

Testing the Effect of Live Oyster Presence and Structural Diversity on Nekton Abundance and Diversity

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ABSTRACT

Biogenic reefs formed by the eastern oyster (*Crassostrea virginica*) provide structurally diverse habitat which supports high densities and diversity of nekton communities relative to other habitat types within estuarine systems. Past studies suggest that the presence of structure alone may be the most important factor in attracting nekton species to reef formations and that increased structural complexity is not a limiting factor for provision of nekton habitat. Few studies, if any, have directly examined the effect of live oyster presence on nekton habitat use. We used a quantitative sampling technique to examine the effect of live oyster presence and structural complexity of experimental reef units on nekton abundance and diversity. Specifically, we created five reef complexity treatments by placing 5 L of substrate collected on-site in sample trays. Treatments consisted of 4 replicate trays each of no shell (control), loose shell, live single oysters, live oyster clusters only, and a combination of reef material comparable to adjacent natural reef, placed over reef and mud habitat in Sabine Lake, LA. Trays were sampled 3 weeks later. We found significantly higher nekton abundance and diversity for all treatments holding shell or oysters as compared to empty control treatments, but found no significant differences in abundance or diversity among experimental units that varied in live oyster presence and structural composition. The presence of reef material had the greatest effect on nekton support.

INTRODUCTION

Oyster reefs formed by the Eastern oyster (*Crassostrea virginica*) are a common feature of bays and estuaries along the U.S. Atlantic and Gulf of Mexico coasts. However, oyster reefs have been degraded in the U.S. and around the world due to overharvesting and coastal degradation (Beck et al 2011). Oysters of different species are found in coastal regions around the world, and Beck et al (2011) estimated that oyster reef habitat has been reduced by 85% globally. This extensive loss is of great concern to natural resource management agencies and conservation groups because of the ecological functions and ecosystem services provided by reefs. Reefs have been shown to support higher abundances and biodiversity of fish and crustaceans as compared to other estuarine habitats such as mud bottom and vegetated marsh edge (Stunz et al 2010). Shervette and Gelwick (2008) found evidence that oyster reefs may serve as a nursery habitat for juvenile white shrimp (*Litopenaeus setiferus*), an economically and ecologically important species, during their development into adult form. Oyster reefs exist at various levels of structural form and complexity, ranging from 3-dimensional living reefs to low-relief shell bottoms consisting of small living clusters and non-living shell rubble within the substrate. While complex habitats are considered to be the most ecologically functional and often support high abundances and diversity of organisms, it remains unclear what aspects of reef structure

(i.e., reef height), or complexity (i.e., interstitial space, live oysters) are associated with enhanced diversity and abundance of species.

Oyster reefs and shell beds provide valuable ecosystem services. Piazza et al (2005) found that created intertidal oyster shell reefs in low wave energy environments significantly slowed shoreline erosion as compared to non-cultched sites, although the effects were insignificant in high wave energy environments. Piazza et al (2005) also observed oyster recruitment and spat growth rates that suggest created oyster shell reefs may be a viable option for creating sustainable reefs. In a similar study, Meyer et al (1997) observed a significant increase in marsh vertical accretion upland of created intertidal shell piles as compared to sites without shell. The findings of Piazza et al (2005) and Meyer et al (1997) suggest that creation of intertidal oyster shell reefs may be a practical possibility for shoreline protection in coastal areas experiencing high rates of shoreline erosion.

Living oysters can also improve water quality through filtration of excess nutrients and suspended solids. The presence of living oysters has resulted in lowered concentrations of suspended solids and chlorophyll downstream of created reefs in tidal marsh creeks (Nelson et al 2004). Although the ability of oysters to improve water quality at large spatial scales has not been thoroughly examined, small-scale local improvements have been observed (Nelson et al 2004, see Coen et al 2007).

