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Changes in the Abundance and Distribution of Benthic Mollusks in Polluted Sediments of a Shallow Subtropical Estuary

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by Rachael Holtsberg Stark

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Abstract

Changes in the Abundance and Distribution of Benthic Mollusks in Polluted Sediments of a Shallow Subtropical Estuary

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The Indian River Lagoon (IRL) has been degraded by decades of eutrophication, and has accumulated an abundance of fine-grained, organic-rich sediments (muck). To quantify the impacts of organic sediments and environmental dredging, benthic mollusks were chosen to serve as bioindicators of environmental change, sediment health, and water quality. Data on species richness, biodiversity, and abundances was collected alongside sediment and water quality data before, during and after dredging. Organic sediment content was found to have an inverse logarithmic relationship benthic mollusk biodiversity, species richness, and abundance. Sediments low in percent organic content (0.7% to 6.1%) were located near the adjacent seagrass beds. Sediments with lower organic content generally had higher biodiversity (up to 1.337). Sediments with higher organic content generally had low biodiversity (0-0.6667). These biological correlations were analogously observed with sediment silt-clay (%) and sediment water content (%). However, variability was high and no significant pre- vs. post-dredging differences were observed in the community data. Post-hoc analyses found that percent

dissolved oxygen was responsible for 29.31-34.12% of the variation in the benthic mollusk community data.

Table of Contents

List of Figures

List of Tables

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Chapter 1:
Introduction

One of the biggest anthropogenic stressors that estuaries around the globe are facing is nutrient loading. According to Bricker et al 2008, “Eutrophication is regarded as one of the greatest threats to coastal ecosystem health”. While some level of nutrients are in estuaries naturally due to geological weathering and upwelling, the extreme nutrient loading is likely due to a combination of anthropogenic influences. Issues related to eutrophication are an increase in the growth rates of “weedy” invasive flora, harmful algal blooms (HABs) and increased turbidity. These two subsequent issues can lead to hypoxic conditions, fish kills, decline in submerged aquatic vegetation, a shift to pelagic-dominated productivity, and loss of biodiversity. Each of these ecosystem impacts can have significant economic impacts (e.g., tourism, fisheries, recreation, and real estate) (Bricker et al 2008). An estuary facing many of these issues is the Indian River Lagoon (IRL, Florida).

The IRL is an ecologically important and biodiverse estuary, with an estimated 2,500 species in residence (Tremain & Adams, 1995; Dawes *et al*, 1995). This is due both to geographic location, where temperate and tropical climates overlap, and the foundation species that serve as habitats and food (Dawes *et al*, 1995). In 1997, the NOAA National Estuarine Eutrophication Survey found that the IRL was “*hypereutrophic* with respect to excessive carbon fixation”, and this due to nutrient pollution (Barile 2018). Despite attempts to address and reduce nutrient pollution, the anthropogenic degradation in the IRL is still evident (Tetra Tech and Close Waters, 2011). A few recent incidents that can be traced back to nutrient pollution include: the "superbloom" event of 2011, recurrent brown tide events, mortality events of marine mammals and shorebirds, and large fish kills due to algal decomposition and anoxia. The IRL also suffers from nutrient pollution and anthropogenic impacts, such as "Stormwater runoff from urban and agricultural areas, wastewater treatment facility discharges, faulty septic systems, and excess fertilizer applications" (Tetra Tech and Close Waters, 2018). The aforementioned bloom events and anthropogenic influences over the past few decades have led to the accumulation of fine-grained, organic-rich sediments on the bottom of the estuary, colloquially known as muck.

Muck is a primary repository for toxic metals, organic substances, and anthropogenic nutrients (Fox and Trefry 2018). IRL muck is comprised of 10-30% organic matter, 60% silt and clay, and a water content of about 75% by weight, as defined by Fox and Trefry (2018). It is estimated to cover around 10% of the IRL, ranging from a few centimeters to several meters in thickness (Bradshaw *et al* 2020). Muck exacerbates the IRL's eutrophication and habitat degradation via water column resuspension, HAB-fueling nutrient fluxes, benthic light shading, hypoxia induction, and benthic smothering (Erftemeijer & Lewis, 2006; Donohue & Molinos, 2009; Fox & Trefry, 2018). Turbidity, HABs, and smothering can lead to a loss in important benthic habitat, including seagrass meadows (Trefry *et al* 2007). The loss of critical habitats decreases biodiversity, species richness, and benthic community abundances. Hypoxic conditions alter community composition and may selectively eliminate sensitive species, thereby promoting the growth and recruitment of those with a higher tolerance for less ideal conditions (Nerlović *et al* 2011).

Restoration projects for polluted and impaired estuaries may include dredging and other forms of mitigation and restoration (Tetra Tech and Close Waters, 2011). Environmental dredging is a remedial process attempting to remove contaminated sediments, improve water quality, and restore benthic habitats (Cox *et al* 2018). In the complex Indian River Lagoon System (Florida), environmental dredging for restoration has been carried out in several locations including Crane Creek, the Eau Gallie River, Sykes Creek, and the Mims Boat Ramp canal.

Mollusca is a diverse phylum in estuaries and coastal habitats. Among metazoan animals, they are second only to arthropods in taxonomic diversity (Mikkelsen *et al*, 1995, Fedsov & Puillandre 2012, Parkhaev 2017), and arguably more easily identified to lower taxonomic levels than other benthic groups (Nerlović *et al* 2011). Many benthic mollusks are relatively sessile, and even errant species tend to stay within a localized region. They have relatively longer life cycles and are sensitive to environmental changes (Coelho *et al* 2014). Due to these characteristics, they may serve as effective bioindicators of environmental change, sediment health, and water quality (Kim *et al* 2018, Wu *et al* 2017, Coelho *et al* 2014, McKeon *et al* 2015, Moraitis *et al* 2018). In the IRL, benthic bivalves and gastropods are especially abundant, both epifaunal (attached or unattached) and infaunal (Mikkelsen *et al*, 1995). Some common species include: *Acteocina canaliculate, Amygdalum papyrium, Astyris lunata, Haminoea succinea, Mulinia lateralis, Parastarte triquetra, Mercenaria mercenaria,* and *Phrontis vibex* (Johnson *et al*. 2019).

Many mollusks have lower metabolic and oxygen consumption rates relative to other benthic invertebrates (Bayne and Newell 1983, Fox and Simmons 1933, Pamatmat 1983, Salvato *et al* 2001), allowing them to persist in polluted organic sediments. Bayne and Newell (1983) compared the oxygen consumption rates of mollusks with different trophic roles and determined their consumption rates were low relative to other groups. This included grazers like the periwinkle snail *Littorina littorea* (oxygen consumption rate 2.052 ml/h), the suspension-feeding oyster *Crassostrea virginica* (oxygen consumption rate 0.496 ml/h), and the predatory snail *Nassarius reticulatus* (oxygen consumption rate 1.63 ml/h). In contrast, Fox and Simmons (1933) compared the oxygen consumption rates of several species of arthropods, including the amphipods *Gammarus marinus* (oxygen consumption rate 191-367 c.mm.*/gr./hr) and *Gammarus locusta* (oxygen consumption rate 188-207 c.mm.*/gr./hr), and the isopod *Idotea neglecta* (oxygen consumption rate 125-321 c.mm.*/gr./hr). Salvato *et* al (2001) compared the effects of several environmental conditions on oxygen consumption by the decapod crustaceans *Palaemon serratus* (mean oxygen consumption rate 0.3519 ml O_2/g wet tissue/hr) and *Panaeus monodon* (mean oxygen consumption rate 0.5287 ml O_2/g wet tissue/hr), and the prosobranch gastropods *Trunc、ulariopsis trunculus* (mean oxygen consumption rate 0.0394ml O_2/g wet tissue/hr) and *Nassarius mutabilis* (mean oxygen consumption rate 0.0687 ml O_2/g wet tissue/hr). Pamatmat (1983) also compared the aerobic and anaerobic metabolic rates of bivalves to benthic polychaetes and also found that those of bivalves were lower. Lower mollusk oxygen consumption rates help them survive in more polluted conditions than other benthic taxa. Some mollusks are also able to withstand physiological stress caused by toxic H_2S, often associated with muck sediments (Bayne 1976, Coelho *et al* 2014). Theede *et al* (1969) found that *Mytilus edulis* can survive 25 days in water containing H_2S, vs 35 days in water with 0.15ml O_2/l. H_2S tolerance is important for benthic organisms in order to survive in hypoxic and anoxic environments (Bayne 1976, Theede *et al* 1969).

Despite being seemingly well-suited to polluted estuarine conditions (Moraitis *et al* 2018, Nerlović *et al* 2011, Coelho *et al* 2014), fine gills and other structures may be clogged by silt and clay particulates, potentially suffocating benthic mollusks (Hope 2016, Pearson 1980). Pearson (1980) found that benthic communities exposed to a high effluent input typically exhibit low diversity, are poorly organized, and are composed of small r-selected species. Pearson (1980) and Rhoades and Young (1970) suggest that, in some systems, this could be due to trophic amensalism, where deposit feeders exclude filter-feeding neighbors by disturbing and resuspending sediments, clogging filter-feeding mechanisms. Since muck is easily resuspended (Hope 2016), smothering or suffocation is a significant threat to benthic mollusks in degraded habitats. Some mollusks in the IRL persist in polluted conditions, yet still are stressed in organic sediments (Hope 2016). Moraitis *et al* (2018) stated that effective bioindicators, like benthic estuarine mollusks, are easily monitored and display the effects of environmental change.

This study addresses the following hypotheses:

(1) There is an inverse relationship in the biodiversity, species richness, and abundances of mollusks with sediment percent organic content.

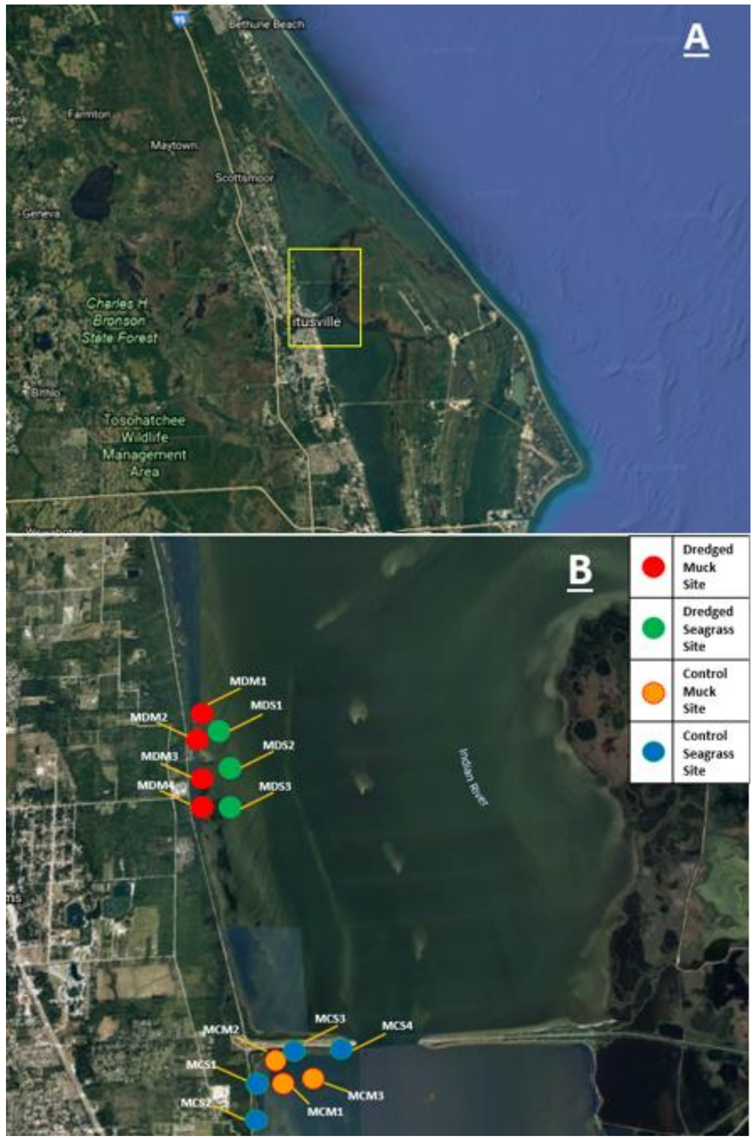
(2) Removal of sediments with high concentrations of fine-grained organic matter by dredging will increase the biodiversity, species richness, and abundances of benthic mollusks.

Chapter 2:
Methods

To determine the impacts of organic sediments and dredging restoration on benthic mollusk communities, benthic grabs, sediment samples, and water quality data were collected before, during, and after dredging at sites-to-be-dredged, as well as undredged control sites. Data were collected quarterly from March 2017 until October 2020 (Table 1) from 14 stations in Mims, Fl (Figure 1). All 14 stations are located within the IRL proper (Figure 1 and Table 2).

Table 1: Seasonal sampling schedule for study sites from 2017-2020. X's indicate which sites were sampled during that quarter.

	Spring	Summer	Fall	Winter
2017 MDS	x	x	x	x
2017 MDM	x	x	x	x
2017 MCS		x	x	x
2017 MCM		x	x	x
2018 MDS	x	x	x	x
2018 MDM	x	x	x	x
2018 MCS	x	x	x	x
2018 MCM	x	x	x	x
2019 MDS	x	x	x	x
2019 MDM	x	x	x	x
2019 MCS	x	x		x
2019 MCM		x		x
2020 MDS		x	x	x
2020 MDM		x	x	x
2020 MCS		x	x	x
2020 MCM		x	x	x



<u>Figure 1</u>: A) The region in the northern IRL in which this study was conducted, including treatment and control sites. **B)** Stations were dredged muck stations (MDM, red), seagrass stations near dredging (MDS, green), control (undredged) muck stations (MCM, orange), and seagrasses near undredged (control) muck stations (MCS, blue).

Table 2: GPS Coordinates for control and treatment sampling stations (see Figure 1).

Site	Stations	GPS Coordinates
Mims Dredged Muck	MDM-1	28°40’51.43” N 80°49’35.32” W
	MDM-2	28°40’46.65” N 80°49’35.50” W
	MDM-3	28°40’38.50” N 80°49’32.36” W
	MDM-4	28°40’30.14” N 80°49’30.80” W
Mims Dredged Seagrass	MDS-1	28°40’50.09” N 80°49’34.30” W
	MDS-2	28°40’39.63” N 80°49’29.50” W
	MDS-3	Originally 28°40’31.83” N 80°49’33.48” W Changed to 28°40’41.07” N 80°49’27.36” W in October, 2020
Mims Control Muck	MCM-1	28°38’51.70” N 80°49’02.52” W
	MCM-2	28°38’57.82” N 80°49’02.24” W
	MCM-3	28°38’55.61” N 80°48’53.69” W
Mims Control Seagrass	MCS-1	28°38’41.50” N 80°49’09.88” W
	MCS-2	28°38’50.20” N 80°49’10.20” W
	MCS-3	28°39’01.10” N 80°48’53.70” W
	MCS-4	28°39’01.40” N 80°48’39.30” W Stopped sampling here in 2020

Water quality was recorded at each sampling station, which included temperature, salinity, percent saturation of dissolved oxygen (DO), mg/L DO, turbidity, and total water column depth. The Secchi depth (0.5-1 m deep) and total water column depth (0.5-5 m deep) were determined for each sampling station. A Yellow Springs Instrument (YSI) Multimeter was calibrated prior to sampling against factory standards and was used to measure water quality at both the Secchi depth and total water column depth.

Four sediment grabs were collected at each station (Figure 1B) with a Petite Ponar grab (benthic sampling area of 225 cm^2), with one grab for sediment analysis and three grabs for the faunal survey. Total sediment volumes were recorded for calculations of organism densities and grab penetration depth. Benthic fauna grabs were sieved through a 0.5mm sieve and placed in labeled plastic bags. One unsieved grab from each station was bagged for sediment characterization (% water content, % organic content, and % silt/clay content). Samples were then transported to the laboratory in a cooler. Fauna samples were frozen pending microscope sorting, and sediment samples were refrigerated while they awaited processing.

Fauna samples were thawed and sorted via light stereomicroscopy (8 – 35x magnification). Higher volume samples were split 1-4 times to allow for processing fauna in a timely manner. Fauna were identified to the lowest possible taxonomic level. Only whole organisms, apparently alive at time of collection, were counted. After processing, each sample was preserved in 4% formaldehyde solution for long-term storage. Counts were extrapolated to whole grabs and field densities.

In order to determine the silt/clay content of the sediments with visibly higher muck content (Folk 1974), ten grams of sample were used. For sandier samples, more sediment was required for accuracy and 30 grams of sediment were used to determine silt/clay content. Samples were then sieved through 63-micron mesh to separate silt/clay from larger sediment particles. Both smaller sample components were dried by baking at 105 degrees Celsius for 24 hours, then re-weighed, with the relative proportions yielding the % silt/clay content (Folk 1974). In a similar process, the % water content of the sediments was determined by weighing un-sieved sediments prior to and after baking them at 105 degrees Celsius for 24 hours (Sheridan et al., 2006). Sediment organic content was determined with the mass loss-on-ignition (LOI) method, where sediment is dried, ground, and weighed before and after baking at 550° C for 4 hours (Dean 1974; Heiri et al. 2001).

Biodiversity was calculated using the Shannon-Weiner index. Abundances, species richness, and biodiversity are being used to evaluate mollusk community responses to dredging. Generalized linear models were utilized to compare how dredged conditions, seasons, time since dredging, and sediment organic content, silt/clay content, and water content affect mollusk species richness, biodiversity, and abundance. 2-Way ANOVA tests were used to examine the influence of the categorical factors, time and season, on the biodiversity, species richness, and abundance of benthic mollusks. ANOSIM tests were conducted to assess the impact of percent sediment organic, silt/clay, percent water content, percent dissolved oxygen, salinity, water temperature, and, where applicable, seagrass percent cover on the biodiversity, species richness, and abundance of benthic mollusks. The ANOSIMs were paired with non-metric multi-dimensional scaling (nMDS) to represent community similarities and dissimilarities in multivariate space. All statistical tests, nMDS plots, and figures were carried out and created in R and Microsoft Excel.

Chapter 3:

Results

A total of twenty-seven species were identified at both the treatment and control sites over the course of this study. These represented two classes in Phylum Mollusca: Gastropoda and Bivalvia.

<u>Table 3</u>: A) Presence absence table of Gastropods and Bivalves at the Treatment and Control stations throughout the seasons. **B)** Presence absence table of Gastropods and Bivalves at the adjacent Seagrass stations throughout the seasons.

A

Gastropods	SMT Pre	SMT Post	SMC Pre	SMC Post	SumMT Pre	SumMT Post	SumMC Pre	SumMC Post	FMT Pre	FMT Post	FMC Pre	FMC Post	WMT Pre	WMT Post	WMC Pre	WMC Post
Acteocina atrata											x					
Acteocina canaliculata	x	x	x	x			x	x	x	x	x		x	x	x	x
Astyris lunata							x			x	x					x
Crepidula atrasolea																
Eulithidium pterocladicum																
Haminoea succinea	x								x							
Haminoea elegans	x						x									
Japonactaeon punctostriatus			x							x		x		x		
Limpit B																
Nassarius vibex		x				x	x	x	x	x	x	x	x	x	x	x
Odostomia laevigata	x									x						
Prunum apicinum																
Snail P														x		
Snail R																
Turbonilla sp.								x		x						
Bivalves	SMT Pre	SMT Post	SMC Pre	SMC Post	SumMT Pre	SumMT Post	SumMC Pre	SumMC Post	FMT Pre	FMT Post	FMC Pre	FMC Post	WMT Pre	WMT Post	WMC Pre	WMC Post
Amygdalum papyrium														x		
Angulus versicolor								x								
Anomalocardia cuneimeris									x					x		
Clam A																
Cyrtopleura costata																
Melongena Corona																
Mercenaria mercenaria	x										x					
Mulinia lateralis	x	x	x	x			x	x	x	x	x	x	x	x	x	x
Parastarte triquetra	x	x		x	x	x		x	x	x		x		x		
Periglypta listeri											x					

SMT	Spring Muck Treatment
SMC	Spring Muck Control
SumMT	Summer Muck Treatment
SumMC	Summer Muck Control
FMT	Fall Muck Treatment
FMC	Fall Muck Control
WMT	Winter Muck Treatment
WMC	Winter Muck Control

B

Gastropods	STS Pre	STS Post	SCS Pre	SCS Post	SumTS Pre	SumTS Post	SumCS Pre	SumCS Post	FTS Pre	FTS Post	FCS Pre	FCS Post	WTS Pre	WTS Post	WCS Pre	WCS Post
Acteocina atrata	x							x		x		x	x			x
Acteocina canaliculata	x		x	x	x	x	x	x	x	x	x	x		x	x	x
Astyris lunata	x	x	x	x			x	x		x	x	x	x	x	x	x
Crepidula atrasolea											x					
Eulithidium pterocladicum									x							
Haminoea succinea	x		x		x	x				x		x		x	x	x
Haminoea elegans				x	x				x	x		x				x
Japonactaeon punctostriatus			x	x	x	x	x	x	x	x	x	x				x
Limpit B						x				x						
Nassarius vibex	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Odostomia laevigata	x		x			x	x	x		x		x		x		x
Prunum apicinum	x		x					x		x			x	x		
Snail P																
Snail R					x	x		x	x			x		x		
Turbonilla sp.				x		x		x		x		x				x
Bivalves	STS Pre	STS Post	SCS Pre	SCS Post	SumTS Pre	SumTS Post	SumCS Pre	SumCS Post	FTS Pre	FTS Post	FCS Pre	FCS Post	WTS Pre	WTS Post	WCS Pre	WCS Post
Amygdalum papyrium			x					x		x	x	x			x	x
Angulus versicolor									x							x
Anomalocardia cuneimeris	x				x	x				x				x		
Clam A											x					
Cyrtopleura costata								x				x				x
Melongena Corona									x							
Mercenaria mercenaria									x							
Mulinia lateralis	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Parastarte triquetra	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Periglypta listeri								x	x			x				

STS	Spring Treatment Seagrass
SCS	Spring Control Seagrass
SumTS	Summer Treatment Seagrass
SumCS	Summer Control Seagrass
FTS	Fall Treatment Seagrass
FCS	Fall Control Seagrass
WTS	Winter Treatment Seagrass
WCS	Winter Control Seagrass

The treatment muck station had an average biodiversity of 0.103 m^{-2}, an average species richness of 0.55 m^{-2}, and an average abundance of 211.11 m^{-2} before dredging. After dredging, these values were 0.141 m^{-2}, 0.6363 m^{-2}, and 182.27 m^{-2} The control muck station had an average biodiversity of 0.21 m^{-2}, an average species richness of 1.056 m^{-2}, and an average abundance of 530.86 m^{-2} before dredging. After dredging, these values were 0.042 m^{-2}, 0.642 m^{-2}, and 767.08 m^{-2}. The seagrass stations adjacent to the treatment muck stations had an average biodiversity of 0.6 m^{-2}, an average species richness of 2.133 m^{-2}, and an average abundance of 758.52 m^{-2} before dredging. After dredging, these values were 0.52 m^{-2}, 2.72 m^{-2}, and 4481.55 m^{-2}. The seagrass stations adjacent to the control muck stations had an average biodiversity of 0.65 m^{-2}, an average species richness of 2.23 m^{-2}, and an average abundance of 919.44 m^{-2} before dredging. After dredging, these values were 0.484 m^{-2}, 3.202 m^{-2}, and 24609.2 m^{-2}.

While only 30% of the identified species were members of Bivalvia, the two species with the highest observed abundances were *Parastarte triquetra* and *Mulinia lateralis*. These species were particularly abundant in sandier stations, such as MDS and MCS (Figure 1). The highest observed abundances of *P. triquetra* and *M. lateralis* were 167733.3 and 3733.3 individuals per m^2 at MCS in 2020 and 2019 respectively (Figure 1). The adjacent seagrass stations (MDS and MCS) were also found to be the stations with the overall highest species richness. The highest species richness (6.33) was found at MCS in the winter of 2019. All 27 species were found to average 5445.426 organisms per m^2 or greater with an average species richness of 1.69 over the course of this study.

2-Way ANOVAS were conducted on treatment stations, control stations, the adjacent seagrass stations, each of the 27 individual species identified over the course of this study, as well as on a categorical breakdown of gastropods and bivalves at each of the treatment and control stations. The results of these ANOVAS have been summarized into a significance table. Individual ANOVA results can be found in the appendix.

Table 4: A) The pooled results of each of the 2-Way ANOVAS conducted on the biodiversity, species richness, and abundance of benthic mollusks throughout the course of the study. **B)** The individual 2-Way ANOVAS conducted on the abundance of each species throughout the course of the study.

A

Overall	Spring	Summer	Fall	Winter	Overall
Overall Biodiversity	X	X	X	X	X
Overall Species Richness	X	X	X	X	X
Overall Abundance	X		X		X
Gastropod Biodiversity	X	X	X	X	X
Gastropod Species Richness	X	X	X	X	X
Gastropod Abundance	X		X	X	X
Bivalve Biodiversity					X
Bivalve Species Richness	X	X	X	X	X
Bivalve Abundance	X		X		X

B

Gastropods	Spring	Summer	Fall	Winter	Overall
Acteocina atrata				X	X
Acteocina canaliculata					X
Astyris lunata					
Caecum pulchellum					
Crepidula atrasolea			X		
Eulithidium pterocladicum			X		
Haminoea succinea		X			X
Haminoea elegans		X			
Japonactaeon punctostriatus		X		X	
Limpit B					
Phrontis vibex			X		
Odostomia laevigata					
Prunum apicinum				X	
Snail P					
Snail R		X	X		X
Turbonilla sp.	X	X			
Bivalves					
Amygdalum papyrium					
Ameritella versicolor			X		
Anomalocardia cuneimeris		X	X		X
Clam A			X		
Cyrtopleura costata					
Melongena corona			X		
Mercenaria mercenaria			X		
Mulinia lateralis					X
Parastarte triquetra	X				X
Periglypta listeri		X	X		

The organic content of the sediments ranged from 0.7% to 36.4%. Sediments generally higher in organic content, ranging from 0.8% to 36.4%, were found in the treatment and control muck stations (Figure 1: MCM 1,2, and 3, and MDM 1,2,3, and 4). Accordingly, these organic-rich stations consistently had the lowest overall biodiversity (0-0.46), species richness (0-2.67), and abundances (0-3318.52 organisms/m^2). Sediments generally lower in percent organic content, ranging from 0.7% to 6.1%, were located near the adjacent seagrass beds. Sediments with higher organic content generally had low biodiversity (0-0.6667). Sediments with lower organic content generally had higher biodiversity (0-1.337). Generalized linear models found that sediment percent organic content had an inverse logarithmic correlation with overall mollusk biodiversity, species richness, and abundance at the treatment and control muck stations. Sediment percent organic content also had an inverse relationship with benthic mollusk abundance at the adjacent seagrass stations.

