

**Growth and Condition of Pacific Sand Lance (*Ammodytes personatus*) after “The Blob”  
Marine Heatwave**

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## **Abstract**

Forage fish are critical keystone prey species that facilitate energy transfer up the food chain in marine ecosystems. The Pacific sand lance (*Ammodytes personatus*, PSL) in particular occupy an intermediate trophic level role and are a rich energy source for their predators. This study investigates the effects of marine heatwaves, specifically “the Blob” (2013-2016), on PSL growth and condition. Fish were collected from two sites in the San Juan Archipelago over the course of ten years, measured, weighted and analyzed along Sea Surface Temperature (SST) data to understand growth dynamics during and after marine heatwaves. The results indicated significant differences between the two sites as well as between each year. The PSL condition recovered 2-3 years after “the Blob” likely due to shifts in zooplankton community structure. Even though recovery is possible, there is still room for concern about forage fish dynamics as marine heatwaves become more intense and frequent. These findings emphasize the need for ongoing monitoring and management to sustain keystone prey species, like Pacific sand lance.

## Introduction

Forage fish are some of the most abundant fishes in the world's oceans and are crucial keystone prey species that facilitate energy transfer up the food chain (Baker, Smeltz, et al., 2023). Forage fish support fisheries that provide important economic, social, and nutritional value. Total fish landings have consistently been higher for forage fishes than for all demersal fish combined, and humans consume these fishes and reap the benefits of using them for fishmeal and fish oil (Engelhard et al., 2014). Although these fish usually have short lifespans and fast turnover rates, drastic changes in age class distributions of forage fish populations, due to predation, may cause a cascading effect due to their unique trophic position (Engelhard et al., 2014).

Sand eels, or sand lance (*Ammodytes spp.*), are small planktivorous forage fishes that play an integral role in pelagic ecosystems throughout the northern hemisphere (Baker, Farley, et al., 2023). Pacific sand lance (*Ammodytes personatus*, PSL) (Orr et al., 2015), found in the Salish Sea, are in particularly high abundance in the San Juan Archipelago (Selleck & Gibson, 2015). PSL are prey to over 100 predators, including sea birds, salmon, cod, lingcod, stellar sealions, harbor seals, and baleen whales (Baker, Smeltz, et al., 2023). They are especially important for birds as they are easy to carry and have high energy content for birds to feed to their young (Huard et al., 2024). They obtain this high lipid density by having a diet consisting of copepods (Sisson & Baker, 2017, Zarubin et al., 2014). As these fish grow, they have been observed to increase in this energy density (Van Pelt et al., 1997).

Sand lances exhibit an uneven distribution in their habitat range, within small patchy habitats that are not well mapped (USGS) the growth of these populations is also not very understood. Fish exhibit indeterminate growth, meaning that their growth does not stop once

they reach sexual maturity (Sebens, 1987). Condition factors can be calculated and used as a proxy for fish growth rates (Fulton 1994, Ricker 1975). Condition is a ratio of the fish's body weight to the cube of its length. This factor can be influenced by a fish's food availability, parasite infections, age, sexual maturity and other environmental variables (Sutton, 2000).

Climatic events, such as marine heat waves, have potential to disrupt fish behavior and regulatory physiology (Wade et al., 2019). A marine heat wave, or warm anomaly in sea surface temperature (SST) is defined by its intensity and duration (Fumo et al., 2020). A general definition of one is a period when temperatures exceed the 90<sup>th</sup> percentile of the local climatology for 5 days or more (Smith et al., 2023). One such marine heat wave that occurred from 2013-2016 was nicknamed the "the Blob". This heatwave was the strongest marine heat wave ever recorded with water temperatures reaching 6 degrees C higher than average (Gentemann et al., 2017). This heatwave was also the only marine heat wave to occur through all four seasons (Suryan et al., 2021). The specific thermal tolerances of fishes could be exceeded during a heatwave, and cause fatal failure in fish physiological processes and potential population decline (Smith et al., 2023).

It is already projected that sand lance populations in the Salish sea may be 63% of what they are today (37% decline) in 25 years under management scenarios (Huard et al., 2024). A decline in sand lance would cause major cascading effects throughout the ecosystem, as predators would lose a major high-energy food source. Sand lance occupy the intermediate trophic level unaccompanied, thus having a wasp-waist control on the ecosystem (Sisson & Baker, 2017). It is important to understand growth dynamics of sand lance populations in order to manage ecosystems and ensure that there is enough high quality and lipid dense prey to sustain marine predators.

We do not yet understand the effect of marine heatwaves on growth of Pacific sand lance in coastal or for offshore habitats. More information is needed to contextualize the Pacific sand lance population in the Salish Sea, as well as the rates at which they are growing. This study aims to interpret the relationships between fish condition and temperature, as well as each factor that comprises condition. Additionally, this study identifies regional distinctions between 1) sites within the Salish sea, and 2) determine how the blob affected PSL over time.