Restoration of oyster populations has become a goal of coastal fisheries management agencies as well as conservation groups such as The Nature Conservancy (Coen et al 2007). Past restoration efforts have proven successful in restoring oyster populations and ecological functions. Meyer and Townsend (2000) found created intertidal shell reefs to be rapidly colonized by oyster spat and other sessile invertebrates, with market-sized oysters present within two years of reef construction. The presence of carnivorous fish and crustaceans along with prey species also indicates that rapid community development comparable to natural reef communities is possible shortly after artificial reef construction (Meyer and Townsend 2000). One issue with oyster restoration has been the lack of standard success criteria for assessing artificial reef condition after construction (Luckenbach et al 2005). Reefs have historically been judged based on fisheries criteria, which focus on oyster size distribution and abundance and the presence of large, market-sized (75mm) oysters (Powers et al 2009). However, recent research has focused on artificial reefs ability to support diverse communities of nekton and sessile invertebrates as one measure of success. Studies have shown that the presence of large oysters is not necessary for a reef to support diverse and abundant assemblages of organisms (Luckenbach et al 2005, Powers et al 2009).

Numerous studies have shown that the presence of structure results in increased abundance of nekton and more diverse communities compared to habitats without structure (Stunz et al. 2010, Shervette and Gelwick 2008, Lehnert and Allen 2002, Humphries et al 2011), but little research has been focused on the presence of live oysters or the characteristics of the shells (i.e., clusters, singles) as a requisite for increased diversity and density of nekton communities. Several studies have examined the effects of reef relief (height), and found inconsistent results

related to reef height and nekton support (i.e. Lehnert and Allen 2002, Lenihan et al. 2001). More recently, Humphries et al (2011) found that while the presence of reef structure increased the density of organisms and diversity of nekton communities relative to mud-bottom habitats, an increase in reef structural diversity, defined by increased interstitial space, did not result in increased nekton density or diversity. No published study has specifically looked at how the presence of live oysters on a reef affects nekton communities. The primary aim of this study is to test for the effects of live oyster presence on nekton community support, with secondary goals of testing the effects of substrate structural diversity (defined as increased interstitial space), habitat setting, and sampling procedures on nekton support. The results of this study may have important implications for the assessment of oyster reef restoration success. If it is found that live oysters are not required for a reef to support complex nekton communities, then the success criteria for restoration projects may be altered by excluding live oyster abundance as a necessary component of success.

MATERIALS AND METHODS

Study Area

The study was conducted in the southern portion of Sabine Lake, a 181 km² estuarine lake forming a border between Cameron Parish, Louisiana, and Jefferson County, Texas. Sabine Lake is fed by the Sabine River and the Neches River to the north and flows south into the Gulf of Mexico via the Sabine Pass Channel. Experimental reefs were placed west of Blue Buck Point (N 29.7946612°/W -93.9029449°), a cape along the eastern shoreline in the southern portion of the lake. Side-scan sonar data from the Louisiana Department of Wildlife and Fisheries shows a wide distribution of oyster beds and vertically developed reef in this area west of Blue Buck Point (Encos, 2008). Sabine Lake is unique in that it holds the country's only oyster reefs that have not been degraded due to commercial oyster harvest. The Texas Parks and Wildlife Department (TPWD) reported very few records of commercial harvest in Sabine Lake. There is no known record of oyster harvest from Sabine Lake since 1965, making it the only area of oyster resources in the Gulf of Mexico that has not been recently impacted by commercial oyster harvest (TPWD 2008).

Study Design

Five treatments, described in more detail below, were created by varying the type of substrate placed in modified experimental trays (Beck, unpublished data). The treatments were chosen to test for nekton response to differences in habitat complexity provided by differences in the population distribution of oyster reefs harvested to different levels. A reference treatment, which was an empty modified experimental tray, tested for the effect of the tray unit on providing habitat. All treatments were replicated 4 times over two different habitat types: existing oyster reef, and existing mud bottom. This design allowed us to examine the effect of surrounding landscape on the reef mesocosms created. In May 2011, we selected two areas, one over existing oyster reef, and one over existing mud bottom and randomly selected 20 sites at least 10 m apart, and located 100 m from the shoreline. In total, 40 sites (5 treatments x 2 habitat types x 4 replicates) were selected. However, due to limited time availability in the field, the field crew was forced to reduce the number of SINGLE treatments deployed. Only 2

and 3 SINGLE treatments were applied in the MUD and REEF habitats, respectively, for a total of 18 and 19 treatments applied to MUD and REEF habitats, respectively. The modified trays were deployed May 18, 2011 and retrieved on June 7, 2011, for a soak time of 20 days. All biological specimens collected were kept on ice and brought back to the USGS Louisiana Fish and Wildlife Cooperative Research lab at LSU for identification and measurement.

