CRFL Final Report

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Project Title: Investigating salinity fluxes on natural and restored shell bottom habitat to better predict disturbance effects driven by climate change.

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Budget:

Category	Expenditures
Personnel	145,574.22
Fringe	23,309.39
Freight	12.57
Supplies	19,718.87
Misc Services	1,577.52
Tuition	6,257.25
Total Direct	196,449.82
Indirect	29,467.49
Total	225,917.31
Remaining Balance	45.59

Introduction:

The integration of "*resiliency"* into coastal habitat management plans has become commonplace in coastal states. The 2010 NC Coastal Habitat Protection Plan identified the goal to "*develop coordinated policies that include management adaptation and guidelines to increase resiliency of fish habitat to climate change"* (Deaton et al. 2010). It is increasingly important to acknowledge environmental change and the range of impacts that may result from environmental change, as well investigate potential adaptive management solutions that can maximize resiliency of dynamic coastal habitats.

Ecological resilience is traditionally understood as the capacity of an ecosystem to respond and recover from disturbance events (Cote and Darling 2010). For shell bottom habitats in naturally variable estuarine systems, Freshwater Inflow Events (FWIs) or freshets, may pose the gravest climate-related disturbances. Increased precipitation and storm intensity will alter seasonal salinity fluxes and stress shell bottom-associated species, some to tolerance limits. We know much about how valued recreationally-fished species utilize North Carolina's shell bottoms during life histories (Table 1). It is the community of resident, non-commercial, and less

motile species, however, upon which desirable finfishes and crustaceans rely as a resource base that will suffer more stress (i.e. reduced growth rates and reproduction) and mortality from FWIs. We know little about the diversity of these species assemblages, but science overwhelmingly suggests that a robust diversity of faunal species enhances the overall resilience of oyster reefs (Elmquist et al. 2003, Stachowitz et al. 2007). There is an acute need to assess and monitor the current faunal diversity of habitat areas across the estuarine environment. To fulfill new resiliency mandates, NC managers deserve a more informed perspective of how oyster-associated assemblages interact with salinity under normal and extreme conditions.

Dr. Harry Wells of the Duke University Marine Laboratory first described the tremendous diversity of North Carolina's shell bottoms over 50 years ago. Wells recorded 284 species from five oyster reef areas across the estuary's salinity gradient (18.90-31.77 ppt annual means) over an 18-month sampling effort in the Newport River (Wells 1961). More importantly, Wells' survey was the first to propose that oyster associated faunal assemblages correlate most strongly with position along a salinity gradient. In other words, localized salinity averages and fluxes determine the upstream limits of faunal species. We now know that habitat patches along a gradient will recruit and retain distinct communities (i.e. algae dominant, clam rich, predator diversity) best suited for their relative position along that gradient (Tolley et al. 2006, Pollack et al. 2011). In order to predict climate-effects, we need to understand how within patch and among patch faunal diversity can diffuse stress across the estuary. Findings from terrestrial ecology suggest that high faunal diversity increases overall resilience to stress, but no one has yet tested these theories for oyster-reef communities in response to freshets (Tilman and Downing 1994, Hughes and Stachowitz 2004, Stachowitz et al. 2007). The productivity of commercial fisheries is directly related to the productivity of their prey, which accounts for most of the shell bottom mollusks, worms, and other small organisms at the center of these questions.

The ecological significance of faunal diversity has been ignored by popular shell bottom management strategies. Having long excluded affiliated fauna in monitoring protocol, managers have little reference data, and few baselines, to make reliable predictions of the type of standing diversity we should expect given certain environmental conditions. For example, the NC Division of Marine Fisheries typically uses spat/clutch ratios, average oyster length, and total numbers as key habitat indicators. To assess resiliency potential across a landscape, we suggest to compliment these data with community level information.

Our new dataset also addresses the lack of spatiotemporal oyster community data by leveraging Wells' original data to reassess the state of oyster-associated communities in the Newport River. Wells' historical baseline of faunal diversity offers a rare opportunity to document if and how communities in comparable salinity regimes have changed over 50 years. No more than ten scientific studies have sampled faunal groups associated with eastern oyster, three of which (Myers and Townsend 2000, Lenihan et al. 2001, Grabowski et al. 2005) were conducted in Carteret County. While these studies are useful qualitative comparisons to our dataset, they exclude certain important functional feeding groups, such as suspension feeders. This ignores organisms within the oyster habitat that contribute to trophic complexity, which as been known to increase fish biomass production (Sherwood et al. 2002). Of concern, previous studies have limited study areas to single biophysical environments and confined measuring environmental variables to field visits.

A better understanding of habitat trajectories can be achieved when comparisons span longer time scales (i.e. fifty years), encompass spatial reaches of salinity, and integrate continuous *in-situ* environmental variables (i.e. salinity, temperature) (Sagarin et al. 1999, Tolley

et al. 2006, Harley 2011). Mean annual salinity has been known to shape shell bottom community structure and assemblage (Sklar and Browder 1998), but little is known about how standard deviations from this mean (i.e. intensity and frequencies of salinity fluctuations) affect the physiology of faunal community. In the case of the Newport River, deviations from annual means are on a magnitude of 4.0-6.0 greater further upstream. With continuous environmental measurements, this research addresses uncertainties regarding which organisms persist and which ones reach tolerance limits as salinity deviates from expected means. Many less motile faunal groups are important fish prey items, and may be especially susceptible to salinity fluctuations (Rodney and Paynter 2006). Thus, this research may improve our understanding of how salinity gradients impact habitat value.

Objectives:

The overarching goal in this study was to quantify the ecological characteristics of shell bottom communities that contribute to salinity resilience. Toward this end, we have identified current knowledge gaps related to the ecological characteristics we believe may enhance resiliency, namely: (1) patch-level community structure, (2) ecological histories (i.e. habitat change over time), and (3) environmental acclimation. To improve our understanding of these characteristics, we asked the following questions:

1) How comparable is faunal community structure among different patches along a salinity gradient? Do species assemblages vary seasonally in response to seasonal changes in salinity and, when possible, episodic freshwater inputs? If so, which species (or functional groups) exhibit greater salinity sensitivity within or among habitat patches?
2) Does faunal community composition and complexity of patches persist over temporal scales (i.e. fifty years on natural reefs, two years on restored reefs)? If not, what are the implicit changes to habitat function and productivity?
3) Do oysters and major taxa grown in areas of greater seasonal fluxes (i.e. brackish areas) exhibit distinct characteristics that can be used to infer salinity acclimation? Do oysters and associated fauna transplanted from extremes of the salinity gradient exhibit stress to new environments? In the event of a large, freshwater inflow, do patch habitats at extremes of the salinity gradient experience less compositional change or faunal mortality?

We acknowledge the distinct differences in ecological histories between natural intertidal and restored subtidal oyster reefs in completing this work. Our goal is to address research objectives simultaneously across the natural patchwork landscape of the Newport River Estuary and the restored patchwork landscape of the North River Estuary, with the intention of making broad ecological comparisons across habitat types.

Methods:

Study sites:

Sites for oyster reef field surveys were selected within the Newport River Estuary (NPRE) and North River Estuary (NRE) in Carteret County, NC (for map, see Figure 1). The NPRE, located north of Morehead City and Beaufort, was selected to revisit habitats originally sampled by HW Wells from 1955 to 1956. The NPRE is a shallow well-mixed system with an average residence time of 6 days or 12 tidal cycles (Kirby-Smith and Costlow 1989, Jennings et

al. 1970). There are extensive salinity records published for the NPRE salinity gradient revealing the observed estuarine gradients: (1) salinity variability increases upstream on an annual range and in maximum hourly gradients, and (2) short term reductions in salinity historically occur following very heavy rainfall in early autumn. The North River Estuary was selected due to it reputable oyster productivity, protection from mechanized harvesting, and five recent cultch plantings (3-5 years old) created by the N.C. Division of Marine Fisheries (C. Caroon, personal communication). Data from the N.C. Division 7 of Marine Fisheries indicate that salinity in the North River is very similar to that of the Newport River, with upstream values varying from 0 to 30 ppt depending on rainfall (Kirby-Smith and Costlow 1989). No information is available for mixing and exchange rates in the North River. Notably, both study systems are important areas for recreational oyster harvesting.

In the NPRE, 5 sites were selected to replicate those sampled by Wells (1961) as closely as possible, considering changes in the shell bottom that have occurred over the past 5 decades, listed here from most saline and least salinity-variable to least saline and most salinity-variable: Pivers Island (NPPI), Newport River Yacht Club (NPYC), White Rock Replacement (NPWRR), Cross Rock Intertidal (NPCRI) and Cross Rock Subtidal (NPCRS). NPPI, also sampled by Wells (1961), is an intertidal reef located on the westward side of Pivers Island. Next, upriver from NPPI, the NPYC is an intertidal reef located on the Eastern bank of the NPRE most closely replicating, "Crab Point" from Wells (1961). Upriver from NPYC, White Rock Replacement exists as an intertidal oyster reef located on the southern bank of the NPRE, most similar in latitude to the Wells (1961) "White Rock" site. Cross Rock, a location sampled by Wells (1961), contains both intertidal and subtidal oysters, were regarded as separate habitats and thus as separate sites in this study.

Six sites were selected for sampling in the NRE, encompassing a similar salinity gradient to that of the NPRE, such that broad comparisons between the two basins are possible. Sites listed from highest to lowest salinity are Carrot Island Subtidal (NRCIS), Carrot Island Intertidal (NRCII), North River Marsh (NRM), South Artificial (NRSA), North Artificial (NRNA), and North Natural (NRNN). Carrot Island Intertidal is a marsh-fringing reef located in Deep Creek within the Rachel Carson National Estuarine Research Reserve, and is natural in origin. Immediately adjacent to NRCII, exists a shallow subtidal reef (NRCIS), most likely owing itself to eroded shell from the intertidal source. Upstream, NRM is a naturally occurring intertidal patch reef within the North River Marsh Complex. The first restored subtidal reef in our sampling regime, termed NRSA (NCDMF 2011 cult planting # 11-011) exists south of the North River bridge. North of the bridge is restored subtidal site NRNA, the NCDMF 2010 cultch planting # 10-012. The freshest site is a natural subtidal reef immediately south from the mouth of the narrow portion of the NRE.

Continuous water monitoring:

Water temperature and conductivity were monitored continuously (10 minute intervals) in the Newport and North River estuaries from September 2013 to December 2015 at each of the 9 sampling locations (a single logger was used at locations with both intertidal and subtidal sites). Odyssey brand conductivity and temperature loggers (http://odysseydatarecording.com/index.php?route=product/category&path=60) were used, with a detection range of 3 to 60 mS/cm, accuracy of +/- 3%, and 25ºC temperature correction. Loggers were suspended ~0.25 m off the bottom within perforated 2" diameter PVC pipes anchored in the sediment. Suspension was achieved by attaching the logger to a PVC cap using

wire and zip cables and then inserting the logger within the perforated PVC pipe effectively containing the logger within the PVC housing. This system allowed for ample water flow to the logger probe, potentially less fouling than if completely exposed to the ambient environment, protection from anthropogenic activity, and ease of collection. Visible PVC stakes marked logger locations. Data was downloaded in the field monthly from November 2013 – June 2014 and bimonthly from August 2014 – December 2015.

Conductivity/salinity data processing:

During logging periods, often a considerable fouling occurred on the logger housing, especially in higher salinity areas during warmer months (personal observation). This fouling contributes to calibration loss which affects the accuracy of conductivity detection differentially across the range of possible conductivities. Thus, it is necessary to calculate the degree to which fouling has affected the logger accuracy with calibration standard testing that can be used to estimate linear drift correction curves. After each download, logger calibration was assessed using three KCl standards (0.1M, 0.3M, and 0.5M), representative of the natural salinity range found in estuarine systems (Dataflow Systems Ltd, personal communication). A calibration run was completed with fouling organisms intact to assess the degree of calibration drift that had occurred over the logging period. After this run, all fouling organisms were scraped from the logger housing and an additional calibration run was completed to serve as a beginning reference for the subsequent salinity sampling period.

Raw conductivity data (mS/cm) was converted from conductivity to salinity (ppt) using the appropriate algorithms developed by Unesco (1983) for computation of seawater properties, and adapted by Douglass (2010) for utilization in Microsoft Excel software. Calibration drift was assumed to have begun immediately following deployment and ending at logger retrieval. Raw salinity was corrected for linear drift using calibration curves from before and after deployment. Curves used for drift correction were constructed as follows: Standard readings following logger collection (end) were subtracted from standard readings taken prior to logger deployment (start). A linear model was then applied using end readings as the independent variable, and the difference between start and end readings as the dependent variable. This model was applied to the salinity data and weighted by the proportion of total time at which a particular reading occurred.

Sampling of Natural Habitats:

In order to assess oyster abundances and community structure of associated faunal assemblages, each site was sampled bimonthly beginning in August of 2013 and concluding in December of 2015. We originally proposed to replicate Wells' 1961 sampling methodology by filling a gallon jar with oyster shell and associates, the lack of specificity regarding the details of this sampling methodology led to the decision to utilize a more modern, rigorous, and less biased sampling design. We utilized the sampling methodology of Grabowski (2005). During each visit to a reef, three $0.1m^2$ quadrats were thrown haphazardly. An aluminum core was placed in the middle of each quadrat, the contents placed in plastic woven sandbags and brought back to the lab for careful processing and enumeration of oyster associated fauna. Shell material surrounding the core and within the quadrat was excavated the the anoxic mud (indicated by presence of FeS in sediment) layer and sieved in the field. Oysters, mussels, and barnacles were counted in the field. Large and mobile fauna within the field seive were placed in plastic bags to be identified in lab, excluding amphipods, isopods, and sessile fouling organisms. Bagged

quadrat fauna and unsorted core samples were brought back to UNC-CH Institute of Marine Sciences. Quadrat fauna were frozen for later processing upon returning to the lab and core samples sieved in water tables, placed in salt water filled jars, and refrigerated at ~40°C until sorting could be completed. This method of sample storage was chosen for two reasons: A number of fauna utilize the calcium carbonate shell of oysters as habitat, and freezing samples would render these organisms too fragile for enumeration, considering the crushing of shells that is required to access them within the oyster shell structure. Second, fauna within porous shell matrices will exit the shell or become exposed when dissolved oxygen becomes scarce in the jar (S. Fegley, personal communication). In quadrat and core samples, all fauna visible to the naked eye were identified to the lowest possible taxonomic level using appropriate field guides, dichotomous keys, and online resources. Fauna not immediately identifiable, often due to high within sample diversity and abundance, such as amphipods, were preserved in 10% formalin solution and transferred to 70% ETOH for long term preservation and eventual enumeration. Additionally, microscopic photography using a Leica EC4 camera was utilized to aid in future identification. All fauna were counted and identified to the lowest possible taxonomic level, abundances were recorded and standardized to 0.1m^2. Oysters in core samples were measured (no more than 20 oysters) from the hinge to the outer edge of the right valve and meats were dried and weighed. Response variables inferred from these methods include species richness and evenness, abundance, oyster length, and oyster biomass.