## **Methods**

### *Fish Collection*

Salish Sea Pacific Sand Lance (*Ammodytes personatus*) were collected in the San Juan Archipelago during October and November from 2019 to 2024 (Fig. 1). Collection was done either through beach seines or Van Veen sediment grabs. Beach seines were done at Jackson beach every 5 days at dawn, in alignment with the sand lance's diel migration with the increasing daylight. 5 seines were done each sampling day, for two minutes each, using a nylon net with a 36.6m width and 3.7 m depth. Van Veen sediment grabs were done at an offshore sampling site in San Juan Channel with the *R/V Rachel Carson* and the *R/V Kittiwake*. The sediment grab maximum volume is 0.026 m<sup>3</sup> with a surface area of 0.12 m<sup>2</sup>. On site, ~10 grabs were completed, and grabs that did not fully close or collect sediment were not included. The contents of the Van Veen were released into large tubs, and the caught sand lance were collected, recorded, and separated by site in containers of seawater.

### *Fish Processing*

Pacific Sand Lance caught in 2024 were euthanized with lethal doses of tricaine methane sulfonate (MS-222) once brought to the lab. The specimens were then measured to the nearest millimeter, weighed to the nearest 0.01 gram with an OHAUS Scout 220 g x 0.01 g balance, and assigned individual identification numbers. Once weighed, their caudal fins were clipped for future genetics studies.

### *Sea Surface Temperature Data Collection*

Water temperature data for this study was collected by deploying a Seabird SBE 19Plus CTD into the water column at North Station (cords) during PEF research cruises (n=6) done with the *R/V Rachel Carson* and the *R/V Kittiwake* annually (n= 10 years). Temperature readings were collected on the equipment's decent.

### *Data analysis*

Fish data (length, weight, site) and annual mean SST data from North Station was compiled in Excel and uploaded to RStudio. Condition factor was calculated with the following equation;

$$K = \frac{100,000 W}{L^3} \quad (1)$$

where W = the weight in grams, and L = standard length in millimeters (Sutton, 2000).

Akaike Information Criterion (AIC) analysis and correlation were done using RStudio.

## **Results**

A total of 4,433 Pacific sand lance were measured over the course of this study, collected from the 2 sites in the San Juan Archipelago over 10 years. In San Juan Channel, lengths of these fish were 83.4 mm on average and weight averaged to be 2.20 g. At Jackson Beach, the average length was 79.8mm and weight was 1.68 g on average. Akaike Information Criterion (AIC) statistical measure was used for the San Juan Channel and Jackson Beach data and determined that these two sites are statistically different from each other.

Correlations were run for length-weight by year and the changes in length to weight annually were determined to be significant (Figure 5). The  $R^2$  values were all above 0.811 except for 2017, where the  $R^2$  value was 0.421 (Figure 5).

Length showed no significant trend for either site. Additionally, weight showed no significant trend for either site. Condition also showed no significant trend with SST, however there is an outlier in 2016 where condition was 0.6 at 10.50 degrees C.

## **Discussion**

Jackson Beach and San Juan Channel were determined to be statistically different sites, which makes sense since different age groups occupy each site. Jackson Beach is home to mostly age-1 fish, followed by age-0 and age-2 fish (Child 2022). It is supported that this beach is a nursery area for sand lance to take advantage of the shallow protected sediment. San Juan Channel is comprised of 2-year-old fish and thought to foster habitat for these older fish as they migrate from shallower intertidal habitats (Child 2022). The differences in age can also be observed by differing average length and weight measurements being higher at San Juan Channel than at Jackson Beach (Fig 4).

The fish were collected via two different methods. The beach seine net was used to collect fish at Jackson Beach, which targets younger fish. Over time, the net became damaged and some of the fish were able to slither through. This method may have resulted in a loss of the smaller and younger group of fish. The Van Veen grab was the other method of collection, and relies on fish being in a certain area at a certain time. Some of the fish get split and damaged if they are in the path of the claw and are unable to be measured. These sampling methods may introduce sampling bias, as certain age class and size representation may escape capture, and this should be considered when interpreting growth patterns.