Environmental variables

Water quality variables (D.O., salinity, and temperature) were measured at the time of tray retrieval using a YSI model 85-10FT Multiprobe (YSI Inc., Yellow Springs, OH, U.S.A.). Total suspended solids, particulate organic matter, and chlorophyll data were gathered from previous studies on oyster reefs of Sabine Lake (Beck 2011, unpublished data). Depth was measured at each tray site to ensure that depth did not vary significantly between tray locations.

Nekton collection

Fish and decapod crustaceans were quantitatively sampled using a modified tray design (Beck 2011). The base of the trap was formed by a beige plastic tray with a basal area of 361 in² (0.23 m²). Attached to the tray was a bag net made of 1/16 in² delta knotless netting (length x width x height; 19" x 19" x 24"), forming a bag with an open top. The bag net was equipped with a cinch line along the upper edge to close the bag and trap any organisms upon retrieval of the trays. The added weight of the shell treatments allowed the traps to rest on an underwater substrate. Attached to the base tray was a 12 foot buoy line to aid in location and retrieval of the traps.

Five different shell treatments were applied to the traps, each treatment using a different type or combination of substrate (Table 1). All treatments consisted of 5 Liters of material for standard comparisons. The first treatment was a control (CONTROL) with no oyster shell applied. Attached to the control trays were two mason bricks to add weight and keep the trays in place on the lake bottom. The next treatment (SHELL) used clean, loose oyster shell cultch only. The third treatment (SINGLE) contained all single live oysters which were non-aggregated. All live oysters were dredged on-site and varied in size. Live oysters were counted based on their status as "market" or "seed" size, with market oysters being greater than 75mm long and seed oysters less than 75mm. The fourth treatment (CLUSTER) contained only clusters of live oysters, with a cluster defined as any aggregate of three or more oysters. The CLUSTER treatment did not differ from the SINGLE treatment in volume of material or live oyster presence, but it does provide larger interstitial spaces that may affect nekton utilization of the substrate. No "box" oysters were included in the cluster treatments in order to avoid the provision of more desirable habitat in some replicates but not others. The final treatment was labeled as a "natural" (NATURAL) composition of oyster shell material, and aimed to replicate the current natural reef conditions of Sabine Lake. For this treatment oysters were selected randomly from reef material dredged on site. This reef material was composed of single live oysters, clusters of oysters, non-living shell material, and box shells. The shell materials in all treatments were quantified based on physical characteristics (Table 2).

Treatment	Volume (L) of single live oysters	Volume (L) of live oyster clusters	Volume (L) of non-living shell material
Control	0	0	0
Shell	0	0	5.0 ± 0.0
Single	5.0 ± 0.0	0	0
Cluster	0	5.0 ± 0.0	0
Natural	0.66 ± 0.38	4.28 ± 0.41	0.06 ± 0.12

Table 1. Volumes (mean ± standard error) of oyster shell used in each treatment. Values averaged across all replicates per treatment.

Treatment	# single live oysters	# oyster clusters	# seed sized oysters	# market sized oysters	# non-living shells	# box shells
Control	0	0	0	0	0	0
Shell	0	0	0	0	Not quantified	0
Single	70.8 ± 12.89	0	14.8 ± 6.06	56.0 ± 7.84	0	0
Cluster	0	21.0 ± 3.29	14.75 ± 5.50	38.63 ± 3.42	0	0
Natural	7.88 ± 3.94	16.88 ± 2.17	17.25 ± 2.43	37.25 ± 4.80	1.5 ± 1.20	7 ± 1.51

Table 2. Quantitative composition of shell treatments based on aggregation, size, and living status. Box shells were not removed from dredged material used in “Natural” treatments and were not present in any other treatments. Presented are mean ± standard error.

Statistical analyses

We used a two-way analysis of variance (ANOVA) to test for differences in catch per unit effort and species richness between treatment types (CONTROL, SHELL, SINGLE, CLUSTER, NATURAL) when separated by habitat type (MUD, REEF). Habitat was not significant, so we used a one-way ANOVA was used to test for differences by treatment type followed by a Student-Newman-Kuels grouping analysis to test for differences in catch per unit effort and species richness by treatment. All data were tested for normality and homogeneity of variance.

RESULTS

Environmental variables

Environmental variables did not differ between habitat types (Table 3). The depth of water at each tray location was an average of 1.8 m (±0.2) and did not significantly differ between habitats.