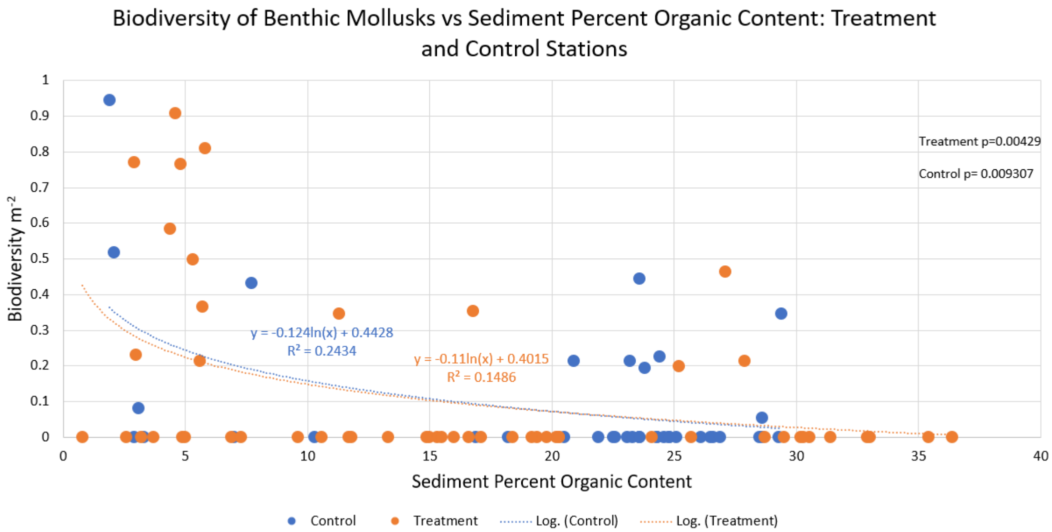


Figure 2: Benthic mollusk biodiversity(m^{-2}) vs sediment percent organic content at dredging treatment (orange) and control stations (blue). Regression shows an inverse logarithmic relationship.

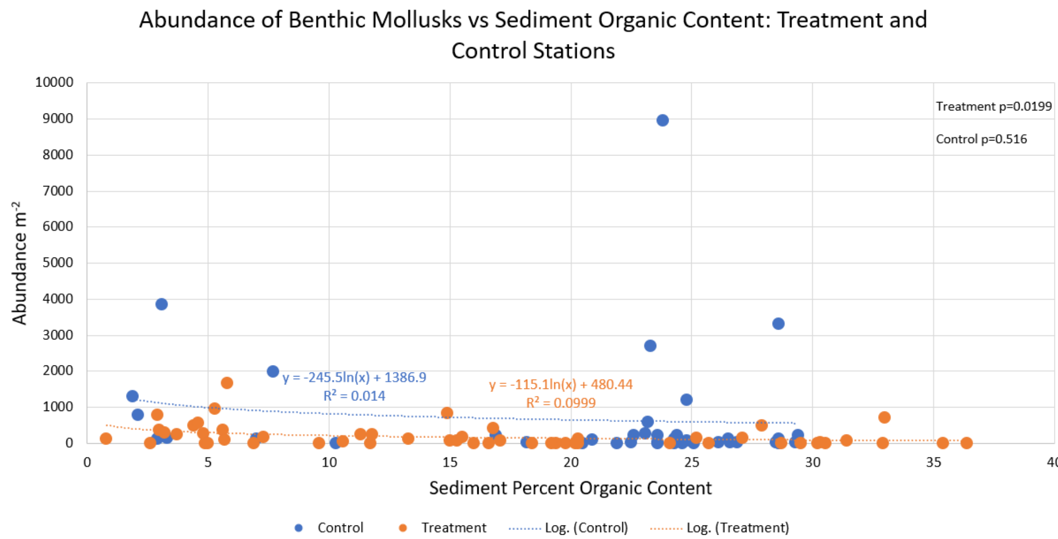


Figure 3: Benthic mollusk abundance(m^{-2}) vs sediment percent organic content at dredging treatment (orange) and control stations (blue). Regression shows an inverse logarithmic relationship.

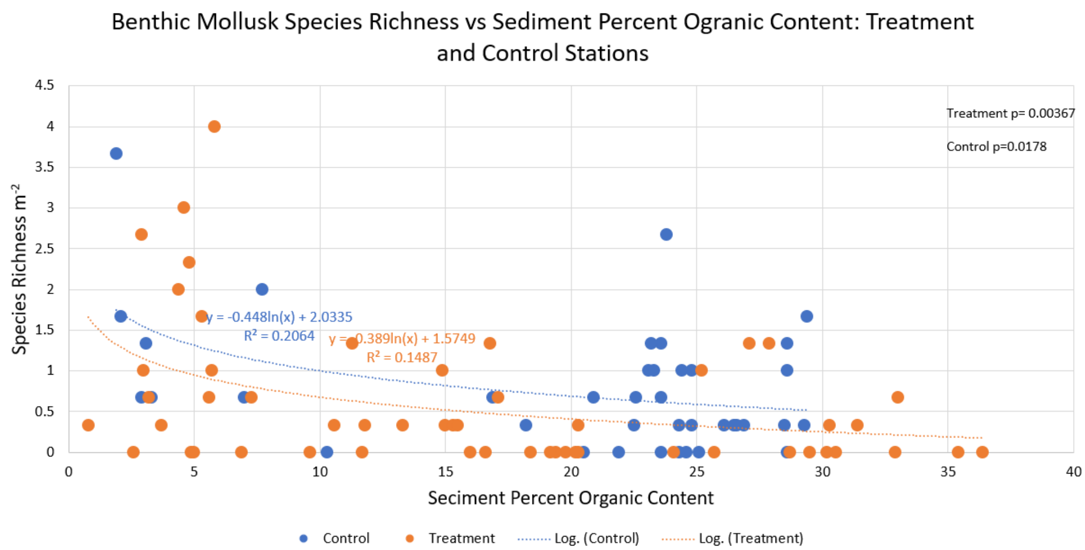


Figure 4: Benthic mollusk species richness (m^{-2}) vs sediment percent organic content at dredging treatment (orange) and control stations (blue). Regression shows an inverse logarithmic relationship.

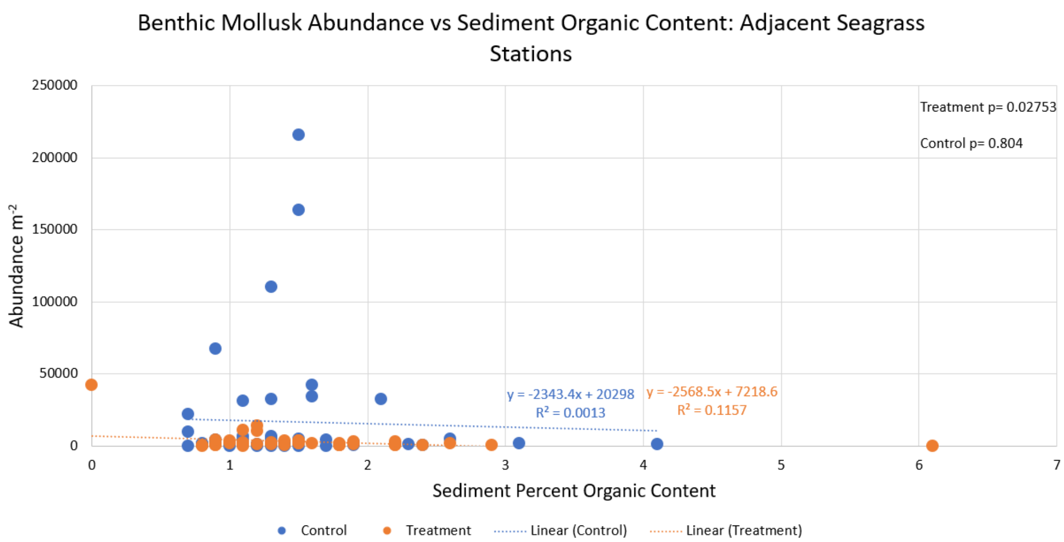


Figure 5: Benthic mollusk abundance (m^{-2}) vs sediment percent organic content at seagrass stations adjacent to the dredging treatment (orange) and control stations (blue). Regression shows an inverse relationship.

When data were separated by taxonomic family, gastropod biodiversity was found to range between 0-0.54 with higher sediment organic content, and 0-1.28 with lower sediment organic content. Bivalve biodiversity was found to range between 0-0.63 with higher sediment organic content, and 0-0.67 with lower sediment organic content.

The water content of the sediments ranged from 21.3% to 86.9%. Sediments generally higher in water content, ranging from 26.3% to 86.9%, were found in the treatment and control muck stations, whereas sediments generally lower in water content, ranging 21.3% to 49.1% water content, were located near the adjacent seagrass stations.

The sediment percent silt clay content of the sediments ranged from 0.2% to 99.7%. Sediments generally higher in silt clay content, ranging from 1.2% to 99.7%, were found in the treatment and control muck stations, whereas sediments generally lower in silt clay content, ranging from 0.2% to 73.7% were found in the adjacent seagrass stations. Generalized linear models found an inverse relationship between sediment percent silt clay content and benthic mollusk biodiversity and abundance.

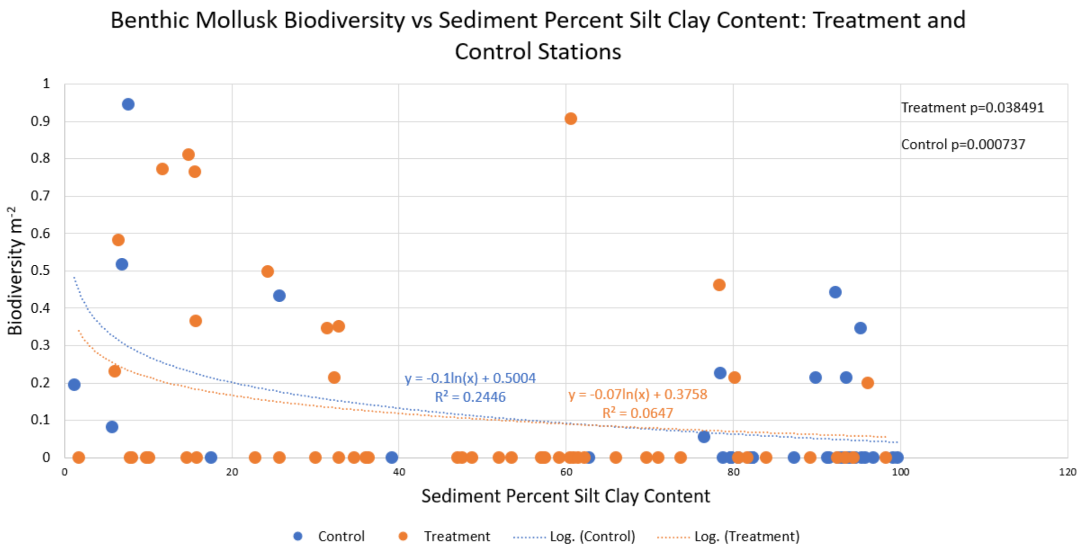


Figure 6: Benthic mollusk biodiversity (m^{-2}) vs sediment percent silt clay content at dredging treatment (orange) and control stations (blue). Regression shows an inverse logarithmic relationship.

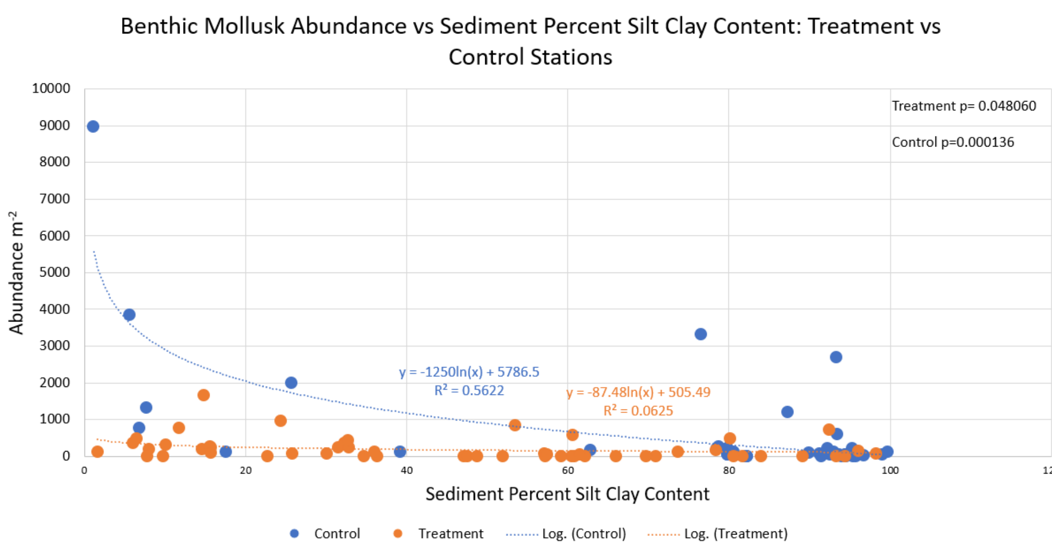


Figure 7: Benthic mollusk abundance(m^{-2}) and sediment percent silt-clay content at dredging treatment (orange) and control stations (blue). Regression shows an inverse logarithmic relationship.

The percent dissolved oxygen of the water ranged from 0.01-141.4%. The treatment and control muck stations typically had the lowest percent dissolved oxygen (0.01-114%). The adjacent seagrass stations typically had the highest percent dissolved oxygen (18.6-141.4%).

An ANOSIM was performed on these data, which found that treatment, year, sediment percent organic content, and sediment percent water content were statistically significant ($p<0.05$). When data was separated by family at the adjacent seagrass stations (Figure 1), it was found that year and treatment were statistically significant ($p<0.05$) for both gastropods and bivalves. Salinity and water temperature were found to be statistically significant for bivalves at the treatment stations.

Table 5: The ANOSIMs conducted on the biodiversity, species richness, and abundances of the benthic mollusk communities at each of the stations throughout the course of the study. Blue X's indicate an even distribution of high and low ranks within and between groups.

	Seasons	Treatment	Year	Sediment Organic Content	Silt Clay Content	Water Content	Percent Dissolved Oxygen	Water Temperature	Salinity	Seagrass Percent Cover
Overall Biodiversity: Treatment						X				
Overall Species Richness: Treatment				X		X				
Overall Abundance: Treatment								X		
Overall Biodiversity: Seagrass			X					X		
Overall Species Richness: Seagrass		X	X							
Overall Abundance: Seagrass		X	X					X		
Gastropod Biodiversity: Treatment										
Gastropod Species Richness: Treatment										
Gastropod Abundance: Treatment										
Gastropod Biodiversity: Seagrass		X								
Gastropod Species Richness: Seagrass		X	X							
Gastropod Abundance: Seagrass									X	
Bivalve Biodiversity: Treatment										
Bivalve Species Richness: Treatment										
Bivalve Abundance: Treatment								X		
Bivalve Biodiversity: Seagrass										
Bivalve Species Richness: Seagrass		X	X							
Bivalve Abundance: Seagrass		X	X						X	

The ANOSIMs were paired with non-metric multi-dimensional scaling (nMDs) figures to display the similarities and dissimilarities between groups. Overall, there was a clear trend in grouping between stations. At all of the treatment and control muck stations, there was a large amount of overlap with all groups, with some separation of the Treatment Before Dredging group. At all of the adjacent seagrass stations, there was also a large amount of overlap, with some separation of the Treatment Post Dredging group. All individual nMDs figures can be found in the appendix. Examples of the aforementioned separation pattern are included below.

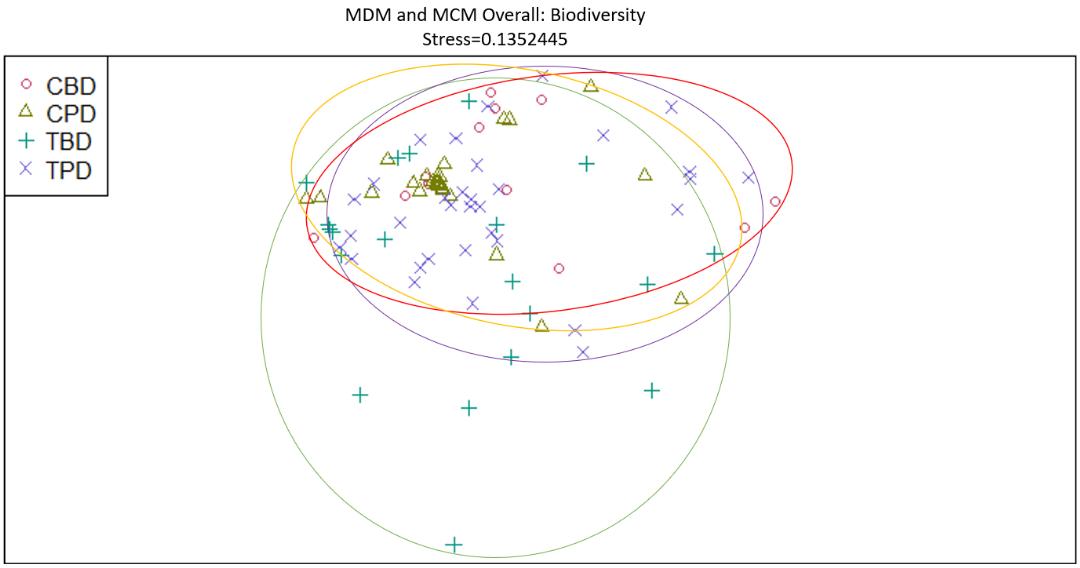


Figure 8: Non-Metric Multidimensional Scaling showing the pooled mollusk biodiversity at the treatment and control muck stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

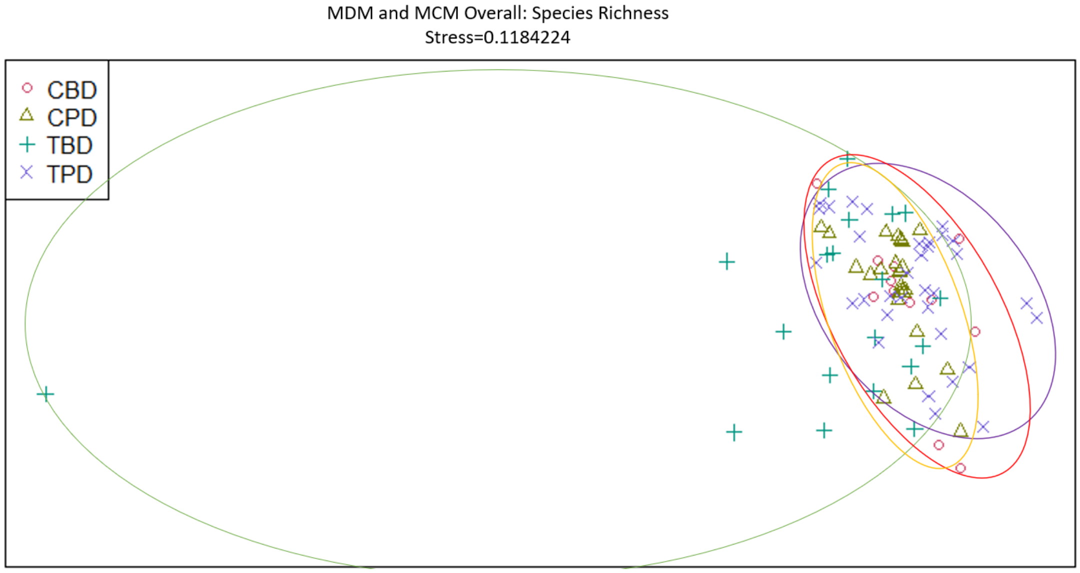


Figure 9: Non-Metric Multidimensional Scaling showing the pooled mollusk species richness at the treatment and control muck stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

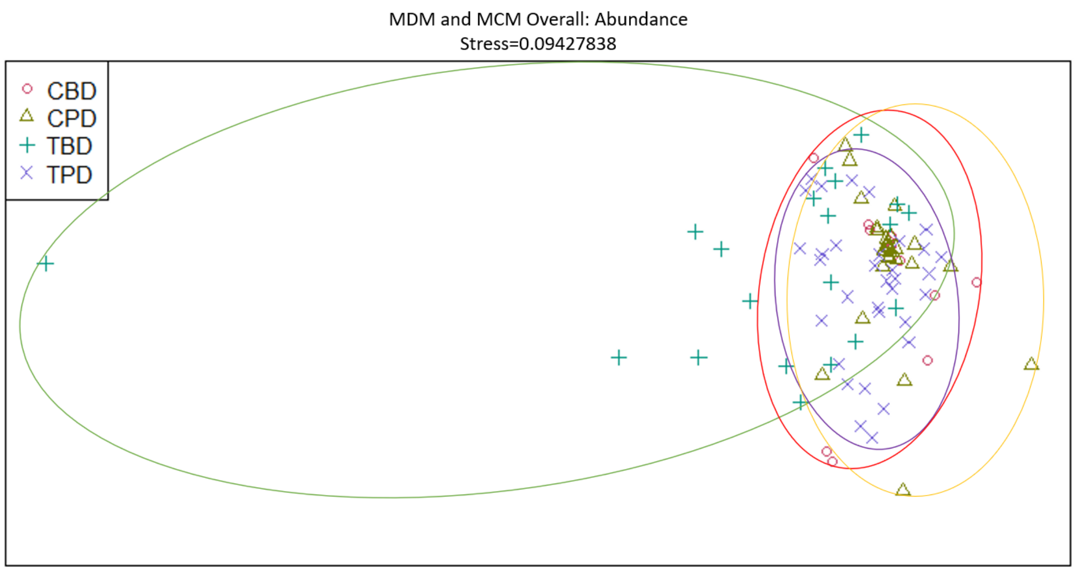


Figure 10: Non-Metric Multidimensional Scaling showing the pooled mollusk abundance at the treatment and control muck stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

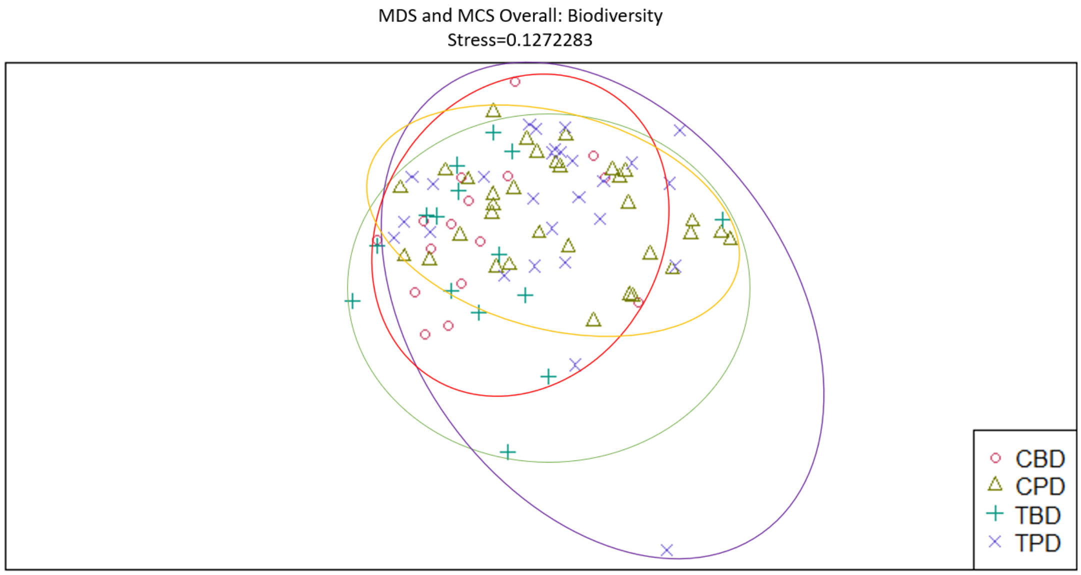


Figure 11: Non-Metric Multidimensional Scaling showing the pooled mollusk biodiversity at the adjacent seagrass stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

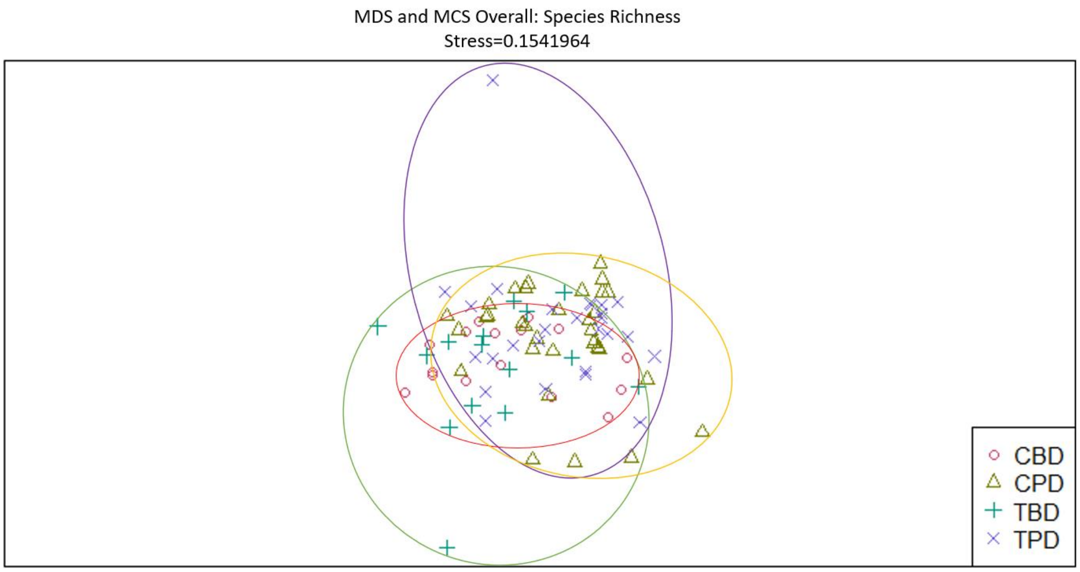


Figure 12: Non-Metric Multidimensional Scaling showing the pooled mollusk species richness at the adjacent seagrass stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

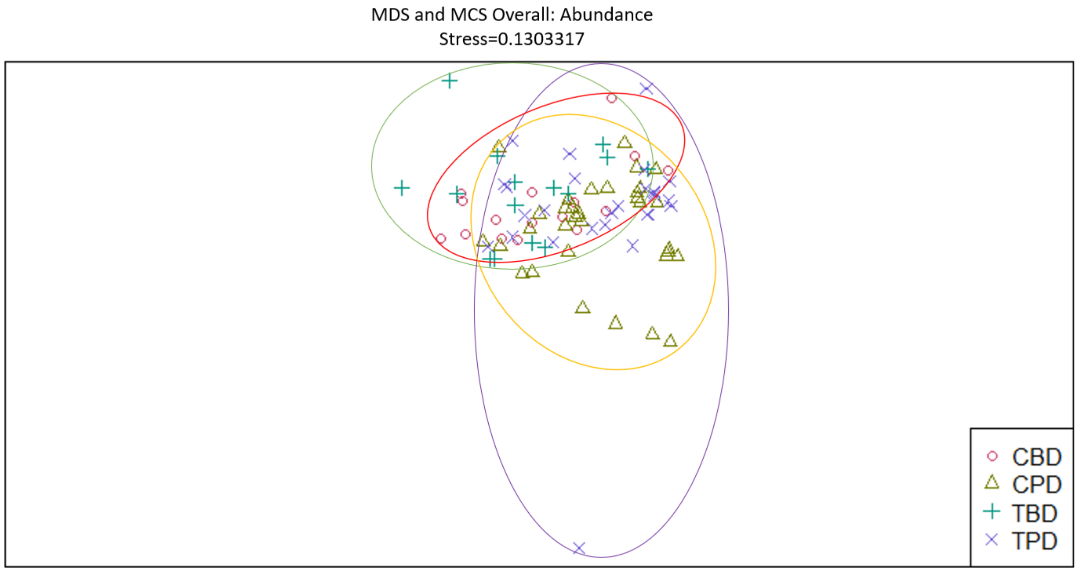


Figure 13: Non-Metric Multidimensional Scaling showing the pooled mollusk species richness at the adjacent seagrass stations similarities and dissimilarities in multivariate space. CBD=Control Before Dredging; CPD=Control Post Dredging; TBD=Treatment Before Dredging; TPD=Treatment Post Dredging. Ellipses represent distinct groups based on similarity.