The largest continuous rainfall event documented during the study period occurred beginning September 9, 2015 and lasted through October 6, 2015, which saw over 500 mm of precipitation (Figure 2). This intense freshwater input produced a severe freshet perturbation which significantly influenced salinity in the Beaufort area, such that our Pivers Island site experienced 50% reductions in conductivity. Our sampling regimen was increased following this event such that two sites from each tidal regime that represented extreme salinities (n=4) were sampled two weeks following the event in order to capture any fine scale community responses.

Statistical analyses:

All univariate statistical analyses in this report were completed using the ggplot2 package in R and JMP Pro 13.0 (SAS). Wilcoxon Rank Sums tests were employed because pooled oyster and richness data did not meet ANOVA assumptions for equality of variances (Welch's test) and normality.

Multivariate statistical tests and ordination, including ANOSIM, SIMPER tests and nonmetric multidimensional scaling were completed in PRIMER (Plymouth Routines in Multivariate Ecological Research) Version 6. In multivariate analyses, all abundance data were 4th-root transformed to downweight the occurrence of common species (Clarke and Warwick 2001). Nonmetric multidimensional scaling (nMDS) was used to explore natural groupings among samples. nMDS is an ordination technique based on Bray-Curtis dissimilarity matrices, and is a valuable tool for exploring relationships between biological communites that may be structured by environmental gradients (Clarke and Warwick 2001). An nMDS plot was determined acceptable for use if stress values were >0.2.

Results:

Salinity and temperature:

Site averaged continuous salinity recorded from September 2013 – December 2015 revealed the expected salinity gradients in the Newport and North Rivers (Table 1). The 1-month pre-sample salinity standard deviation displayed a significant negative relationship with 1-month pre-sample mean salinity at a given site ($F=129.8$, $p<0.0001$) (Figure 3). The Newport River displayed a significant temporal trend in mean salinity, higher temperatures correlating with higher salinities ($F=6.069$, $p=0.01664$) (Figure 4a). Also in the Newport River, salinity standard deviation and temperature displayed a significant negative relationship, with high variability characteristic of colder temperatures and low variability under higher temperatures ($F=6.091$, $p=0.01645$) (Figure 4b). The North River showed no significant temporal trend in salinity mean ($F=0.6694$, $p=0.4159$) (Figure 4c). North River salinity standard deviation also showed no significant relationship with temperature over the study period ($F=0.6694$, $p= 0.4159$) (Figure 4d).

Two major freshets occurred during the study period. The first period occurred from July – September 2014 where over 500 mm of cumulative rainfall occurred contributing to reduced salinities in the Newport and North River estuaries. The second freshet was more severe, and occurred in October 2015. While sampling was increased immediately following this freshet, only resistance to this event can be analyzed, as sampling commenced due to budgetary and personnel restrictions. In 2014 however, sampling was continued immediately after the freshet occurrence, and bimonthly following this fresh period, which will allow for univariate comparisons between biological and community metrics from before the freshet to immediately after, to assess the degree of community resistance to disturbance, as well community recovery at bimonthly time steps.

Oyster densities:

Across both the Newport and North Rivers, oyster abundances were higher on sampled natural intertidal reefs than on subtidal reefs in all salinity regimes (Wilcoxon, $Z=-9.8$, $p<0.0001$). Intertidal low salinity (<20ppt average salinity) oyster reef samples contained significantly lower oyster densities (#/0.1m2) than on reefs at intermediate salinity regimes (25-29ppt average salinity) (Wilcoxon, $Z=2.19$, $p=0.0285$). Oyster densities on high salinity (>30ppt average salinity) intertidal reefs were not significantly different from densities at either intermediate or low salinity locations (Figure 5). Subtidal oyster densities at low salinities and at intermediate salinities were similar. Subtidal high salinity oyster densities were significantly high than intermediate salinity subtidal densities ($Z=-4.55$, $p<0.0001$) as well as low salinity subtidal densities ($Z=-3.41$, $p=0.0006$) (Figure 5). Oyster abundance on intertidal reefs showed no significant relationship with 1-month pre-sample averaged salinity (Figure 8a). Subtidal oyster reefs also showed no significant trend in oyster abundance with salinity (Figure 8b).

Oyster density was a poor predictor of species richness in intertidal oyster reef settings across salinities (Figure 9a). However, in subtidal settings, there was a strong linear correlation between oyster density and species richness ($F=17.85$, $p<0.0001$) (Figure 9b).

Diversity:

In the Newport and North Rivers, intertidal oyster reef species richness varied very little between low, intermediate, and high salinity regimes. Additionally, species richness was highly invariable within salinity regimes as well as among different salinity regimes. On subtidal oyster reefs at high salinities, species richness was highest of any salinity and aerial exposure regime, averaging 20.08 species per $0.1m^2$. Intermediate salinity, subtidal oyster reefs were significantly

less species rich than high salinity subtidal reefs (Wilcoxon, Z=-3.796, p=0.0001) and significantly more species rich than low salinity, subtidal reefs (Wilcoxon, Z=-4.039, p<0.0001). High salinity subtidal reefs were also significantly more diverse than low salinity subtidal reefs over the course of the study (Wilcoxon, Z=-5.034, p<0.0001). No significant correlations were found between 1-month pre-sample averaged salinity and species richness on intertidal reefs (Figure 9c). Subtidal reef species richness displayed a significant positive linear relationship with salinity (F=21.92, p<0.0001) (Figure 9d).

Faunal composition:

In total, 273 species were collected and identified from August 2013 – December 2015, comprising 12 phyla. Major groups found on oyster reefs in this study include errant polychaetes (Subclass: Errantia; 29 species), sedentary polychaetes (Subclass: Sedentaria; 25 species), bivalves (Class: Bivalvia; 54 species), anthozoans (Class: Anthozoa; 6 species) fish (Class: Actinopterygii; 12 species), decapods (Order: Decapoda; 35 species), amphipod crustaceans (Order: Amphipoda; Infraorders: Gammaridea, Corophiida, Caprellida, Talitrida; 22 species), isopod crustaceans (Order: Isopoda; 5 species), gastropods (Class: Gastropoda: 26 species), barnacles (Class: Maxillopoda: 6 species, Hexanauplia; 1 species), oligochaetes (Order: Haplotaxida; 1 species), Collombola (1 species), porifera (Class: Demospongiae; 3 species), and bryozoans (Gymnolaemata; 4 species). Other groups collected in this study, but were not typically abundant or common include sea spiders (Class: Pycnogonida), peanut worms (phylum: Sipuncula), flatworms (Class: Rhabditophora), and ascidians (Class: Ascidiacea).

Multivariate community analysis:

Data exploration via nonmetric multidimensional scaling (nMDS) ordinatino initially revealed potential grouping of communities based on aerial exposure regime (intertidal or subtidal). Dispersion between samples was more pronounced in subtidal oyster-associated faunal communities than with intertidal communities, suggesting intertidal communities were more similar to one another. nMDS ordination by salinity bin (low, mid, high) revealed some clustering of communities based on salinity differences, but it was apparent that a combined approach of salinity bin and aerial exposure regime was appropriate (Figure 8). Ordination based on a combined salinity and exposure factor guided subsequent multivariate analyses to understand differences in community structure across estuarine salinity gradients between aerial exposure regimes. Across groups combinations of salinity and exposure regime, community structure on oyster reefs significantly varies (ANOSIM, global R=0.66 p>0.01). Subsequent pairwise comparisons reveal significant differences in community structure between all combinations except for high salinity and mid salinity intertidal reefs (ANOSIM, global R=0.042, p=.285). Three species characterized the high salinity intertidal, *Maryphysa sanguinea, Cirratulus grandis, and Sphenia antillensis* that were not abundant in the mid salinity intertidal, while mid salinity intertidal reefs were characterized by just 1 species not abundant in the high intertidal, *Nereiphylla fragilis* - these faunal differences insufficient for statistically significant differences in community structure. All pairwise comparisons were significant at the p<0.001 level, except for the comparison between low salinity intertidal and mid salinity intertidal reef community structure, for which p=0.008.

SIMPER analysis for oyster reef communities pooled by exposure regime (intertidal, subtidal) reveals intertidal sites were 48.67% similar to one another on average, while subtidal sites were less similar to one another at 31.12%. Excluding Porifera and Bryozoa

(presence/absence), on intertidal reefs across salinity regimes, 14 species account for 90% of the cumulative similarity, listed in order of percent contribution: *Alitta succinea, Eurypanopeus depressus, Panopeus herbstii, Geukensia demissa, Boonea impressa, Balanomorpha spp., Brachidontes exustus, Anurida maritima, Loxothylacus panopeae, Polydora websteri, Melita nitida, Marphysa sanguinea, Amphipod spp.,* and *Sphaeroma quadridentata*. Across salinities on subtidal oyster locations, 24 species account for 90% of the cumulative similarity, listed in order of percent contribution: *Alitta succinea, Marphysa sanguinea, Hydroides dianthus, Corophiid spp., Urosalpinx cinerea, Amphipod spp., Panopeus herbstii, Eurypanopeus depressus, Balanomorpha spp., Alpheus heterochaelis, Dyspanopeus sayi, Gobiosoma bosc, Mercenaria mercenaria, Mytilid sp., Boonea impressa, Polydora websteri, Sedentaria sp., Terebellid sp, Amphibalanus eburneus, Crepidula fornicata, Anomia simplex, Diodora cayenensis, Doriopsilla pharpa, and Rhepoxynius epistomium.*

SIMPER analysis for combinations of salinity regime (Low, Mid, High) and exposure regime (intertidal, subtidal) indicates that at low salinity intertidal sites, NPCRi and NPWRR, community structure was 53.67% similar on average. At intermediate salinity intertidal sites, NPYC and NRM, community structure was 60.11% similar on average. At high salinity intertidal sites, NPPI and NRCI, community structure was 50.57% similar on average. Low salinity subtidal sites, NRNN and NPCR, were 32.64% similar to one another on average. Intermediate salinity subtidal community structure at NRNA and NRSA was 48.52% similar on average, while high salinity subtidal site community structure at NRCIs was 39.45% similar on average. The main contributing species (accounting for 90% of similarity) to each combination of salinity and exposure regime can be found in Table 2 along with the average abundance of each species. Additionally, the average % dissimilarity between salinity-exposure treatments (ie. Low salinity intertidal vs. low salinity subtidal) is provided in Table 3.

1-way ANOSIM showed temperature to be an insignificant factor in structuring oyster reef communities in this study.

Discussion:

Oysters and associated fauna:

Our findings on oyster densities across environmental contexts warrant a few points of discussion. First, it is well known that oysters find refuge from biotic stressors such as parasitic commensalism, predation, and spatial competition in the intertidal, where desiccation stress prevents bioeroders (ie. Boring sponge *Cliona celata.*), predators (ie. Oyster drills *Urosalpinx cinerea*), and biofoulers (ie. Red bearded sponge *Microciona prolifera*) from persisting (Bahr and Lanier 1981). Following this theory, our findings of high intertidal oyster densities at high and mid salinity regimes are unsurprising. Subtidal oysters should flourish in lower salinities, where they escape the desiccation and heat stress of the intertidal, are able to feed for 24 hours a day constantly submerged, and escape biotic stressors not adapted to the low salinity environment. Our results suggest that in Carteret county, that the intertidal is a more suitable environment for oyster success than in the subtidal, anywhere along the estuarine salinity gradient.

Among intertidal salinity regimes, maximal oyster densities occurring in mid-salinity locations suggest a balance between escapement from periodic low salinity and salinity sensitive biotic stressors. While in general, intertidal oysters are removed from bioeroding factors and predation, in salinities over 20ppt, where boring sponge and oyster drills occur in abundance, oysters harboring those pests in the low-elevation intertidal were documented in our study (Wells

1962, Hopkins 1962). The lessened role of salinity on species richness in the intertidal may be partially explained by the tendency for stress tolerant organisms to display resistance to multiple stressors.

The two North River restored sites in this study, NRNA and NRSA, planted in 2010 and 2011 respectively, encompass the mid-salinity subtidal group in the analyses presented in this report. Both of these sites were heavily infested with *Cliona celata* and oyster drills were abundant. It is reasonable to assume therefore, that the low oyster densities at these sites were a result of post-settlement mortality by sponge invasion, predation from oyster drills or xanthid crabs. Although these sites received considerable freshwater pulses in July-August 2014, salinity reductions were clearly insufficient in magnitude to cause any significant mortality in boring sponge populations (Niels Lindquist, personal communication). A similar suite of biotic factors exists at NRCIs, where boring sponge and oyster drills were consistently collected. These species may confer significant post-settlement mortality in oyster spat. The average oyster length at NRCIs was only 16.75mm, indicating disproportionately high settlement rates to spat survival. The highest degree of variation in oyster size occurred during summer months at this site, which substantiates this idea (see Appendix for oyster length time series). It is possible that given the significantly higher species richness in the high salinity subtidal, that top down control on oyster pests would play a role in releasing some oysters from predation. Finally, although, we did not quantitatively assess boring sponge infestation, the infestation at NRCIs was substantially less severe than at the mid-salinity North River sites. The freshest subtidal site sampled in this study, NRNN, experienced significant degradation during the study period. After Winter 2013, oyster densities were effectively zero. We believe excessive sedimentation from the narrow portion of the North River buried significant portions of the reef following periods of high flow, as evidenced by the thin layer of mud covering the shell bottom. Sampling of NRNN continued to document the influence of this change on the shell bottom biological community, and was included in analyses because salinity and aerial exposure were found to be the most influential variables affecting oyster reef communities.

The strong association between salinity and species richness on subtidal oyster reefs is an important consideration for shellfish management and is consistent with the literature (Wells 1961). As oysters provide refuge for a high diversity of soft bodied invertebrates (Wells 1961, this study), they are highly suitable foraging grounds for juvenile and adult fish species, including those of recreational and commercial value (Lenihan et al. 2001). The total faunal abundances found at NRCIs were relatively low when compared to other oyster reef settings, indicating species richness may not confer high biological productivity. It could be said that if a primary goal in restoring shell bottoms is to provide a high diversity habitat and resource subsidies for economically valuable fish species, then focusing subtidal restoration efforts in more saline areas may be worthwhile, as a larger suite of fauna will colonize reefs in those areas. However, the persistence of boring sponge and oyster drills on restored subtidal reefs, as documented in this study, indicate that the long-term outlook for shell bottom restoration in the saltier portions of the North River is bleak.

One goal of this study was the question of whether oyster faunal communities were indicators of oyster reef "health". As a healthy oyster reef should be accreting and accumulating new oyster recruits, the quantitative measure of species richness should have some association with oyster density if it is to be used as an indicator of reef health. The high diversity found at high and mid salinity reefs in this study are clearly not a function of oyster density, but most likely due to the retained structure of the shell bottom within subtidal salinity environments

suitable for a high diversity of fauna. It is a fair argument however, that there is a suite of species one should expect to find in a particular environmental context, evidenced by our multivariate analyses of community structure. With the exception of high and mid salinity intertidal communities, retain distinct communities over time. Wells (1961) clearly supports this idea, but does not break down oyster reefs based on aerial exposure regime, which from our results, is clearly important in regulating the types of fauna found on a particular shell bottom. Indeed, differences between intertidal and subtidal reef community structure and composition are more pronounced than differences across salinity regimes, within a particular aerial exposure regime.