Date	Habitat	Top Temperature	Bottom Temperature	Top Salinity	Bottom Salinity	Top D.O.	Bottom D.O.
7 June 2011	Mud	29.8	29.8	19.8	19.8	4.01	4.08
7 June 2011	Reef	29.5	29.5	19.8	19.5	4.09	4.12

Table 3. Water temperature, salinity, and dissolved oxygen recorded at time of tray retrieval and nekton collection. Variables taken near surface and near lake bottom. Temperature reported in degrees Celsius, salinity as parts per thousand, and dissolved oxygen as mg L⁻¹

Nekton assemblages

Of the 37 experimental reef units deployed, 30 units were retrieved. We attribute failed retrieval to loss of buoys during deployment dates, trays overturned by wave action, or accidental overturning of trays during retrieval process. Trays not retrieved from MUD habitat include: (1) Single treatment, (2) Cluster treatments, and (2) Natural treatments. Trays not retrieved from REEF habitat include: (1) Cluster treatment and (1) Natural treatment.

We collected a total of 514 individuals (39 fishes and 475 decapod crustaceans) representing 14 species (7 fishes and 7 decapod crustaceans) with a total biomass of 558 g wet weight (58 g and 500 g for fishes and decapods crustaceans, respectively). See Tables 3 and 4 for detailed species account.

Crustacean species	Total catch		CONTROL		SHELL		SINGLE		CLUSTER		NATURAL	
	MUD(M) n=13	REEF(R) n=17	M n=4	R n=4	M n=4	R n=4	M n=1	R n=3	M n=2	R n=3	M n=4	R n=3
All crustacean spp.	178	297	19	49	43	62	22	57	33	62	61	67
<i>Alpheus</i> spp.	15	7	1	0	6	3	1	1	2	1	5	2
<i>C. sapidus</i>	2	0	1	0	0	0	1	0	0	0	0	0
<i>E. depressus</i>	36	86	0	5	2	25	1	21	14	12	19	23
<i>M. mercenaria</i>	0	1	0	0	0	0	0	0	0	1	0	0
<i>Palaemonetes</i> spp.	86	123	15	36	14	14	14	17	10	34	33	22
<i>P. simpsoni</i>	39	78	2	7	21	20	5	17	7	14	4	20
Xanthidae spp.	0	2	0	1	0	0	0	1	0	0	0	0

Table 3. List of decapod crustacean species and abundances per tray by habitat type and shell treatment.

Fish species	Total catch		CONTROL		SHELL		SINGLE		CLUSTER		NATURAL	
	MUD(M) n=13	REEF(R) n=17	M n=4	R n=4	M n=4	R n=4	M n=1	R n=3	M n=2	R n=3	M n=4	R n=3
All fish spp.	15	24	2	2	4	5	3	7	2	5	4	5
<i>H. ionthas</i>	0	1	0	0	0	0	0	0	0	1	0	0
<i>Gobiidae</i> spp.	2	1	1	0	0	0	0	0	0	0	1	1
<i>G. strumosus</i>	5	7	0	0	1	4	0	1	2	1	2	1
<i>G. boleosoma</i>	1	0	0	0	0	0	1	0	0	0	0	0
<i>G. bosc</i>	5	6	1	0	3	0	1	4	0	1	0	1
<i>O. beta</i>	2	8	0	2	0	1	1	1	0	2	1	2
<i>M. punctatus</i>	0	1	0	0	0	0	0	1	0	0	0	0

Table 4. List of fish species and abundances per tray by habitat type and treatment.

Two-way ANOVA showed that habitat type (MUD, REEF) had no significant effect ($\alpha=0.05$) on nekton density (Figure 1) or species richness (Figure 2). Because habitat type had no significant effect on nekton density or richness, we combined data from each habitat to strengthen the statistical results of our analysis of nekton density and species richness. There was a significant difference by treatment type (CONTROL, SHELL, SINGLE, CLUSTER, NATURAL) on nekton density ($p=0.0048$, Figure 3) and on species richness ($p=0.0014$, Figure 4). Student-Newman-Keuls (SNK) grouping analysis ($\alpha=0.05$) indicated a significant effect of treatment type on both nekton density (Table 5) and species richness (Table 6). Specifically, nekton density from CONTROL was significantly lower than the NATURAL and SINGLE treatments. Nekton density from CLUSTER and SHELL did not differ significantly from any of the other treatments. The richness of CONTROL treatments was significantly lower than all other treatments.