The abundance spread of each of the 27 identified species were also analyzed as a community. These results also reflect the aforementioned overlap pattern.

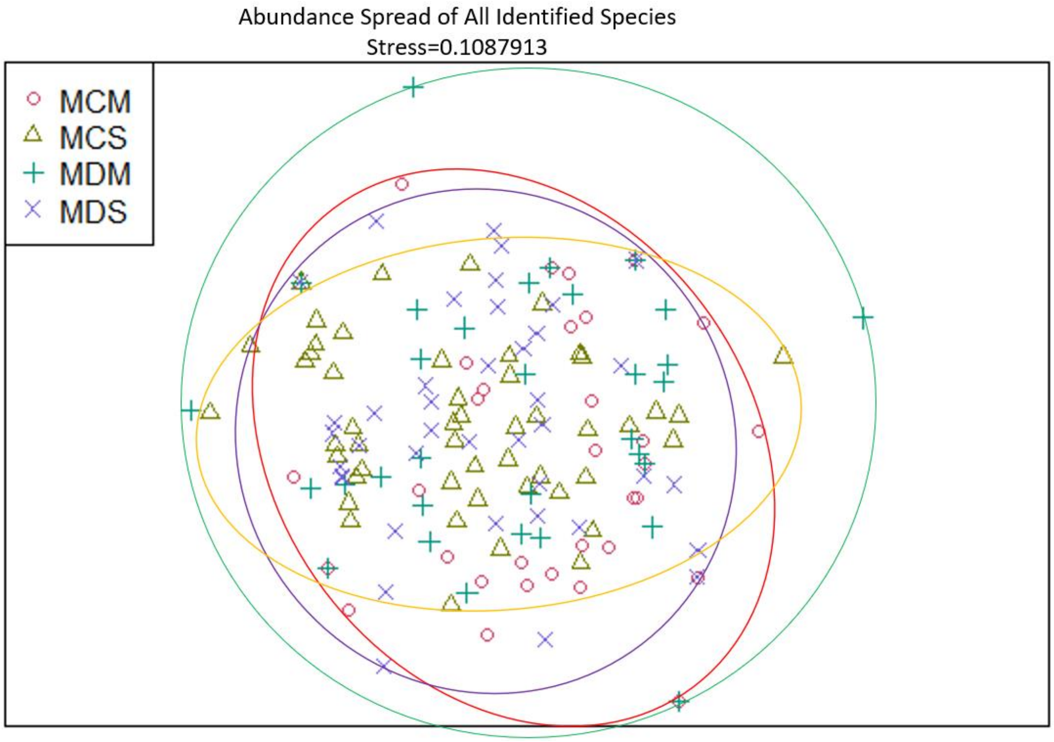


Figure 14: Non-Metric Multidimensional Scaling showing the spread of 27 identified mollusk species abundances at all stations similarities and dissimilarities in multivariate space. MCM=Mims Control Muck; MCS=Mims Control Seagrass; MDM=Mims Dredged Muck; MDS=Mims Dredged Seagrass. Ellipses represent distinct groups based on similarity.

Chapter 4:
Discussion

The purpose of this study was to determine the effects of environmental dredging on benthic mollusk communities in a shallow and diverse estuary. We also examined the differences in taxonomic family in responding to dredging. The results of this study show a distinct repeating inverse logarithmic relationship between benthic mollusk community composition and sediment conditions.

The sediment percent organic content and silt-clay content have an inverse relationship with benthic mollusk biodiversity, species richness, and abundances (Figures 2-7). These findings support the first hypothesis, that mollusk biodiversity, species richness, and abundances are inversely related to sediment percent organic content. This inverse relationship, with biological parameters dropping off as muck organic content increases, is likely due to increased stress levels associated with the many impacts of living in polluted sediments.

In this study, sediments generally higher in organic content were found in the treatment and control muck stations (Figure 1). Muck stations had lower percent dissolved oxygen in the boundary bottom water (47.55% ± 29.99%) and, accordingly, consistently had the lowest overall biodiversity (0.11 ± 0.227 m^{-2}), species richness (0.67 ± 0.84 m^{-2}), and abundances (405.636 ± 1118.44 organisms/m^2). Sediment organic content is considered a possible representative for benthic community health because it has a large influence on the biology and water chemistry of the benthos (Hope, 2016). As fine-grained organic matter (a.k.a. muck) accumulates in the benthos, it binds to sediments and silt-clay particulates (Milliman 1994, Hedges and Kail 1995). Benthic bacteria then commence decomposing organic matter, which depletes dissolved oxygen and increases H_2S (Wang and Chapman 1999). Degradation of organic material, and the accompanying chemical impacts, is a natural phenomenon in many ecosystems. However, with the excessive concentrations of organic matter in IRL sediments, this process exposes members of the benthic community to lethal levels of hypoxia and toxic hydrogen sulfide. These conditions can alter community composition by excluding sensitive species and restricting sediment bioturbation (Mermillod-Blondin *et al*. 2004, Giblin *et al*. 1997, Aller 1994). Lack of bioturbation can allow greater accumulation of muck sediments. This creates a positive feedback loop, further increasing inhospitable conditions (Gray 1979).

Inverse relationships of benthic mollusk community composition with degraded sediment conditions have been observed and modeled. The Pearson and Rosenberg model (1978) showcases a pattern of faunal richness and abundance increasing with lower levels of sediment organic content, and then decreasing in response to higher concentrations. Other studies have also found that species richness and diversity increase with organic matter concentration, up to about 3% in some cases (Kodoma *et al*. 2012), but then rapidly plummet as organic content continues to increase (Hyland 2005, Magni *et al*. 2009, Hope 2016). These corroborating studies all show a pattern similar to a logarithmic distribution, not unlike the ones found in this study. However, the Pearson and Rosenberg model may need to be modified for coastal environments due to the difference in system energies, since systems with less wave energy are more subject to sedimentation and lower levels of dissolved oxygen (Puente and Diaz 2015). Abundant oxygen and low toxicity generally foster healthier benthic communities. As adverse conditions increase, some taxa are better adapted than others for withstanding the impacts.

There was no discernable difference in benthic mollusk community composition between muck that was dredged vs. undredged. Removal of sediments with high concentrations of fine-grained organic matter by dredging did not increase the biodiversity, species richness, and overall community abundance of benthic mollusks during the time period of the study. Since the decay of organic matter creates stressful hypoxic or anoxic conditions, low dissolved oxygen is a likely limiting factor for some benthic infauna (Gray *et al*. 2002, Diaz and Rosenberg 1995, Kodama *et al*. 2012, Hope 2016). However, this did not translate to substantial distinctiveness between communities in this study (Figures 8-14). This could be due to the lower metabolic and oxygen consumption rates of mollusks, which allow them to persist in polluted sediments where oxygen is more limiting (Bayne and Newell 1983, Fox and Simmons 1933, Pamatmat 1983, Salvato *et al* 2001). When oxygen is not a limiting factor, more tolerant species will gain an advantage in polluted/organic rich sediments over the more sensitive competitors (Gray 1982, Pearson and Rosenberg 1978, Hope 2016). This can be seen with the high abundances of *Parastarte triquetra* and *Ameritella versicolor* in this study. *P. triquetra* was the most abundant mollusk in this study, reaching counts of 8578 individuals m^{-2} at the control muck stations, and up to 215289 individuals m^{-2} at the control seagrass stations. *A. versicolor* was recorded at only 3 station sampling events in this study, reaching counts of 15 individuals m^{-2} at the control muck stations, and 356 individuals m^{-2} at the control seagrass stations. It was arguably logical to postulate that lower metabolic rates in mollusks might cause oxygen to emerge as a factor shaping benthic community variability. However, variability was high and no significant pre- vs. post-dredging differences were observed in the community data based on the nMDs and PCA figures (Figures 8-14). This could be due to the fact that dredging does not remove all of the muck, and organic sediments persist even in the dredging treatment.

The anoxic environment created through the mass decomposition of organic matter fosters conditions that encourage sulfur-reducing bacteria (Viaroli *et al*. 2008, Diaz and Rosenberg 1995). These bacteria release H_2S that can saturate the benthic environment, making hypoxic habitats even more hostile to fauna and flora (Wang and Chapman 1999). Fauna with greater resistance to H_2S tend to have higher survival rates in hypoxic environments (Theede *et al*. 1969, Bayne 1976). Gray *et al*. (2002) summarized that crustaceans and echinoderms are the most sensitive to environments polluted with fine-grained organic-rich sediments, then annelids, and mollusks are the most tolerant of organic sediments. This is likely due to their documented ability to withstand the physiological stressors of hypoxia and H_2S (Bayne 1976).

Competition is a major factor in the shaping of community structures in many ecosystems (Glassom 1992). However, Thistle (1981) found that colonizing species' patterns of succession may be driven by the nature of the resource base, rather than competition. Additionally, Virnstein (1977) observed, that in the absence of predation, *Mulinia lateralis* persisted at high densities and could exclude other species. In this study, *M. lateralis* was one of the most abundant species identified, reaching counts of 4267 individuals m^{-2} at the control seagrass stations and 3793 individuals m^{-2} at the control muck stations. However, Virnstein (1977) postulated that the potential for *M. lateralis* to reach these densities and exclude other species could have been due to predation on settling larvae or another amensalistic interaction, as some species are poor "predation avoiders". Other corroborating predator exclusion studies have also reported an absence of competitive exclusion, even where benthic fauna occurred at higher densities (Virnstein 1978, Quammn 1984). Peterson (1979) postulated that this absence of competitive exclusion in soft sediments could be due to reduced opportunities for interference competition, and, rather, increased opportunities for amensalistic interactions. Since the introduction of the trophic amensalism hypothesis by Rhoades and Young (1970), it has been used to explain the distribution of deposit feeders and suspension feeders in numerous polluted and other soft-sediment benthic environments (Probert 1984, Chardy and Clavier 1988, Woodin 1999, Peterson 1979, Glassom 1992). Rhoades and Young's trophic amensalism hypothesis posits that deposit feeders exclude filter-feeding neighbors by disturbing and resuspending fine-grained sediments that can clog their fine gills and feeding structures (Rhoades and Young 1970). However, the results of this study did not see a discrepancy in the abundances of suspension feeding vs. deposit feeding mollusks before or after dredging, despite the polluted sediment conditions.

Many benthic macroinvertebrates are used as bioindicators for environmental change because they are easy to monitor, have limited escape mechanisms to avoid disturbances, and provide a good indication of change over time (Pelletiera *et al.* 2010, Engel *et al.* 1994). Numerous studies have shown that the benthos responds relatively rapidly to stressors, both natural and anthropogenic (Dauvin 2007). Benthic mollusks are typically very abundant, relatively sessile, and tend to lead longer life cycles (Coelho *et al* 2014, Dauvin 2007). Some studies on macrofaunal succession found that mollusks dominate less polluted habitats and that degraded habitats replace mollusks with unshelled organisms (eg: polychaetes) (Engel *et al.* 1994). However, our study found that mollusks can tolerate very degraded conditions, reaching a high of 8963 individuals m^{-2} and 1659 individuals m^{-2} at the control and treatment muck stations, respectively. In one study conducted by Pelletiera *et al*. (2010), it was found that *Acteocina* sp. is a "pollution sensitive species", making it a potential bioindicator for detecting pollution presence in estuarine environments. Two species of *Acteocina* were identified in this study, *Acteocina atrata* and *Acteocina canaliculata*. *A. atrata* was only recorded at 13 station sampling events over the course of this study, 12 of which were at seagrass stations. *A. atrata* reached counts of 830 individuals m^{-2} at the control seagrass stations and 59 individuals m^{-2} at the one control muck station it was identified. *A. canaliculata* was much more abundant than *A. atrata* and was recorded more frequently. *A. canaliculata* was recorded at 79 station sampling events over the course of this study, reaching counts of 1822 individuals m^{-2} at the control seagrass stations and 267 individuals m^{-2} at the control muck stations. Two-Way ANOVAs were conducted on all 27 species identified over the course of this study. The ANOVAs conducted on both *A. atrata* and *A. canaliculata* found statistically significant differences in the abundances of both species between the seagrass stations and the muck stations. These findings, along with the documented sensitivity to pollution, could make *A. atrata* and *A. canaliculata* potential indicator species for future studies on benthic restoration. An index of ecological integrity could also be adopted into future studies. Ecological integrity indices exist to quantify the quality/health of an environment in order to aid in forming management decisions regarding environmental conditions (Borjaa *et al.* 2007). They serve as a promising measure of benthic habitat quality because of their ability to integrate physical habitat structure with benthic communities (Borjaa *et al.* 2007, Dauvin 2007). Borjaa *et al.* 2007 found that if the same ecological basis was used, different indices could produce a level of agreement. This means that different indices produce quantifiably similar results when used on the same environment.

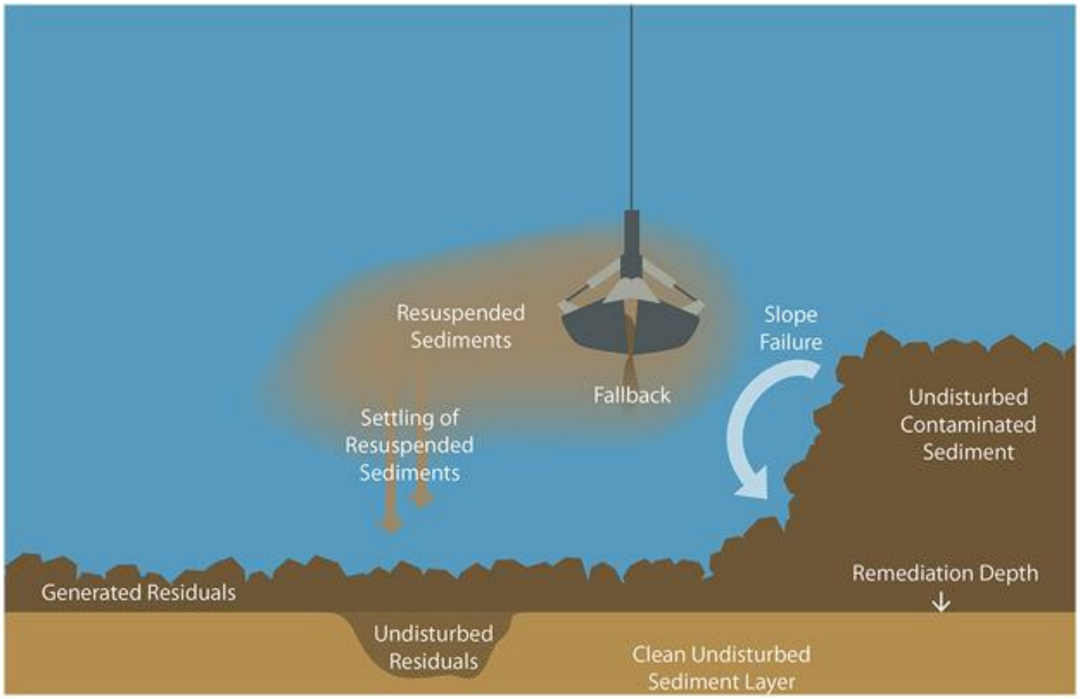


Figure 15: Diagram of environmental dredging and its residuals (Patmont *et al*. 2018). Dredging machinery is used to remove polluted or harmful sediments. However, it is often not possible to remove 100% of contaminated sediments and neighboring areas may also have organic-rich sediments that may slide into the dredge hole after dredging is completed.

There was no shift in the benthic mollusk community found due to dredging, which could be due to the tolerance that mollusks have for degraded habitat conditions (Bayne and Newell 1983, Fox and Simmons 1933, Pamatmat 1983, Salvato *et al* 2001). However, this study is limited because it only focused on the benthic mollusk communities at the bottom of the dredge line. There could be significant changes found if the objectives and restrictions on environmental dredging were changed. There is still much to be learned of the cause–effect relationships relating dredging processes to potential impacts (Bridges *et al*. 2010). One study posed "4 Rs of Environmental Dredging": Resuspension, Release, Residuals, and Risk (Bridge *et al*. 2008). Resuspension of polluted sediments can cause them to disperse and be spread. The removal of contaminated sediments, and resuspended sediments (Figure 15), can release contaminants that were stored in the muck into the water column after the completion of the dredging (Bridges *et al*. 2010). Currently, one of the top objectives of environmental dredging is to dredge with enough accuracy that deeper, clean sediments are not impacted or dredged out (Patmont *et al*. 2018, Palermo *et al*. 2008). However, this approach inevitably leaves behind a residual layer of contaminated/polluted sediment. Additionally, muck from the top of the dredge slope may slide down and join the residual layer (Figure 15), potentially re-establishing high organic content and preventing significant shifts in benthic faunal communities. The aforementioned sloughing of the organic rich sediments to the bottom of the dredge pit could create a scenario in which the benthic pit environment experiences little-to-no change following dredging. dredging deeper and completely removing the residual layer, on the other hand, could result in cleaner, less organic sediments that are not quickly inundated with sloughing organic sediments. This could potentially support a more abundant and diverse benthic community, including sensitive filter- and deposit-feeders. The latter would increase sediment bioturbation, potentially breaking up the aforementioned positive feedback loop of anoxic, organic rich, sediment accumulation.

Chapter 5: Conclusion

Benthic mollusk abundance, biodiversity, and species richness have an inverse logarithmic relationship with sediment organic content. This could be due to hypoxic and/or anoxic conditions in boundary bottom water (Hope 2017). However, removal of some sediments with high concentrations of fine-grained organic matter by dredging did not substantially increase the biodiversity, species richness, and abundances of benthic mollusks. It may be that the high tolerance of many mollusks to stressful environmental conditions prevents community divergence in organic sediments, relative to cleaner sandy sediment associated with seagrasses.

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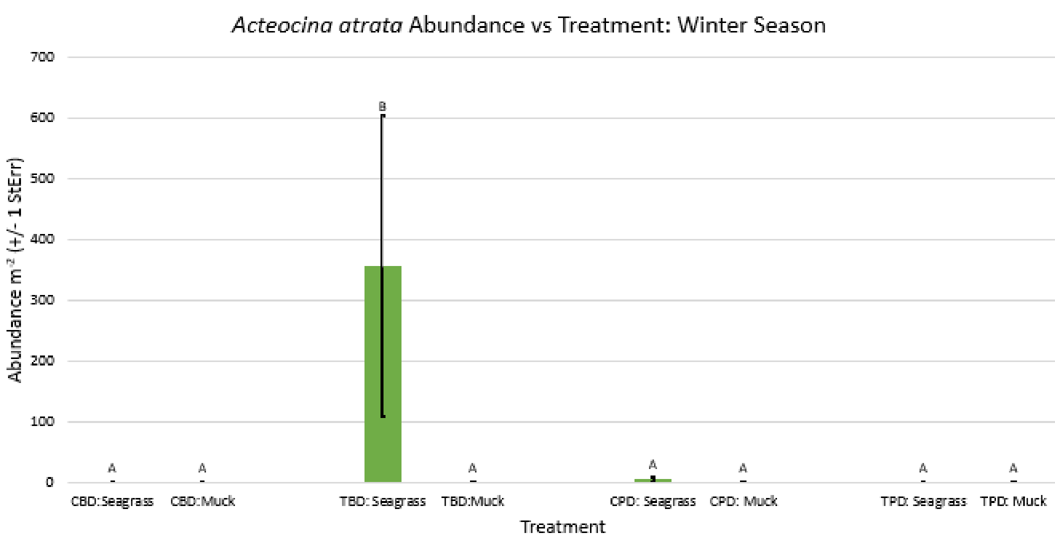
Appendix

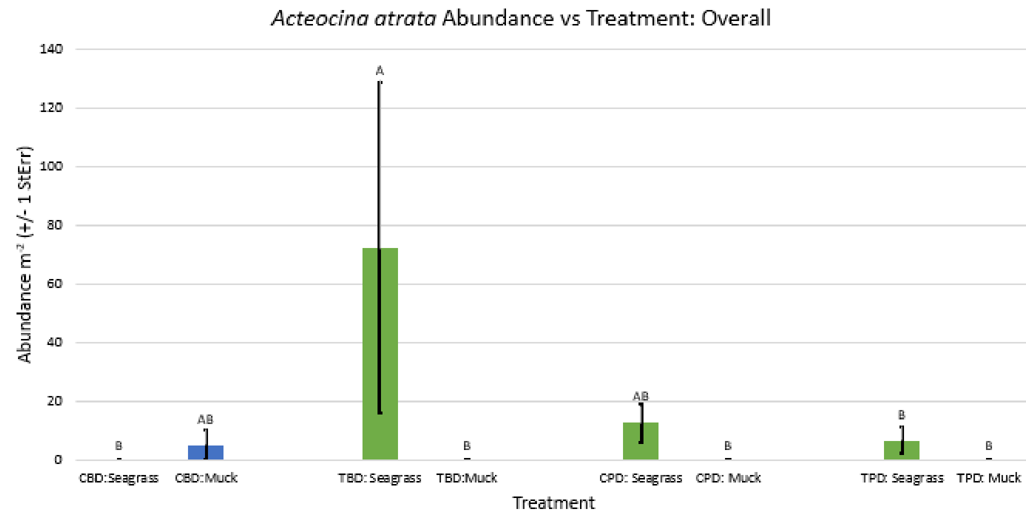
2-Way ANOVA P-Values

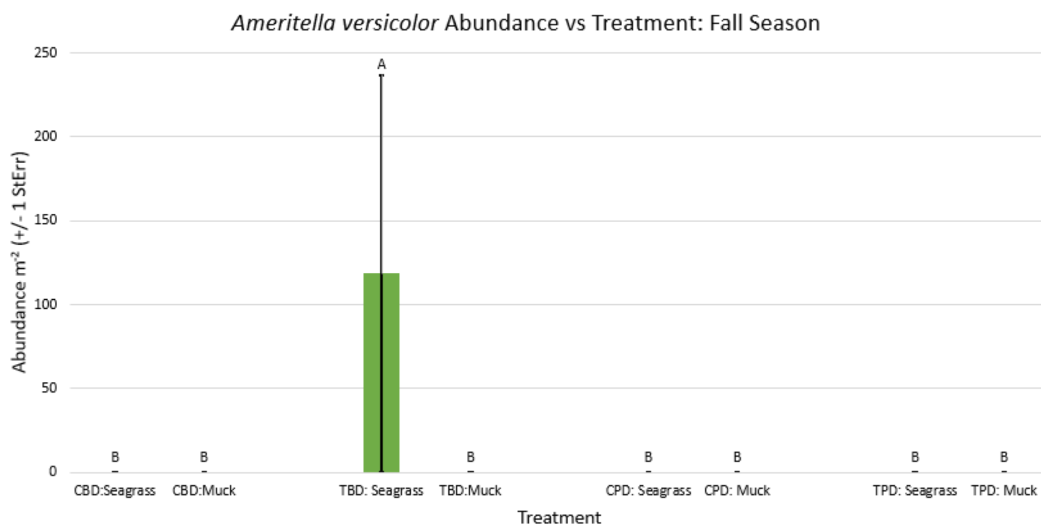
Gastropods	Spring: Treatment	Spring: Time	Spring: TxT	Summer: Treatment	Summer: Time	Summer: TxT	Fall: Treatment	Fall: Time	Fall: TxT	Winter: Treatment	Winter: Time	Winter: TxT	Overall: Treatment	Overall: Time	Overall: TxT
Acteocina atrata	0.458	0.512	0.717	0.588	0.579	0.866	0.244	0.382	0.37	0.0395	0.0087	0.0000596	0.1113	0.1967	0.0343
Acteocina canaliculata	0.0569	0.5817	0.9783	0.00279	0.92795	0.92953	0.0686	0.3461	0.2483	0.0373	0.4631	0.6169	0.00000824	0.282	0.212
Astyris lunata	0.27	0.269	0.439	0.187	0.307	0.782	0.163	0.992	0.127	0.3382	0.1324	0.0348	0.0235	0.0936	0.2381
Crepidula atrasolea	0	0	0	0	0	0	0.4084	0.0811	0.0574	0	0	0	0.456	0.134	0.108
Eulithidium pterocladicum	0	0	0	0	0	0	0.3395	0.0592	0.0075	0	0	0	0.3123	0.166	0.0985
Haminoea succinea	0.585	0.275	0.789	0.0499	0.149	0.009	0.701	0.992	0.388	0.0822	0.9072	0.1052	0.013	0.192	0.355
Haminoea elegans	0.316	0.438	0.163	0.004128	0.000579	0.0000445	0.3146	0.6509	0.0978	0.0293	0.2428	0.3268	0.1659	0.31918	0.00669
Japonactaeon punctostriat	0.286	0.17	0.365	0.0311	0.0422	0.024	0.482	0.29	0.683	0.0149	0.1977	0.2552	0.00516	0.33601	0.86651
Limpit B	0	0	0	0.257	0.469	0.565	0	0	0	0	0	0	0.326	0.448	0.593
Phrontis vibex	0.0368	0.5173	0.9632	0.21	0.389	0.462	0.0135	0.2795	0.1088	0.3257	0.0639	0.7646	0.0137	0.0169	0.6172
Odostomia laevigata	0.699	0.319	0.856	0.23	0.605	0.787	0.665	0.339	0.911	0.589	0.421	0.879	0.3	0.653	0.895
Prunum apicinum	0.565	0.239	0.657	0.359	0.469	0.745	0.124	0.457	0.57	0.1068	0.951	0.0229	0.0243	0.96	0.9981
Snail P	0	0	0	0	0	0	0	0	0	0.494	0.559	0.83	0.459	0.439	0.691
Snail R	0	0	0	0.179	0.36	0.111	24169	0.06408	0.00726	0.352	0.579	0.771	0.1388	0.1427	0.0406
Turbonilla sp.	0.0305	0.0328	0.0812	0.0353	0.1395	0.2078	0.274	0.184	0.714	0.0808	0.3173	0.4669	0.0409	0.0464	0.895
Bivalves															
Amygdalum papyrium	0	0	0	0.402	0.491	0.772	0.484	0.608	0.835	0.197	0.199	0.222	0.0173	0.8773	0.9925
Ameritella versicolor	0	0	0	0.446	0.598	0.816	0.2295	0.0592	0.0075	0.494	0.559	0.83	0.3475	0.1937	0.0916
Anomalocardia cuneimeris	0.458	0.512	0.717	0.000351	0.0184276	0.086936	0.4301	0.0882	0.0551	0.409	0.525	0.797	0.019	0.995	0.143
Clam A	0	0	0	0	0	0	0.4084	0.0811	0.0574	0	0	0	0.456	0.134	0.108
Cyrtopleura costata	0	0	0	0.588	0.579	0.866	0.494	0.559	0.83	0.494	0.559	0.83	0.0487	0.2558	0.3211
Melongena corona	0	0	0	0	0	0	0.2295	0.0592	0.0075	0	0	0	0.3123	0.166	0.0985
Mercenaria mercenaria	0.644	0.522	0.833	0	0	0	0.3078	0.0183	0.0171	0	0	0	0.6333	0.0251	0.4107
Mulinia lateralis	0.666	0.7248	0.0667	0.261	0.893	0.999	0.504	0.713	0.85	0.13	0.414	0.306	0.00641	0.46121	0.44192
Parastarte triquetra	0.011	0.0137	0.0131	0.0845	0.2278	0.4821	0.0581	0.1924	0.4153	0.108	0.29	0.52	0.000979	0.05187	0.065198
Periglypta listeri	0	0	0	0.16539	0.0146	0.00476	0.4471	0.0936	0.0179	0	0	0	0.42	0.3782	0.0318