The location of an oyster reef with regards to surrounding habitats, such as salt marsh, mudflat, and seagrass may play a role in the faunal communities that colonize and persist on a particular reef (Grabowski et al. 2005). Unfortunately, it was impossible to select sites across salinity gradients that were directly comparable in scale and proximity to other habitats. For instance, Cross Rocks intertidal has accreted enough sediment such that marsh patches are growing immediately adjacent to the reef, whereas White Rock Replacement borders mudflat. Marsh associated talitrid amphipods were collected at Cross Rocks more often than at White Rock Replacement, however, these were representative oyster community constituents of Cross Rocks, according to SIMPER analyses.

Future analyses:

This work represents the core of a Master Thesis (Maxwell Tice-Lewis, who was involved in all sampling and computational analyses, and who is scheduled to defend in Spring, 2018). As such, a number of analyses are still underway and will be followed by manuscript submission (which will be conveyed to NC DMF as we have done with previous CRFL projects). First, we will employ generalized linear mixed effects models (GLMMs) to determine how environmental variables may interact to influence univariate faunal abundance and diversity metrics. Additionally, we hope to use regression tree analysis to investigate the relative influence of environmental variables (ie. salinity, temperature, depth, rainfall) on oyster community metrics.

Freshet disturbance resilience analyses are also pending. We will compare oyster abundance and biomass, faunal diversity, faunal abundance and biomass from before and at subsequent 2-month time intervals following the freshet to determine resistance of oyster community constituents to the salinity reduction at each site, and determine recovery and time. We will employ multivariate methods to assess changes in community structure that may have occurred as a result of the 2014 freshet. Of particular interest is whether oyster community resilience should be assessed on a species to species basis or across functional groups.

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Table 1. Sampling locations in the Newport and North River estuaries. Mean and standard deviation of salinity, measured in parts per thousand, were calculated with continuously logged salinity (10-minute intervals) from September 2013-December 2015.

River	Site	Latitude/Longitude	Mean Salinity (ppt)	Standard deviation of Salinity (ppt)
Newport	Cross Rock Intertidal	34°45.107'N 76°40.567'W	18.46465709	8.265350276
Newport	Cross Rock Subtidal	34°46.107'N 76°40.567'W	18.46465709	8.265350276
Newport	White Rock Replacement	34°46.143'N 76°40.580'W	22.67329856	6.609997913
Newport	Yacht Club	34°46.143'N 76°40.580'W	25.40386569	5.553255296
Newport	Pivers Island	34°43.263'N 76°40.551'W	31.76738418	3.513213165
North	North Natural	34°48.353'N 76°37.162'W	23.16618036	6.554795572
North	North Artificial	34°47.727'N 76°36.573'W	26.27751036	5.642571388
North	South Artificial	34°46.624'N 76°36.583'W	28.51026454	5.342901763
North	North River Marsh	34°43.124'N 76°36.497'W	29.61960021	3.557393213
North	Carrot Island Intertidal	34°42.175'N 76°38.235'W	32.26905878	3.468236913
North	Carrot Island Subtidal	34°42.180'N 76°38.254'W	32.26905878	3.468236913

Table 2. SIMPER analysis results showing the major species and species groups responsible for community similarities between oyster reef sampling locations. Numbers denote the average density of each species found in a sample.

Species accounting for 90% similarity between samples at different salinity and aerial exposure regimes

Species	**Low Salinity Intertidal**	**Mid Salinity Intertidal**	**High Salinity Intertidal**	**Low Salinity Subtidal**	**Mid Salinity Subtidal**	**High Salinity Subtidal**
Cnidarians						
Actiniaria sp.						0.31
Errant polychaetes						
Alitta succinea	2.22	2	1.6	1.52	1.45	1.43
Nereis falsa						0.74
Nereiphylla fragilis		0.67				
Oxydromus obscura					0.68	
Harmothoe aculeata						0.47
Marphysa sanguinea			0.82	0.59	1.41	1.24
Lumbrineris sp.						0.78
Sedentary polychaetes						
Amphitrite ornata						0.33
Terebellid sp.					0.74	0.72
Cirratulus grandis			0.78			
Hydroides dianthus					3.16	1.29
Sabellaria sp.						1.1
Polydora websteri	1.78	1.48	0.53	1.05		
Piromis eruca						0.53
Sedentaria sp.					0.79	0.6
Decapods						
Alpheus heterochaelis					0.78	0.96
Eurypanopeus depressus	1.5	2.04	1.58	0.45	1.17	0.59
Panopeus herbstii	1.03	1.49	1.43		0.9	1.32
Dyspanopeus sayi					0.72	0.64
Menippe mercenaria						0.41
Pinnixa chaetopterana						0.41
Megalobrachium soriatum						0.34
Amphipods						
Amphipod spp.	1.34		0.66	0.81	1.08	1.66
Melita nitida	1.86	1.25				
Rhepoxynius epistomus						1.06
Corophiid spp.				1.55	1.48	0.76
Isopods						
Sphaeroma quadridentatum	2.32	1.02				

Tanaids						
Tanaid sp.						0.65
Barnacles						
Amphibalanus eburneus				0.67		
Balanomorpha spp.	1.09	0.88	0.89	1.52		0.97
Loxothylacus panopeae	0.71	1.23	0.59			
Bivalves						
Anadara transversa						0.33
Anomia simplex					0.58	0.36
Brachidontes exustus		0.93	1.12			0.52
Geukensia demissa	1.58	1.51	0.87			
Mytilid sp.	2.64	2.63	2.16	0.71		0.9
Sphenia fragilis			0.44			0.81
Mercenaria campechiensis				0.34		
Mercenaria mercenaria				0.58		
Leiosolenus bisulcata						0.71
Anurida maritima		1.88	1.1			
Gastropods						
Pyrgocythara plicosa					0.45	
Seila adamsi						0.62
Urosalpinx cinerea				0.37	1.2	0.84
Boonea impressa	1.8	1.84	1.19			0.96
Chaetopleura apiculata						0.82
Crepidula fornicata						0.61
Diodora cayenensis					0.36	0.8
Doriopsilla pharpa					0.57	0.52
Fish						
Gobiosoma bosc				0.36	0.44	
Ascidians						
Molgula manhattensis					0.45	
Brittle stars						
Ophiothrix angulata						0.66

Table 3. SIMPER analysis results showing % dissimilarity between different salinity-aerial exposure treatment groups. Higher % dissimilarity indicates community composition and structure is more different between a set of two oyster reef environmental contexts.

Comparison	% dissimilarity
Low-Inter & Mid-Inter	47.43
High-Inter & Mid-Inter	49.26
Low-Inter & High-Inter	57.36
High-Sub & Mid-Sub	67.07
Low-Inter & Low-Sub	71.23
Low-Sub & Mid-Inter	73.25
High-Inter & High-Sub	73.52
Low-Sub & High-Inter	73.97
High-Inter & Mid-Sub	74.44
Low-Sub & Mid-Sub	74.72
Mid-Inter & Mid-Sub	74.97
Mid-Inter & High-Sub	75.39
Low-Inter & Mid-Sub	77.38
Low-Inter & High-Sub	77.51
Low-Sub & High-Sub	79.42

Figure 1. Oyster reef sampling locations.

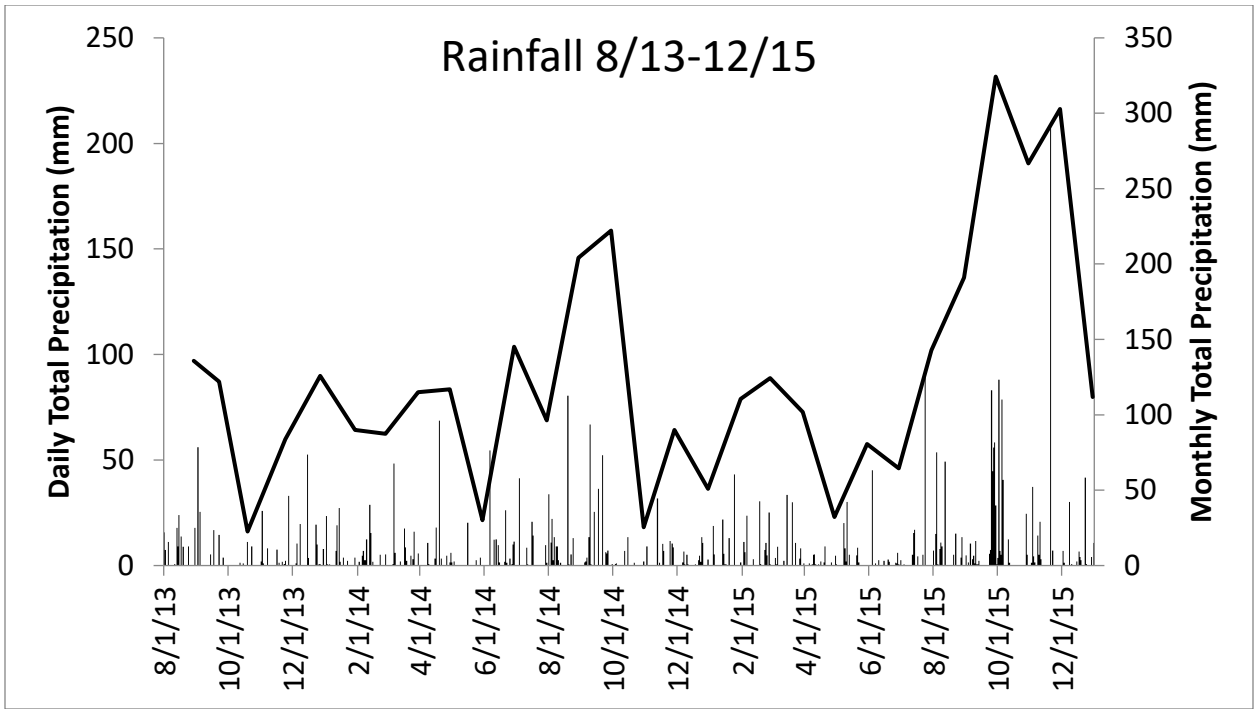


Figure 2. Daily rainfall (mm) and monthly total rainfall (mm) for the entirety of the study period, August 2013 – December 2015 (Data courtesy: National Climactic Data Center, NOAA)

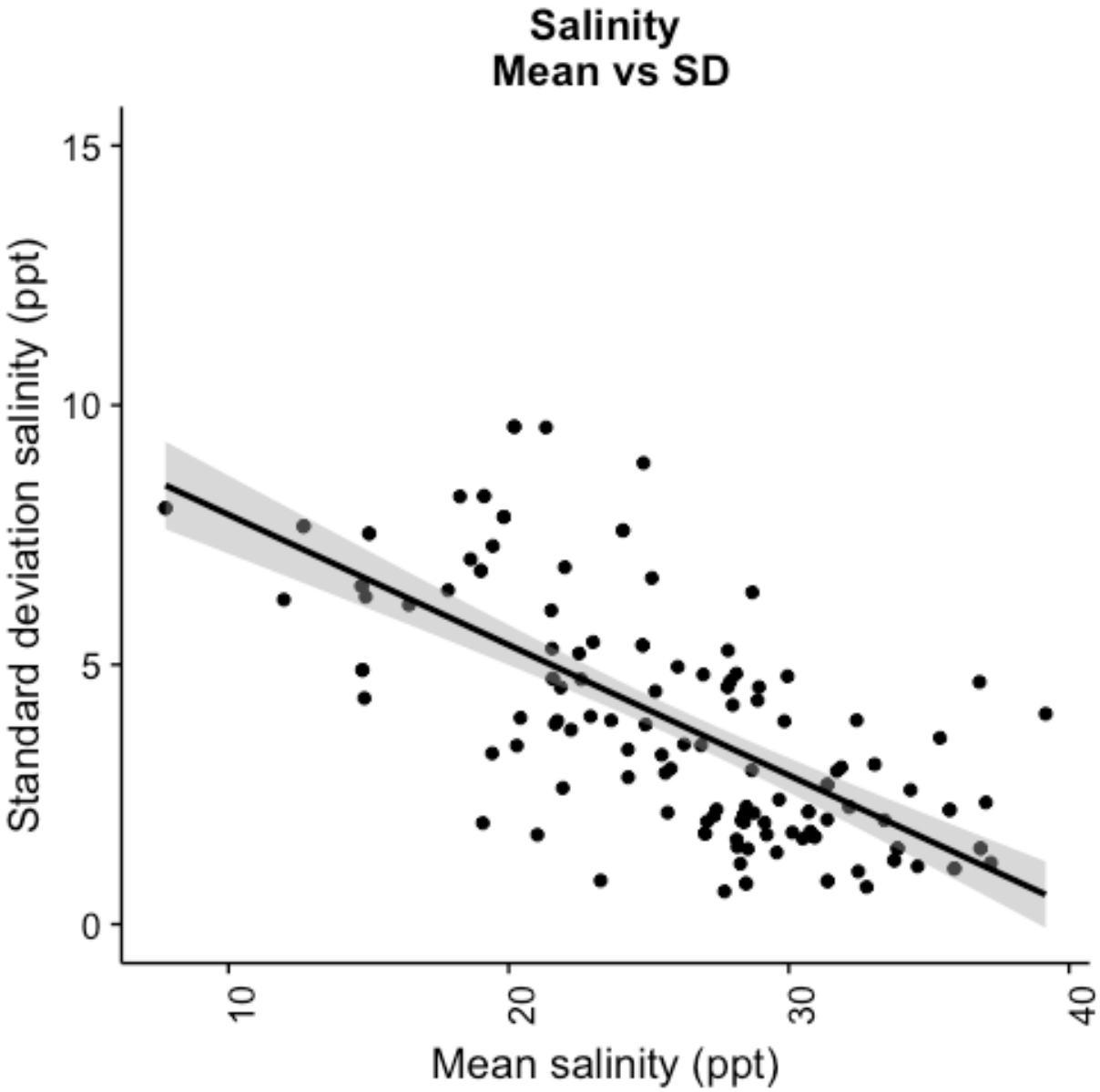


Figure 3. Relationship between mean salinity and salinity variation (standard deviation). Means and standard deviations were calculated from the 1-month (28 days) prior to sampling. The linear regression model ($p<0.001$) indicates a significant negative relationship between mean salinity and salinity variation.