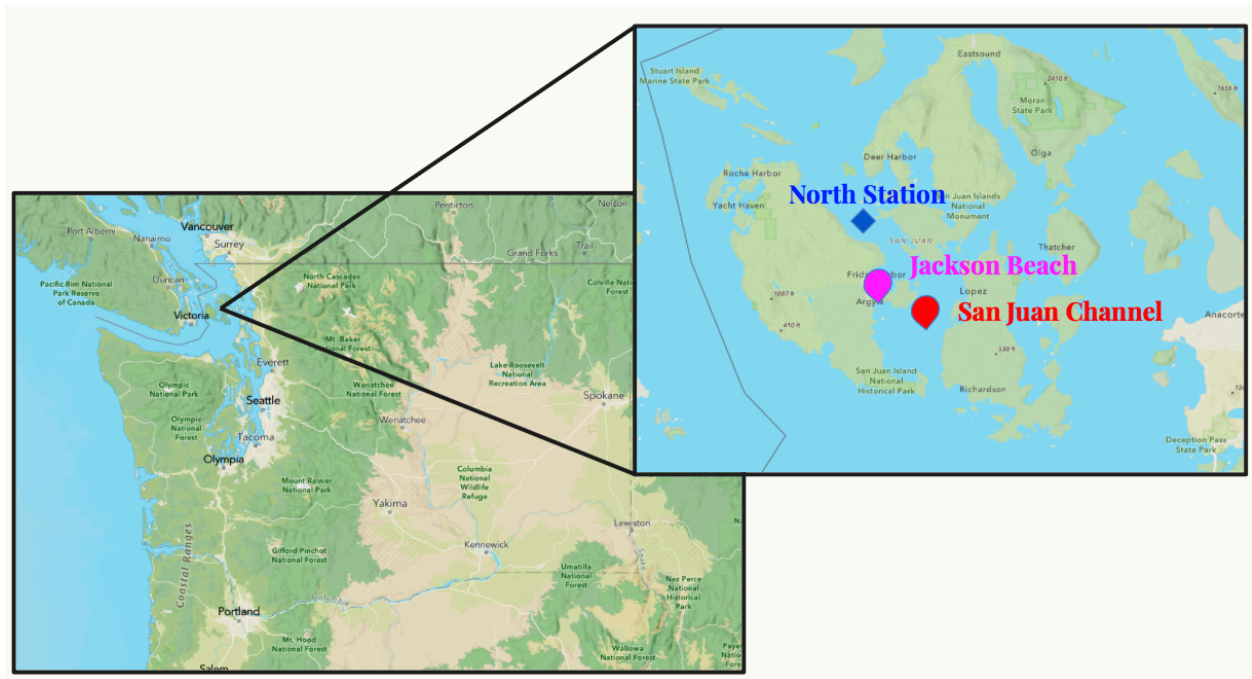
The depths at which fish were collected at Jackson Beach were around 1.5 meters. In this water, the SST is a very representative measure of the entire water column. San Juan Channel is a deeper water basin; however, the thermocline is uniform at San Juan channel with no temperature or salinity differentiation down 80 meters, so SST is still representative (Michelle Hoge 2018). PSL range considerably throughout the water column and may use currents to drift several kilometers away for foraging, and they would encounter consistent thermal environments throughout the mixed water column. (Sisson & Baker, 2017).

The variance in condition observed during this study may be influenced by changes in prey availability, particularly in zooplankton. The recovery of PSL to pre-blob levels in 2-3 years (Fig 9) may be attributed to a shift in zooplankton community structure during and after the heatwave. Cold water zooplankton showed a neutral to positive response to the blob's warm water period and there was an increase in zooplankton biomass that was dominated by smaller warm water species (Suryan et al., 2021). The lowest  $R^2$  value, and the only one under 0.8 occurred in 2017, one year after the end of "the Blob" marine heatwave. The relationship between length and weight in PSL during 2017 was very weak- this may have been a time where

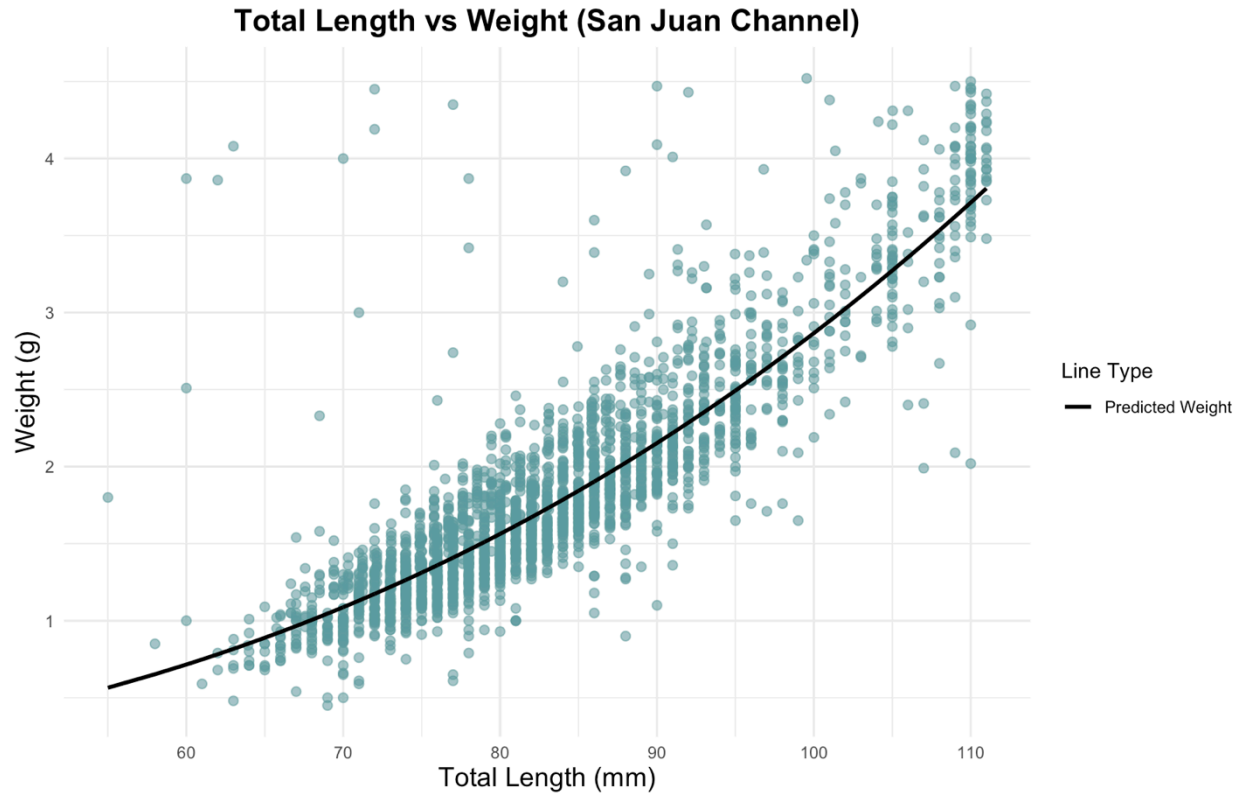
the food options were mainly smaller warm water zooplankton. The lack of a significant condition trend with SST may imply that sand lance has some resilience to moderate temperature increases. This may affect their physiological or behavioral adaptations, such as their energy allocation. As marine heat wave become longer and more frequent over time, sand lance population recovery periods may shorten and reduce their resilience (Oliver et al., 2018). If recovery times are insufficient, there is a possibility that cascading effects could occur, given the critical role of PSL as a keystone prey species in the ecosystem.