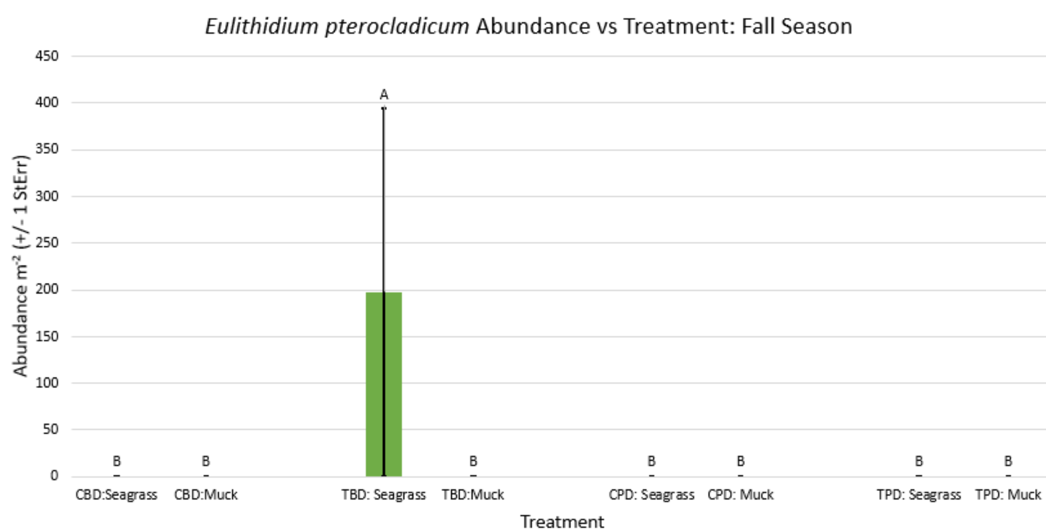
Overall	Spring: Treatment	Spring: Time	Spring: TxT	Summer: Treatment	Summer: Time	Summer: TxT	Fall: Treatment	Fall: Time	Fall: TxT	Winter: Treatment	Winter: Time	Winter: TxT	Overall: Treatment	Overall: Time	Overall: TxT
Overall Biodiversity	0.0000506	0.0676	0.2738	0.00017	0.04079	0.05249	0.0293	0.7415	0.0538	0.000073	0.699	0.804	6.81E-14	0.102	0.407
Overall Species Richness	0.000000124	0.0372	0.0153	0.0000235	0.611	0.24	0.000135	0.27368	0.009492	0.00000052	0.045	0.291	2E-16	0.0754	0.0678
Overall Abundance	0.00268	0.01397	0.00653	0.123	0.234	0.551	0.00537	0.06813	0.0515	0.0575	0.2694	0.4679	0.000286	0.032926	0.030637
Gastropod Biodiversity	0.00000365	0.499	0.002	0.000208	0.030088	0.154543	0.00945	0.59089	0.05834	0.00142	0.44913	0.27736	8.63E-13	0.859	0.189
Gastropod Species Richnes	0.000000235	0.83358	0.00674	0.0000566	0.19	0.347	0.00124	0.2881	0.01273	0.0000782	0.541	0.154	2E-16	0.694	0.045
Gastropod Abundance	0.00244	0.89009	0.5332	0.001	0.773	0.74	0.0117	0.4978	0.0353	0.000805	0.608643	0.142383	4.81E-10	0.3305	0.0359
Bivalve Biodiversity	0.0427	0.37	0.6788	0.162	0.533	0.652	0.0471	0.8341	0.0658	0.0529	0.1177	0.8793	0.000000987	0.0184	0.2806
Bivalve Species Richness	0.00000129	0.00648	0.00787	0.00103	0.18592	0.21469	0.00329	0.18669	0.10776	0.000019	0.00154	0.68118	4.53E-16	0.0000583	0.0212
Bivalve Abundance	0.00653	0.01161	0.00554	0.127	0.229	0.534	0.00552	0.05939	0.05473	0.105	0.281	0.547	0.00053	0.03305	0.03307

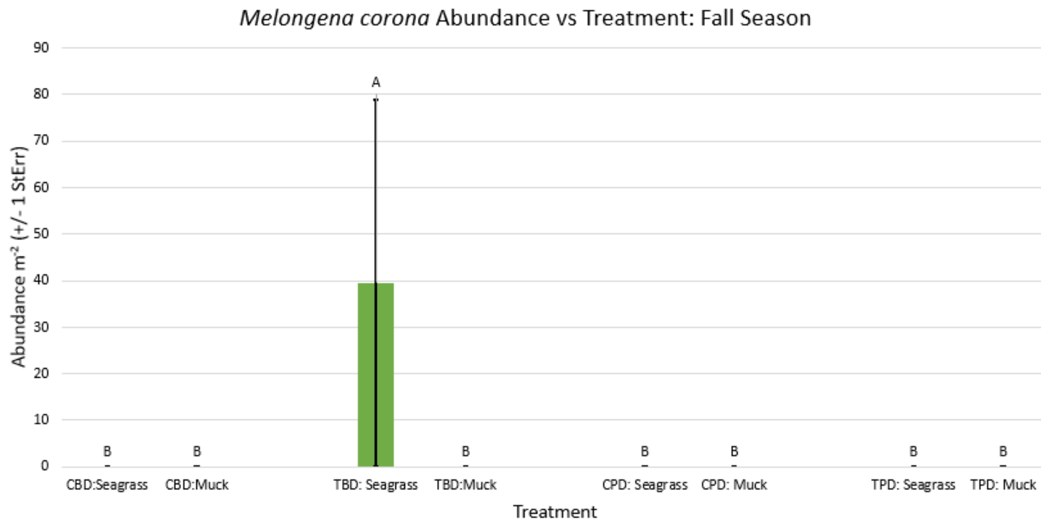
2-Way ANOVA: Figures

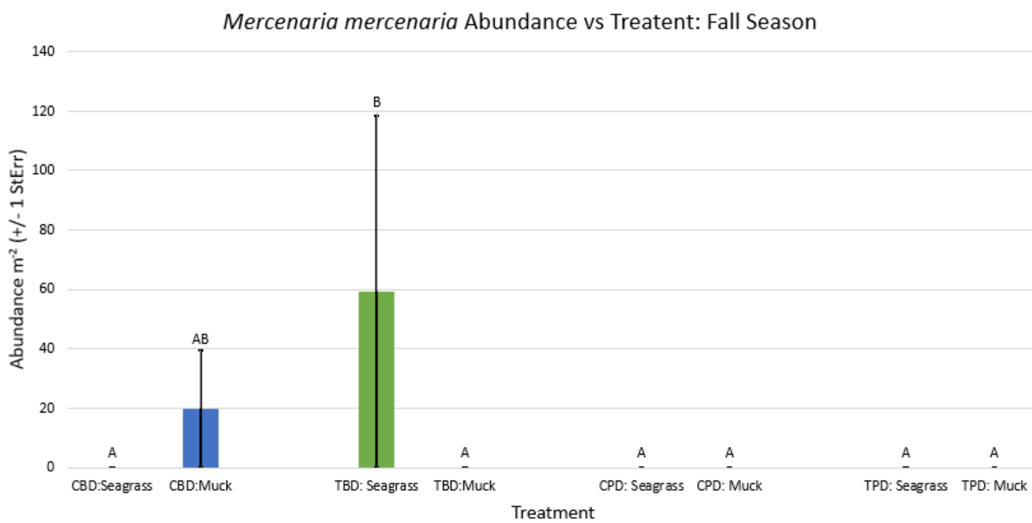


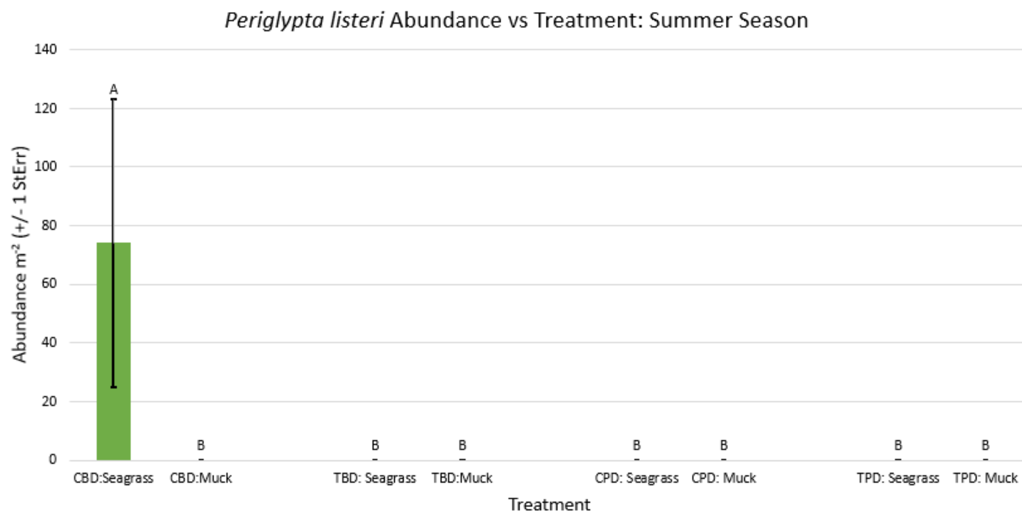

Acteocina atrata Abundance vs Treatment: Overall
Abundance m⁻² (+/- 1 StErr)
140
120
100
80
60
40
20
0
B
AB
A
B
AB
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

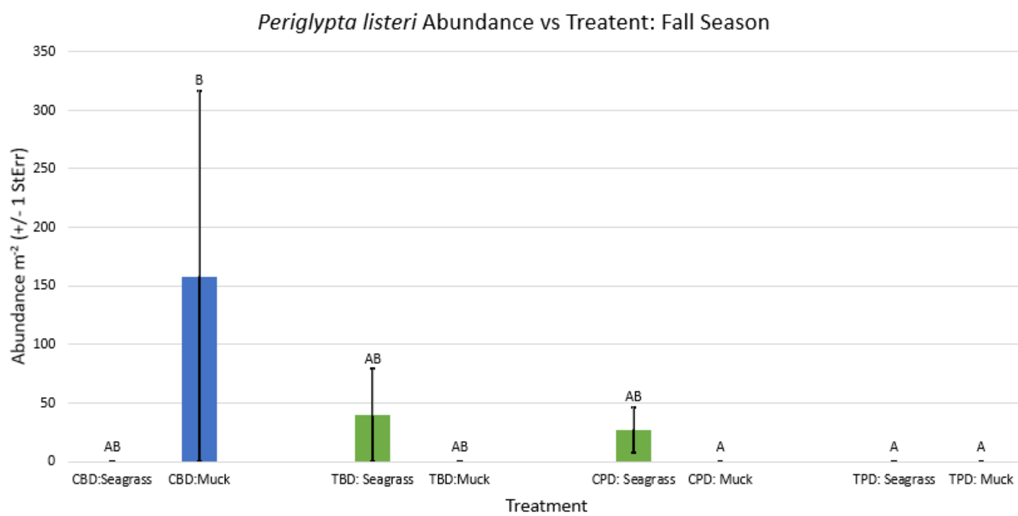

Ameritella versicolor Abundance vs Treatment: Fall Season
Abundance m⁻² (+/- 1 StErr)
250
200
150
100
50
0
B
B
A
B
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

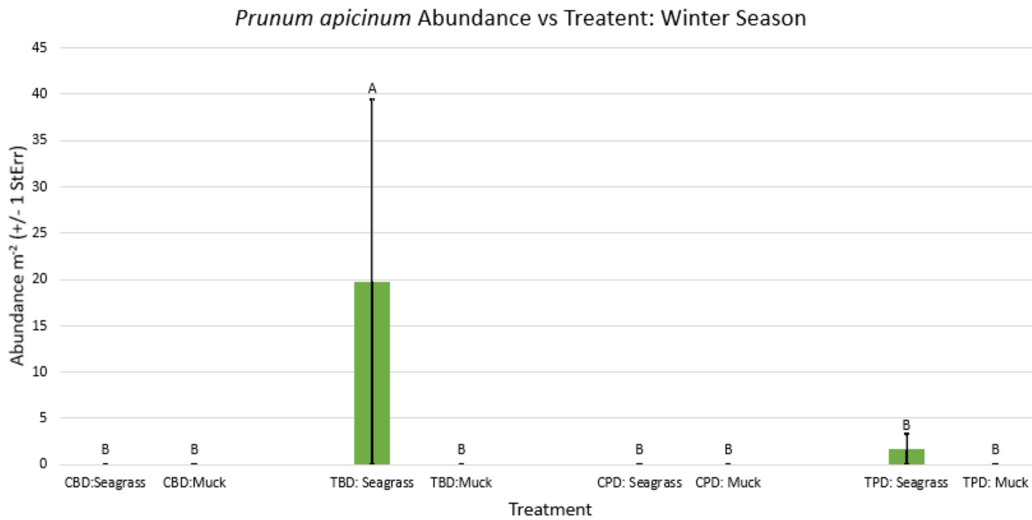

Eulithidium pterocladicum Abundance vs Treatment: Fall Season
Abundance m⁻² (+/- 1 StErr)
450
400
350
300
250
200
150
100
50
0
B
B
A
B
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

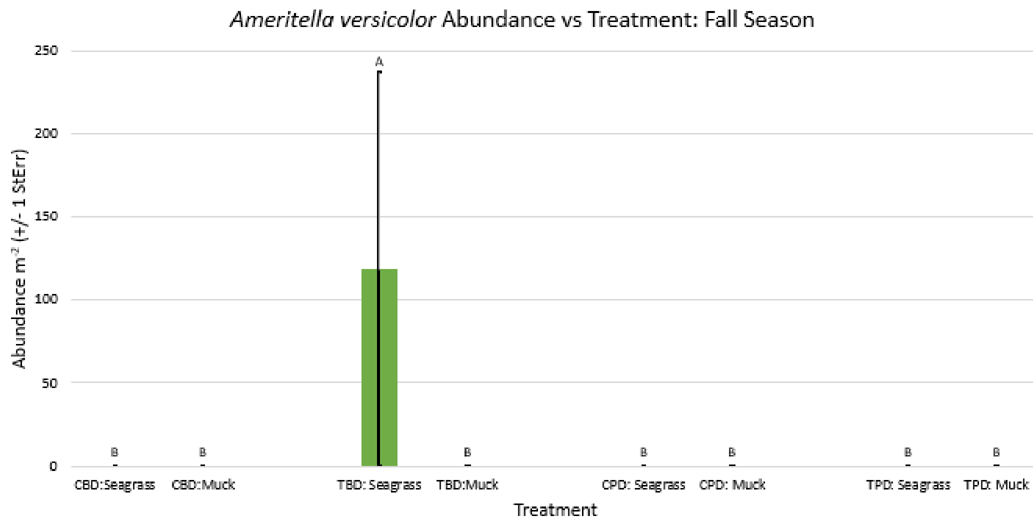

Melongena corona Abundance vs Treatment: Fall Season
Abundance m^{2} (+/- 1 StErr)
90
80
70
60
50
40
30
20
10
0
A
B
B
B
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

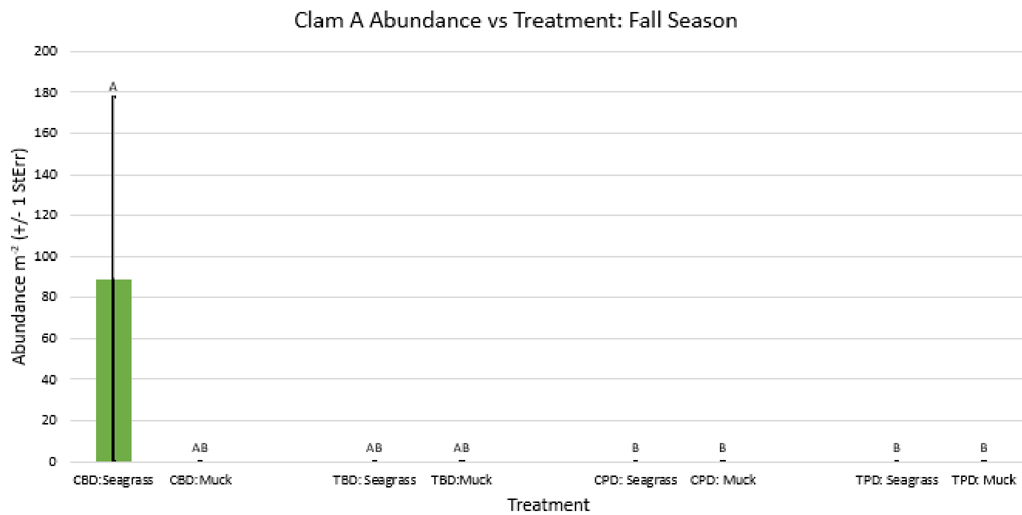

Mercenaria mercenaria Abundance vs Treatent: Fall Season
Abundance m^{2} (+/- 1 StErr)
140
120
100
80
60
40
20
0
A
AB
B
A
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

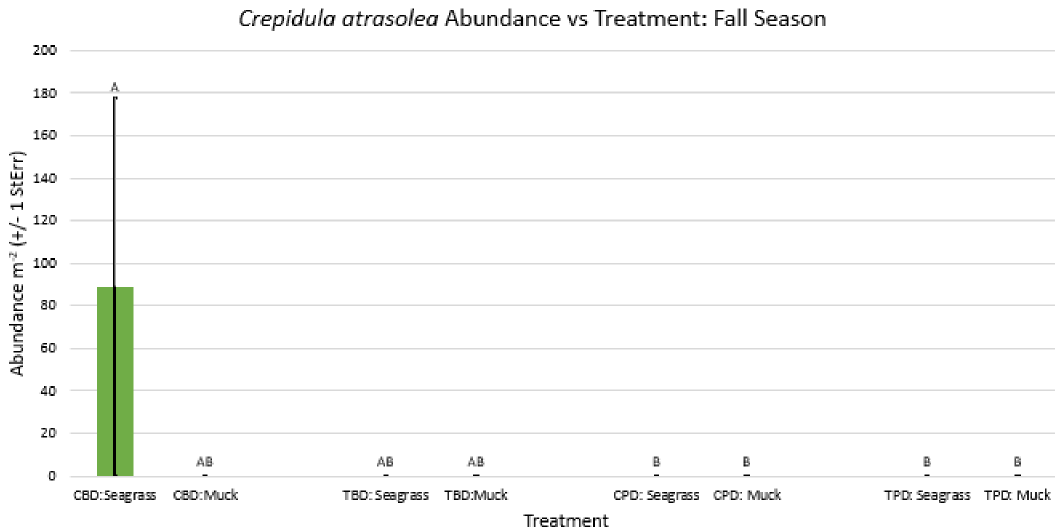

Periglypta listeri Abundance vs Treatment: Summer Season
Abundance m² (+/- 1 StErr)
140
120
100
80
60
40
20
0
A
B
B
B
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Periglypta listeri Abundance vs Treatent: Fall Season
Abundance m² (+/- 1 StErr)
350
300
250
200
150
100
50
0
AB
B
AB
AB
AB
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

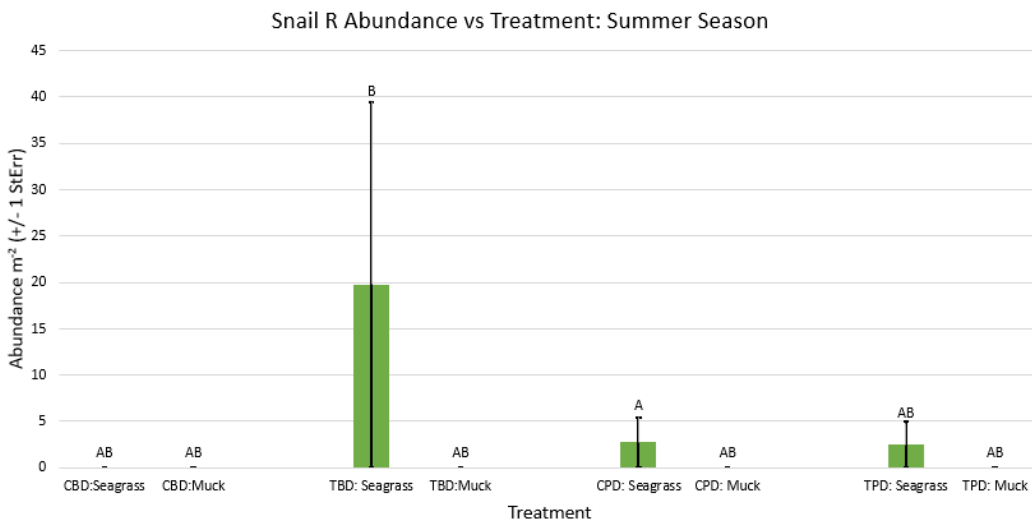

Prunum apicinum Abundance vs Treatent: Winter Season
Abundance m² (+/- 1 StErr)
45
40
35
30
25
20
15
10
5
0
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Ameritella versicolor Abundance vs Treatment: Fall Season
Abundance m-2 (+/- 1 StErr)
0
50
100
150
200
250
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

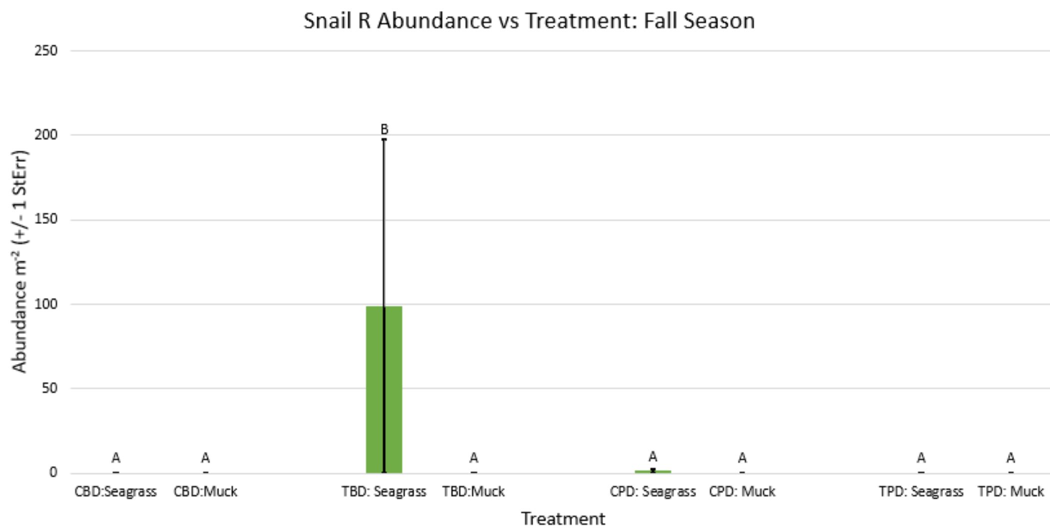

Clam A Abundance vs Treatment: Fall Season
Abundance m-2 (+/- 1 StErr)
0
20
40
60
80
100
120
140
160
180
200
A
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