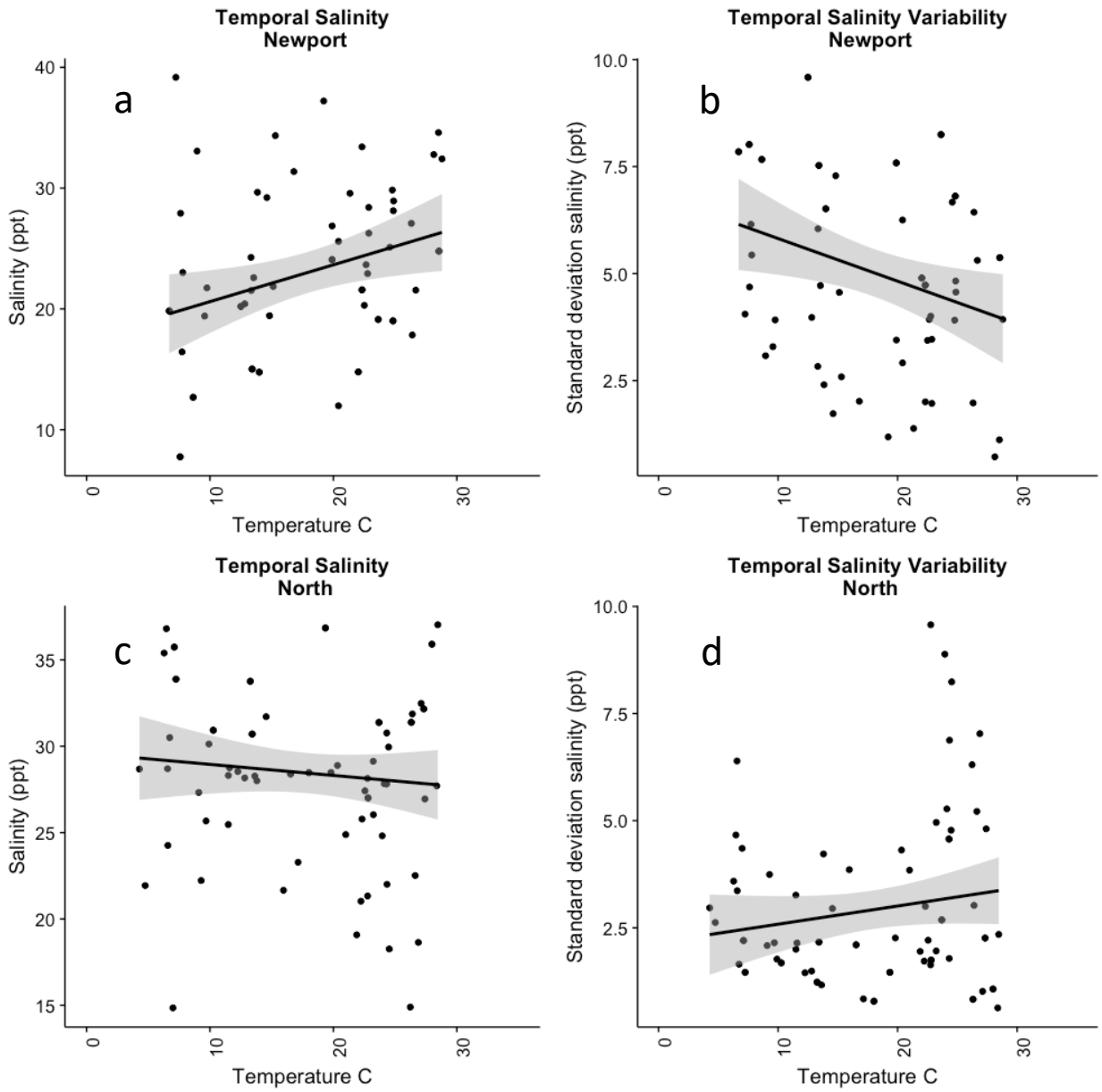


Figure 4. (a) Relationship between month pre-sample average temperature and average salinity in the Newport River (b) Relationship between month pre-sample average temperature and standard deviation of salinity in the Newport River (c) Relationship between month pre-sample average temperature and average salinity in the North River (d) Relationship between month pre-sample average temperature and standard deviation of salinity in the North River

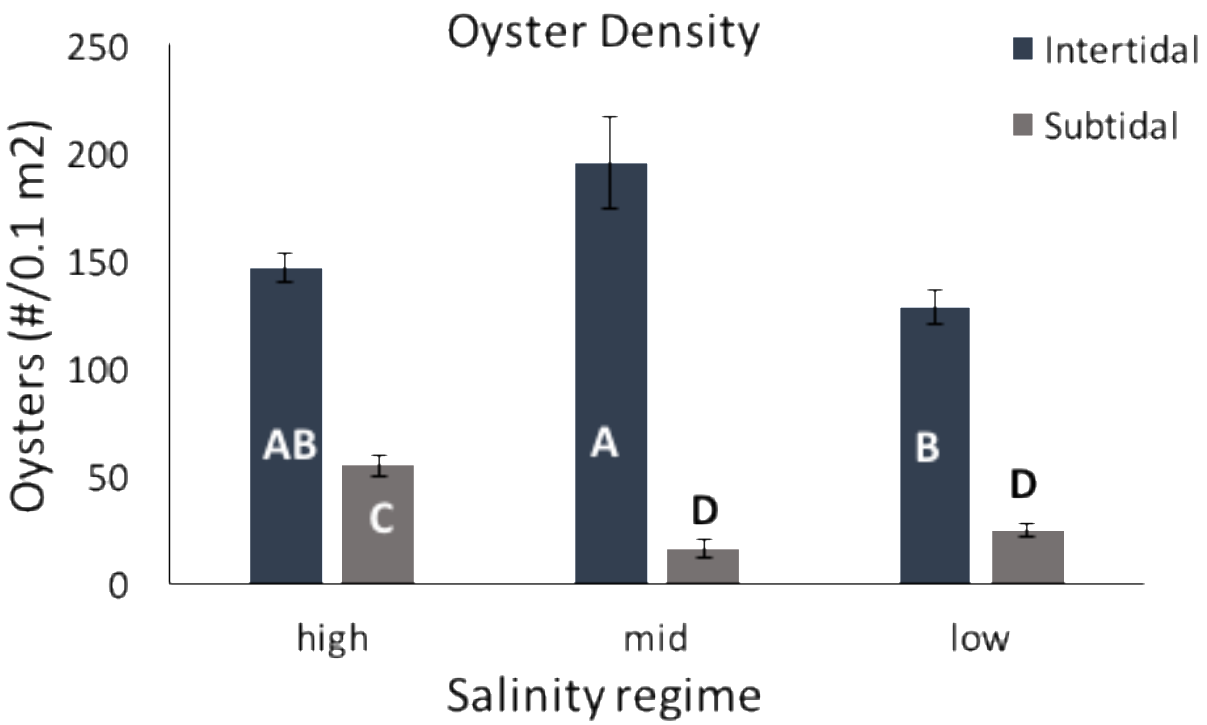


Figure 5. Pooled oyster densities at intertidal and subtidal oyster reefs in high, mid, and low salinity regimes. Capital letters denote statistically different oyster densities.

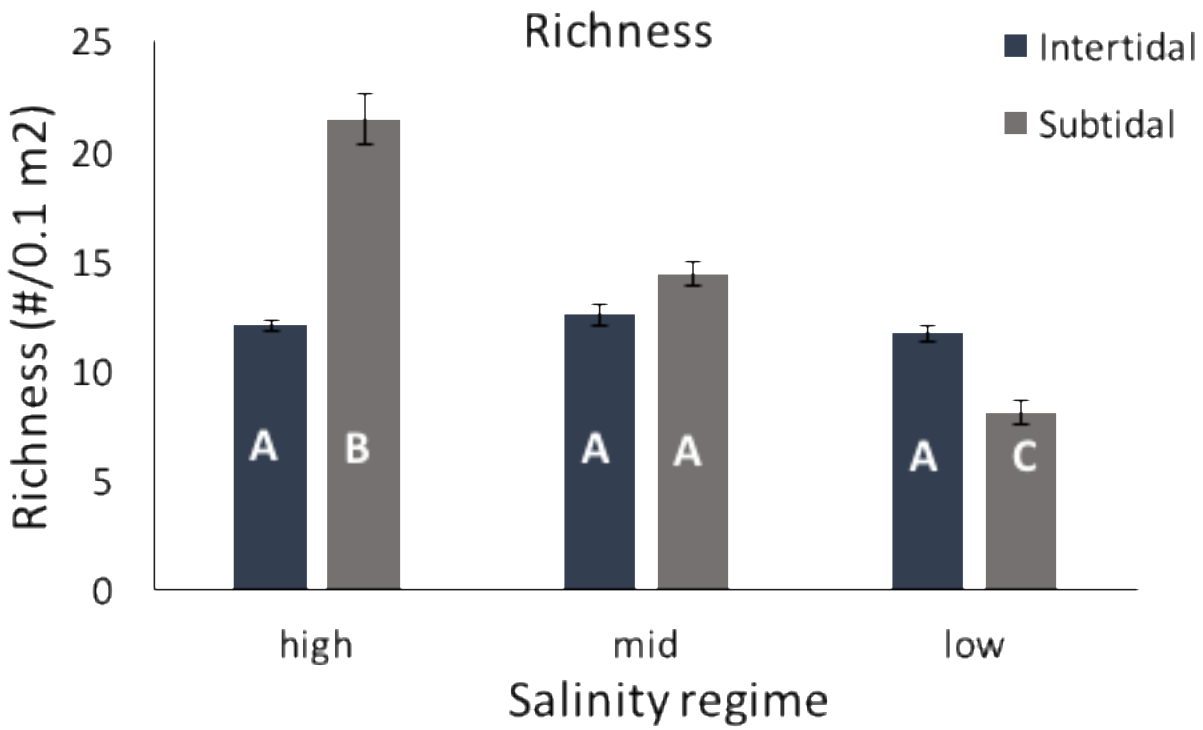


Figure 6. Pooled species richness at intertidal and subtidal oyster reefs in high, mid, and low salinity regimes. Capital letters denote statistically different oyster densities (Kruskal Wallis Test, $p>0.05$)

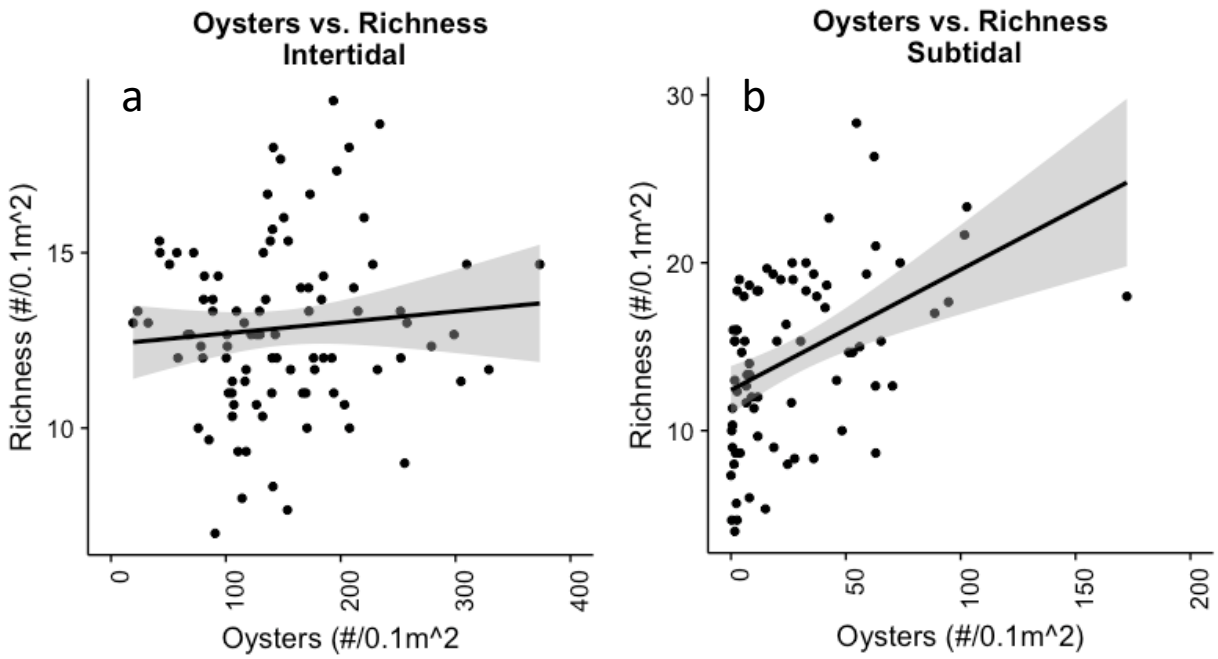


Figure 7. (a) Relationship between oyster abundance and species richness on intertidal oyster reefs. (b) Relationship between oyster abundance and species richness on subtidal oyster reefs.

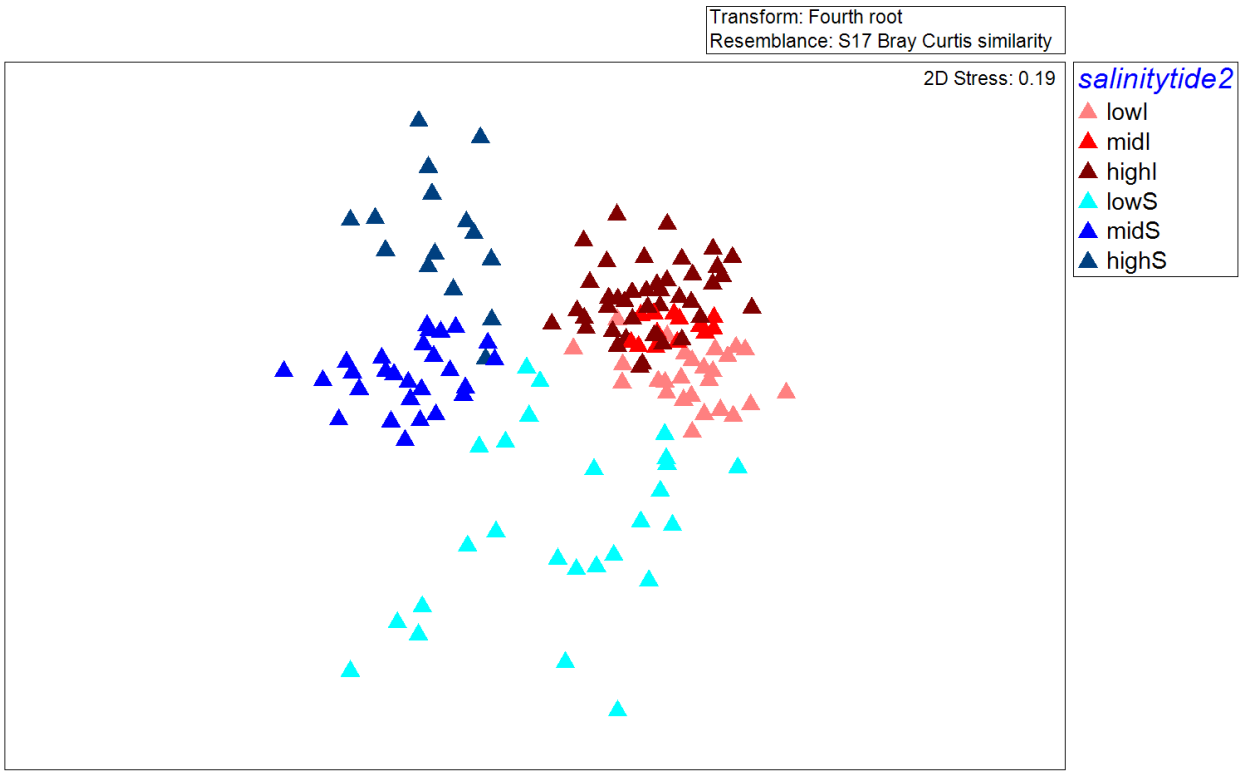


Figure 8. Nonmetric multidimensional scaling plot (nMDS) of all samples. Red toned triangles represent intertidal communities and blue toned triangles represent subtidal communities. Darker colors indicate high salinity sites, middle colors indicate mid salinity sites, and lighter colors indicate low salinity sites.