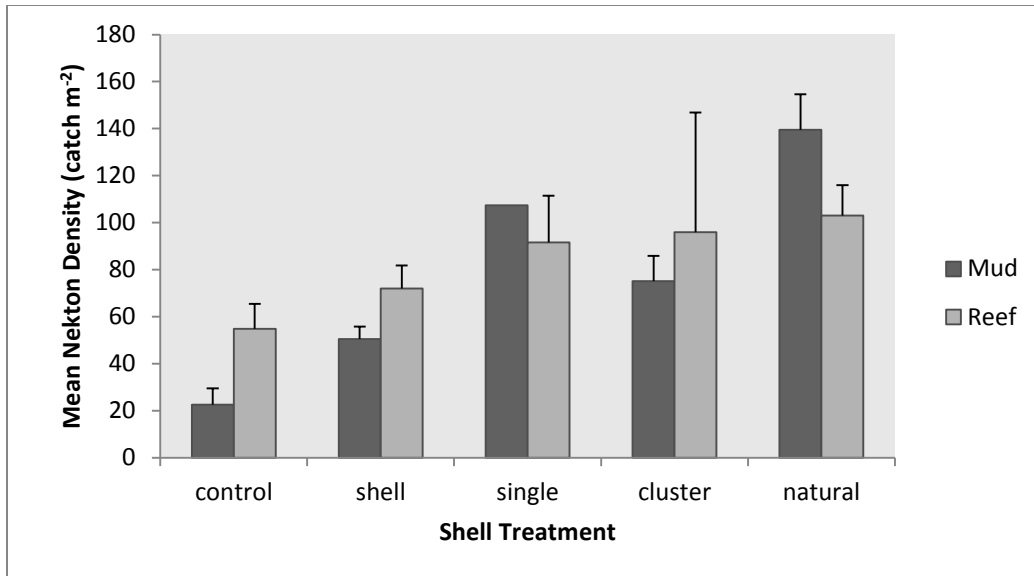


Figure 1. Mean nekton density separated by shell treatment and habitat type. Density defined as catch of all nekton specimens collected per square meter. Shell treatments vary by types of oyster shell used to fill trays (Control=no shell used; Shell=unaggregated oyster shell cultch; Single=unaggregated live oysters; Cluster=aggregated live oysters; Natural= combination of aggregate and single live oysters representative of natural reef conditions in Sabine Lake). All treatments consisted of 5L of shell material. Two-way ANOVA showed no significant difference between mud and shell habitats. One-way ANOVA shows a significant trend in shell treatments.