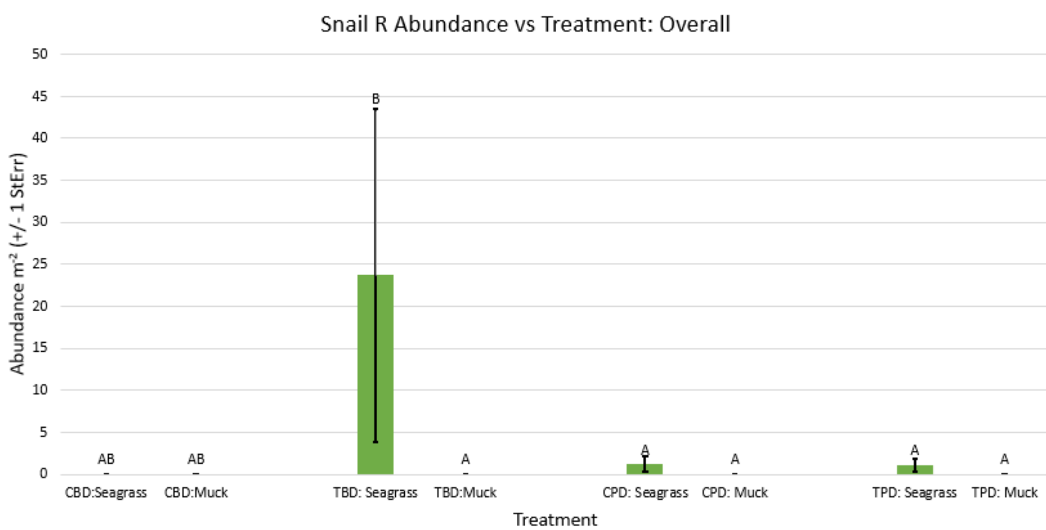


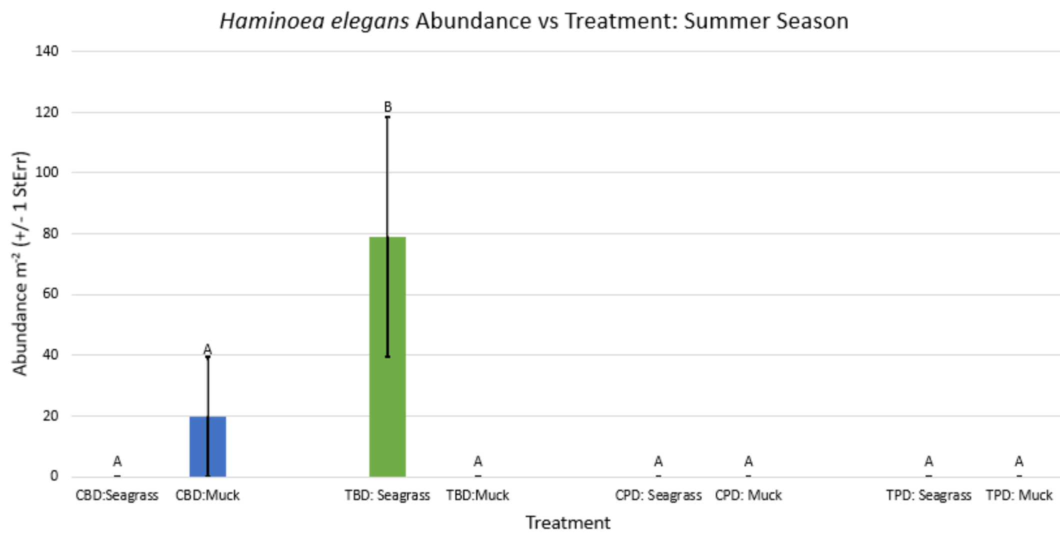
Crepidula atrasolea Abundance vs Treatment: Fall Season
Abundance m⁻² (+/- 1 StErr)
200
180
160
140
120
100
80
60
40
20
0
A
AB
AB
AB
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

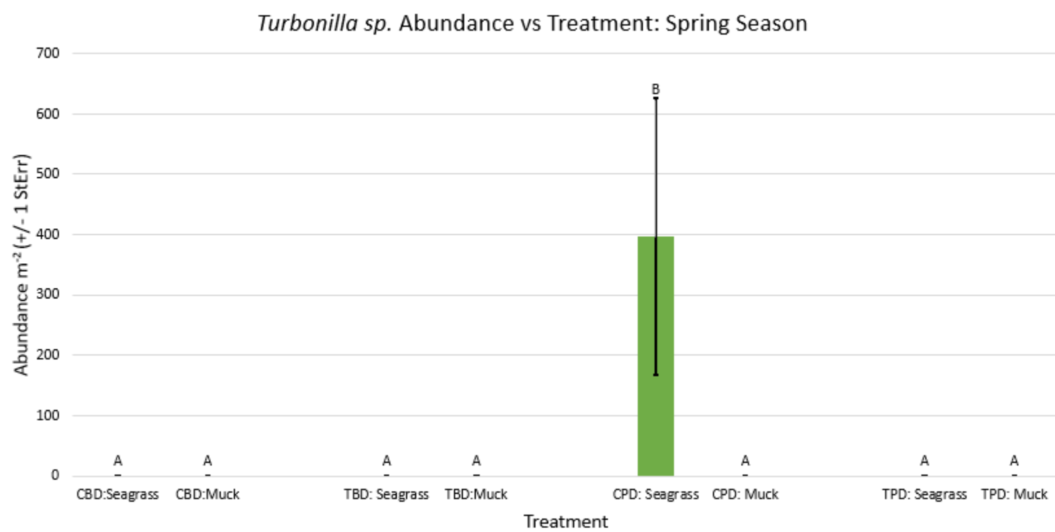


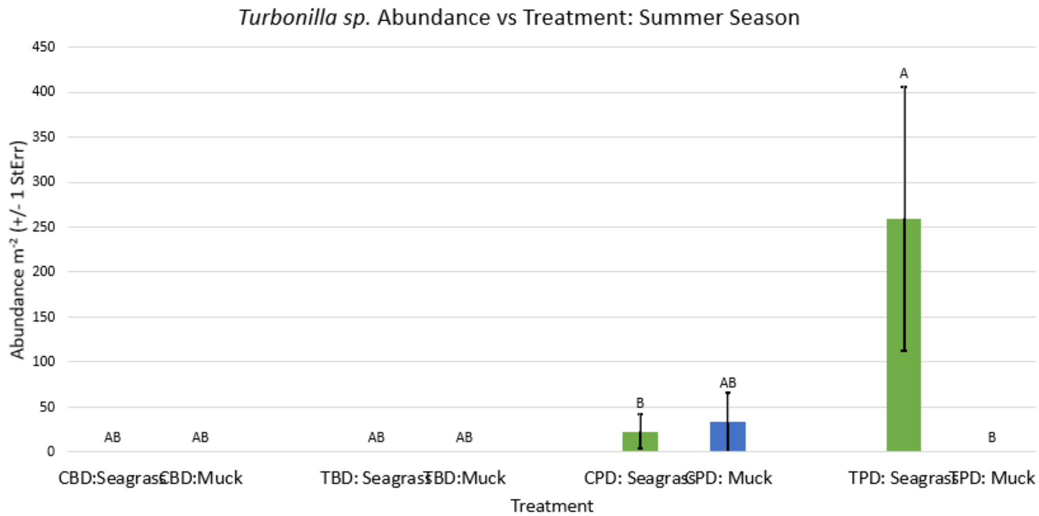
Snail R Abundance vs Treatment: Summer Season
Abundance m⁻² (+/- 1 StErr)
45
40
35
30
25
20
15
10
5
0
AB
AB
B
AB
A
AB
AB
AB
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Snail R Abundance vs Treatment: Fall Season
250
200
150
100
50
0
Abundance m² (+/- 1 StErr)
B
A
A
A
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

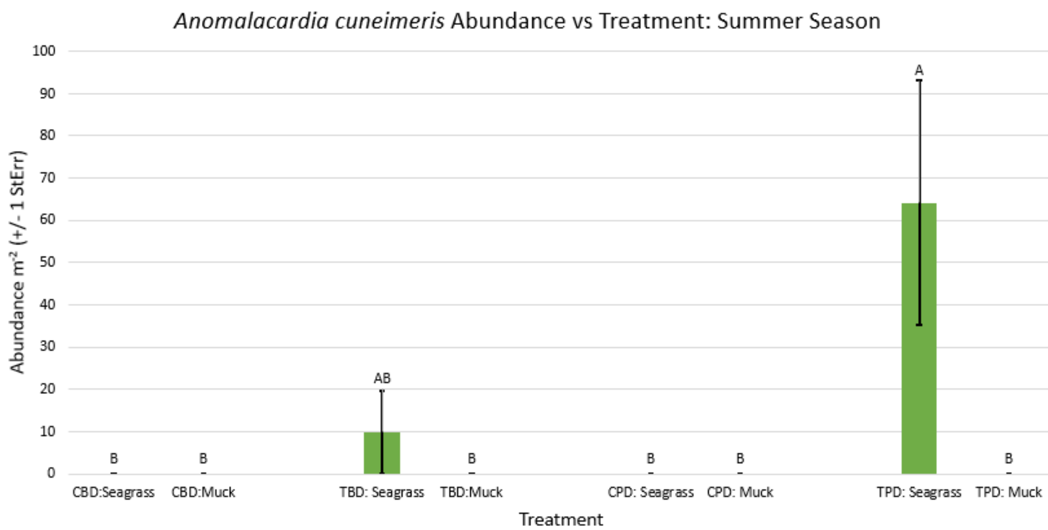

Snail R Abundance vs Treatment: Overall
50
45
40
35
30
25
20
15
10
5
0
Abundance m² (+/- 1 StErr)
B
AB
AB
A
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Haminoea elegans Abundance vs Treatment: Summer Season
Abundance m-2 (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
0
20
40
60
80
100
120
140
A
B

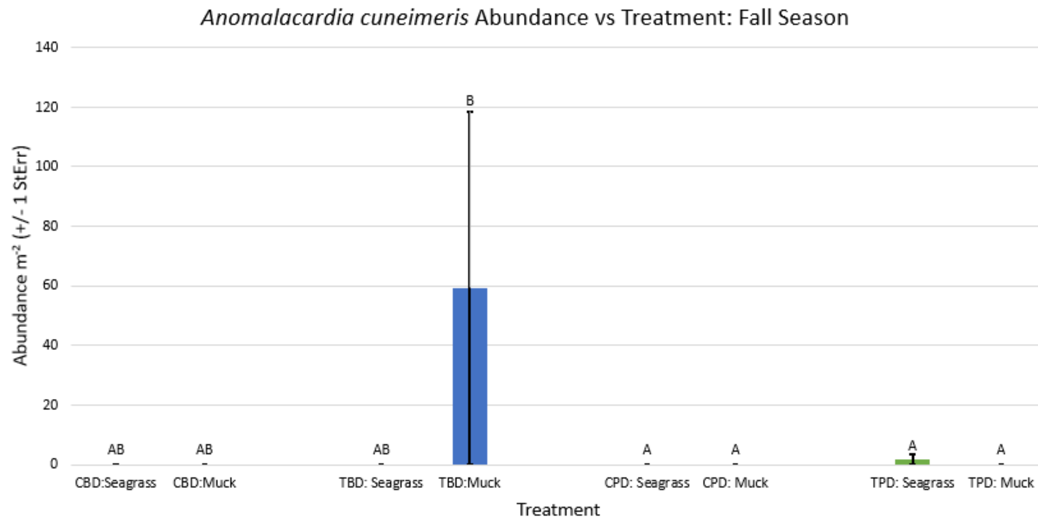

Turbonilla sp. Abundance vs Treatment: Spring Season
Abundance m-2 (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
0
100
200
300
400
500
600
700
A
B



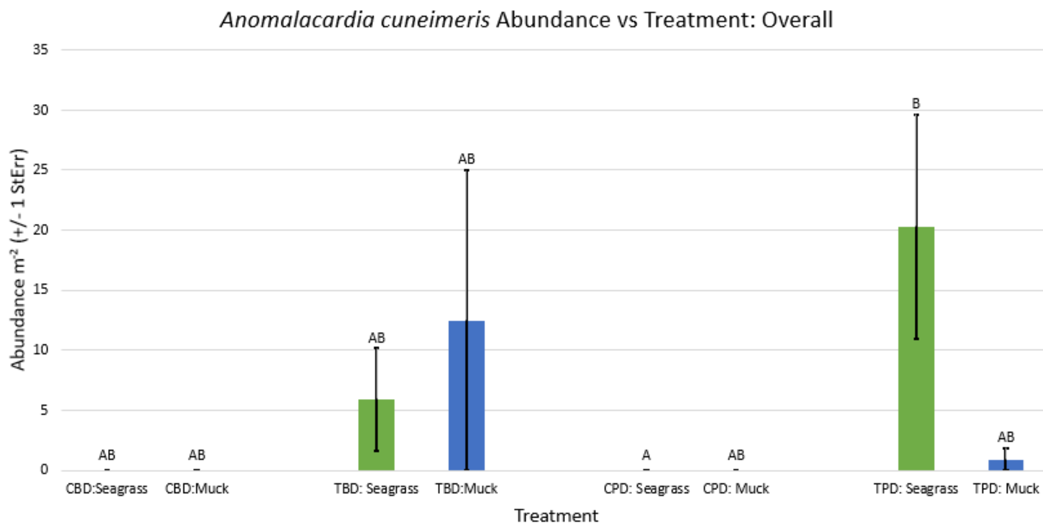
Turbonilla sp. Abundance vs Treatment: Summer Season
Abundance m-2 (+/- 1 StErr)
450
400
350
300
250
200
150
100
50
0
A
B
AB
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment



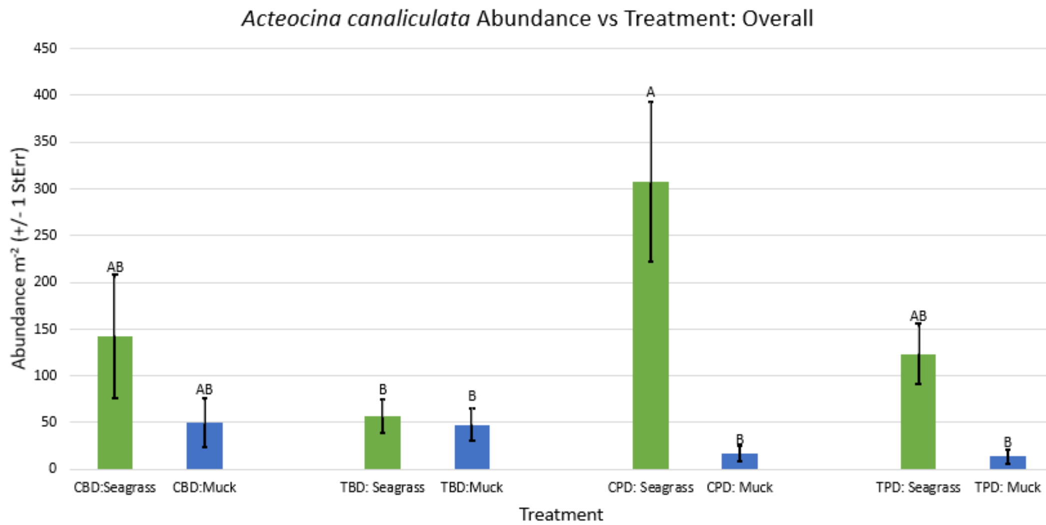
Anomalacardia cuneimeris Abundance vs Treatment: Summer Season
Abundance m-2 (+/- 1 StErr)
100
90
80
70
60
50
40
30
20
10
0
A
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

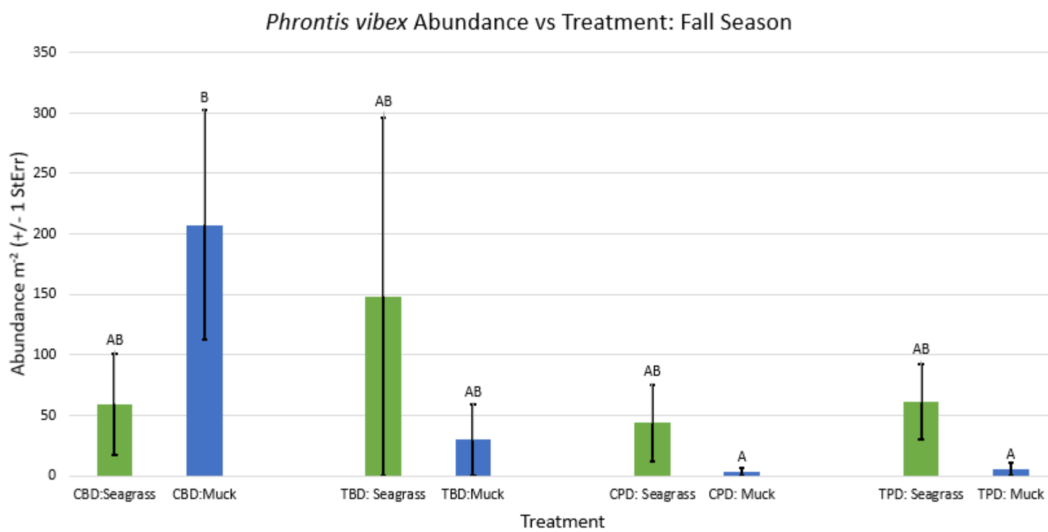


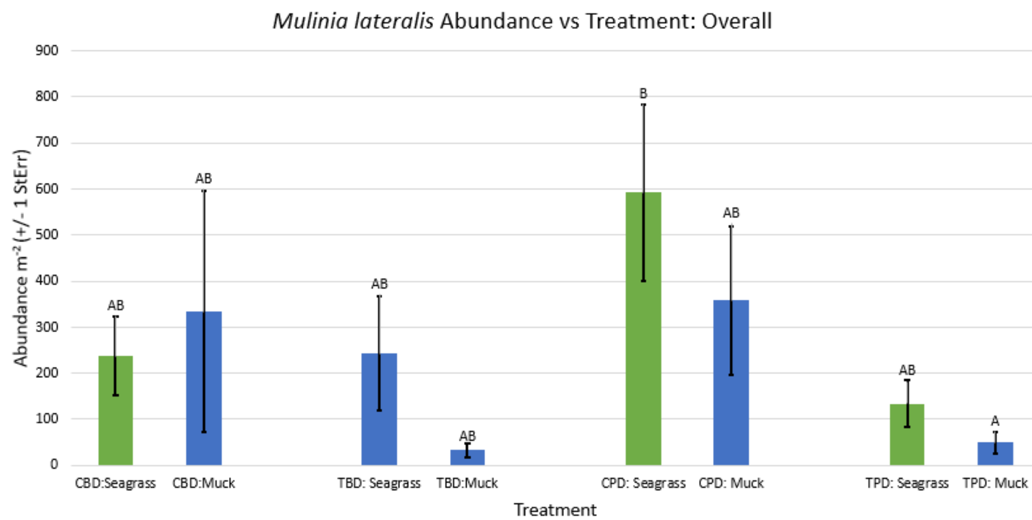
Anomalacardia cuneimeris Abundance vs Treatment: Fall Season
Abundance m-2 (+/- 1 StErr)
140
120
100
80
60
40
20
0
B
AB
AB
AB
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

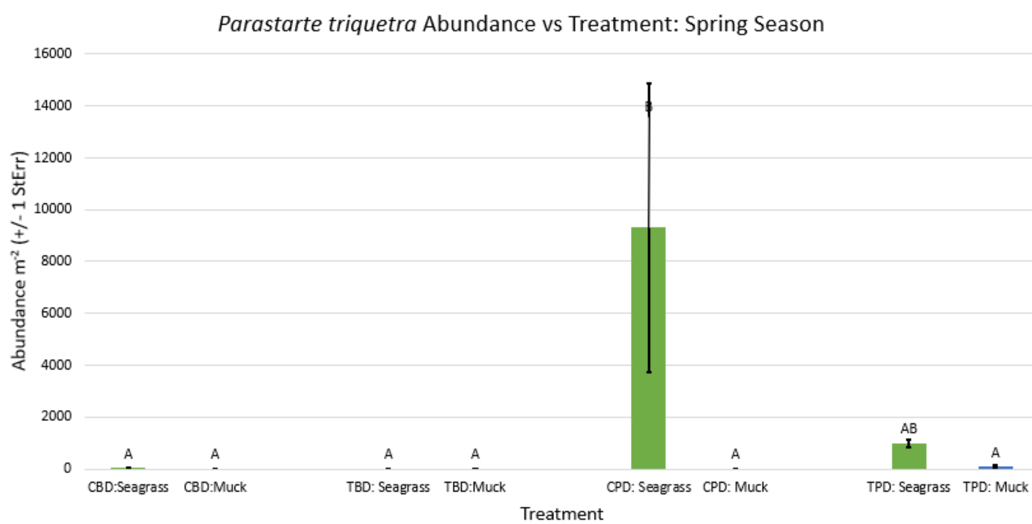


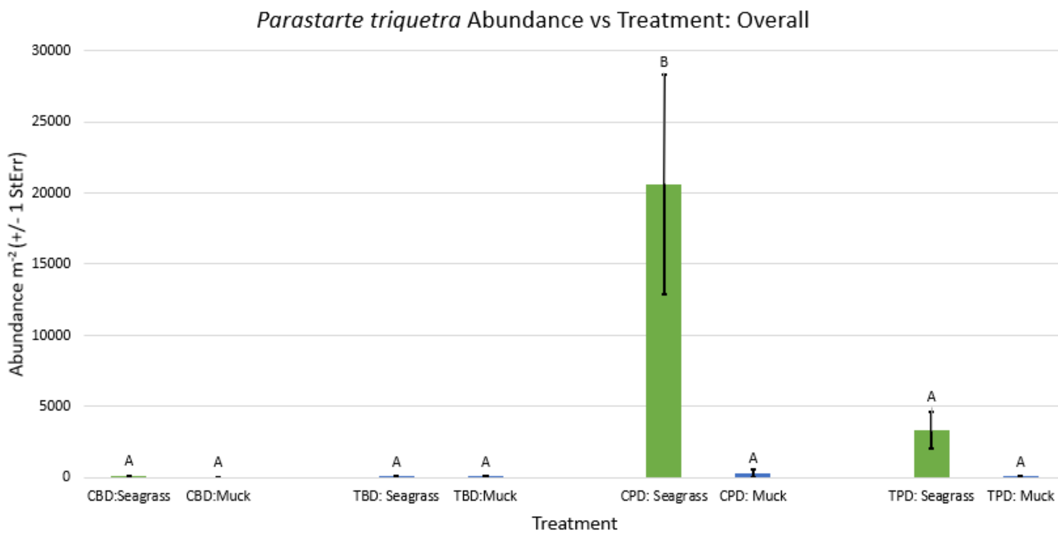
Anomalacardia cuneimeris Abundance vs Treatment: Overall
Abundance m-2 (+/- 1 StErr)
35
30
25
20
15
10
5
0
AB
AB
AB
AB
A
AB
B
AB
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

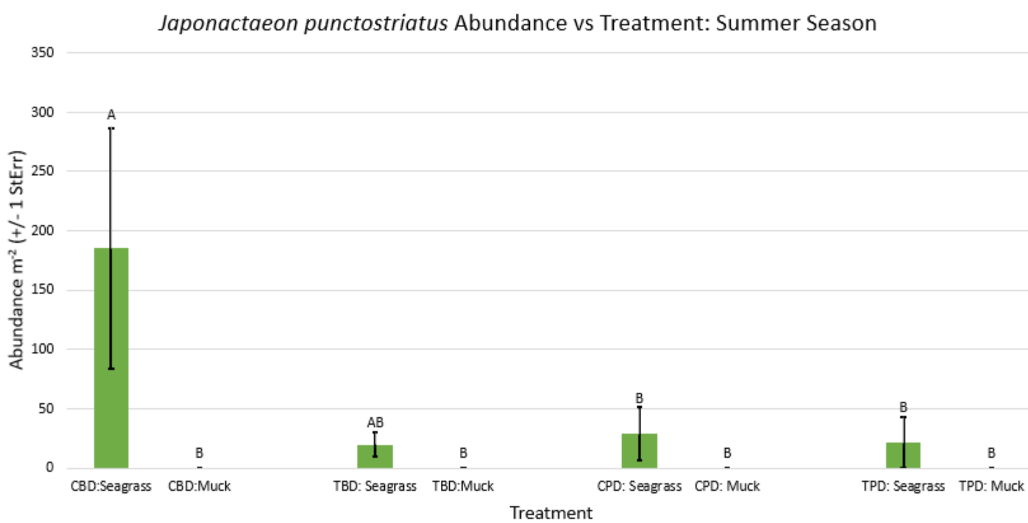

Acteocina canaliculata Abundance vs Treatment: Overall
Abundance m^{-2} (+/- 1 StErr)
450
400
350
300
250
200
150
100
50
0
AB
AB
B
B
A
B
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

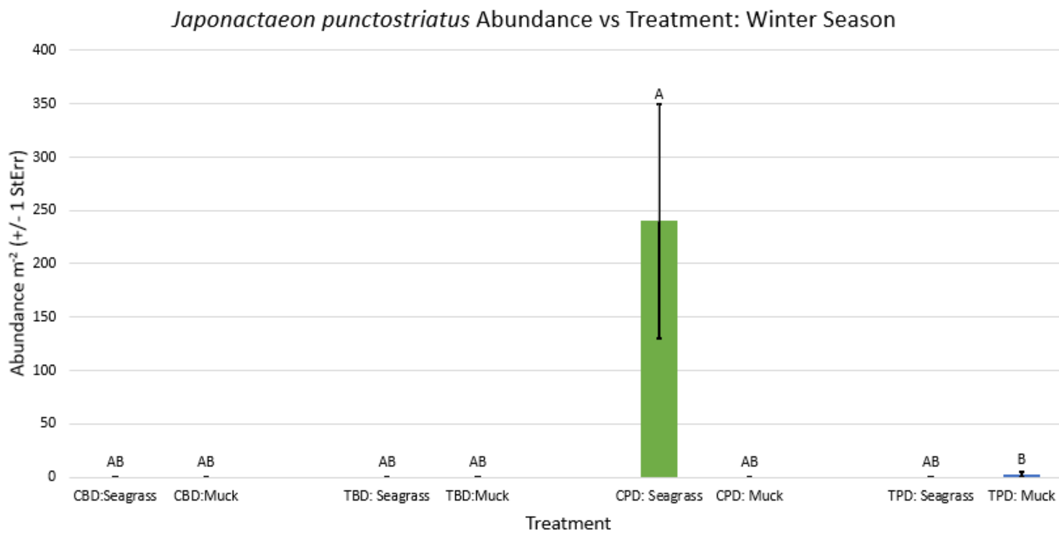

Phrontis vibex Abundance vs Treatment: Fall Season
Abundance m^{-2} (+/- 1 StErr)
350
300
250
200
150
100
50
0
AB
B
AB
AB
AB
A
AB
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

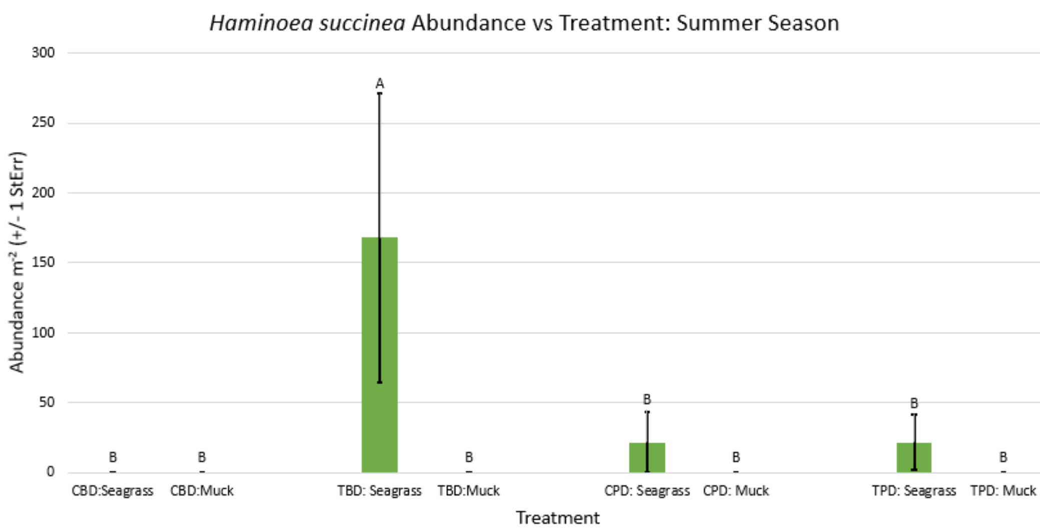

Mulinia lateralis Abundance vs Treatment: Overall
Abundance m-2 (+/- 1 StErr)
900
800
700
600
500
400
300
200
100
0
AB
AB
AB
AB
B
AB
AB
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