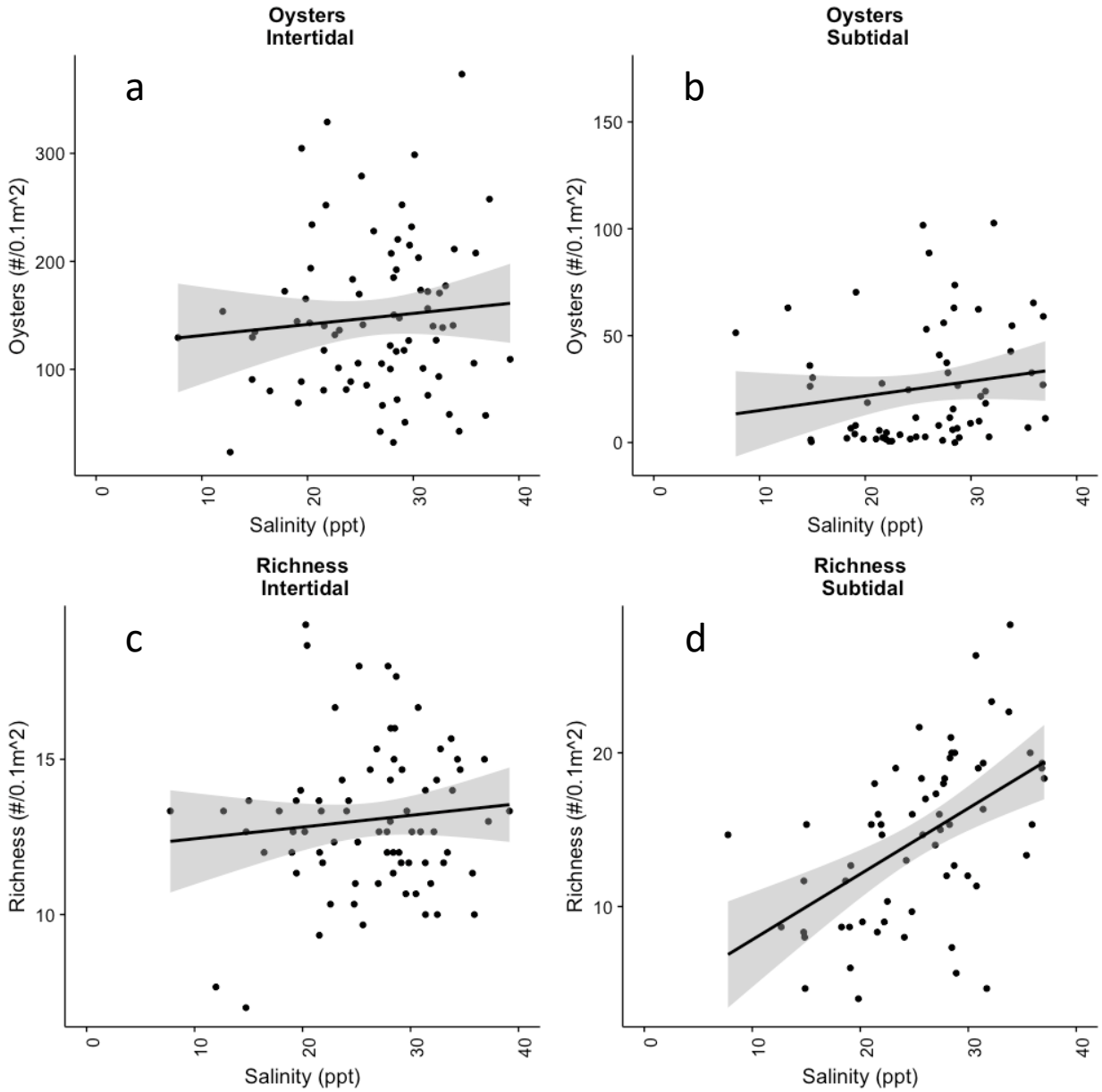
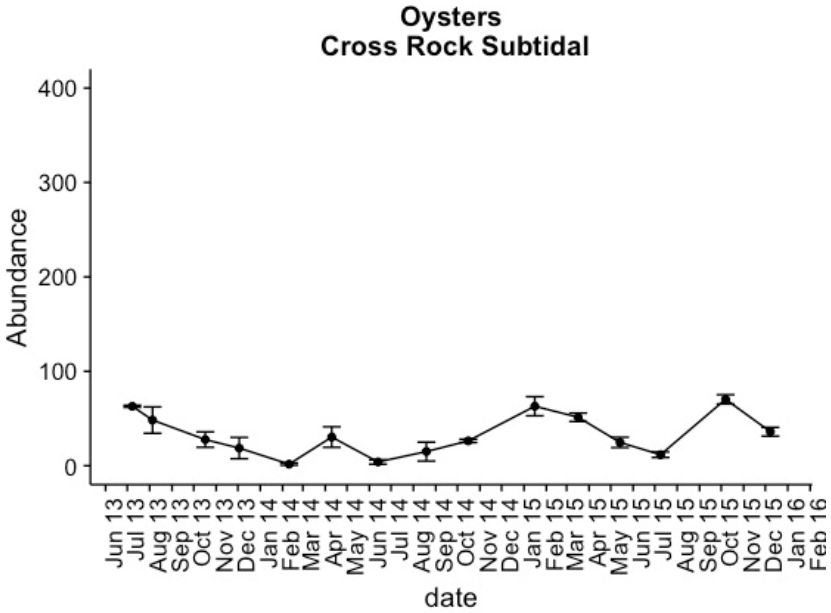
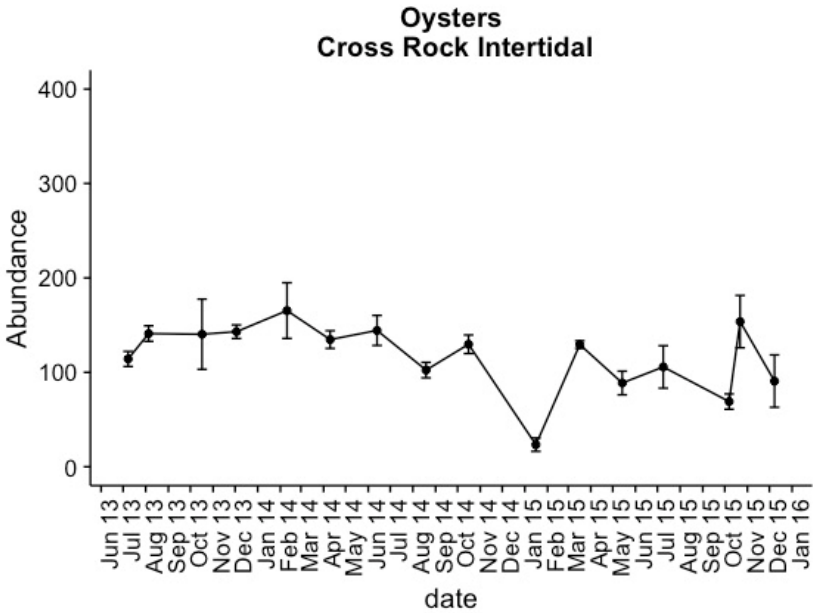
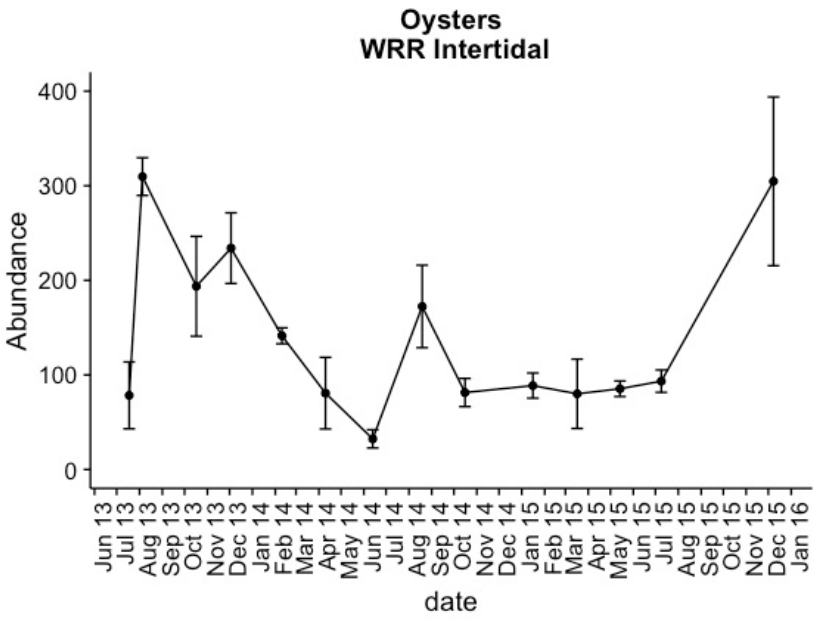


Figure 9. **(**a) Relationship between pre-sample month averaged salinity and oyster density at intertidal sites. (b) Relationship between pre-sample month averaged salinity and oyster density at subtidal sites. (c) Relationship between pre-sample month averaged salinity and species richness at intertidal sites. (d) Relationship between pre-sample month averaged salinity and species richness at subtidal sites.

Appendix 1. Time series figures of oyster abundance, length, and diversity.






Oysters
WRR Intertidal
Abundance
0
100
200
300
400
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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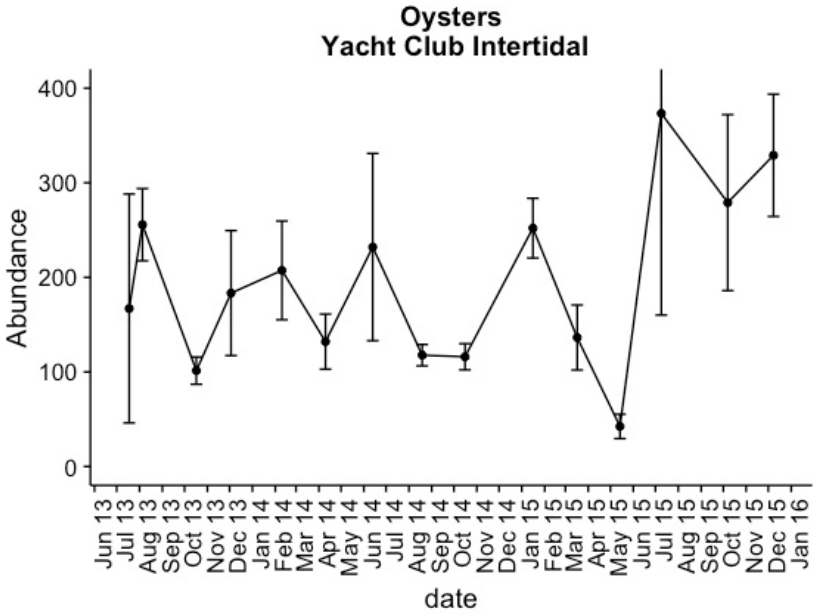
Mar 15
Apr 15
May 15
Jun 15
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
date


Oysters
Yacht Club Intertidal
Abundance
0
100
200
300
400
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
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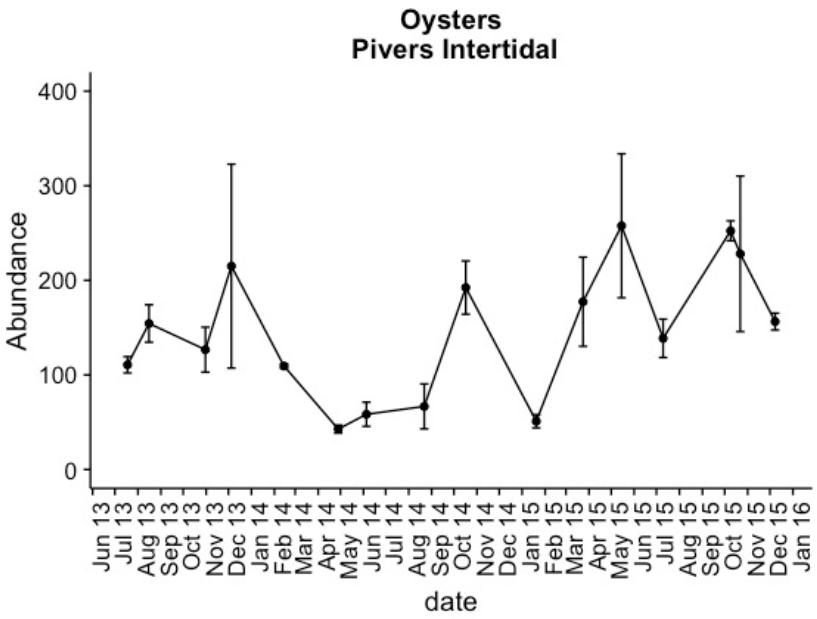
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
date


Oysters
Pivers Intertidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
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Oct 14
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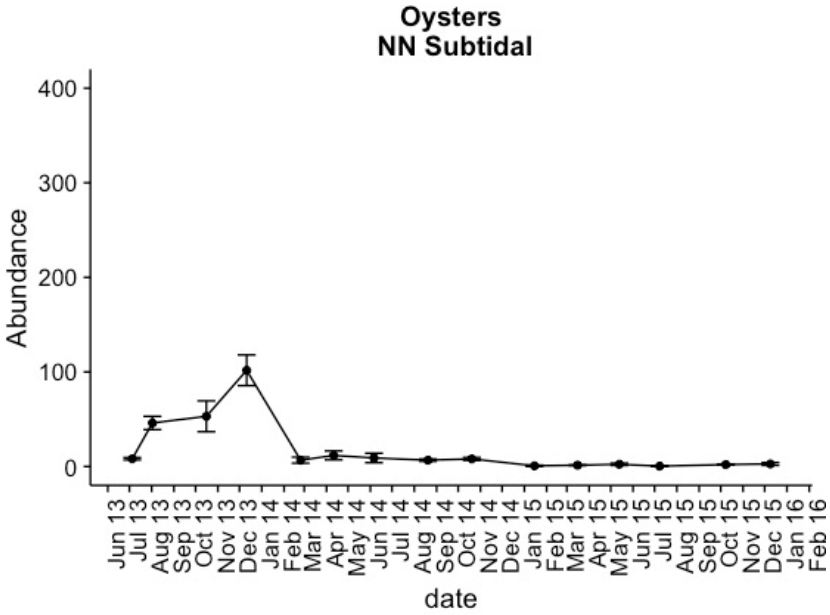
date