Heatwave frequency and sand lance populations should continue to be monitored. Further research should include other datasets, such as a long-term zooplankton data set to better understand the sand lance's prey items during "the Blob". It would also be of interest to continue looking at the ages of these fish, through otolith dissection and analysis, to investigate if fish are getting longer or heavier younger in anticipating for a climatic challenge.

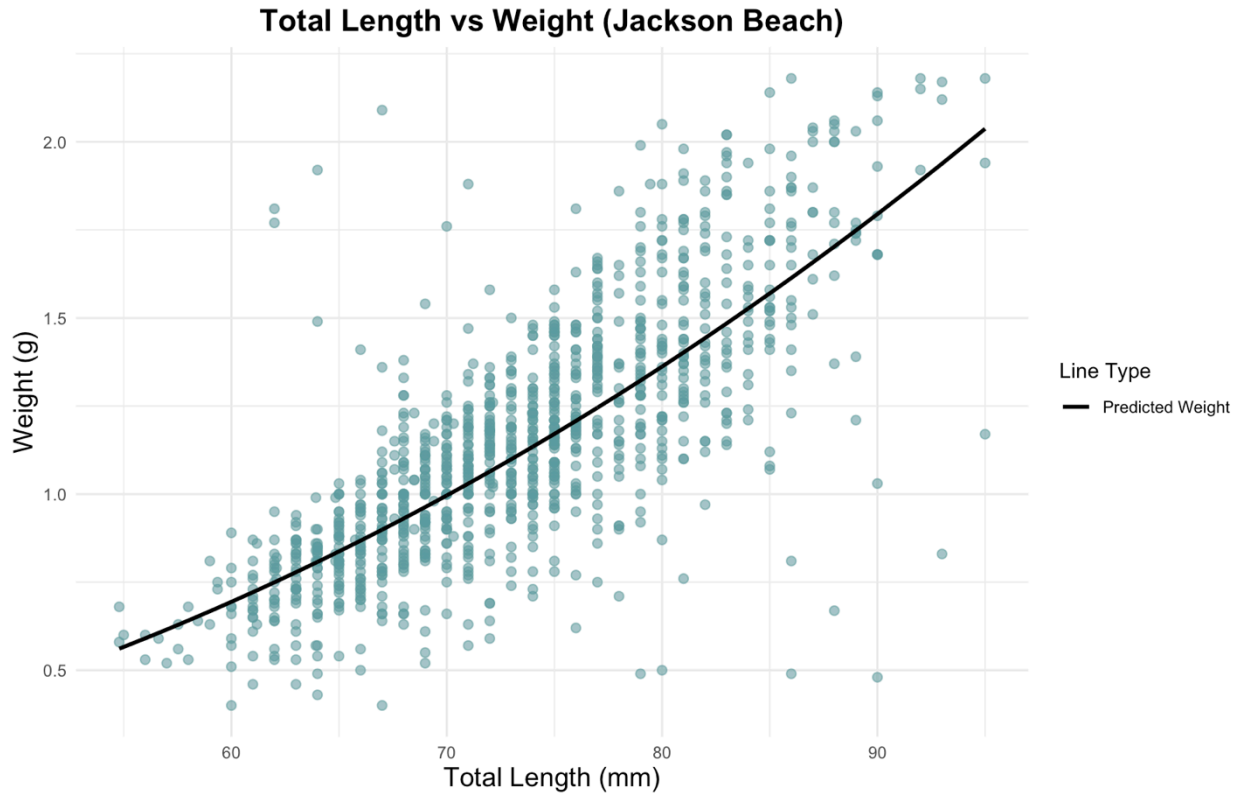
## Figures



**Figure 1:** Map of the San Juan Archipelago within the borders of Washington State, USA. Sample sites (North Station, Jackson Beach, and San Juan Channel) are labeled in different colors (Blue, Pink, and Red, respectively).