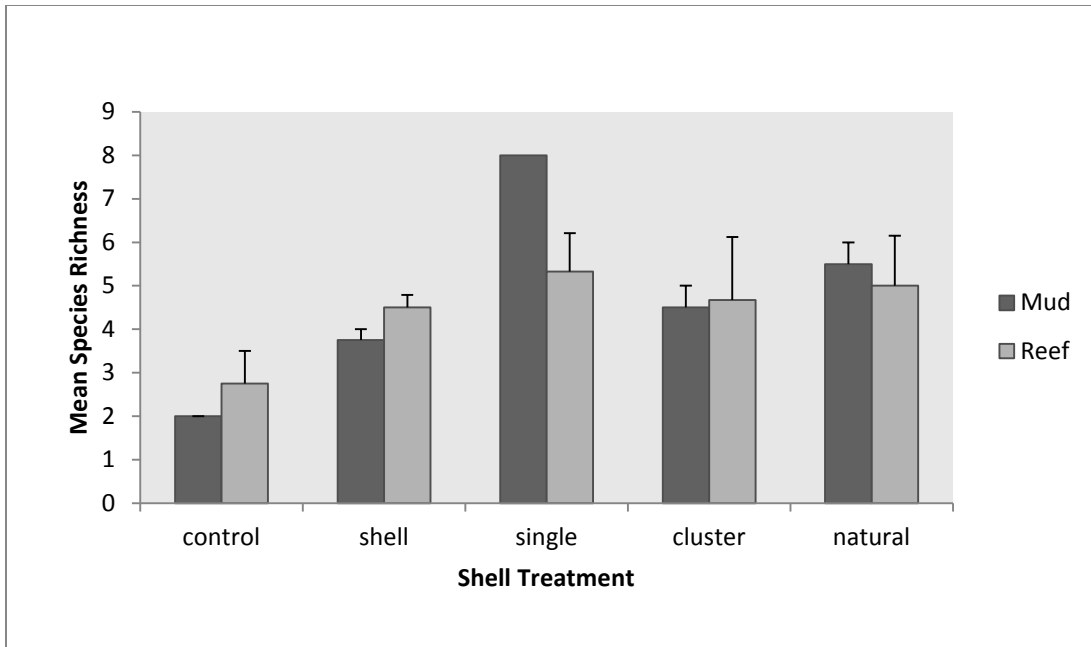


Figure 2. Mean species richness by shell treatment and habitat type. Richness defined as the number of species collected in each tray. Shell treatments varied by types of oyster shell used to fill trays (Control=no shell used; Shell=unaggregated oyster shell cultch; Single=unaggregated live oysters; Cluster=aggregated live oysters; Natural= combination of aggregate and single live oysters representative of natural reef conditions in Sabine Lake). All treatments consisted of 5L of shell material. Two-way ANOVA showed no significant difference between mud and shell habitats. One-way ANOVA showed a significant trend in shell treatments.

Shell Treatment	NATURAL	SINGLE	CLUSTER	SHELL	CONTROL
Mean Nekton Density (m^{-2})	117.646	95.533	87.590	61.184	38.643
SNK Group	A	A	AB	AB	B

Table 5. SNK grouping analysis of mean nekton density by treatment type. Groups of different letters indicate significant variations ($\alpha=0.05$).

Shell Treatment	SINGLE	NATURAL	CLUSTER	SHELL	CONTROL
Mean Species Richness	6.000	5.200	4.600	4.125	2.375
SNK Group	A	A	A	A	B

Table 6. SNK grouping analysis of mean species richness by treatment type. Groups of different letters indicate significant variations ($\alpha=0.05$).

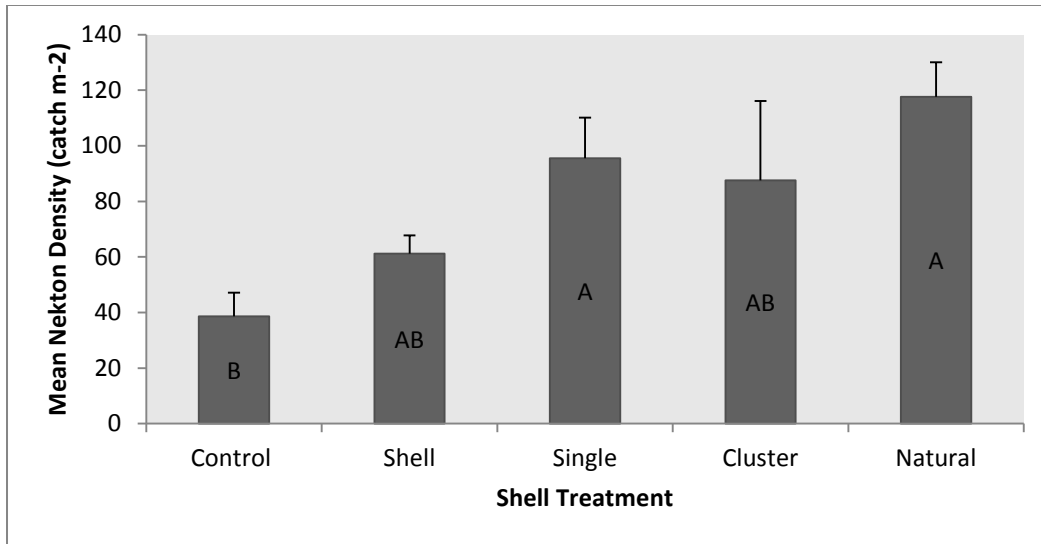


Figure 3. Mean nekton density by treatment type. Density defined as catch of all nekton specimens collected per square meter. Different letters indicate significant differences in means (SNK, $\alpha < 0.05$).