Oysters
NN Subtidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
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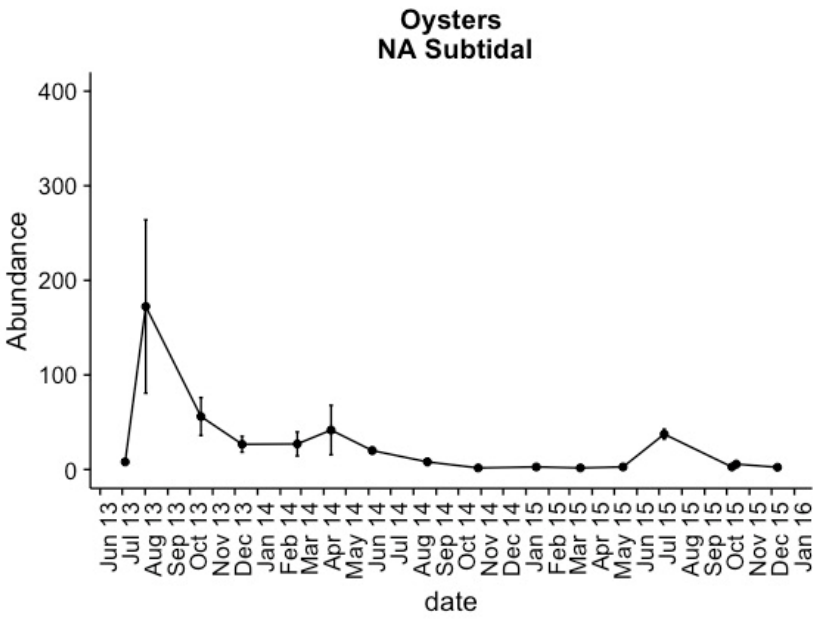
date


Oysters
NA Subtidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
Aug 13
Sep 13
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Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
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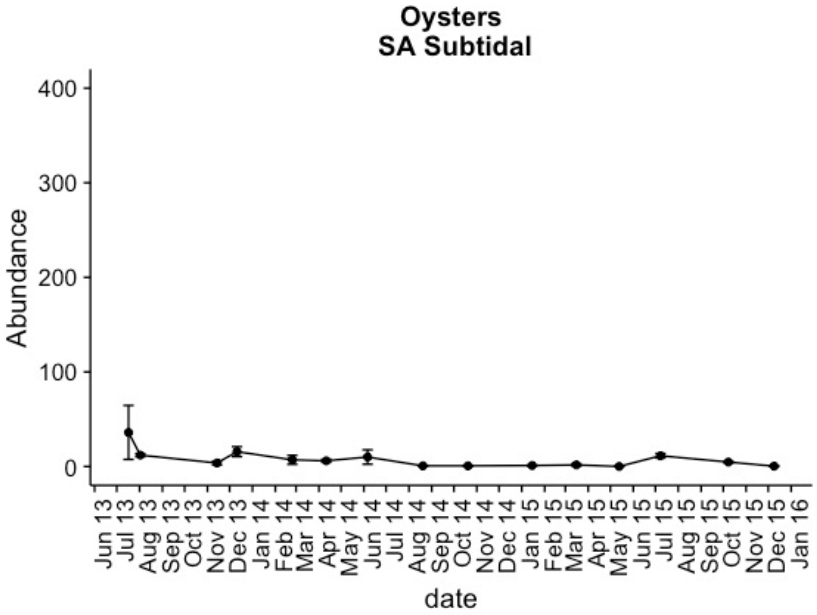
date


Oysters
SA Subtidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
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Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
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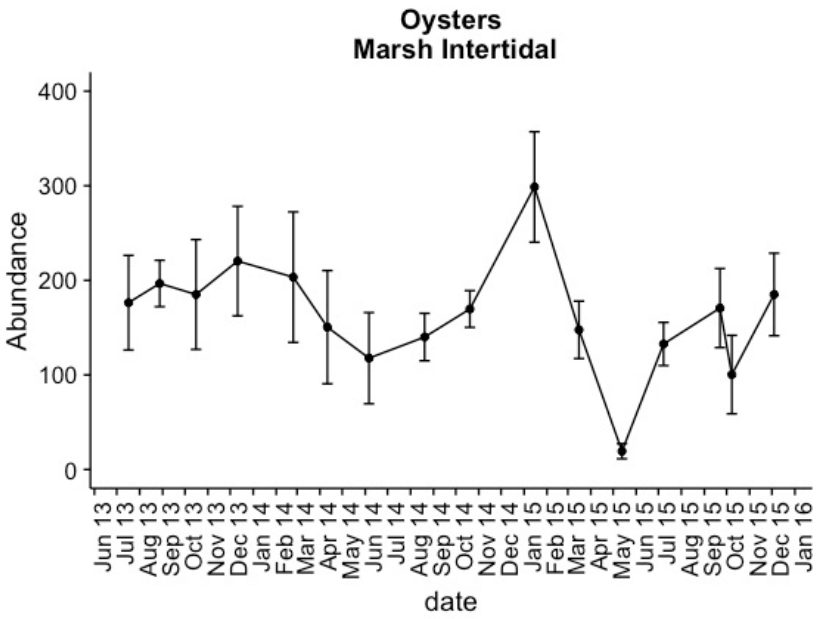
Oysters
Marsh Intertidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
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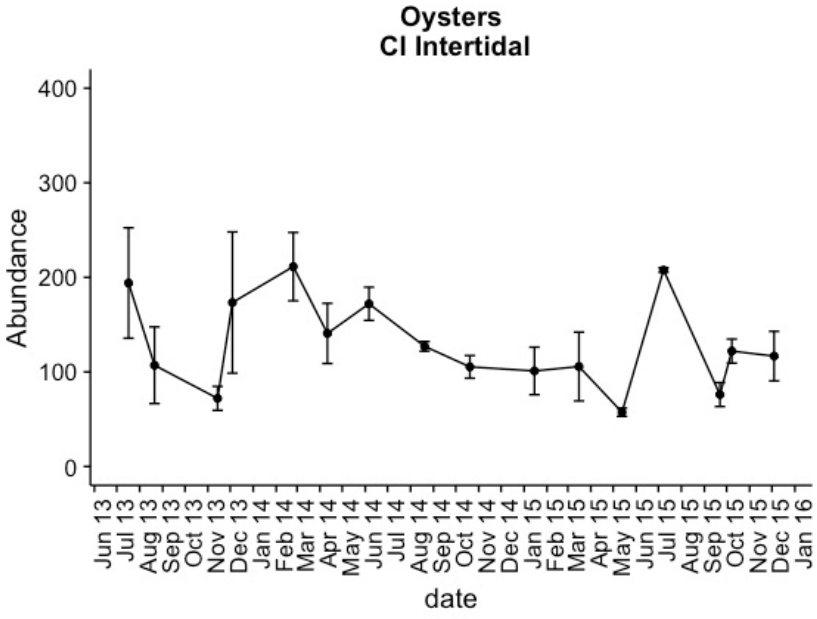
Oysters
CI Intertidal
Abundance
400
300
200
100
0
Jun 13
Jul 13
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Jan 14
Feb 14
Mar 14
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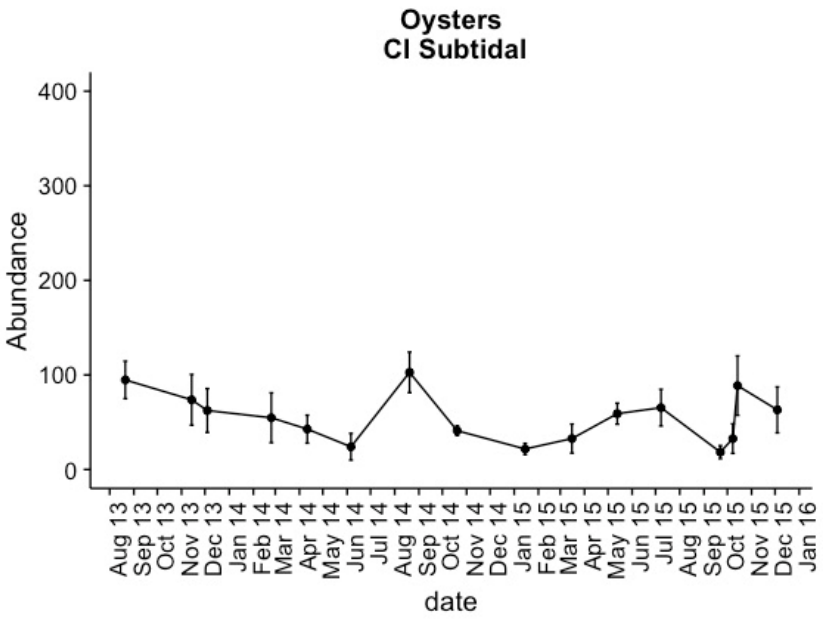
Oysters
CI Subtidal
Abundance
400
300
200
100
0
Aug 13
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Apr 14
May 14
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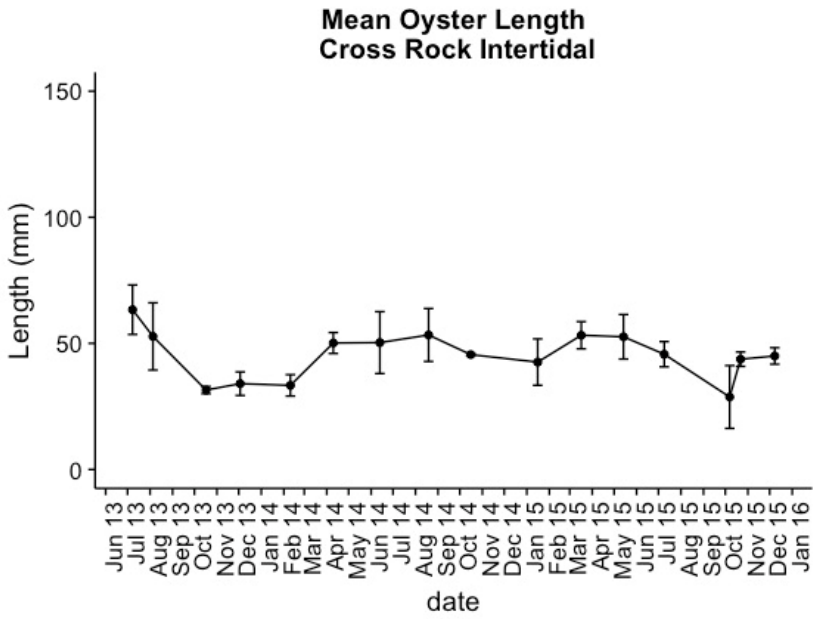
Mean Oyster Length
Cross Rock Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
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Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
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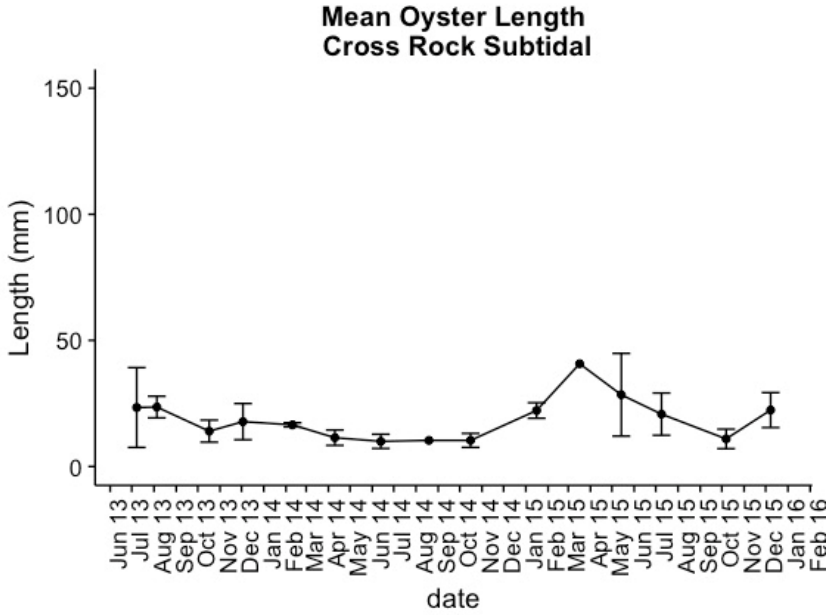
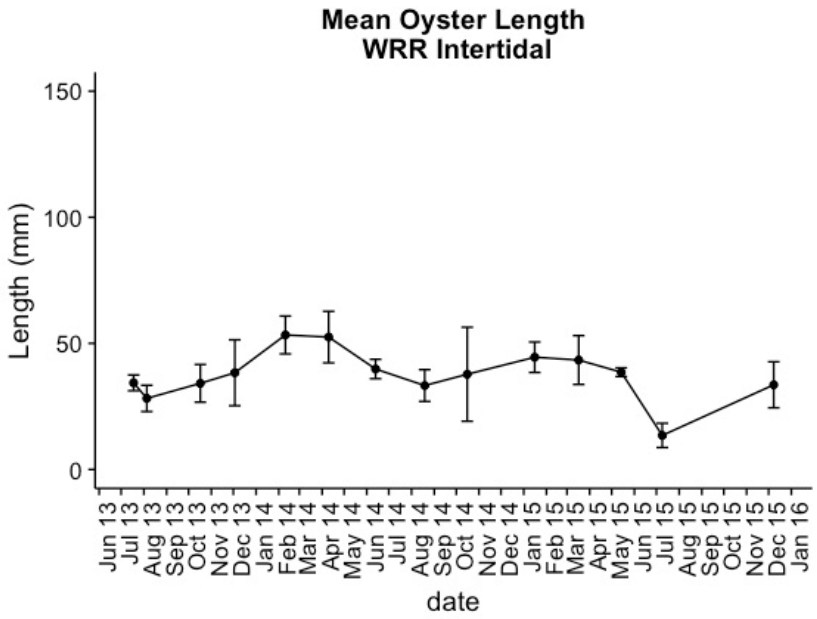
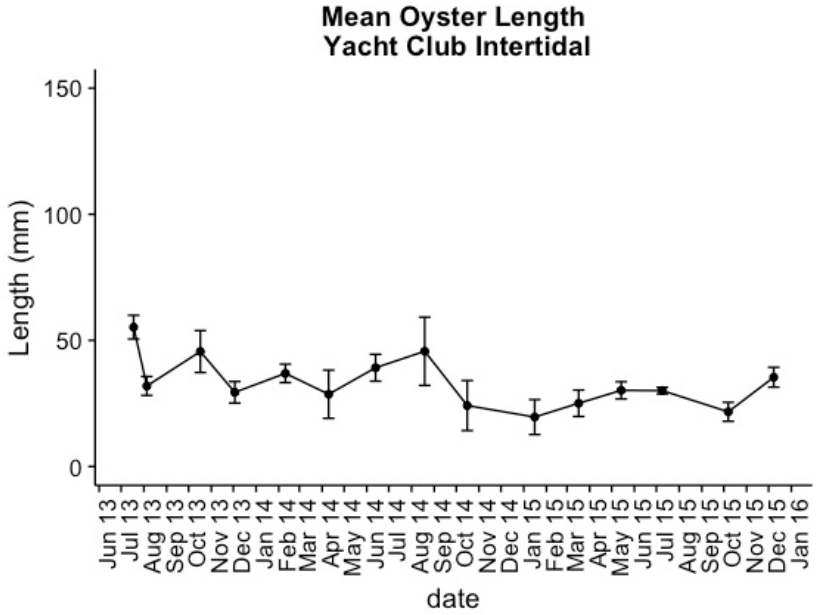
Dec 15
Jan 16
date


Mean Oyster Length
Cross Rock Subtidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
Dec 14
Jan 15
Feb 15
Mar 15
Apr 15
May 15
Jun 15
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
Feb 16
date