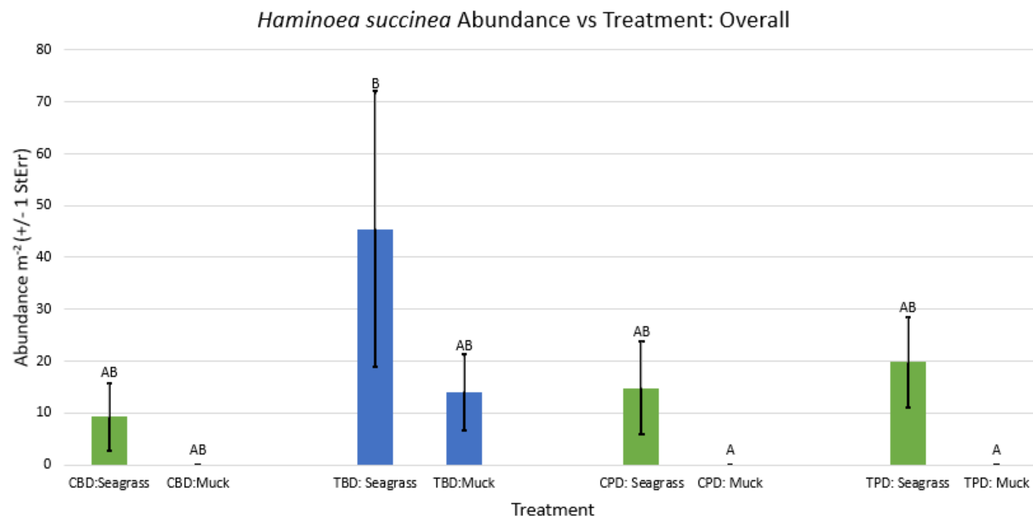

Parastarte triquetra Abundance vs Treatment: Spring Season
Abundance m-2 (+/- 1 StErr)
16000
14000
12000
10000
8000
6000
4000
2000
0
A
A
A
A
B
A
AB
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

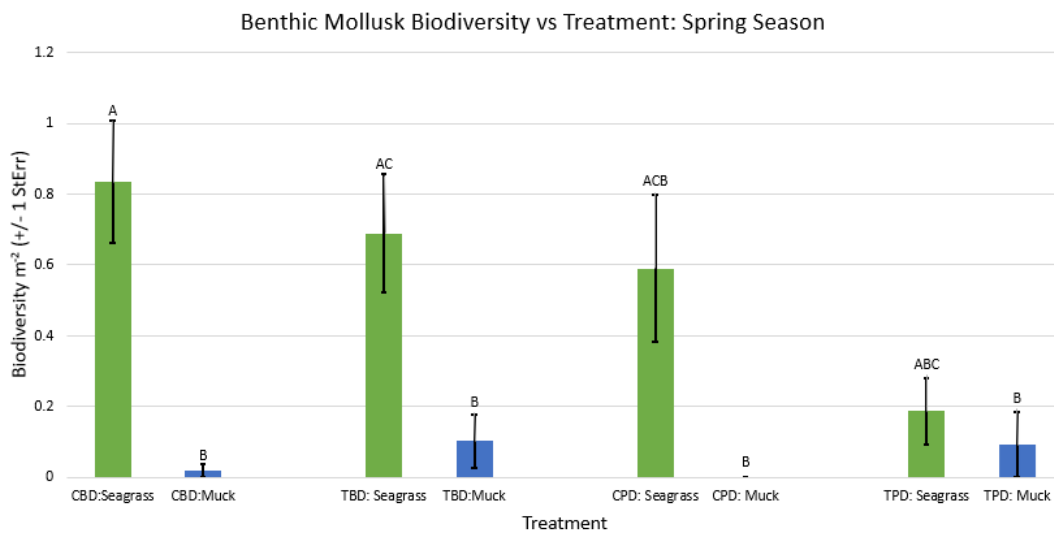

Parastarte triquetra Abundance vs Treatment: Overall
30000
25000
20000
15000
10000
5000
0
Abundance m-2 (+/- 1 StErr)
B
A
A
A
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

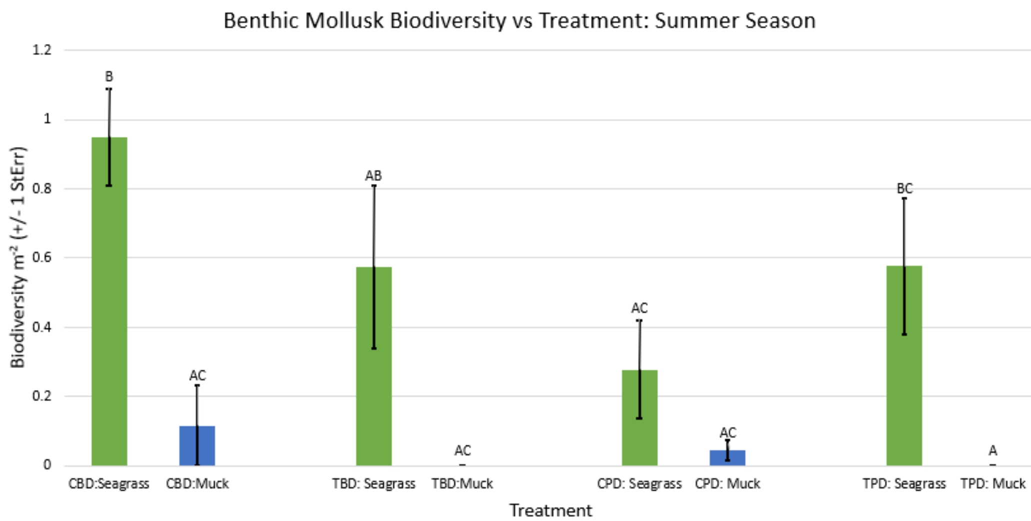

Japonactaeon punctostriatus Abundance vs Treatment: Summer Season
350
300
250
200
150
100
50
0
Abundance m-2 (+/- 1 StErr)
A
B
AB
B
B
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

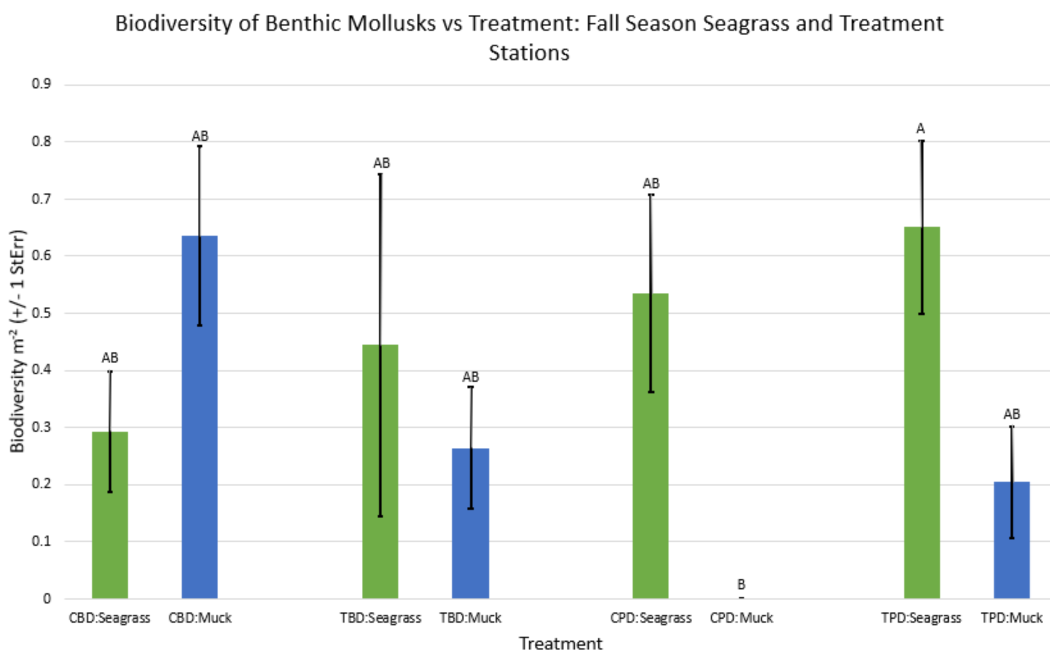

Japonactaeon punctostriatus Abundance vs Treatment: Winter Season
Abundance m² (+/- 1 StErr)
400
350
300
250
200
150
100
50
0
A
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

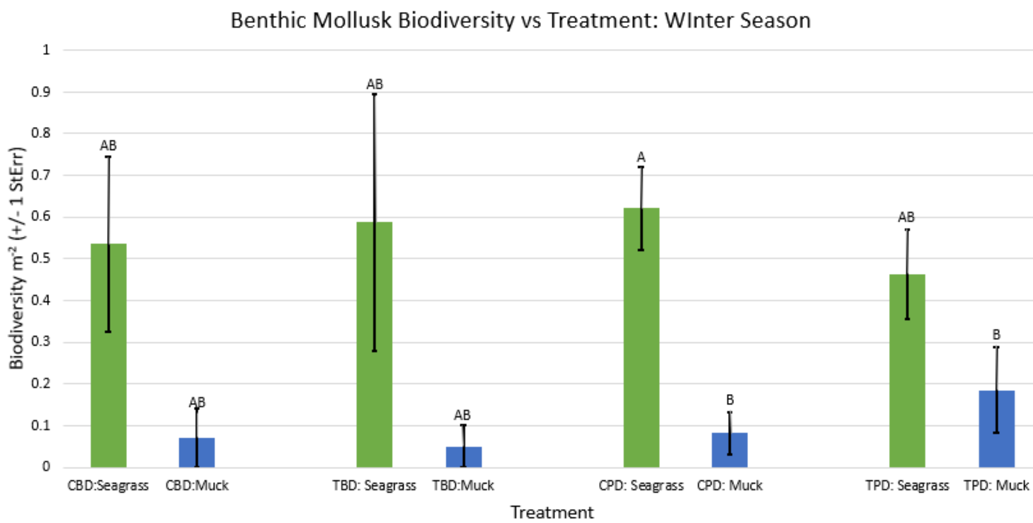

Haminoea succinea Abundance vs Treatment: Summer Season
Abundance m² (+/- 1 StErr)
300
250
200
150
100
50
0
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

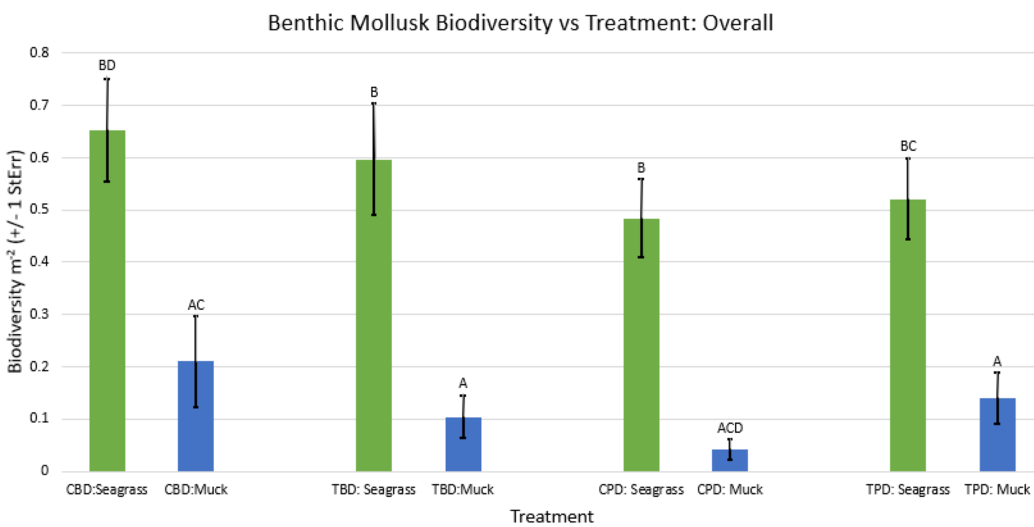

Haminoea succinea Abundance vs Treatment: Overall
Abundance m-2 (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
AB
AB
B
AB
AB
A
AB
A

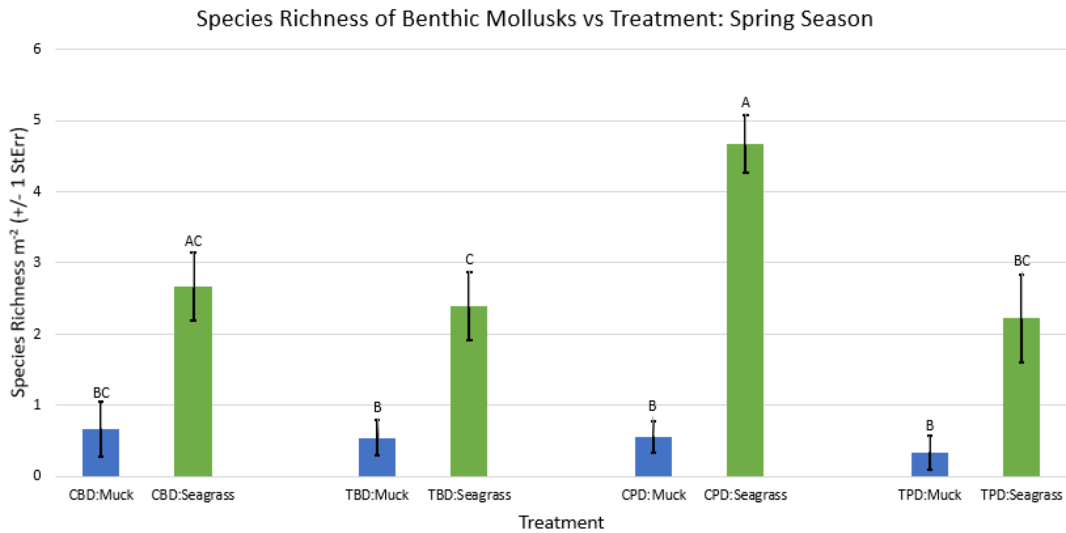

Benthic Mollusk Biodiversity vs Treatment: Spring Season
Biodiversity m-2 (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
A
B
AC
B
ACB
B
ABC
B

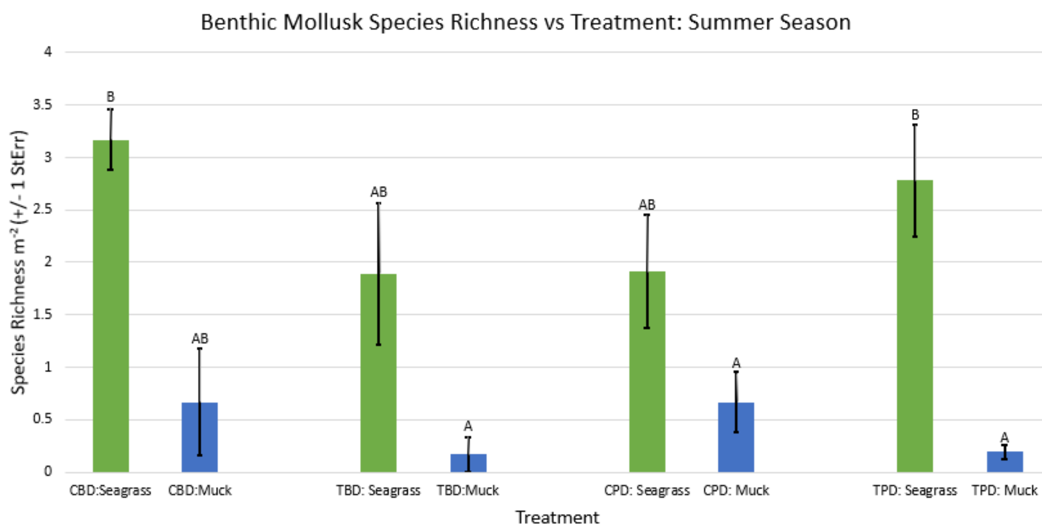

Benthic Mollusk Biodiversity vs Treatment: Summer Season
Biodiversity m² (+/- 1 StErr)
1.2
1
0.8
0.6
0.4
0.2
0
B
AC
AB
AC
AC
AC
BC
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

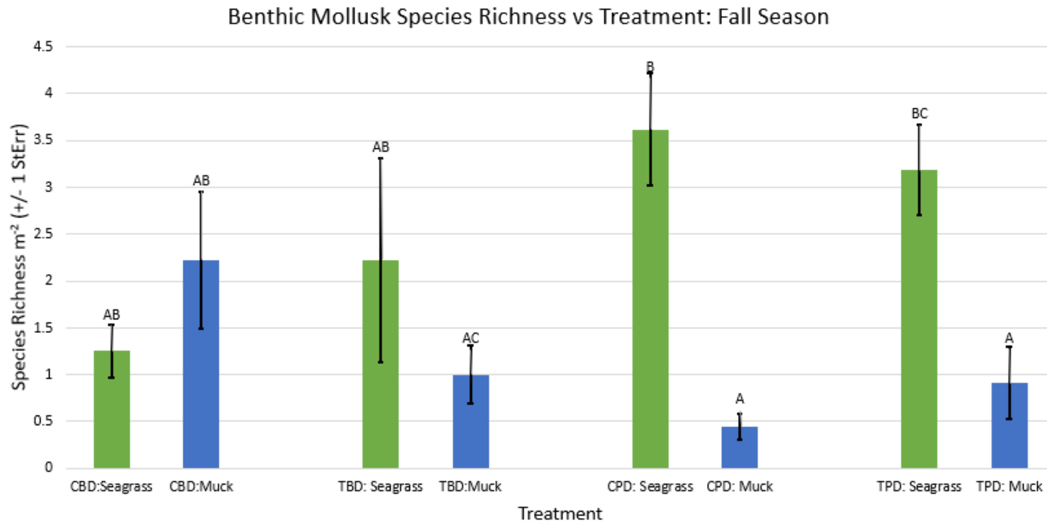

Biodiversity of Benthic Mollusks vs Treatment: Fall Season Seagrass and Treatment Stations
Biodiversity m² (+/- 1 StErr)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AB
AB
AB
AB
AB
B
A
AB
CBD:Seagrass
CBD:Muck
TBD:Seagrass
TBD:Muck
CPD:Seagrass
CPD:Muck
TPD:Seagrass
TPD:Muck
Treatment

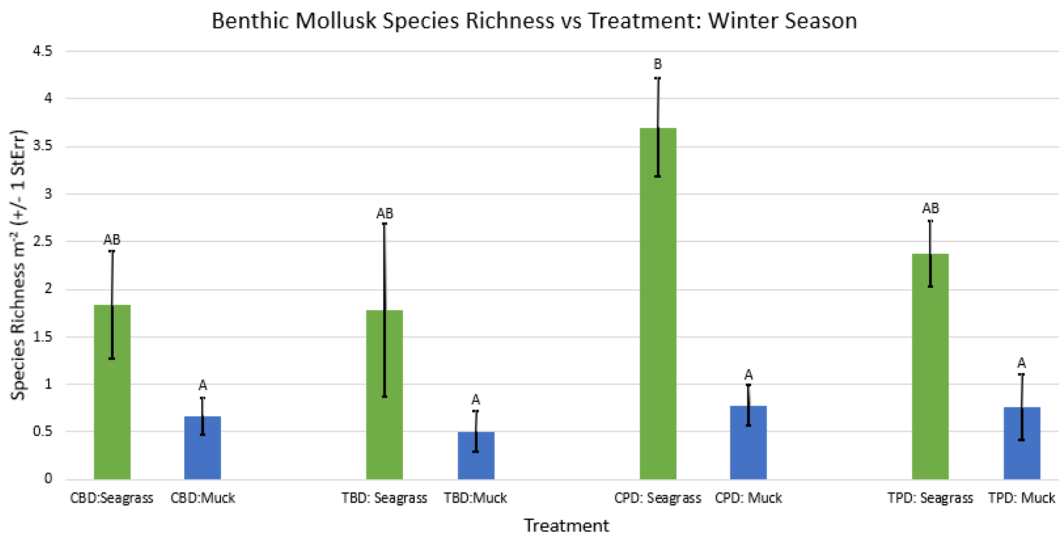

Benthic Mollusk Biodiversity vs Treatment: WInter Season
Biodiversity m² (+/- 1 StErr)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AB
AB
AB
AB
A
B
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

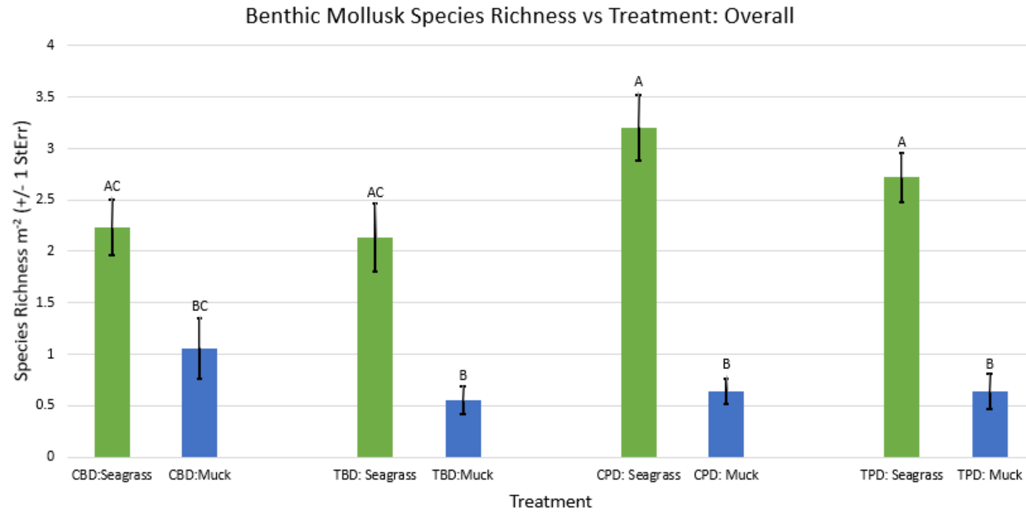

Benthic Mollusk Biodiversity vs Treatment: Overall
Biodiversity m² (+/- 1 StErr)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
BD
AC
B
A
B
ACD
BC
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

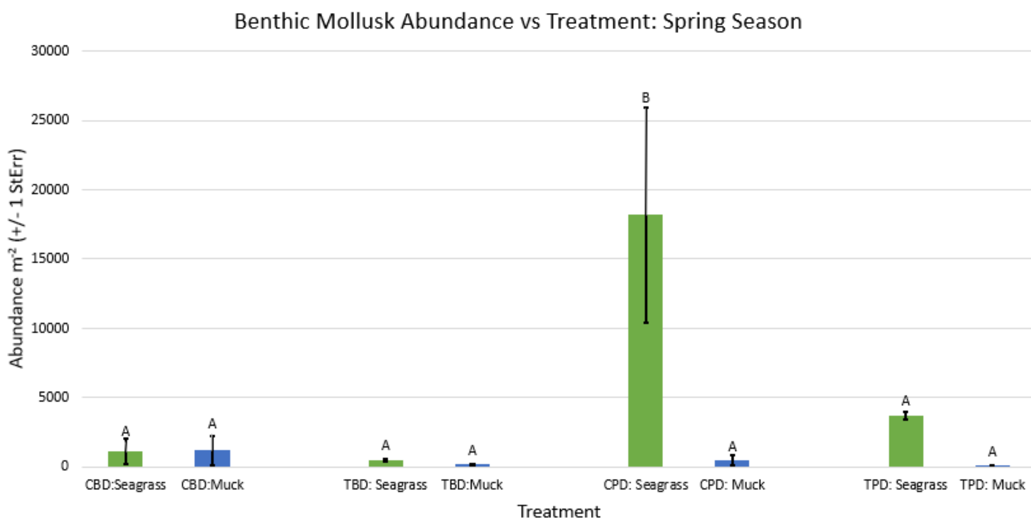

Species Richness of Benthic Mollusks vs Treatment: Spring Season
Species Richness m⁻² (+/- 1 StErr)
6
5
4
3
2
1
0
BC
AC
B
C
B
A
B
BC
CBD:Muck
CBD:Seagrass
TBD:Muck
TBD:Seagrass
CPD:Muck
CPD:Seagrass
TPD:Muck
TPD:Seagrass
Treatment

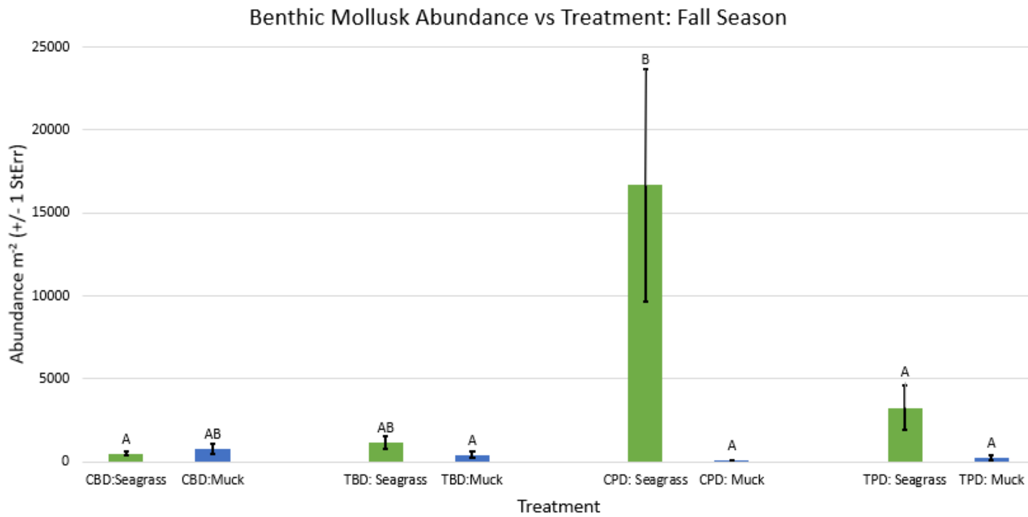

Benthic Mollusk Species Richness vs Treatment: Summer Season
Species Richness m⁻² (+/- 1 StErr)
4
3.5
3
2.5
2
1.5
1
0.5
0
B
AB
AB
A
AB
A
B
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Benthic Mollusk Species Richness vs Treatment: Fall Season
Species Richness m⁻² (+/- 1 StErr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
AB
AB
AB
AC
B
A
BC
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

