Distribution and Variation between Populations of Pacific Sand Lance in the San Juan Archipelago

Charles Paul Heller

cph9@u.washington.edu

12/9/2012

Keywords: Pacific Sand Lance, Condition Factor, Young-of-Year, Migration Between Populations

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Abstract

In the San Juan Islands, the immediate trophic levels of the marine food web represent a critical link that is largely constituted by forage fish, including the Pacific Sand Lance. This document contains the results of an in-depth study of the morphological and conditional differences between Pacific Sand Lance populations at different depths. Beach seines were used to retrieve fish from shallow water (Jackson Beach), and Van Veen grabs were used to sample from deep water (the San Juan channel wave field). The fish observed at the wave field were larger and heavier than those at Jackson Beach, both across the season and on a discrete, week-by-week scale. There was a slight disparity in hibernation periods between depth populations. In the wave field, most of the fish at that site began hibernating during the second half of October as interpreted from the stomach fullness of fish. In contrast, the majority of the fish at Jackson Beach began hibernating two weeks earlier, during the first half of October. Finally, the dietary analyses of both sites suggested multiple hypotheses of life histories, including that the Pacific Sand Lance are selective feeders, and that their preferences vary with age.

Introduction

In the San Juan Islands, the immediate trophic levels of the marine food web represent a critical link. This level is predominately represented by the surf smelt (*Hypomesus pretiosus*), the Pacific herring (*Clupea pallasi*), the Pacific sardine (*Sardinops sagax*), the northern anchovy (*Engraulis mordax*) and Pacific sand lance (*Ammodytes hexapterus*). This focus of this study centered on the Pacific Sand Lance, due partially to their abundance and reflexive ease of study, but more importantly, due to the surprising lack of analysis done on them to date.

The Sand Lance is a small, sardine-sized fish with genera widely distributed across the coastlines of the northern Pacific Ocean, from Southern California to the seas of Japan (Bargman 1999). The specific species studied, the Pacific Sand Lance (*Ammodytes hexapterus*) is commonly found on the western coast of North America, particularly in the San Juan Islands, which is our study site. As of this writing, a recent CPUE calculation put the estimate of the Salish Sea population alone at roughly 109 million members. Additional behavioral patterns include characteristically being found in relatively shallow waters and a wide variety of substrates (Robards *et al.* 1999a); daily feeding migration between their substrate and the water column (Blaine 2006; Clayman 2001; Quinn 1999; Robards *et al.* 1999a), and a winter hibernation period that is loosely dependent on the fall transition, during which time they do not leave the substrate (Quinn 1999; Robards *et al.* 1999a).

The reason the Pacific Sand lance is a vital component of its marine ecosystem's food web can be primarily attributed to their size: they are well proportioned to hunt macro-zooplankton and other primary marine consumers, and are good prey items for larger predators like tuna, salmon, and marine birds. Additionally, as previously mentioned, they are one of a small handful of fish species occupying this trophic level in the San Juan Channel. These aspects, combined with their extreme abundance, denote the Pacific Sand Lance as one of the most important species to the marine ecology of the San Juan Archipelago. They are important as an indicator of ecosystem health, and are an integral component of marine food webs in this region. For these reasons, doing an in-depth study of this particular species represents an opportunity to develop a reasonable indicator of the marine environment's overall health.

In spite of this, the dietary habits and feeding behaviors of the Pacific Sand Lance in the Puget Sound area have gone widely unstudied. More careful inspection of multiple populations' feeding habits will provide increased comprehension of the food web interactions they are involved in, and how specific environmental variations do and will affect them, as well as provide a better understanding of their life histories, and how these affect their prey-predator relationships. The specific goals of my study were to: 1) Compare morphological metrics of different populations of Pacific Sand Lance at two different depths in the San Juan Islands; and 2) comprehensively study the dietary habits of these two populations over time, with specific emphases on variation in prey species (species diversity of stomach contents), and consumption patterns (stomach fullness), with the intent of determining the approximate period at which both populations entered their winter hibernation phases.

Methods: Sampling and Measuring

Two areas of study were chosen for deep- and shallow-water comparisons: the San Juan Wave Channel for the former, and Jackson Beach for the latter (Fig. 1). Sand Lance were sampled via beach seines from Jackson Beach and Van Veen drops from the San Juan Wave Channel, respectively. Van Veen drops were performed from the R/V Centennial between 12:00 and 15:00, and on a smaller skiff between 07:00-09:00 and 18:00-22:00. For each Centennial cruise, the Van Veen was dropped twice at each location, between 4 to 10 times, depending on the limitations of that particular day. The drops made from the smaller skiff were performed in a similar fashion. Beach seines occurred roughly once every two weeks, using a net made of knotless nylon mesh and measured 36.6m long by 3.7m deep. Seines were conducted by tying two ropes to either end of the net, keeping the end of one rope on shore and taking the other rope and the net in a rowboat out until the first rope had been fully extended. The net was then splayed out parallel to the shore, and when the net was fully deployed, both ropes were simultaneously hauled in. All Sand Lance collected via these methods during this study period were humanely euthanized using tricaine methanesulfonate (MS-222), then immersed in no less than 0.75 fl. oz. of formalin, as well as as much sea water as necessary to cover the specimens. All non-target organisms were released.

The fish were measured by fork length, and dry-weighed to the nearest 0.01 gram. Approximate age and condition factor were calculated for each fish from their length and weight. Condition factor was calculated using the formula K' = (weight*10^7)/($length^3$), where weight is measured in grams and length in millimeters (Robards et al. 1999). As for age, all fish shorter than 70mm were assumed to be young of year; all longer fish were assumed to be one year old, or older (Wyllie-Echeverria 2010, unpublished data). To examine stomach contents, ten fish from each collection date were selected: five young-of-year, and five one-year-olds or older. In the cases where a specific sample date didn't contain at least ten fish, all fish were examined. The stomach was removed, and its contents were examined and recorded. Fullness and degree of digestion were also recorded for each stomach, both on a scale from zero (empty / undigested) to four (full / completely digested).