Mean Oyster Length
WRR Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
Dec 14
Jan 15
Feb 15
Mar 15
Apr 15
May 15
Jun 15
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
Yacht Club Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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Mar 15
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Jul 15
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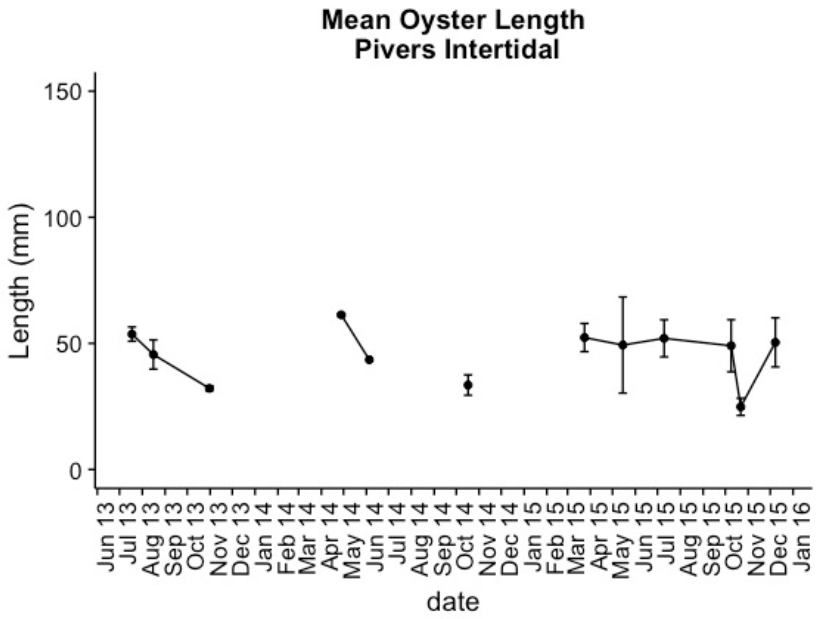
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
Pivers Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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Jan 15
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Mar 15
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May 15
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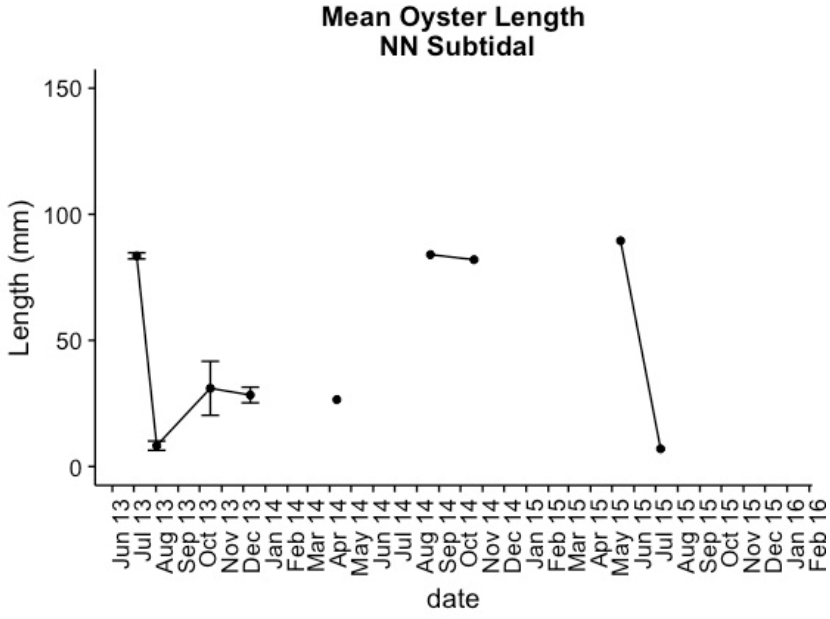
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
NN Subtidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
Dec 14
Jan 15
Feb 15
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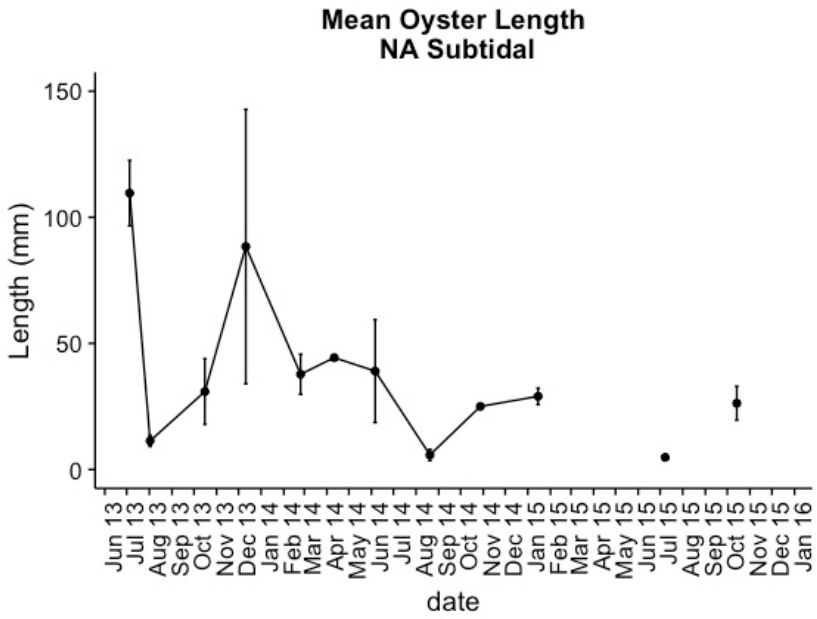
May 15
Jun 15
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
Feb 16
date


Mean Oyster Length
NA Subtidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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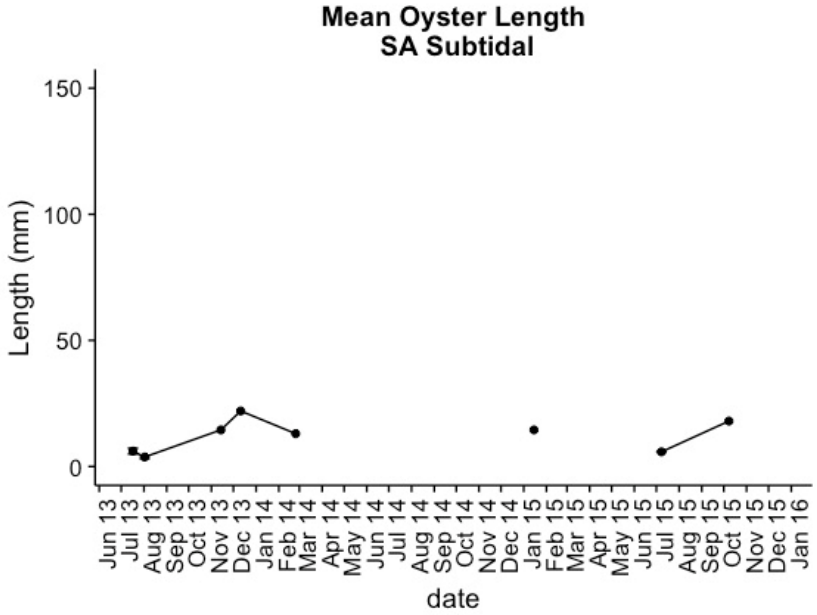
Jun 15
Jul 15
Aug 15
Sep 15
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
SA Subtidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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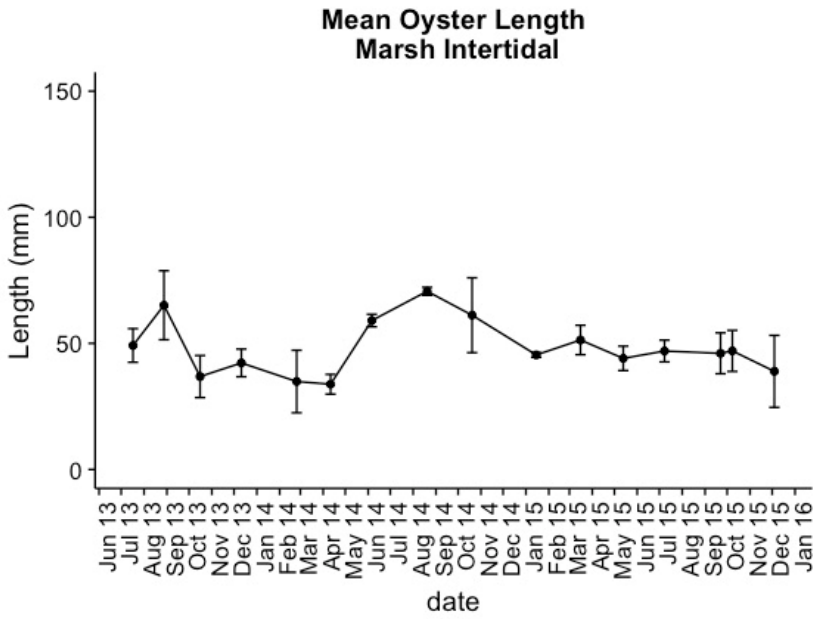
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
Marsh Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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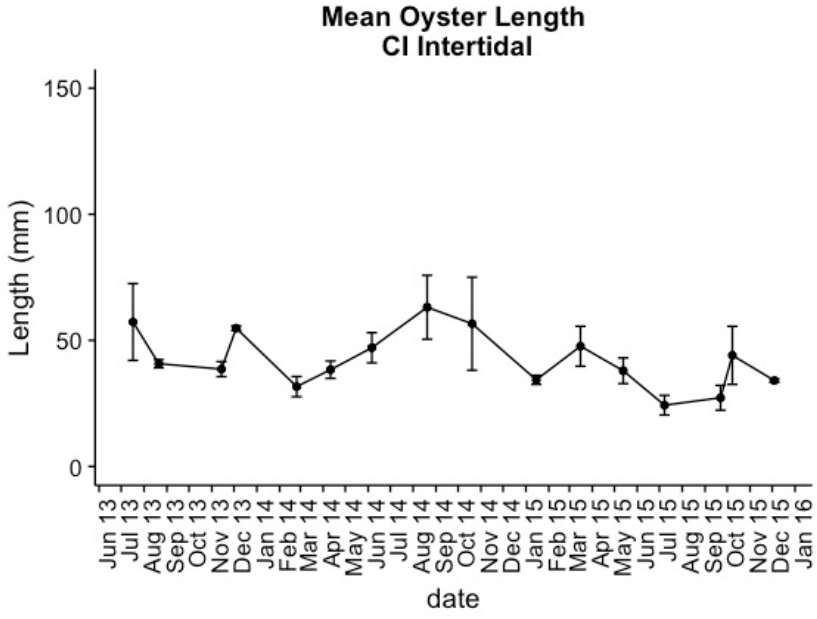
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
CI Intertidal
Length (mm)
150
100
50
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
Dec 14
Jan 15
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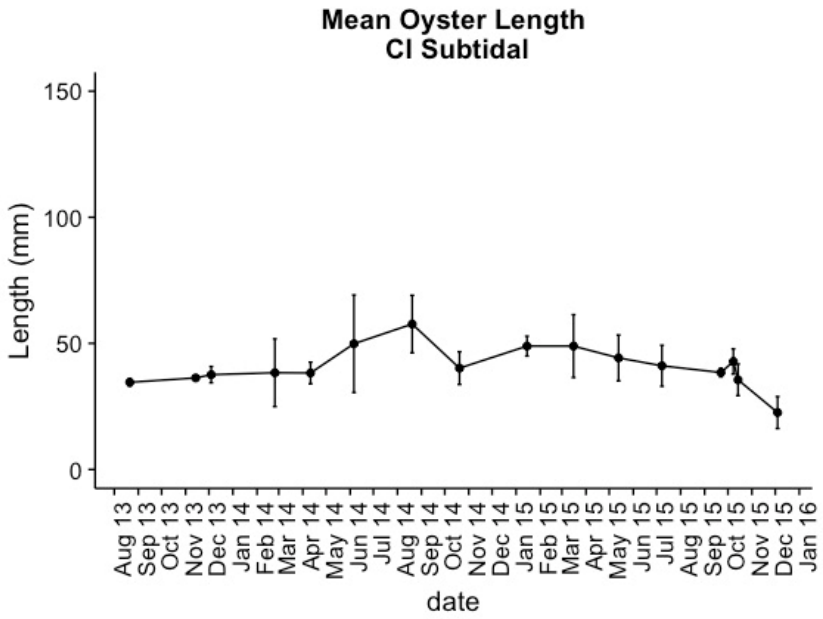
Oct 15
Nov 15
Dec 15
Jan 16
date


Mean Oyster Length
CI Subtidal
Length (mm)
150
100
50
0
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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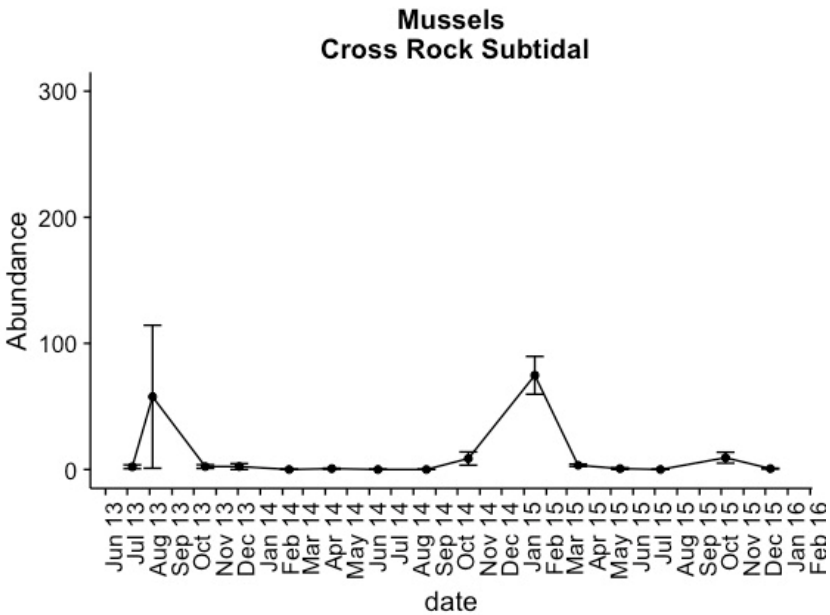
Oct 15
Nov 15
Dec 15
Jan 16
date


Mussels
Cross Rock Subtidal
Abundance
300
200
100
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
Nov 14
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Feb 15
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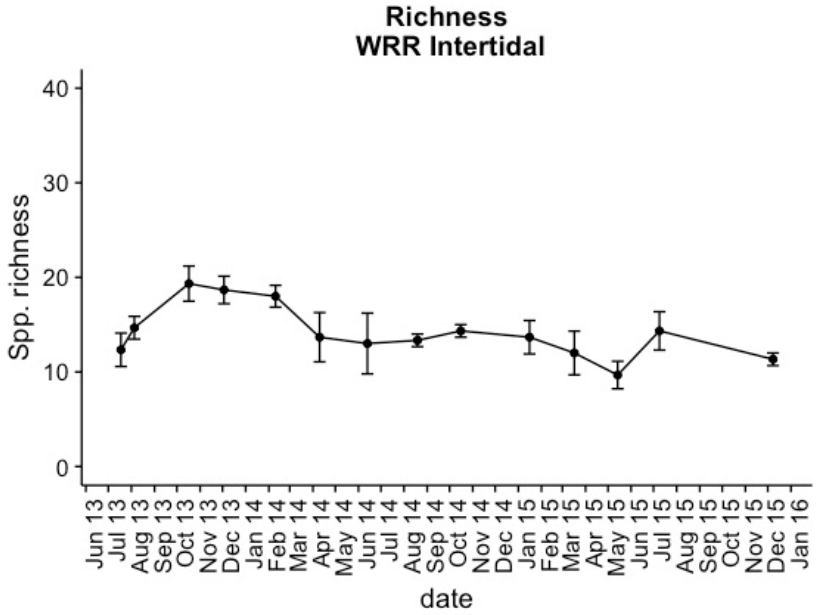
Oct 15
Nov 15
Dec 15
Jan 16
Feb 16
date