**Figure 2:** Total length of PSL (mm) compared to the weight (g) at San Juan Channel. Predicted weight is layered on as a black line.



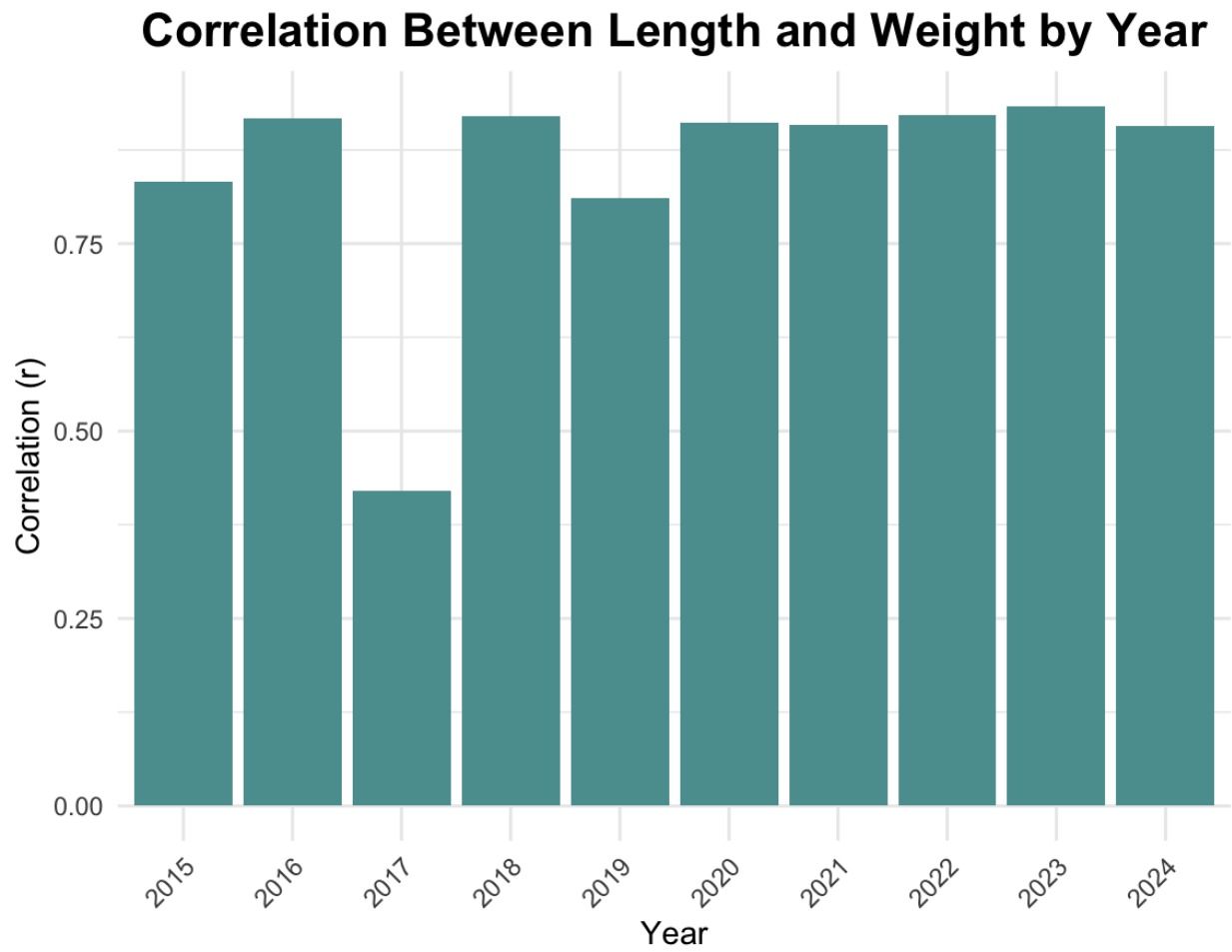
**Figure 3:** Total length of PSL (mm) compared to the weight (g) at Jackson Beach. Predicted weight is layered on as a black line.