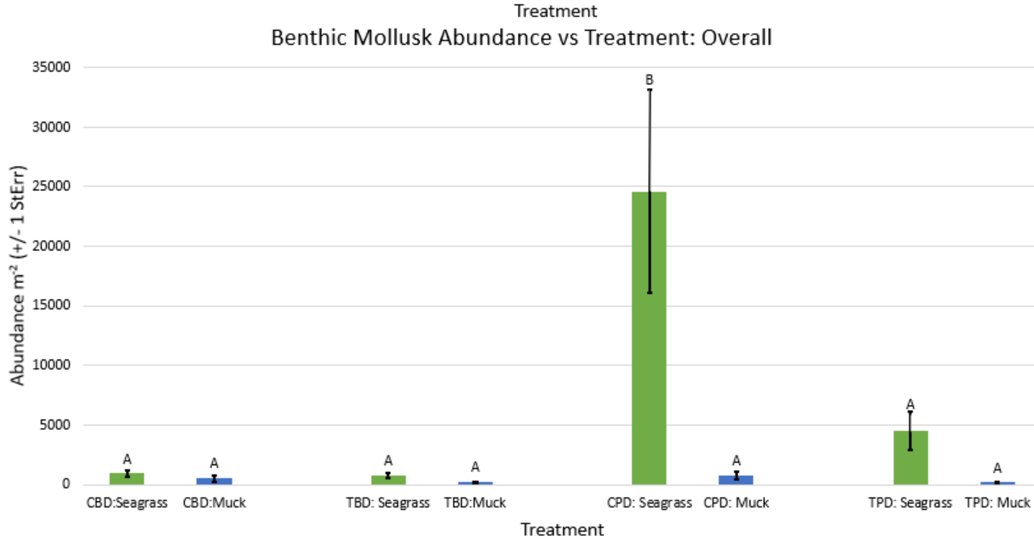

Benthic Mollusk Species Richness vs Treatment: Winter Season
Species Richness m⁻² (+/- 1 StErr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
AB
A
AB
A
B
A
AB
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Benthic Mollusk Species Richness vs Treatment: Overall
Species Richness m² (+/- 1 StErr)
4
3.5
3
2.5
2
1.5
1
0.5
0
AC
BC
AC
B
A
B
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

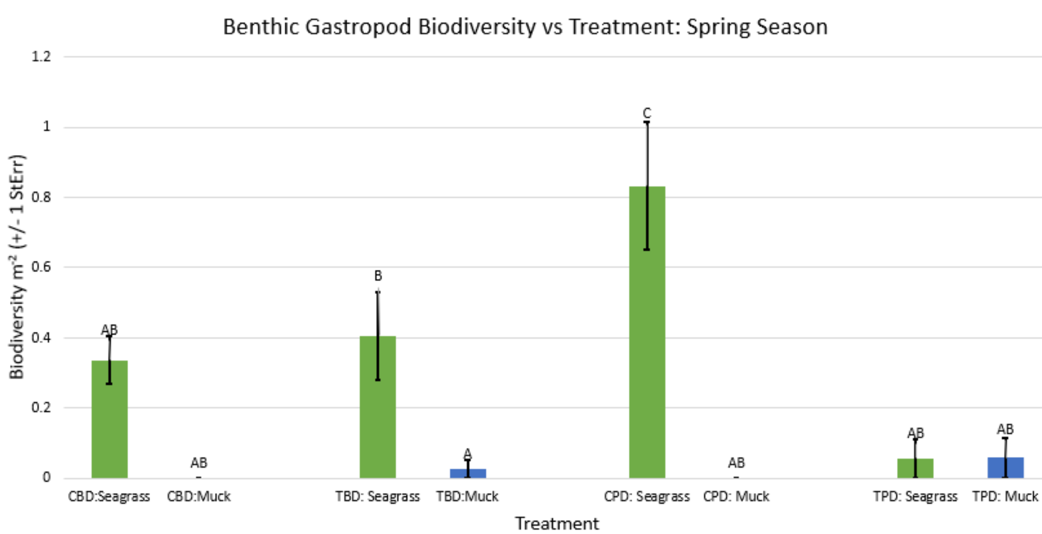

Benthic Mollusk Abundance vs Treatment: Spring Season
Abundance m² (+/- 1 StErr)
30000
25000
20000
15000
10000
5000
0
A
A
A
A
B
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment



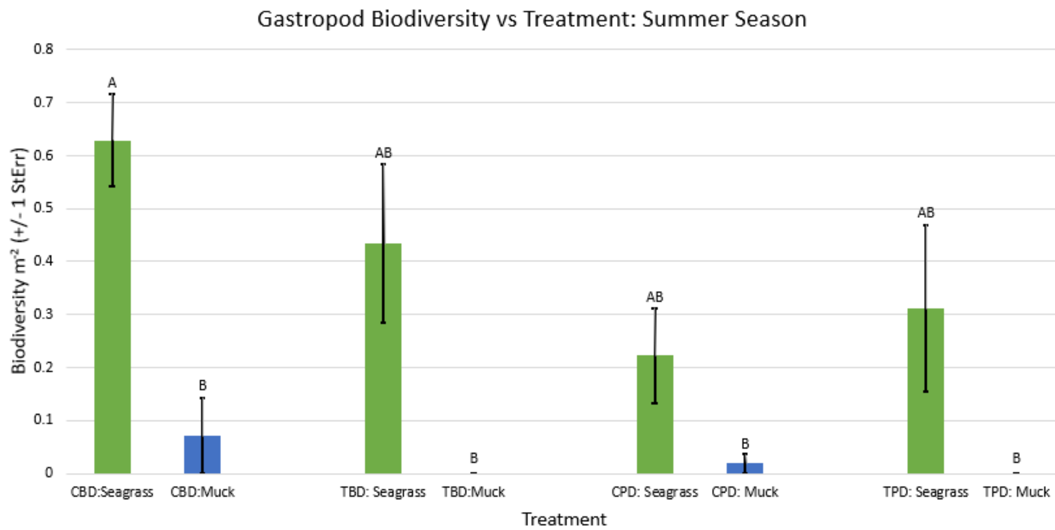
Benthic Mollusk Abundance vs Treatment: Fall Season
Abundance m² (+/- 1 StErr)
25000
20000
15000
10000
5000
0
A
AB
AB
A
B
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

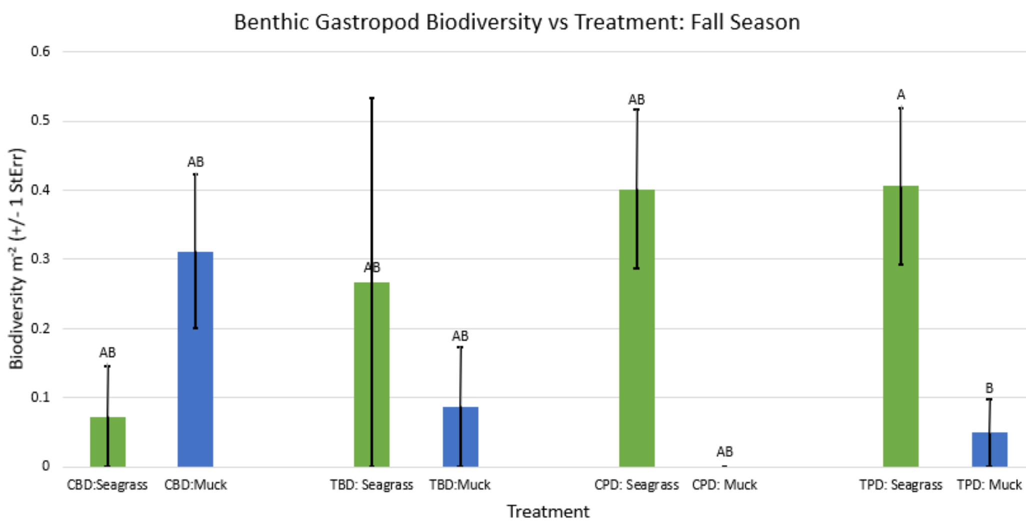


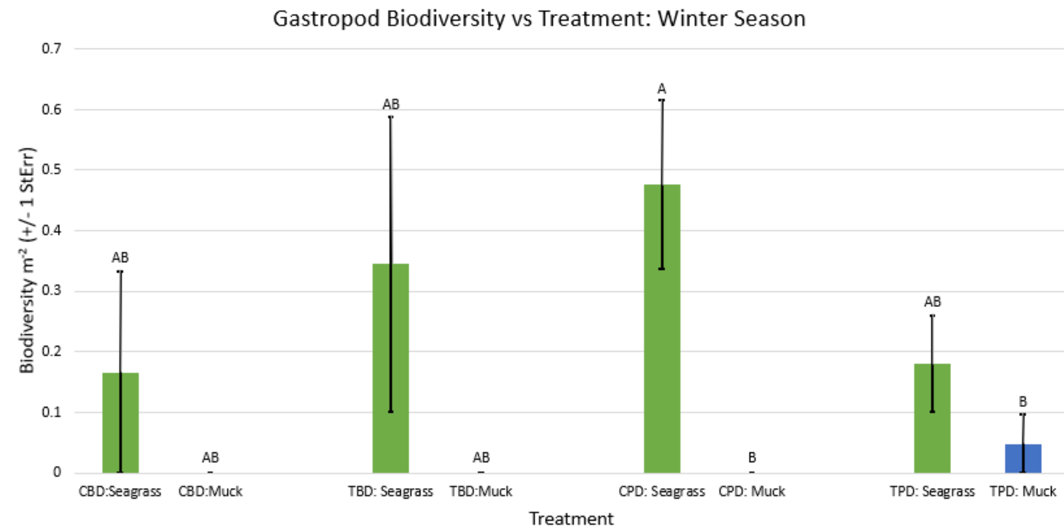
Benthic Mollusk Abundance vs Treatment: Overall
Abundance m² (+/- 1 StErr)
35000
30000
25000
20000
15000
10000
5000
0
A
A
A
A
B
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

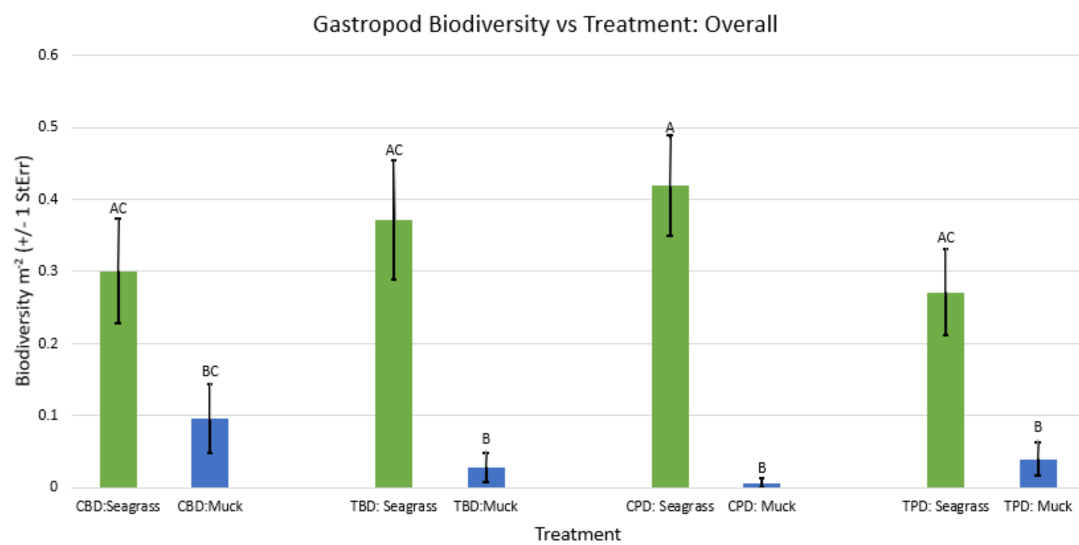


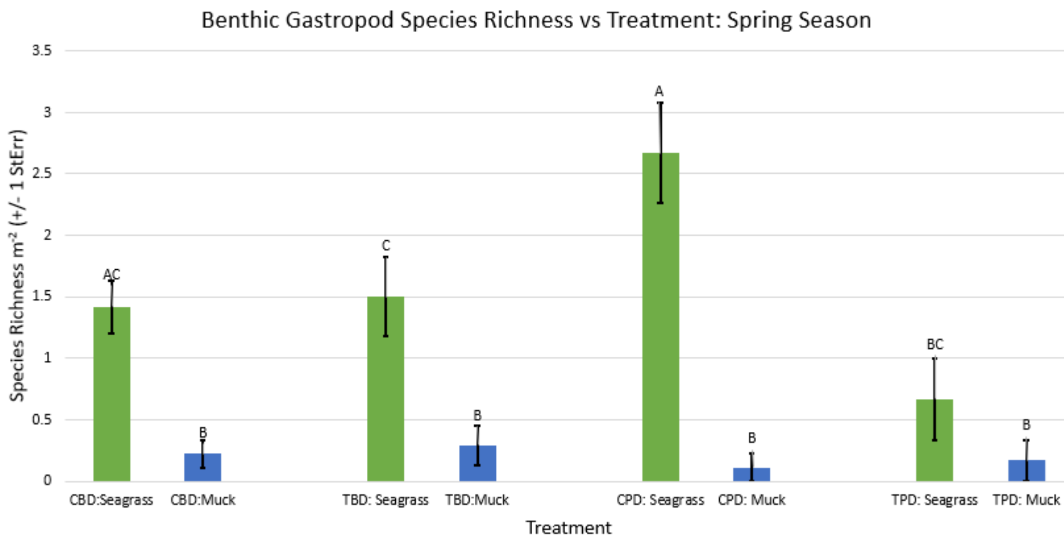
Benthic Gastropod Biodiversity vs Treatment: Spring Season
Biodiversity m² (+/- 1 StErr)
1.2
1
0.8
0.6
0.4
0.2
0
AB
AB
B
A
C
AB
AB
AB
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

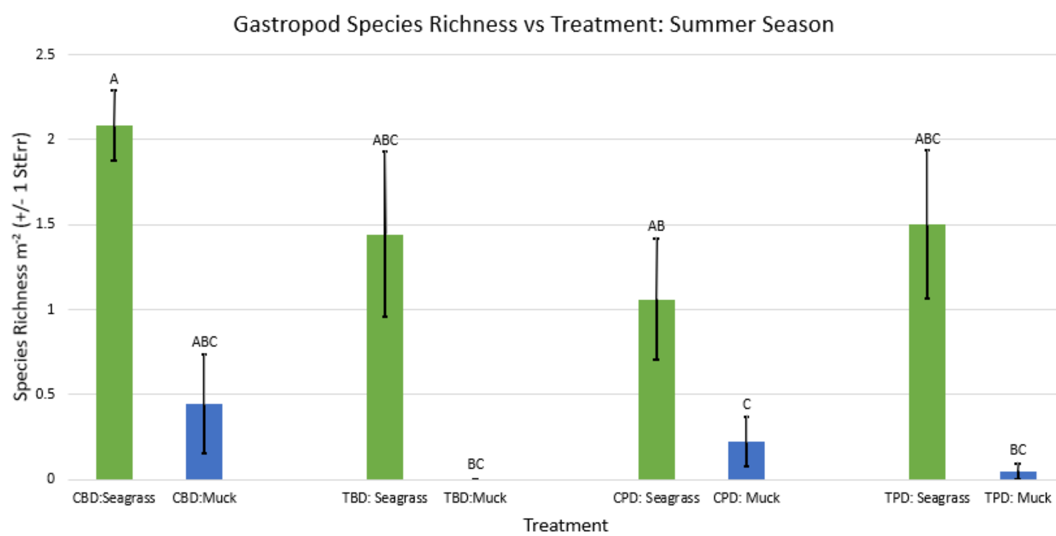

Gastropod Biodiversity vs Treatment: Summer Season
Biodiversity m² (+/- 1 StErr)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
AB
B
AB
B
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

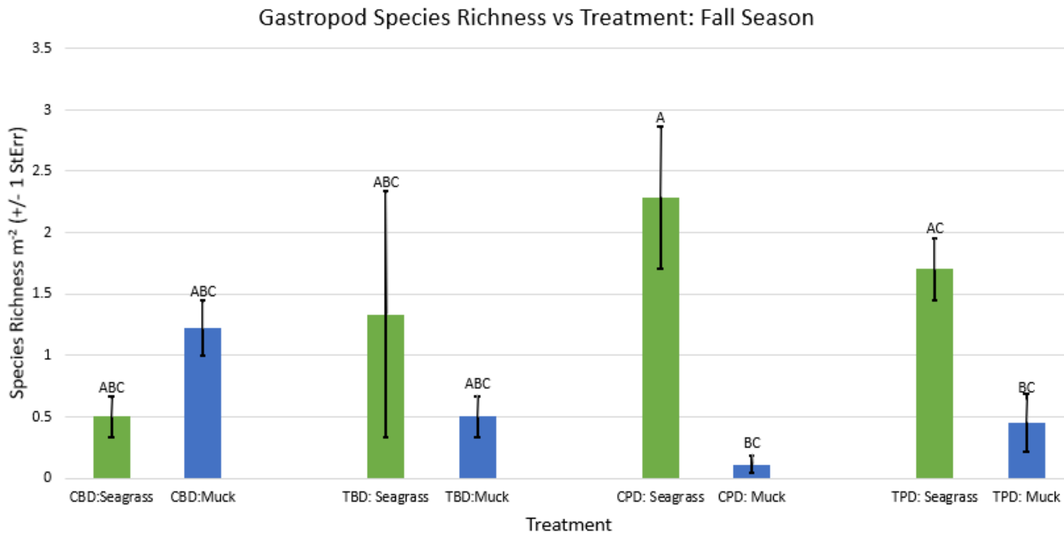

Benthic Gastropod Biodiversity vs Treatment: Fall Season
Biodiversity m² (+/- 1 StErr)
0.6
0.5
0.4
0.3
0.2
0.1
0
AB
AB
AB
AB
AB
AB
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

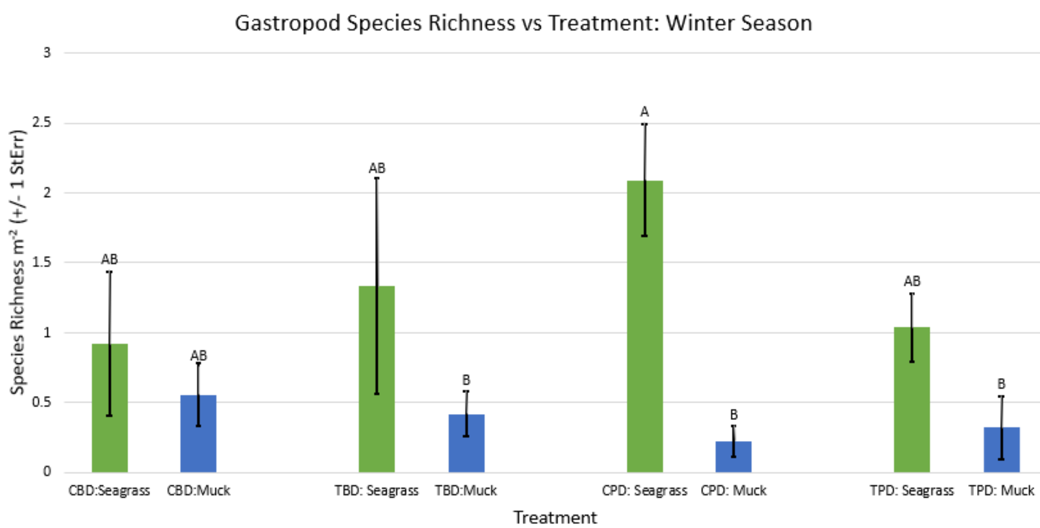

Gastropod Biodiversity vs Treatment: Winter Season
Biodiversity m-2 (+/- 1 StErr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AB
AB
AB
AB
A
B
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

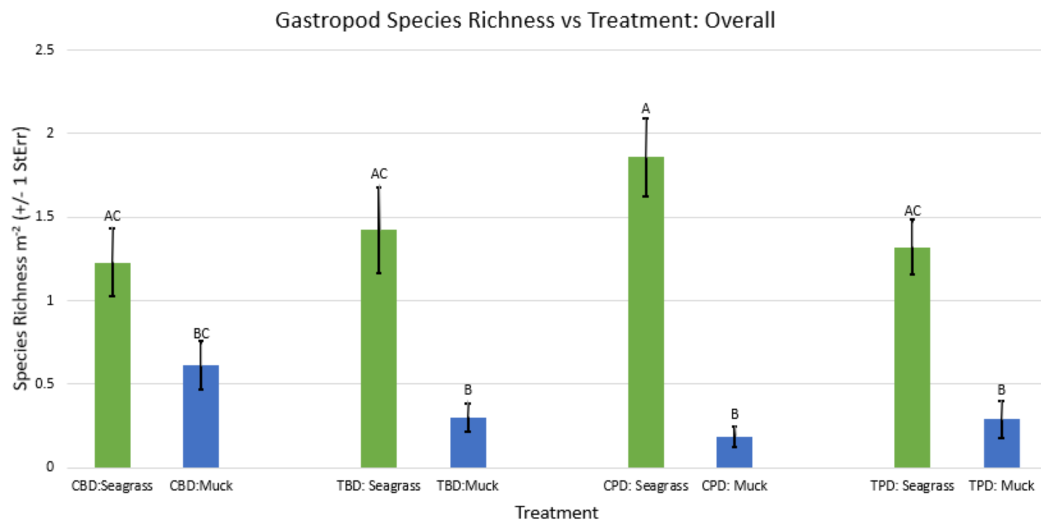

Gastropod Biodiversity vs Treatment: Overall
Biodiversity m-2 (+/- 1 StErr)
0.6
0.5
0.4
0.3
0.2
0.1
0
AC
BC
AC
B
A
B
AC
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

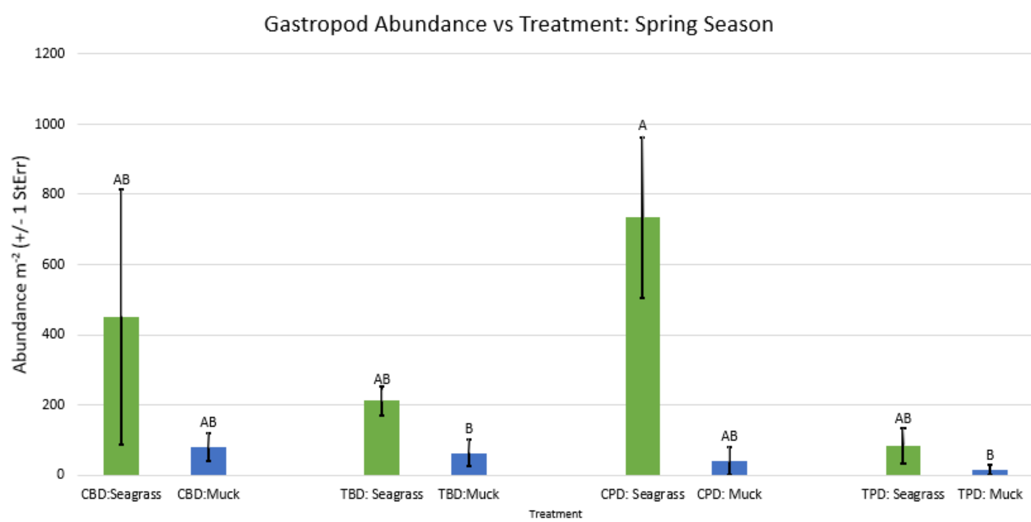

Benthic Gastropod Species Richness vs Treatment: Spring Season
Species Richness m^{-2} (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
AC
B
C
B
A
B
BC
B

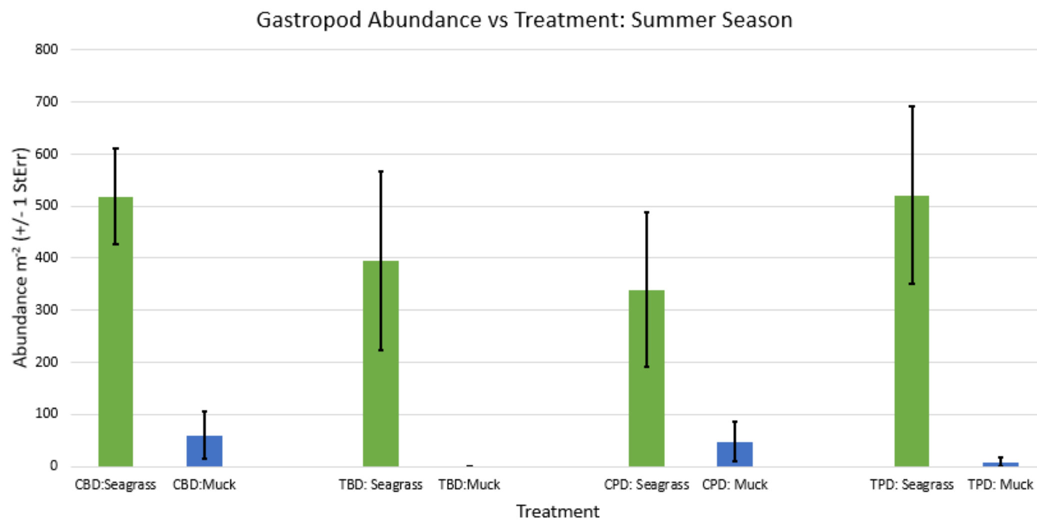

Gastropod Species Richness vs Treatment: Summer Season
Species Richness m^{-2} (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
A
ABC
ABC
BC
AB
C
ABC
BC

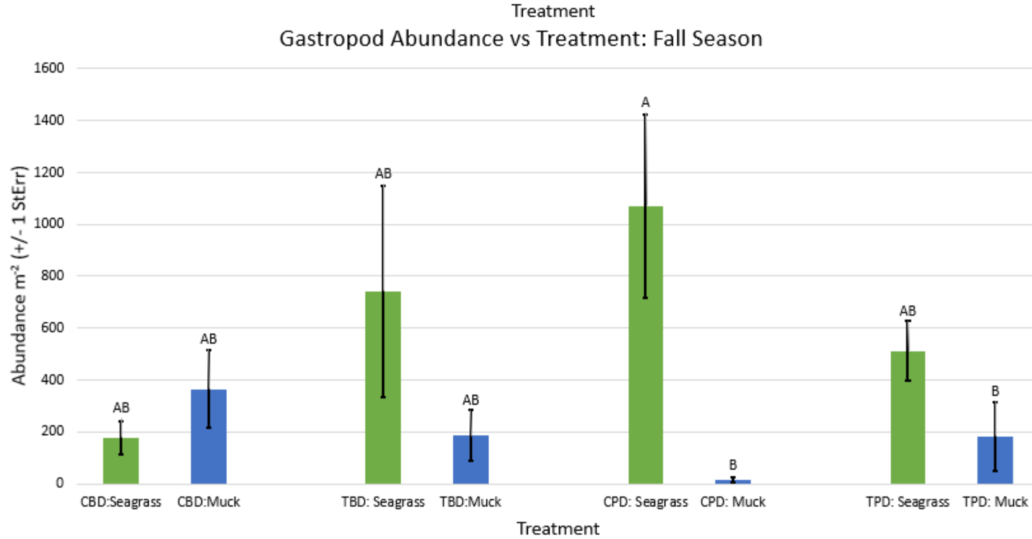

Gastropod Species Richness vs Treatment: Fall Season
Species Richness m⁻² (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
ABC
ABC
ABC
ABC
A
BC
AC
BC