Richness
WRR Intertidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
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Jan 15
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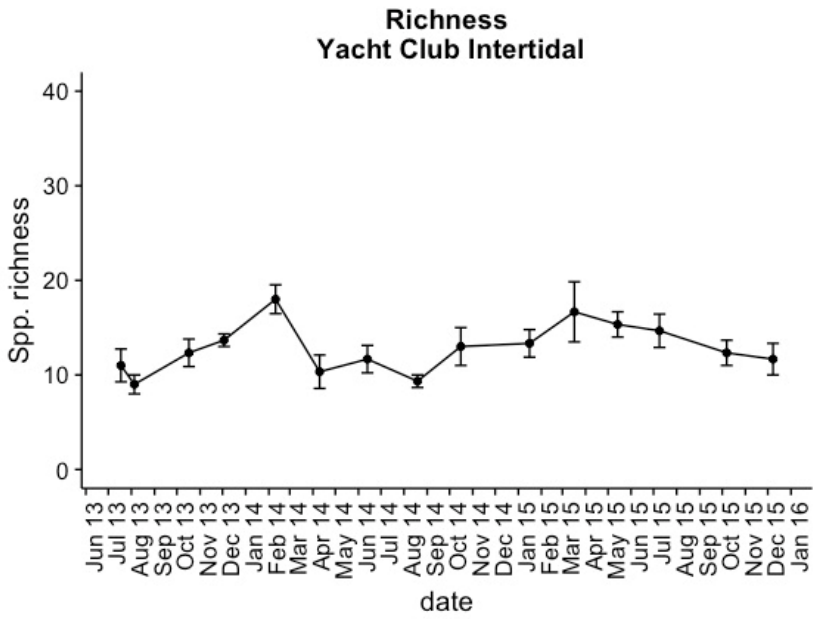
Oct 15
Nov 15
Dec 15
Jan 16
date


Richness
Yacht Club Intertidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
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Aug 14
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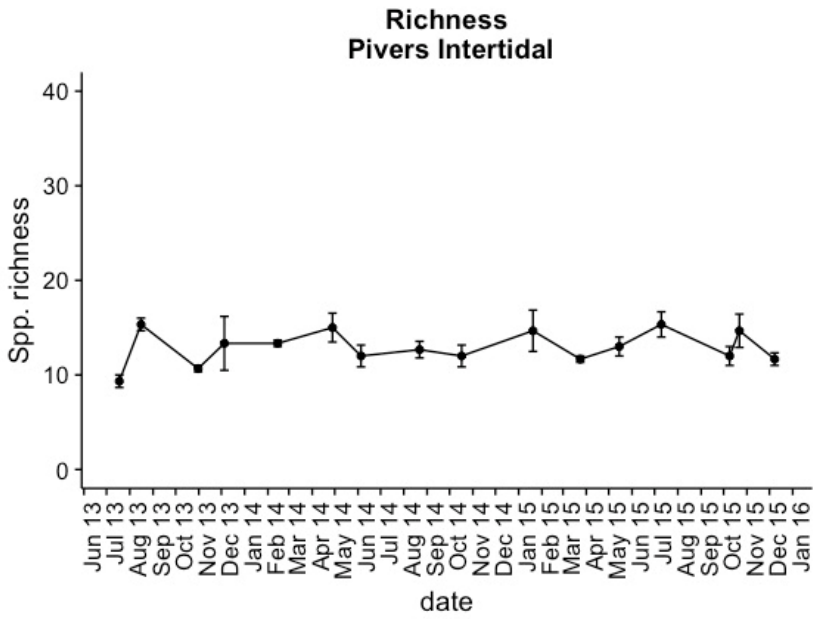
Nov 15
Dec 15
Jan 16
date


Richness
Pivers Intertidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
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Apr 14
May 14
Jun 14
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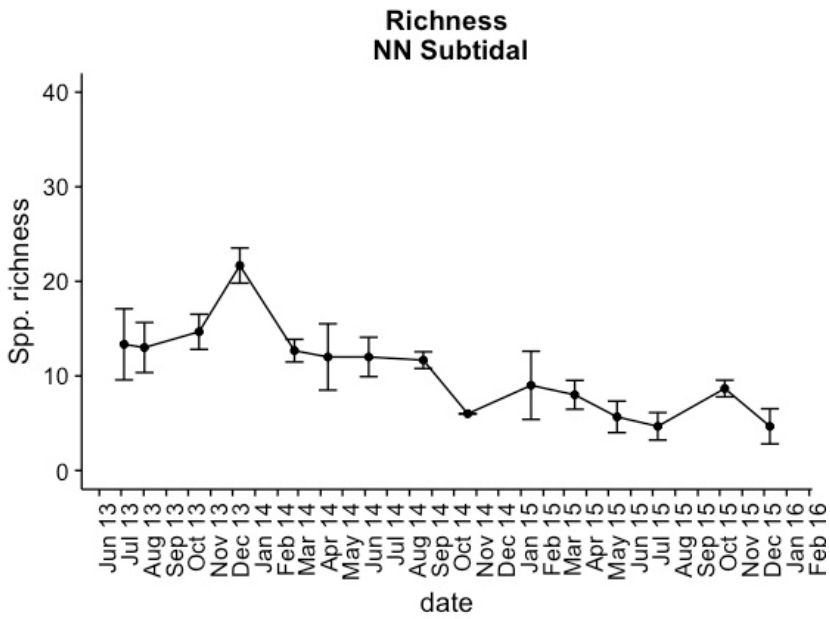
Oct 15
Nov 15
Dec 15
Jan 16
date


Richness
NN Subtidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
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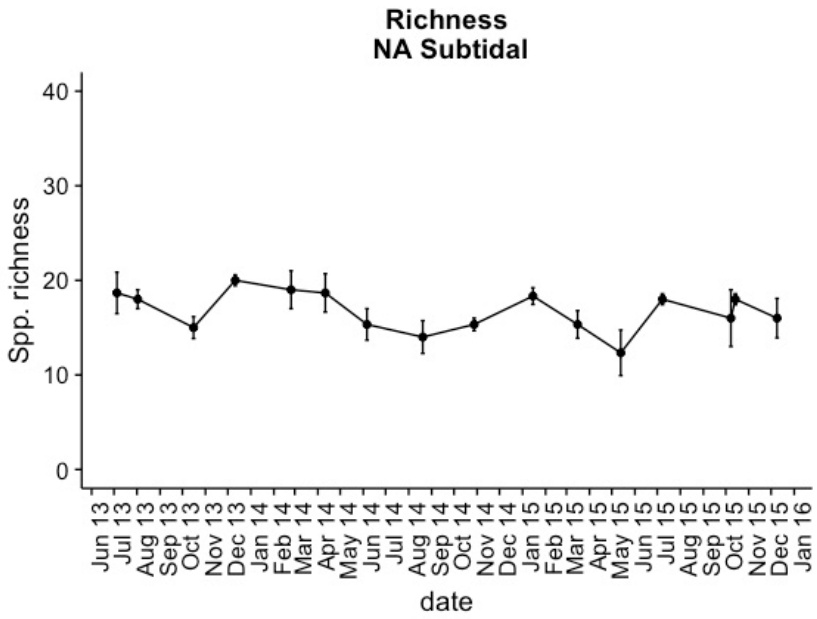
Jan 16
Feb 16
date


Richness
NA Subtidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
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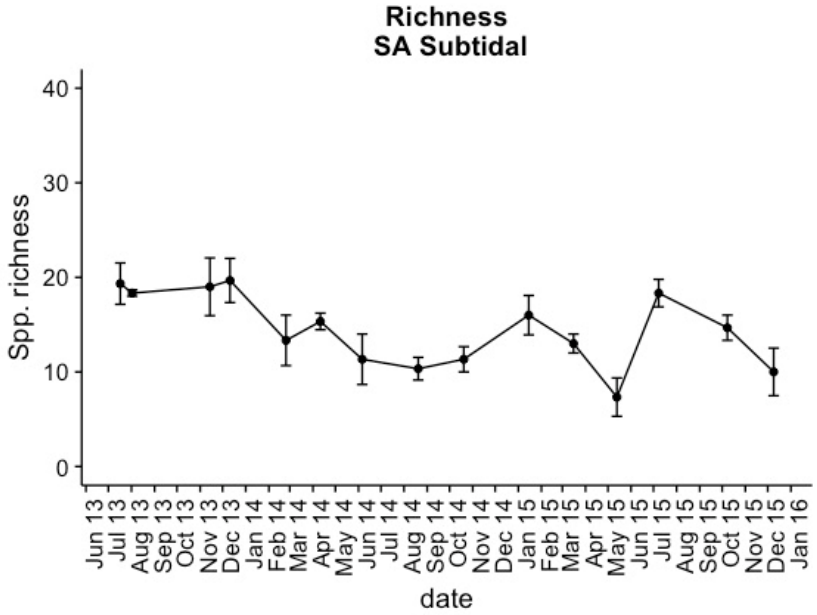
Nov 15
Dec 15
Jan 16
date


Richness
SA Subtidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
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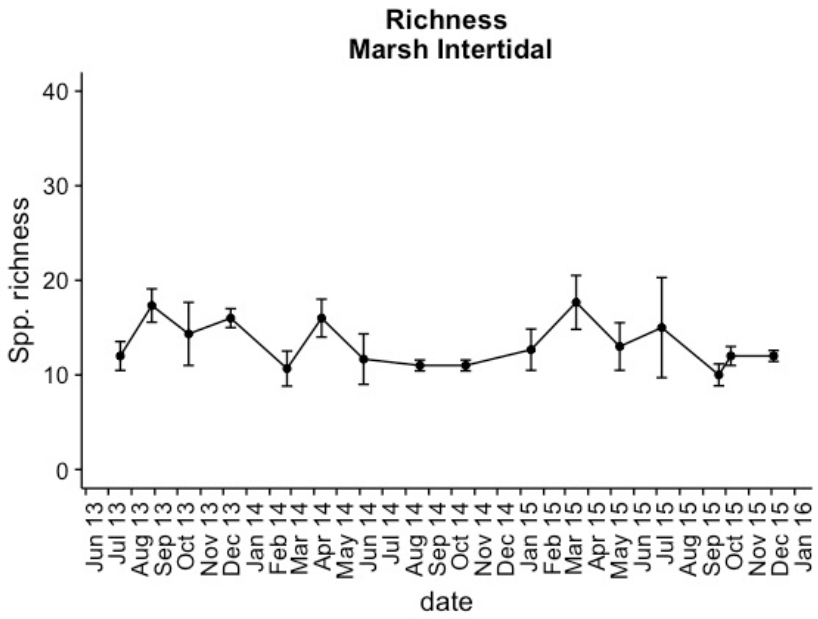
Oct 15
Nov 15
Dec 15
Jan 16
date


Richness
Marsh Intertidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
Oct 14
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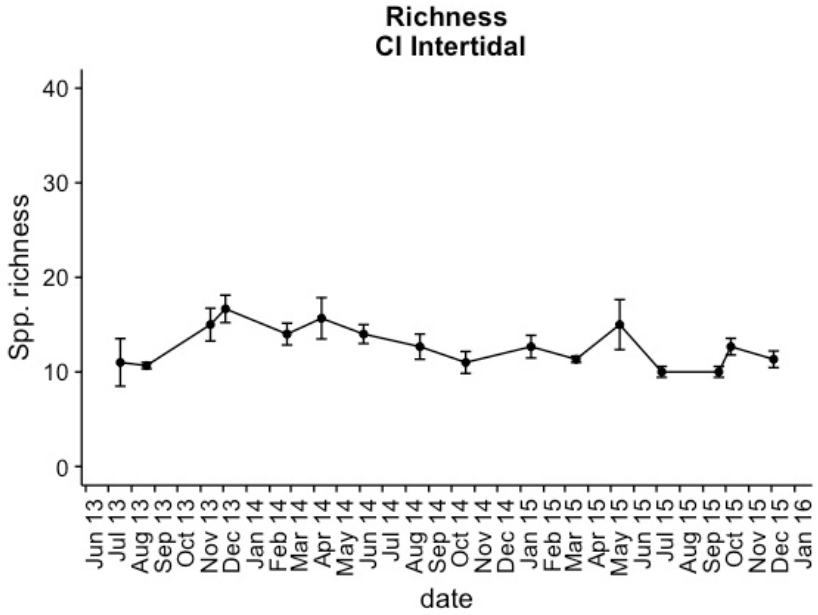
Oct 15
Nov 15
Dec 15
Jan 16
date


Richness
CI Intertidal
Spp. richness
40
30
20
10
0
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
Sep 14
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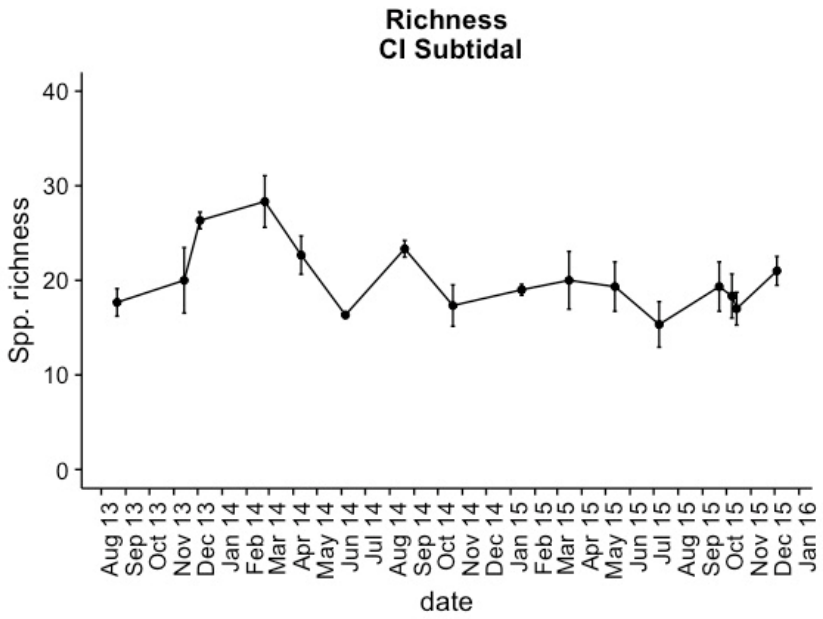
Oct 15
Nov 15
Dec 15
Jan 16
date


Richness
CI Subtidal
Spp. richness
40
30
20
10
0
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Aug 14
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Nov 15
Dec 15
Jan 16
date