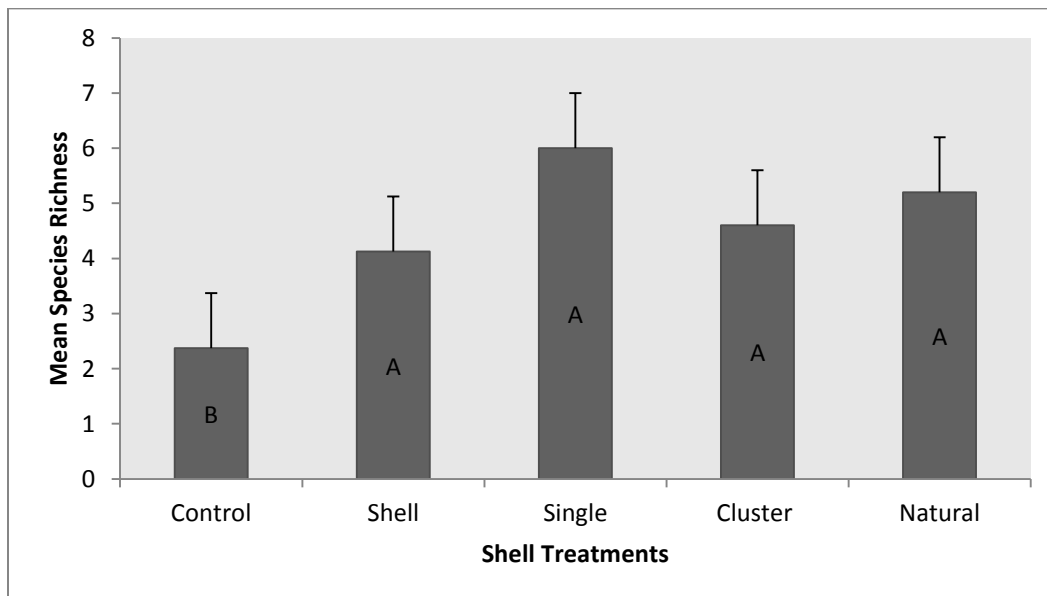


Figure 4. Mean species richness by treatment type. Species richness defined as number of species collected in each tray. Different letters indicate significant differences in means (SNK, $\alpha < 0.05$).

DISCUSSION

The presence of live oysters did not have a significant effect on nekton density within the experimental reefs. However, all three treatments with live oysters (SINGLE, CLUSTER, NATURAL) supported higher nekton densities than those without live oysters (CONTROL, SHELL). All treatments containing oysters or shell material supported greater nekton densities than control treatments lacking any oyster material, although not all oyster treatments were significantly greater than control treatments. Control treatments may have caused a sampling effect resulting from the structure of the trays alone. When considered together, these results suggest that the presence of structure alone may be the most important factor determining nekton densities within reefs.

All treatments containing oysters or shell material supported significantly greater diversity of nekton species as compared to control treatments, but oyster material treatments did not vary significantly from each other. This result suggests that the presence of structure may also be the most important factor in determining the diversity of nekton communities within reefs.

There were no significant differences in either nekton density or species diversity between SINGLE and CLUSTER treatments. This suggests that an increase in interstitial space within reefs may not be limiting factor in nekton community support. However, these treatments were not assessed at a species-specific level and therefore we cannot conclude that variations in interstitial space do not affect habitat use by any particular species.

The surrounding habitat type (MUD, REEF) did not have a significant effect on either nekton density or species diversity, suggesting that landscape setting was not a factor in this study. However, we are not concluding that landscape setting and adjacent habitat types are not a factor in other settings. The distance between MUD habitat and REEF habitat treatment placement was greater than 100 m apart, but the actual distance between treatment placement and adjacent habitat types is not known for sure. At larger spatial scales, surrounding habitat type may have a significant effect on the ability of a reef to support nekton communities, i.e. reef islands surrounded by extensive mud habitat may support lower densities and diversity of nekton as compared to experimental reefs surrounded by reef habitat. Our experimental reefs were also placed greater than 100 m from the shoreline to reduce the effect of adjacent marsh edge habitat, but the influence of marsh edge was not evaluated in this study.

Despite the lack of significant differences in treatment types on nekton density or species diversity, we observed a trend in nekton density based on treatment type. The lowest densities were observed in the CONTROL treatments and all three treatments with live oysters (SINGLE, CLUSTER, NATURAL) were greater than the non-living SHELL treatment (figure 3). Perhaps with a larger sample size these differences would have become more clear and indicated that live oyster treatments may in fact support higher nekton densities than non-living shell treatments, but the results of this study do not provide evidence supporting that conclusion.

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