Results & Discussion

1. Morphological Statistics

A cumulative total of 1,896 fish were sampled cumulatively between the dates of 9/28/2012 and 11/14/2012, of which 1,031 were taken from the Wave Field and 865 from Jackson Beach. For both populations, statistical age distribution and fork length data correlated with previous research on *A. hexapterus* in similar environments during this time of year (Johnson 2008; Blaine 2006).

The mean fork length for the wave field and Jackson Beach populations were 79.93 mm, and 66.84 mm respectively; the mean mass for the wave field and Jackson Beach populations were 1.64 g and 0.89 ± g respectively. It is important to note that the above values are the mean morphometric statistics for both populations independent of seasonal changes, tidal cycles, or time of day (Fig. 2). The mean approximate ages were 0.96 years old for the wave field population, and 0.34 years old for Jackson Beach.

Both mean fork length and weight for the wave field population were pointedly larger than that of Jackson Beach, and the large sample sizes of both populations allow us to state that the differences are statistically significant (for both length and weight, $p < 0.001$). This trend supports the belief that young-of-year fish prefer more shallow habitats than adults (Robards et al. 1999). Additional evidence stems from the distribution of outliers for fork length and weight: 45.39% of fish collected from the wave field were too long to be classified as YOY (>70mm); in contrast, this was true for only 6.59% of the Jackson Beach fish. This implies that larger, older fish generally prefer deeper water. However, it's important to bear in mind that the age determinations are only approximations, and as such, it would be rash to rule out the possibility that fish longer than 79 mm could be young-of-year, and, conversely, that there could be especially short 1 year old fish.

The calculated values for mean condition factor are 30.87 in the wave field, and 28.66 at Jackson Beach. Despite the aforementioned disparities in morphometrics between the two populations, the difference between their mean condition factor values was relatively small, especially when considering the large range of values exhibited in individuals from both sites. However, condition factor for individuals should visibly decrease across the winter months due to their hibernation, since their mass decreases substantially during their period of dormancy (Robards et al. 1999a). Because of this, the above method of viewing the data for condition factor may be too simplistic. 98% of the Jackson Beach sample population were collected very early in the study period (10/02, 848 fish). This probably caused the observed mean condition factor to be higher than it should have been, according to previous research that showed a decline in condition factor for all sand lance during the last few months of the year (Robards et al. 1999).

Of important note is the confounding aspect of our sampling methods- specifically, the disparity between Van Veen drops and beach seining. Seining only selects for fish that are currently in the water column; while the net does have a lead line that drags along the sediment at the bottom, it would not have dug beneath it. The Van Veen, on the other hand, only selects for fish that are currently burrowed in the sediment. Any sand lance that were currently feeding or otherwise active in the water column in the wave field went completely undocumented in this study, in the same way that the seine net would have missed any individuals that were beneath at the time of sampling.

2. Variation in morphometric statistics over time

The mean values for all morphometric data observed for fish sampled from the wave field showed marked reduction between 9/27 and 11/15 (Fig. 3). Although the downward trend in mean fork length over time is loosely correlated and not very strong ($R^2 = 0.21$, $p < 0.01$), if this trend was due to something other than the nature of random sampling, it could be that the YOY fish from shallow water populations recruited to deeper water during first few weeks of the study period, which decreased the mean length observed in the wave field as time passed (Fig. 4). Additionally, there was a continuously increasing trend in CPUE over the season for the wave field, with the greatest slope occurring during the beginning of the study period (Catch per Unit Effort is an approximation of how many individuals are contained within a particular population). These two trends work in concert as evidence that the YOY populations started recruiting to the wave field: presumably, young-of-year migrated to the wave field. This would account for mean fork length decreases and increase CPUE over time.

3. Hibernation study

Mean mass also decreased over time in the wave field, and variations of data points from the trendline coincide well with those observed in fork length. In contrast, mean condition factor per week did not match our expectations as previously discussed, as data points for various weeks correlated poorly with the trendline for the data (R^2=0.10, $p < 0.01$); moreover, the overall trend for the season was decreasing, but only gently so ($m = -0.16$). This was atypical, as past research has demonstrated that a statistically significant decreasing trend is found during this time, clearly indicating hibernation has begun (Robards et al. 1999a). In light of this, inferences were not extracted from this data for when hibernation commenced. Instead, hibernation dates were inferred from the number of fish caught per sampling date for Jackson Beach, and from stomach fullness ratios (Fig. 5) for the wave field population.

On a whole, the proportion of empty fish to total fish sampled increased over time for both populations. More than 50% of the fish sampled from the wave field were empty on a weekly basis. Although there is an overarching increasing trend in the proportion of empty stomachs observed per week, the sharpest increase occurred between weeks 4 and 5 (October 24-31), which stands to reason that this was the period during which hibernation really took off. If the proportions of empty stomachs in the sample population correlated with those in the wave field during this time, then more sand lance began to hibernate during these two weeks than any other during the study period. In contrast, the guts of the Jackson Beach fish went from all full to all empty in the span of four weeks; however, due to the sampling limitations inherent with seining at Jackson Beach, the hibernation commencement period for this population was determined using the CPUE for seining.

