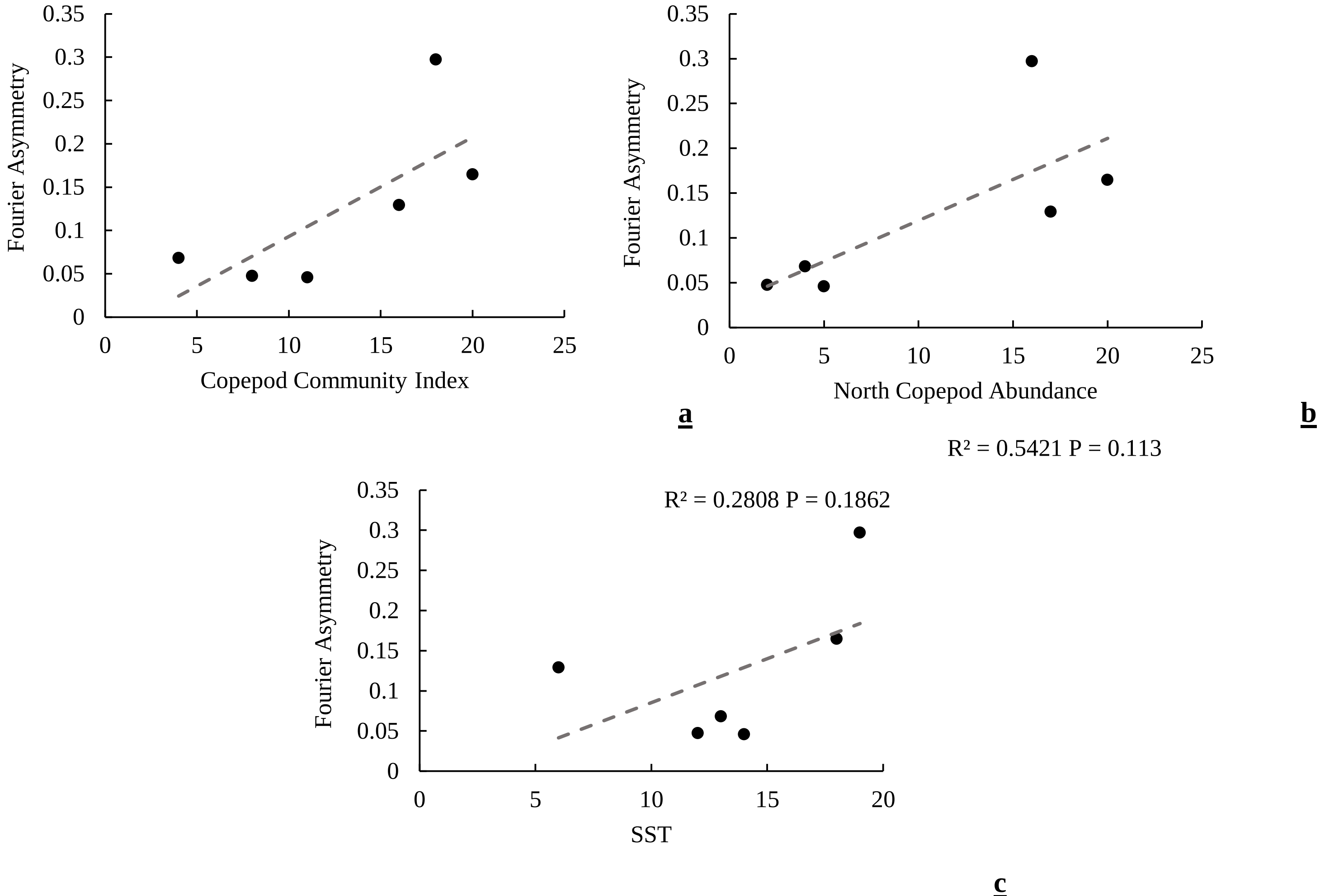


Figure 7: Relationship between the mean otolith asymmetry values from Fourier harmonics and (a) copepod community index (b) northern copepod abundance (c) SST. No relationship was significant; a non-significant trend line is shown for visual purposes only.

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