**Figure 4:** Average morphometrics of Jackson Beach and San Juan Channel fish.

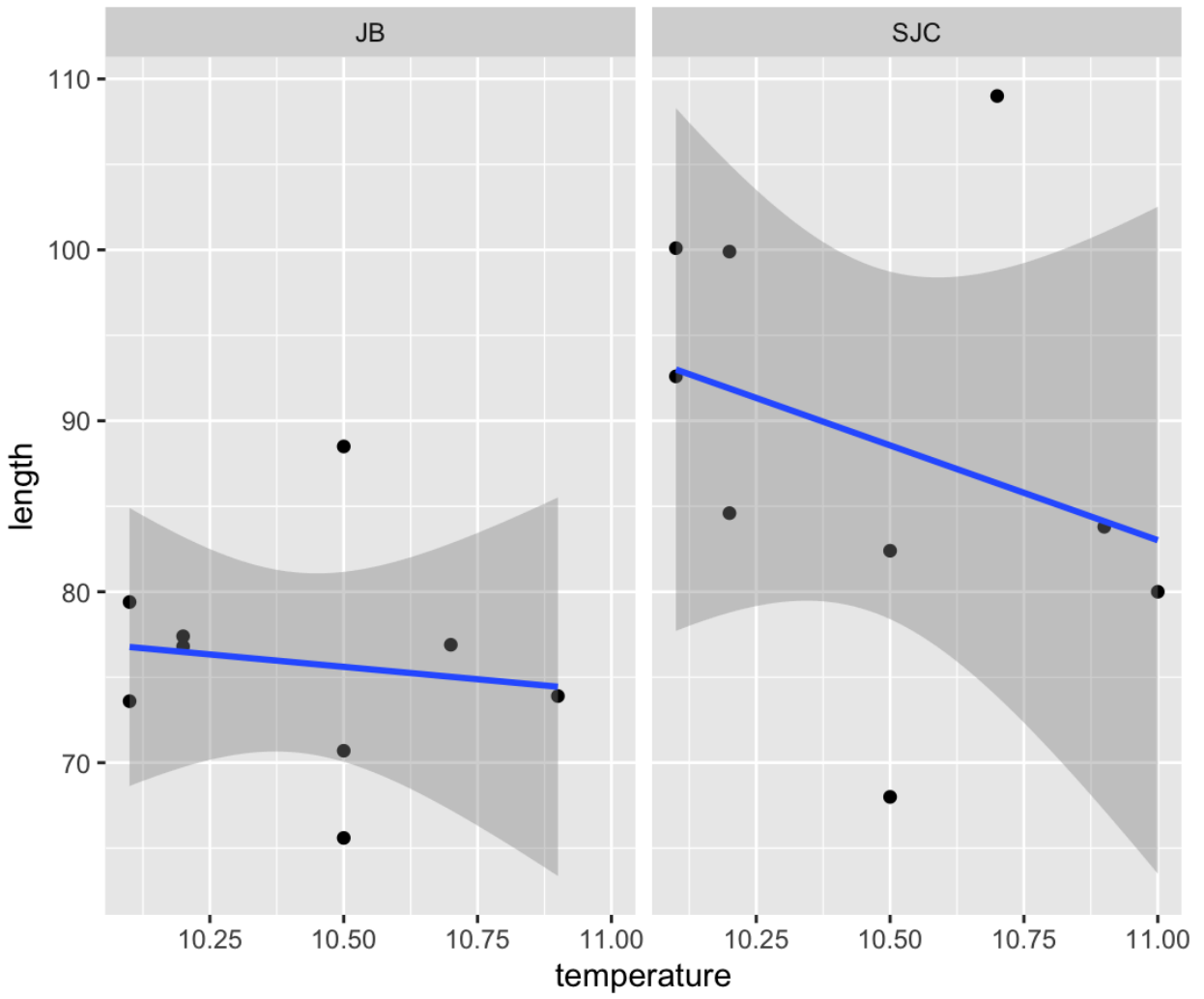
Site	Average Length	Average Weight
Jackson Beach	79.8 mm	1.68 g
San Juan Channel	83.4 mm	2.20 g

**Figure 5:** Table of sample size of sand lance (n), p value, and R<sup>2</sup> value from running a correlation on each year's relationship between length and weight of PSL (2015-2024).