4. Temporal Dietary Analyses: Prey Species' Variation and Abundance

In the first week (Fig. 6), only four of thirteen fish's stomach contents examined indicated that they had been feeding in the wave field. The diets of those four primarily consisted of Calanoid copepods. At Jackson Beach, all ten of the fish dissected from that same week were actively feeding and had highly diverse diets, primarily consisting of polychaete worms. In the second week (Fig. 7), seven of the eight fish sampled from the wave field were empty, and the eighth's contents were too well digested to identify. At Jackson Beach, a high species diversity was observed in the stomach contents again, but much less than what was observed from week one (37 individuals vs. 610); additionally, only 3 of the 7 fish sampled during this time were feeding. In the third week (Fig. 8), eight of the eighteen fish sampled from the wave field were actively feeding. Those eight were observed to have a similar species distribution and fullness to those of the wave field from the first week. The two fish caught at Jackson Beach during this week were both empty. In the fourth week (Fig 9), two of the twenty-one fish sampled from the wave field were actively feeding; however, those two were nearly empty, and had equal numbers of amphipods and unidentifiable copepods. The three fish caught at Jackson Beach during this week were all empty.

The variety and proportions of the zooplankton species observed in both populations' guts loosely correspond to those present at the sample sites. However, there are certain anomalies; for example, only the shallow water population had consumed polychaete worms, although they were observed in the zooplankton counts in the wave field as well (data not shown). It is therefore possible to infer that *A. hexapterus* not only selectively feeds, but that their preferences might also change as they age. However, it's also possible that these fish are simply eating what's most available to them; Calanoid copepods make up a substantial portion of the zooplankton found pelagically in the wave field. As for the young-of-year, one of the consequences of their habitat being so shallow is that there is not much distance between the benthic and pelagic environments. It's possible that this causes the Jackson Beach fish to feed on a higher proportion of zooplankton that are traditionally found benthically, regardless of the depth at which they prefer to feed.

Conclusions

On a whole, the fish observed at the wave field were larger and heavier than the ones at Jackson Beach, both across the season and on weekly scale. This correlates with reported data for populations farther north (Johnson et al. 2008). There was a slight disparity in the predicted hibernation periods between shallow and deep populations: in the wave field, most of the fish at that site began hibernating during the second half of October as interpreted from the stomach fullness of fish. In contrast, the majority of the fish at Jackson Beach began hibernating two weeks earlier, during the first half of October. Finally, the dietary analyses of both sites suggested that the Pacific Sand Lance are selective feeders, and that their preferences may vary with age; further study is required to confirm this hypothesis.

Acknowledgements

I would like to thank the professors directly involved in this apprenticeship- W. Breck Tyler, Jan Newton, and Matt Baker, and our teaching assistant, Ryan McLaughlin, for their time and guidance. I would also like to thank all of my fellow classmates, with special shout-outs to Annie Thompson, Nicholas Sisson, and Todd Sigley for offering data and support. Additionally, I would like to thank Dennis Willows and Woolf Krieger, whose help on the R/V Centennial was invaluable. I would also like to thank Phil Green, Gary Greene, Loren Tuttle, Julie Keister, Craig Staude, Alan Cairns, David Duggins, Jeannie Meredith, Kristy Kull, Pema Kitaeff, Maureen Nolan, and the entire FHL Staff. Finally, I'd like to thank the Friday Harbor Laboratories, the University of Washington, UW Provost, and Henry & Holly Wendt for providing this amazing learning experience.

References

Bargmann, G. 1998. Forage Fish Management Plan. Washington Department of Fish and Wildlife. Olympia, WA.

Blaine, J. 2006. Pacific sand lance (Ammodytes hexapterus) present in the sandwave field of central San JuanChannel, WA: Abundance, density, maturity, and sediment association. Friday Harbor Laboratories, WA.

Clayman, S. 2001. Light intensity as an environmental cue for the burial and emergence behavior of the Pacific sandlance,Ammodytes hexapterus. Friday Harbor Laboratories, WA.

Johnson, S. W., J. F. Thedinga and K. M. Munk. 2008. Distribution and Use of Shallow-Water Habitats by Pacific Sand Lances in Southeastern Alaska. Transactions of the American Fisheries Society.

Quinn, T. 1999. Habitat characteristics of an intertidal aggregation of Pacific sandlance (Ammodytes hexapterus) at a North Puget Sound Beach in Washington. Northwest Science.

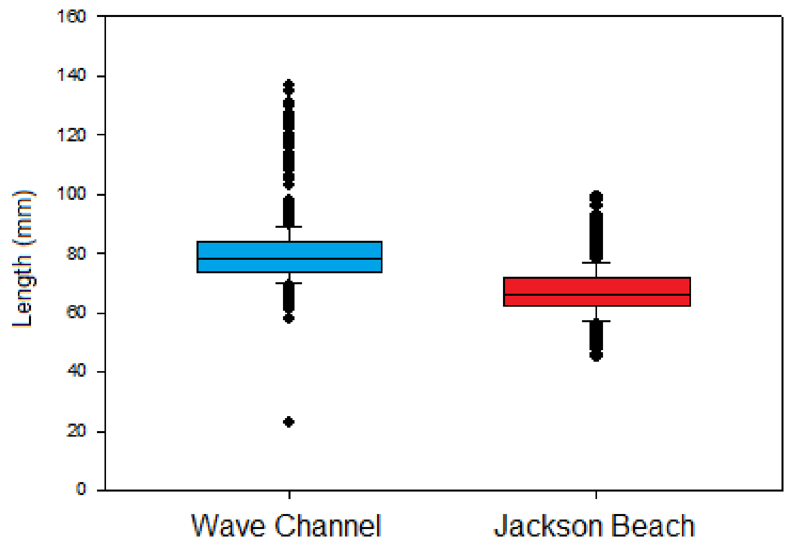
Robards, M. D. and J. F. Piatt. 1999a. Biology of the genus Ammodytes, the sand lances. Usda Forest Service Pacific Northwest Research Station Research Paper.

Robards, M. D., J. F. Piatt and G. A. Rose. 1999b. Maturation, fecundity, and intertidal spawning of Pacific sand lance in the northern Gulf of Alaska. Journal of Fish Biology.

Wyllie-Echeverria, T. 2010. *Unpublished data*.

Figure 1. Map of the geographic locations of the involved study sites in the San Juan Channel.

Mean Length



Mean Weight

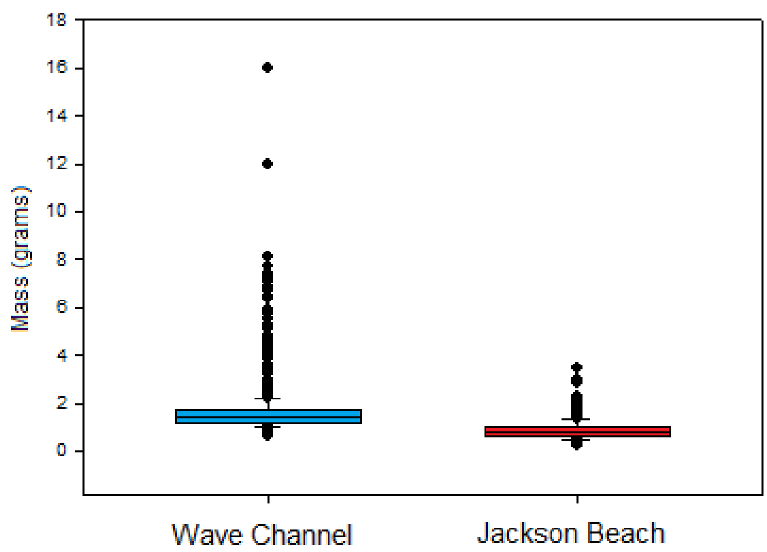
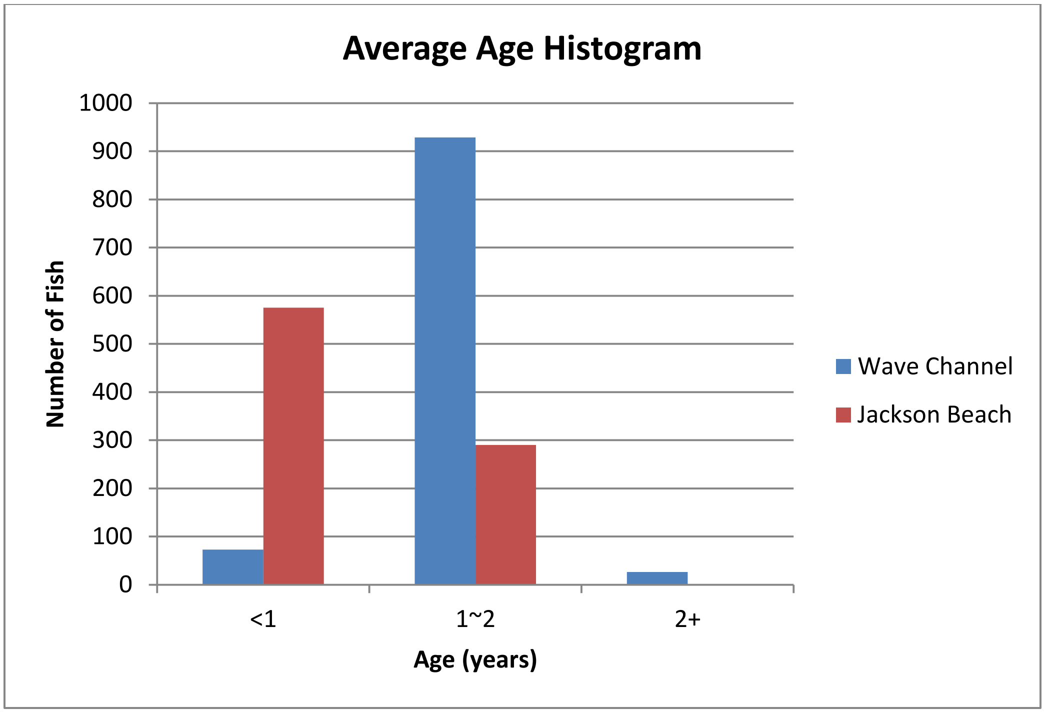


Figure 2. Side-by-side comparisons of box plots for length (mm) and mass (g); stats displayed here are independent of time.



Length (mm)	0-69	70-110	111-130	131-150	>150
Age (years)	0	1	2	3	4

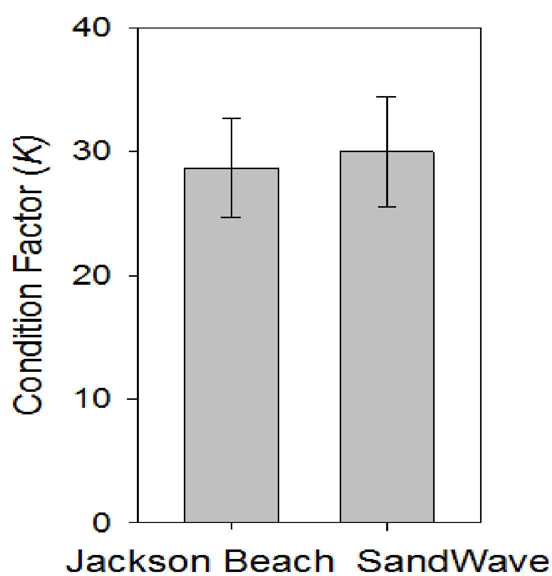


Figure 2 (cont). Side-by-side comparisons of age approximation data and mean condition factor; stats displayed here are independent of time.