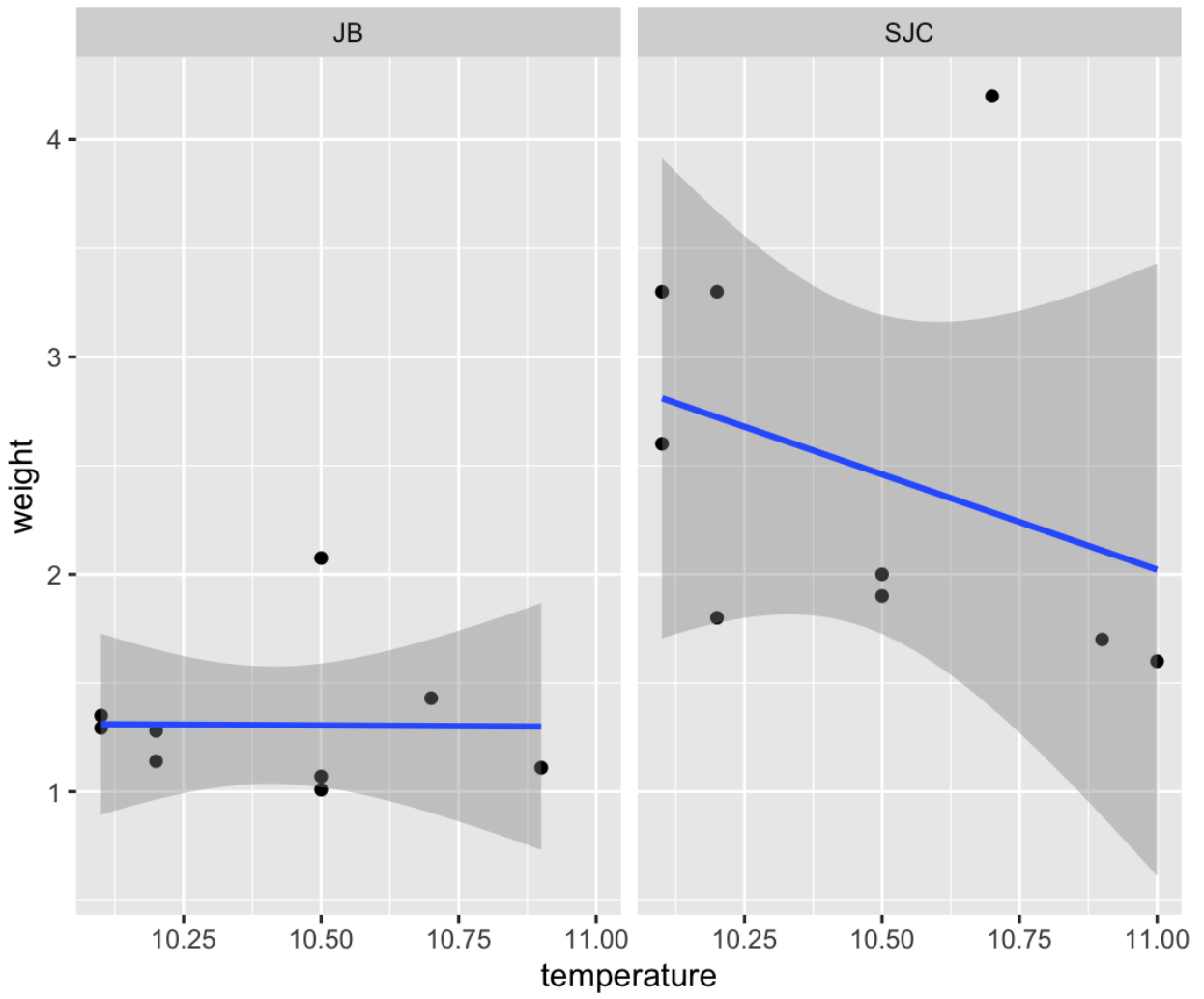
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
<b>N=</b>	1032	462	314	63	397	343	330	243	592	358
<b>P</b>	2.70e-266	2.76e-186	6.77e-15	1.90e-26	3.93e-126	2.05e-133	3.43e-126	8.47e-101	7.00e-265	5.23e-136
<b>R<sup>2</sup></b>	0.832	0.917	0.421	0.920	0.811	0.911	0.908	0.921	0.933	0.907



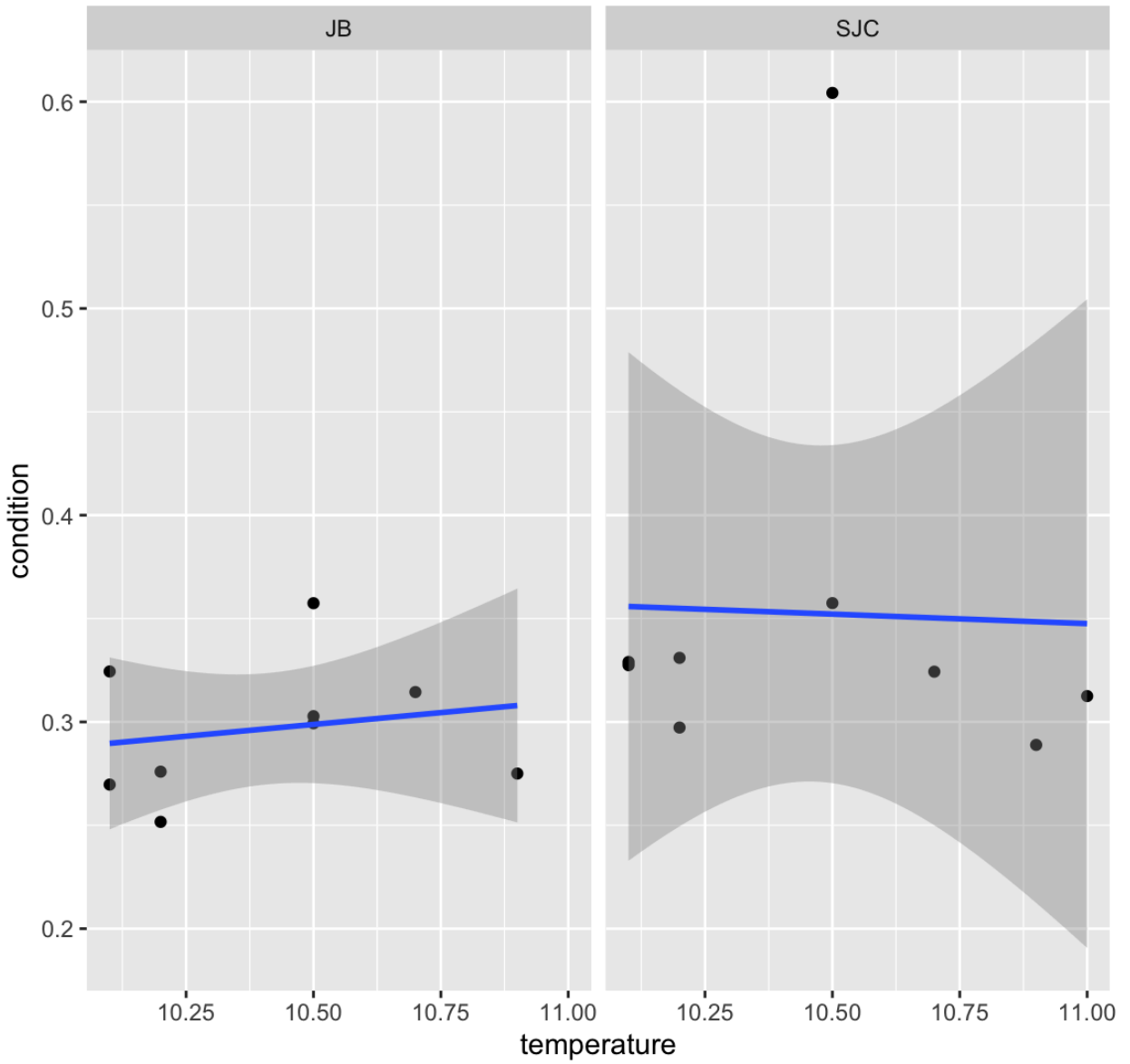
**Figure 6:**  $R^2$  values from a correlation of each year's length to weight (from 2015-2024).