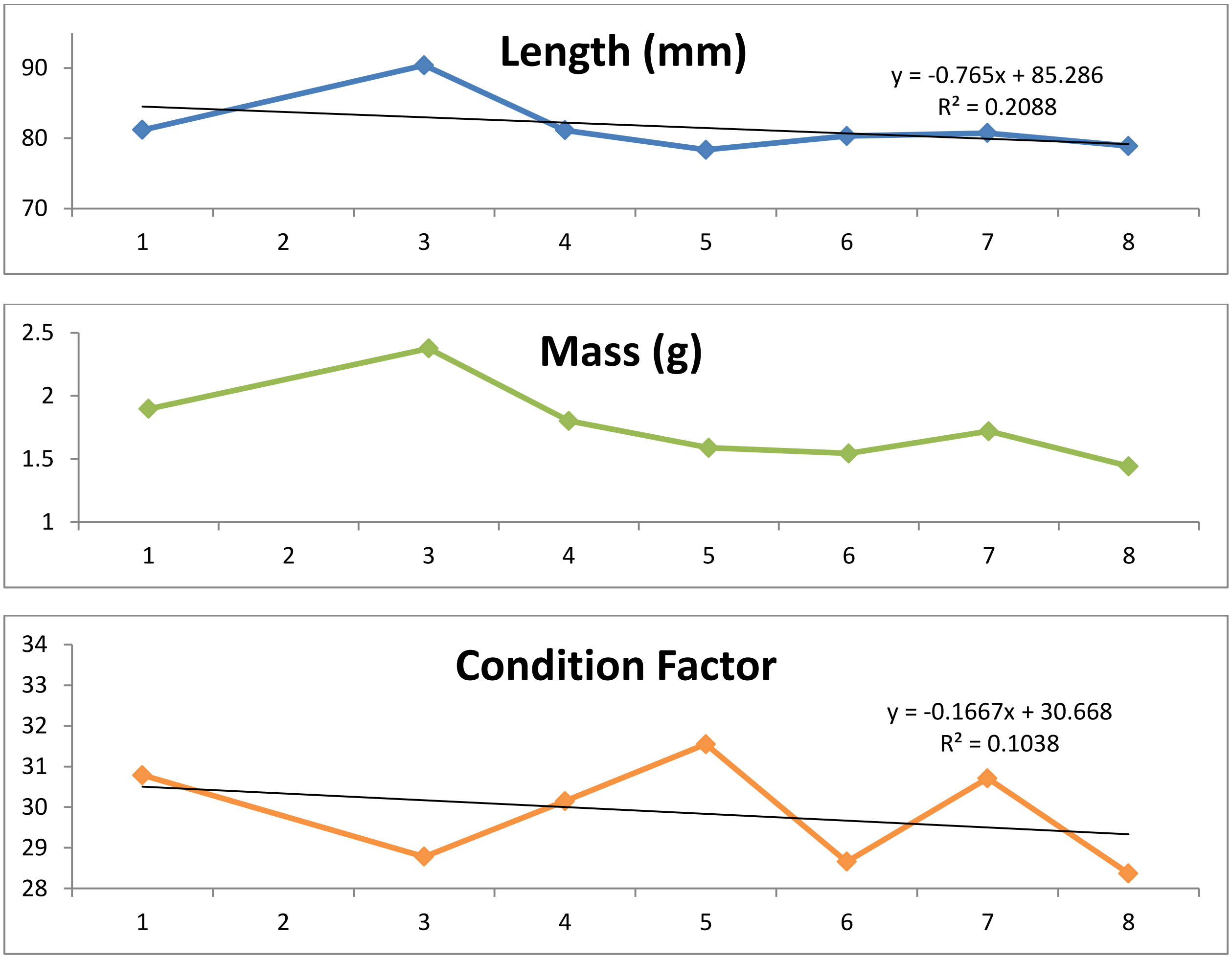
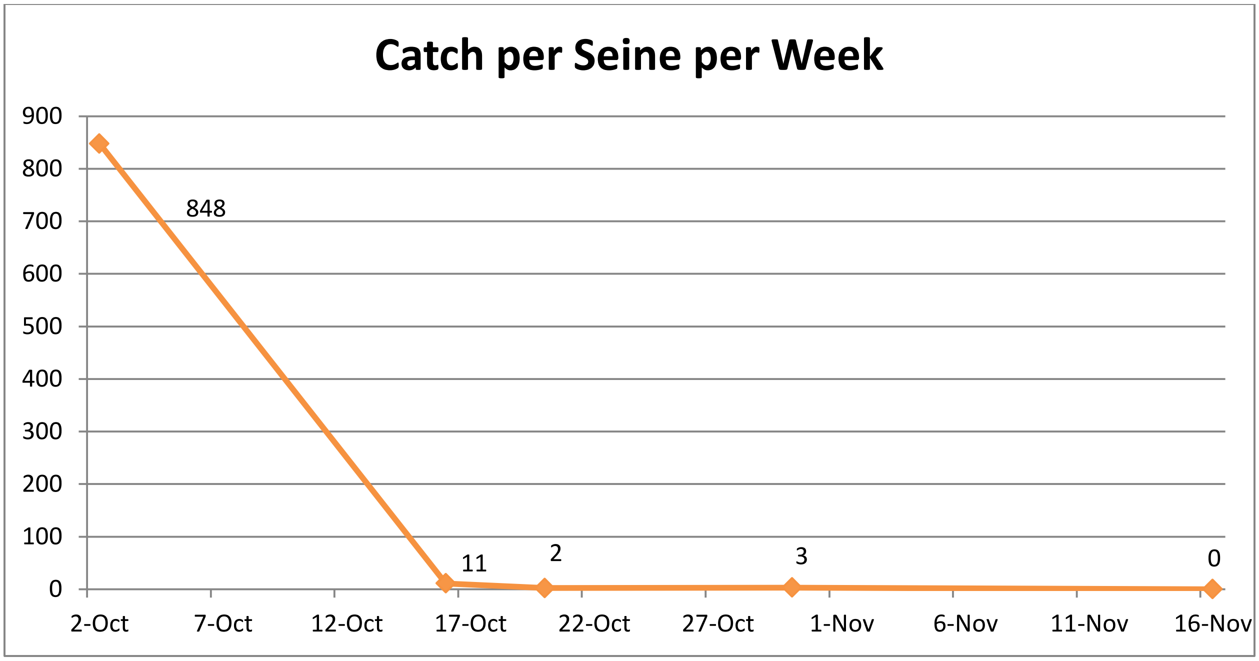


Figure 3. Mean statistics for length, mass, and condition factor for the wave field per week. Week 1 started on 9/26/2012; week 8 ended on 11/21/2012.



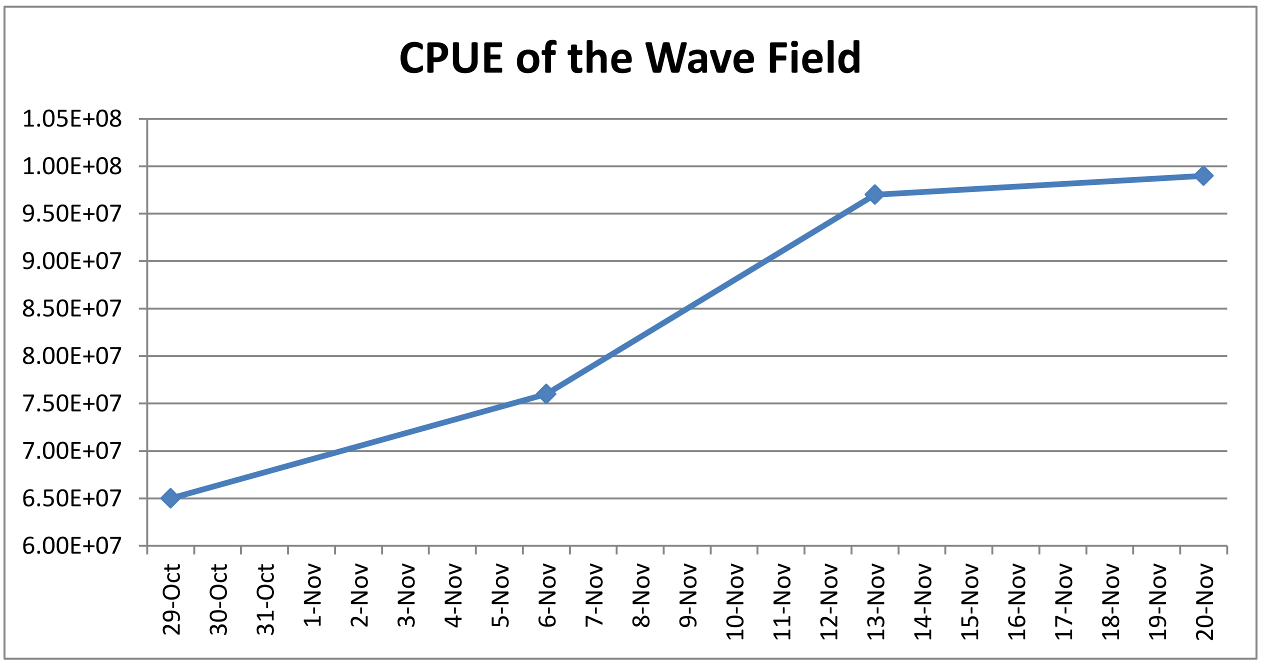
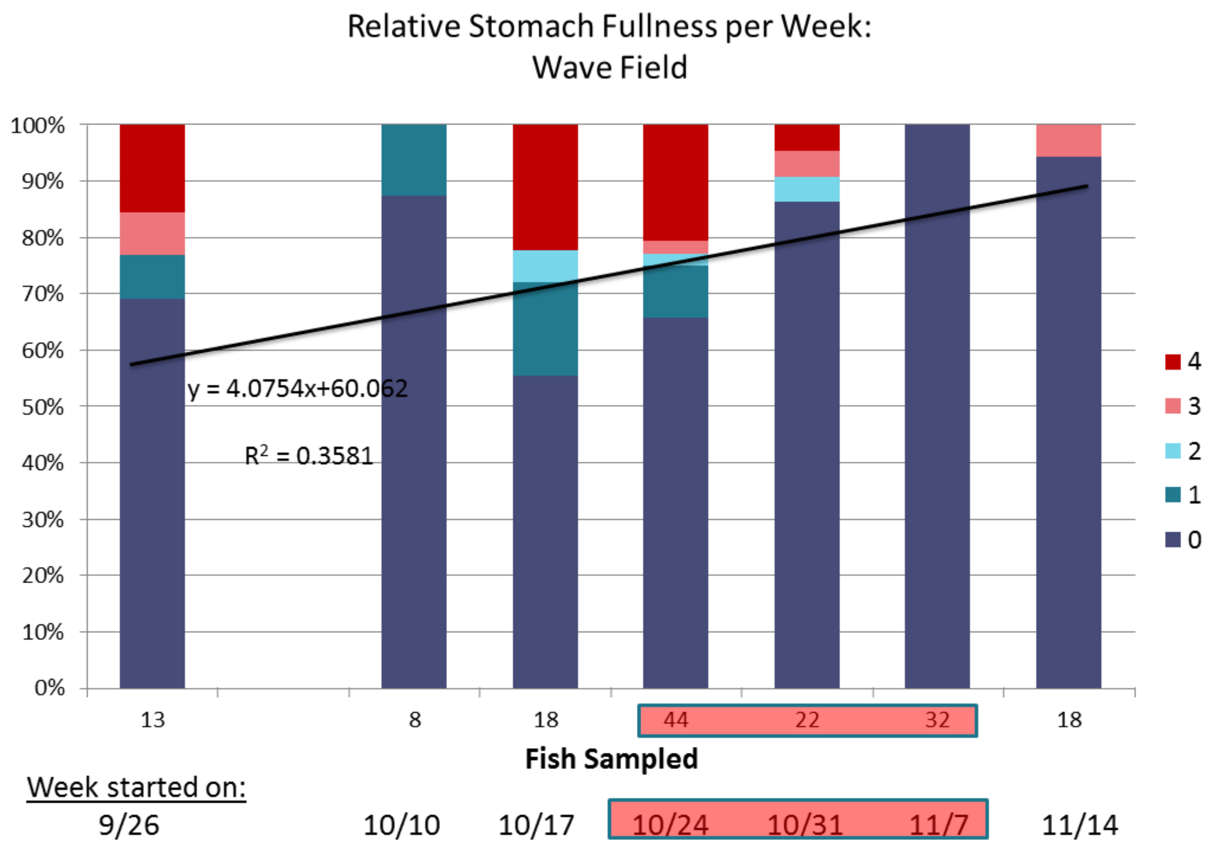