**Figure 7:** Scatterplot of mean SST (C) to average length (mm) for 10 years with a blue trend line.

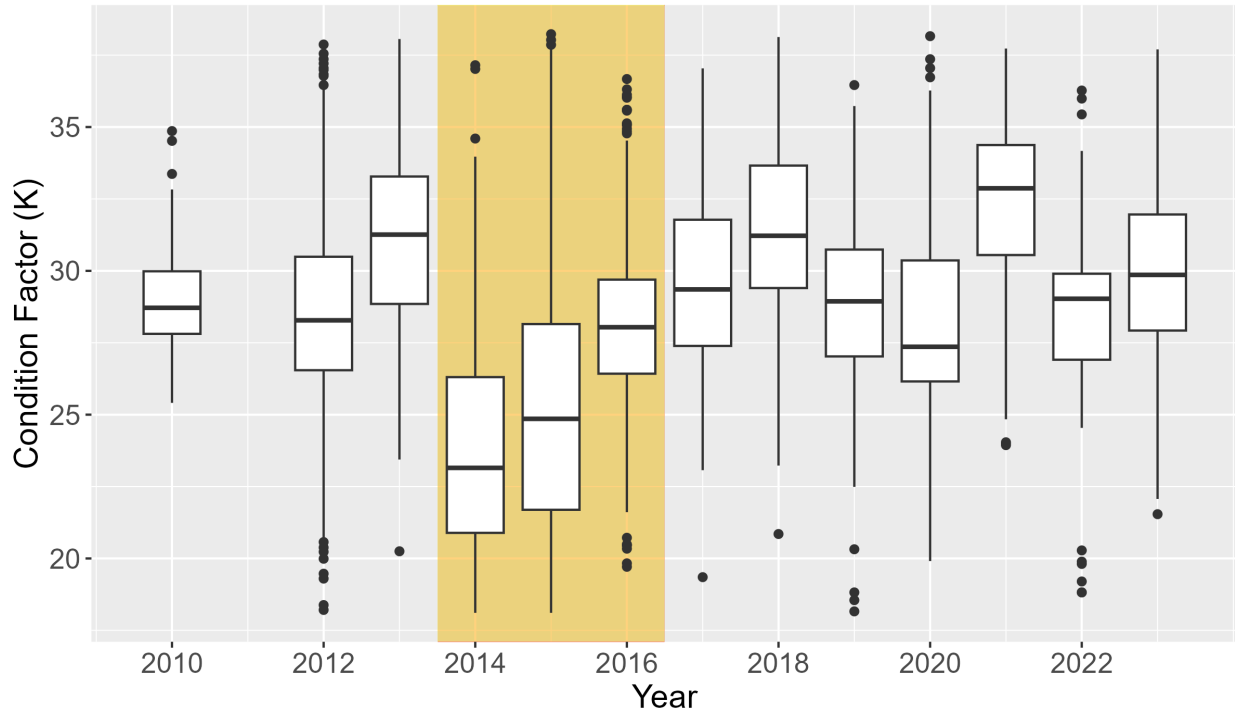


**Figure 8:** Scatterplot of mean SST (C) to average weight (g) for 10 years with a blue trend line.



**Figure 9:** Scatterplot of mean SST (C) to fish Condition (K) for 10 years with a blue trend line.

Condition of Pacific Sand Lance 2010-2023



**Figure 10:** Boxplot of fish condition factor over time from 2010-2023. The blob years are highlighted in yellow. This figure was created by Sarah Hensley in 2023.

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