Figure 4. Catch number per sampling date at Jackson Beach, paired alongside a sample of the catch per unit effort values for the wave field. These contrasting trends imply that Sand Lance in shallow water populations were recruiting to deeper water as the season progressed.



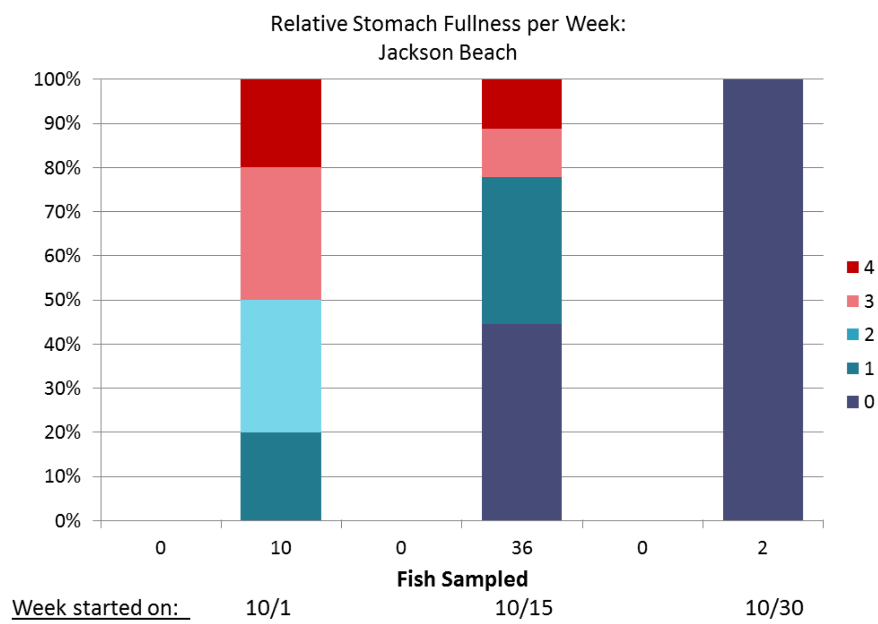
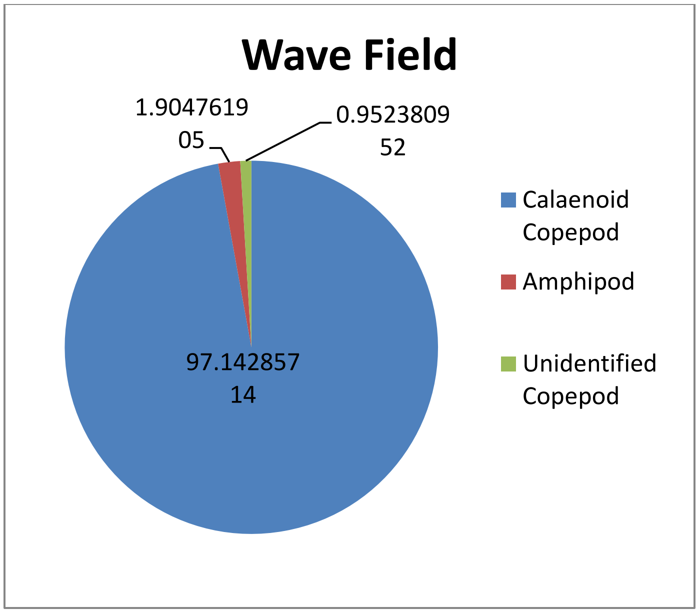


Figure 5. Stomach fullness ratios of fish sampled per week from Wave Channel and Jackson Beach. Values range from zero (empty) to four (full). Week 1 started on 9/26/2012; week 6 ended on 11/6/2012.



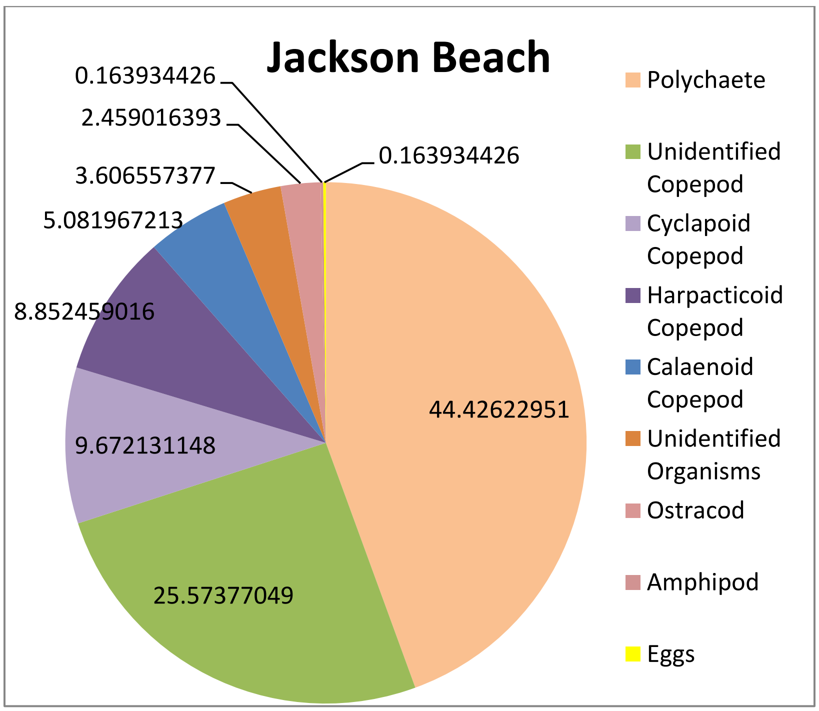


Figure 6. Side-by-side comparisons of relative abundances of prey species discovered in sand lance stomachs sampled between 9/26/2012 and 10/9/2012.

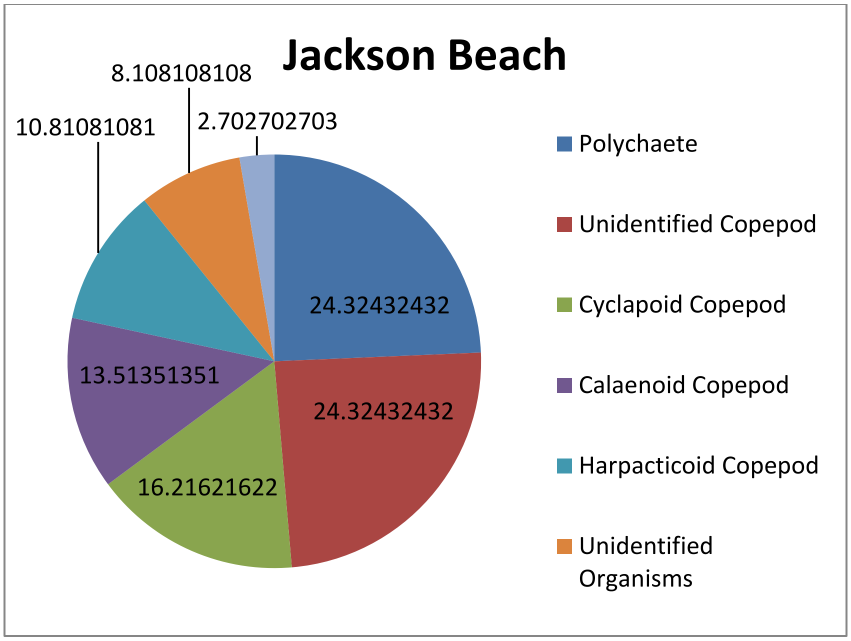


Figure 7. Relative abundances of prey species discovered in sand lance stomachs sampled between 10/10/2012 and 10/16/2012. Wave field data not shown for this period due to lack of diversity.

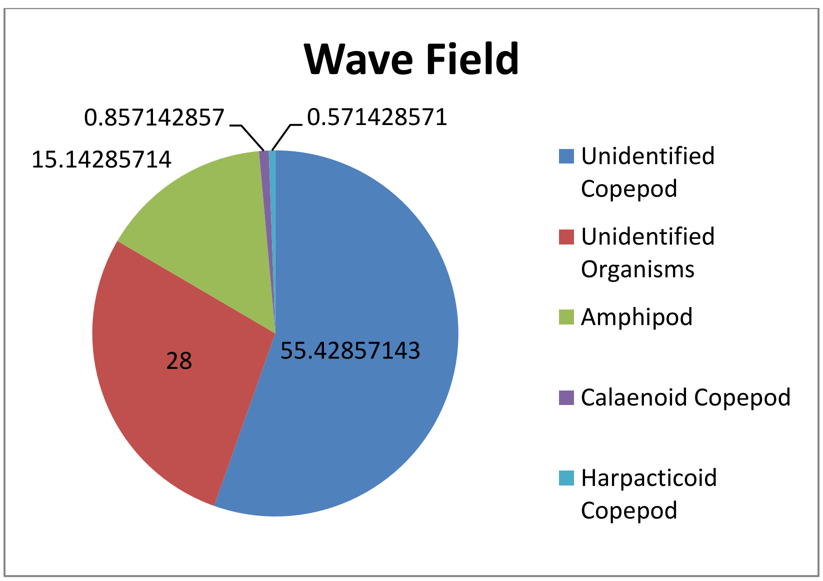


Figure 8. Relative abundances of prey species discovered in sand lance stomachs sampled between 10/17/2012 and 10/23/2012. Jackson Beach data not shown for this period due to lack of abundance.

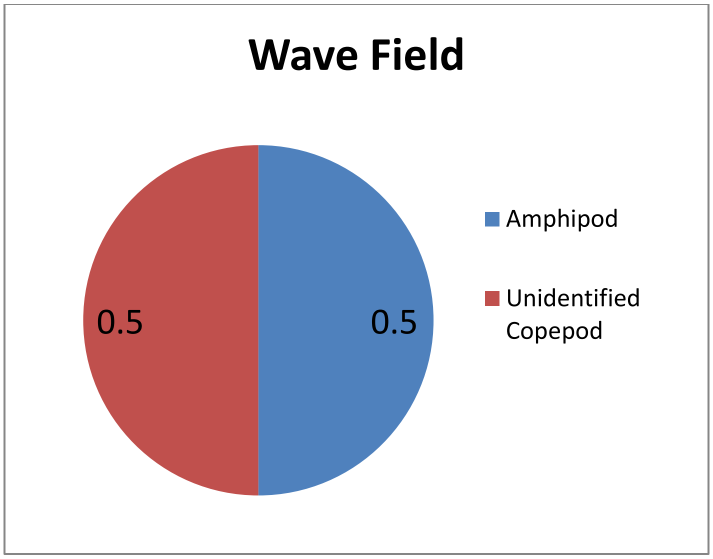


Figure 9. Relative abundances of prey species discovered in sand lance stomachs sampled between 10/24/2012 and 11/1/2012. Jackson Beach data not shown for this period due to lack of abundance.