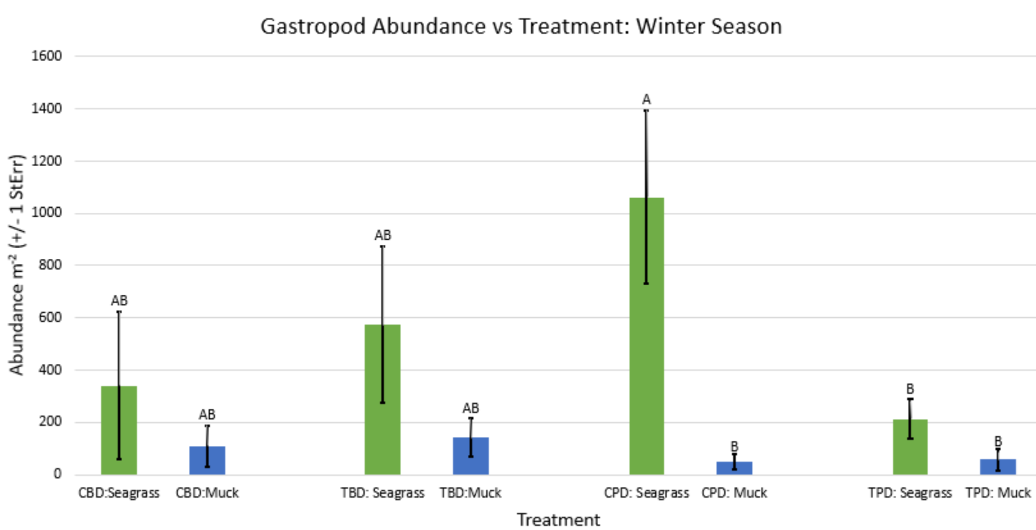

Gastropod Species Richness vs Treatment: Winter Season
Species Richness m⁻² (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
AB
AB
AB
B
A
B
AB
B

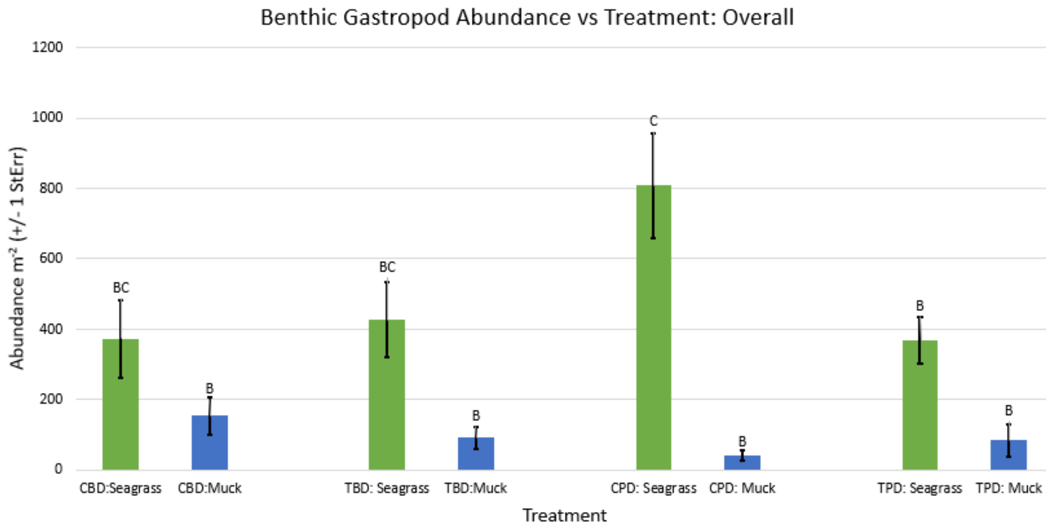

Gastropod Species Richness vs Treatment: Overall
Species Richness m⁻² (+/- 1 StErr)
2.5
2
1.5
1
0.5
0
AC
BC
AC
B
A
B
AC
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

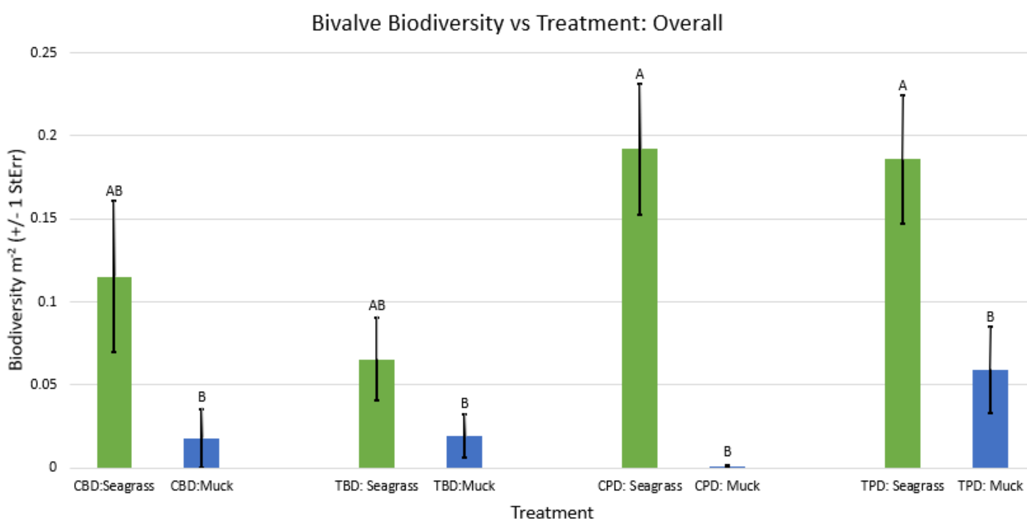

Gastropod Abundance vs Treatment: Spring Season
Abundance m⁻² (+/- 1 StErr)
1200
1000
800
600
400
200
0
AB
AB
AB
B
A
AB
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

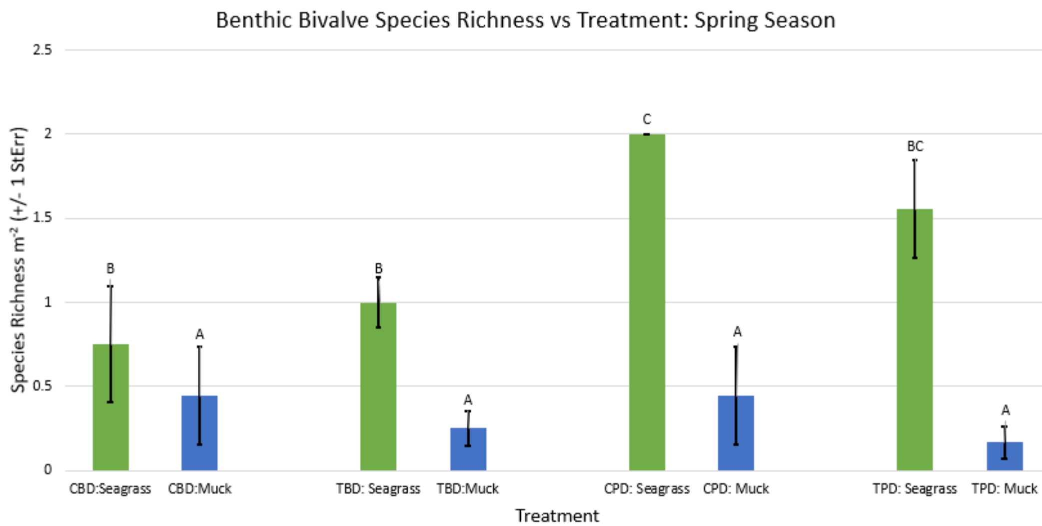

Gastropod Abundance vs Treatment: Summer Season
Abundance m-2 (+/- 1 StErr)
800
700
600
500
400
300
200
100
0
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

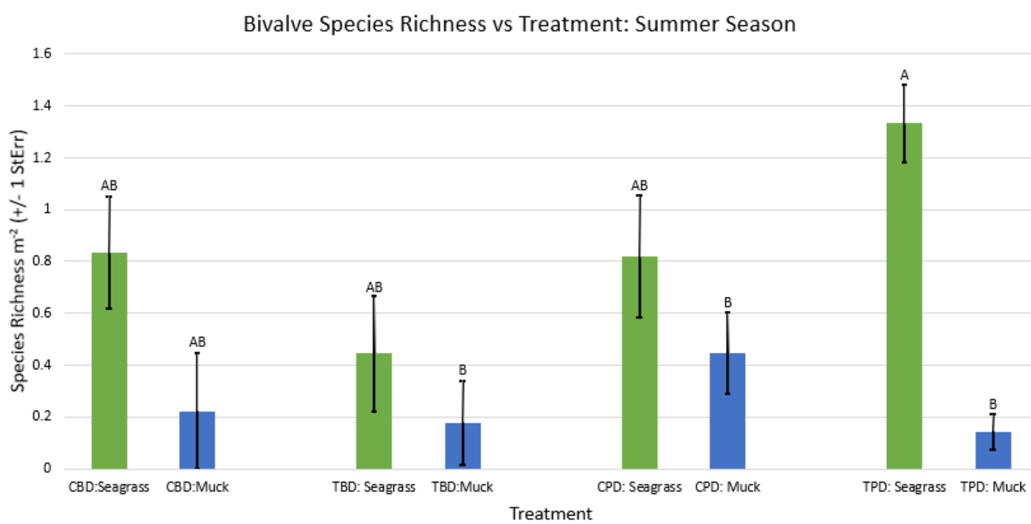

Gastropod Abundance vs Treatment: Fall Season
Abundance m-2 (+/- 1 StErr)
1600
1400
1200
1000
800
600
400
200
0
AB
AB
AB
AB
A
B
AB
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

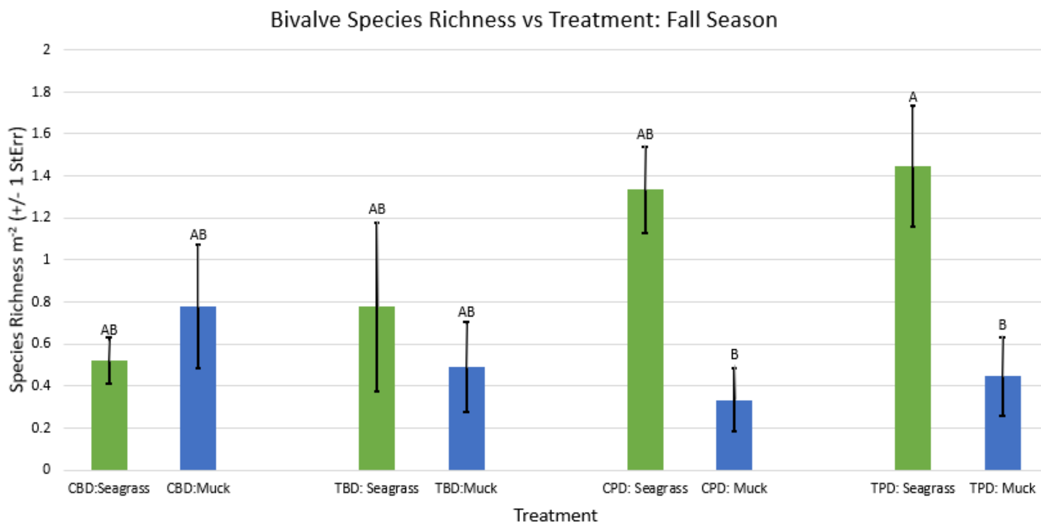

Gastropod Abundance vs Treatment: Winter Season
Abundance m-2 (+/- 1 StErr)
1600
1400
1200
1000
800
600
400
200
0
AB
AB
AB
AB
A
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

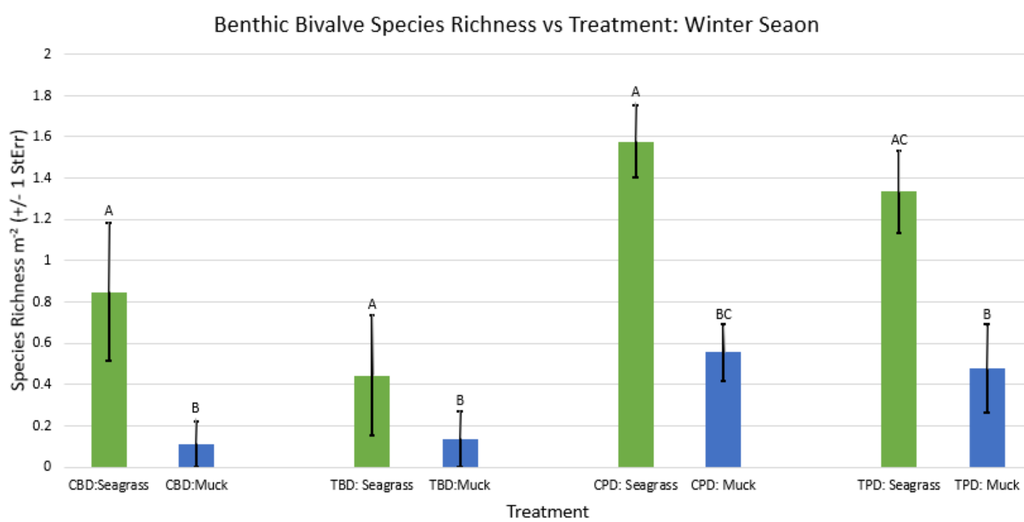

Benthic Gastropod Abundance vs Treatment: Overall
1200
1000
800
600
400
200
0
Abundance m² (+/- 1 StErr)
BC
B
BC
B
C
B
B
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

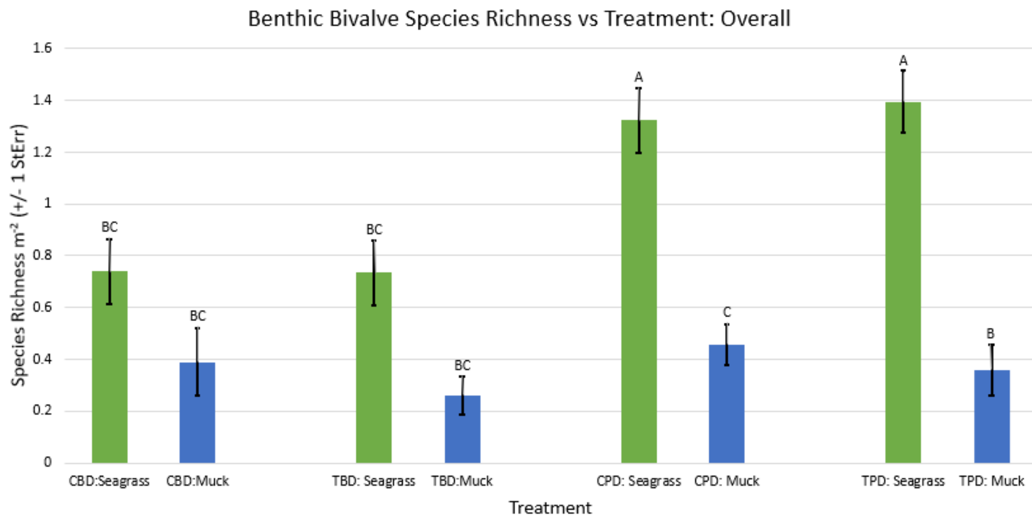

Bivalve Biodiversity vs Treatment: Overall
0.25
0.2
0.15
0.1
0.05
0
Biodiversity m² (+/- 1 StErr)
AB
B
AB
B
A
B
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Benthic Bivalve Species Richness vs Treatment: Spring Season
Species Richness m-2 (+/- 1 StErr)
2.5
2
1.5
1
0.5
0
B
A
B
A
C
A
BC
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

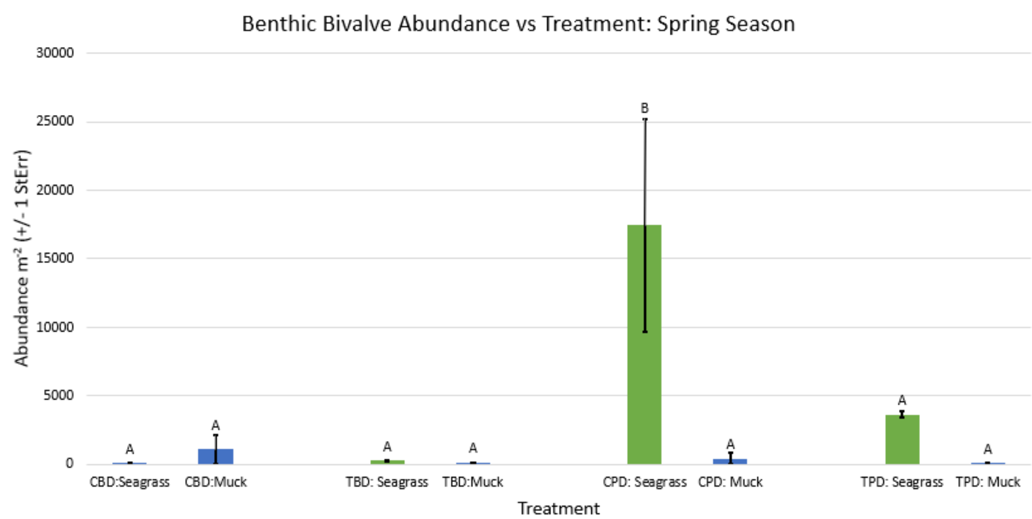

Bivalve Species Richness vs Treatment: Summer Season
Species Richness m-2 (+/- 1 StErr)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
AB
AB
AB
B
AB
B
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Bivalve Species Richness vs Treatment: Fall Season
Species Richness m² (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
AB
AB
AB
AB
AB
B
A
B

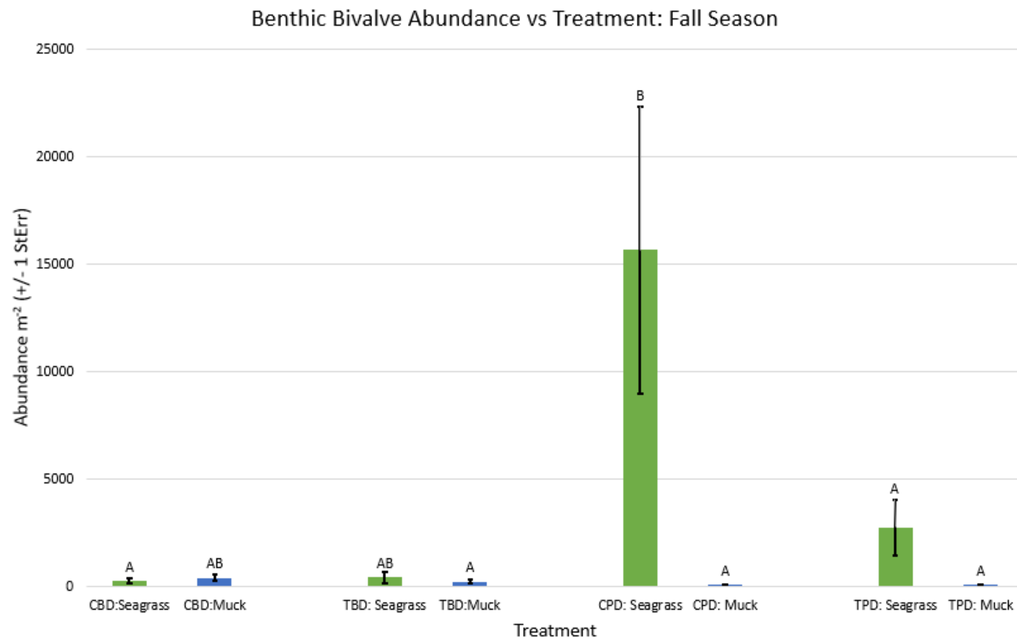

Benthic Bivalve Species Richness vs Treatment: Winter Seaon
Species Richness m² (+/- 1 StErr)
Treatment
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
A
B
A
B
A
BC
AC
B

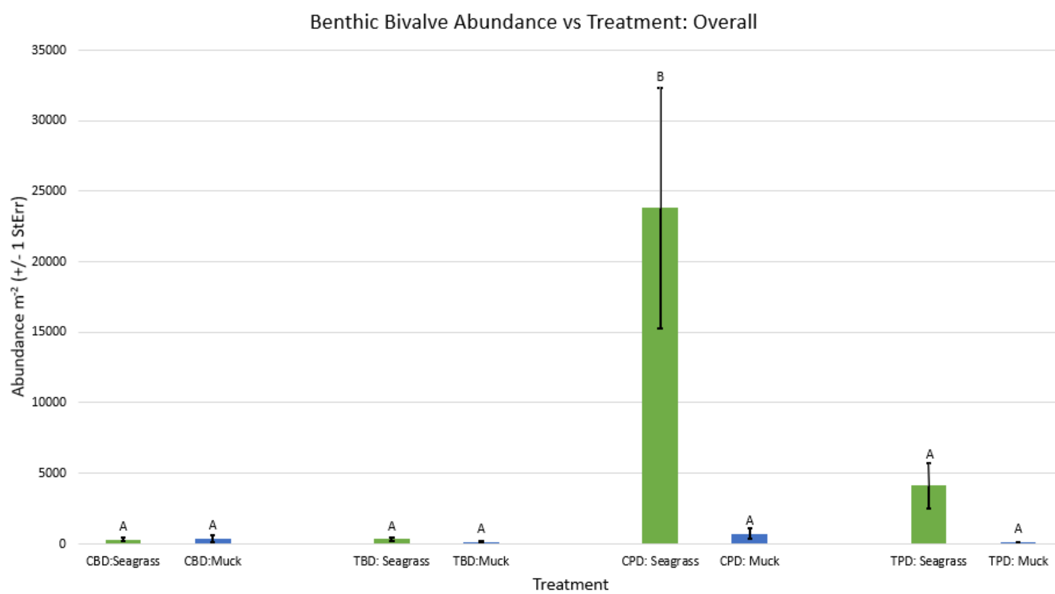


Benthic Bivalve Species Richness vs Treatment: Overall
Species Richness m² (+/- 1 StErr)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
BC
BC
BC
BC
A
C
A
B
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

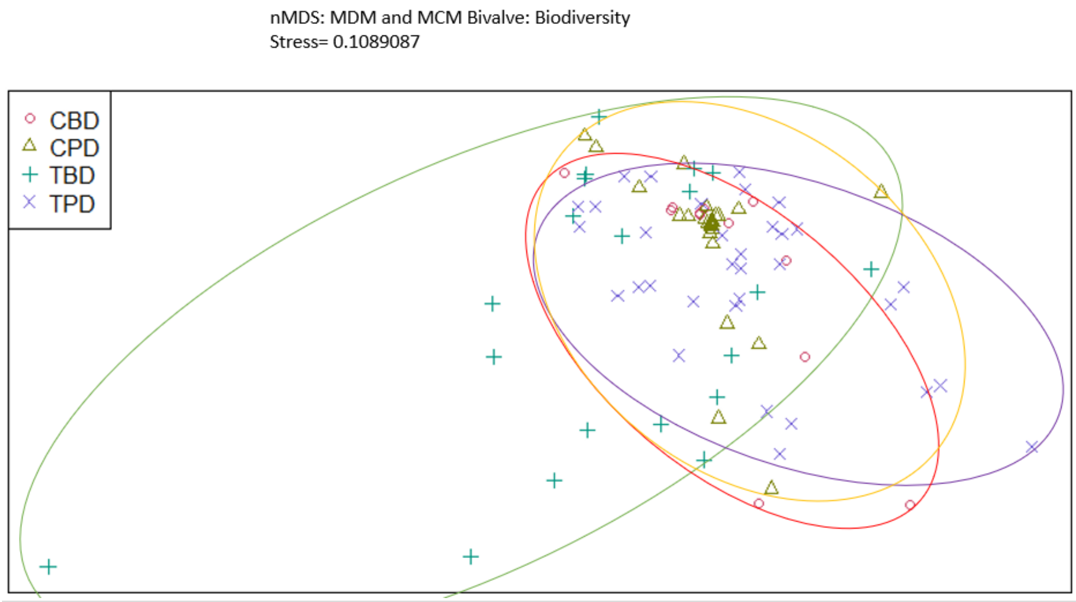


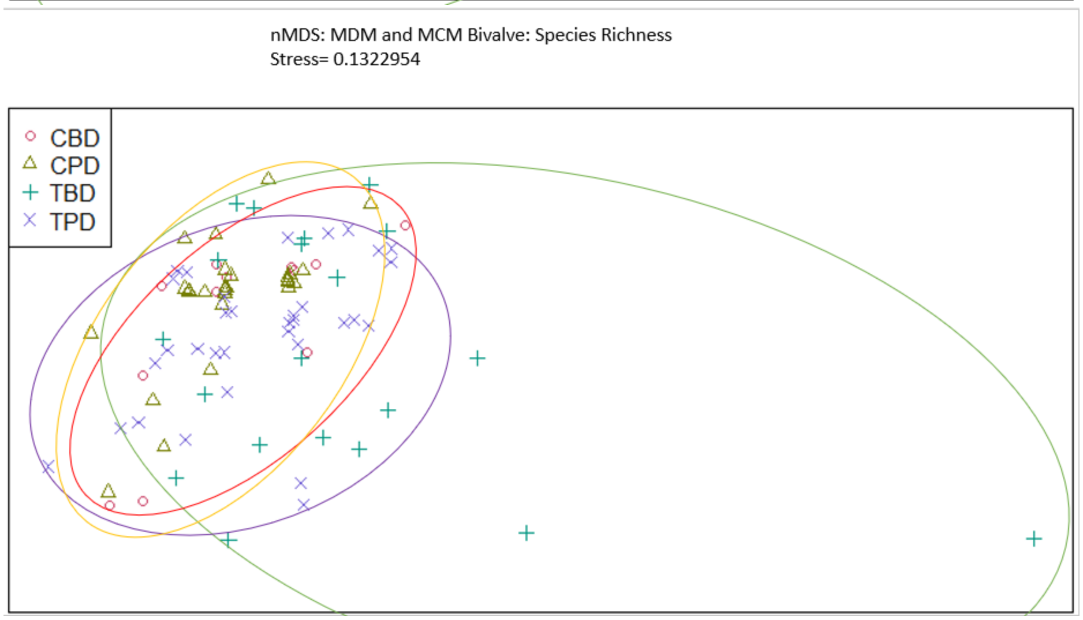
Benthic Bivalve Abundance vs Treatment: Spring Season
Abundance m² (+/- 1 StErr)
30000
25000
20000
15000
10000
5000
0
A
A
A
A
B
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment


Benthic Bivalve Abundance vs Treatment: Fall Season
25000
20000
15000
10000
5000
0
Abundance m⁻² (+/- 1 StErr)
B
A
AB
AB
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

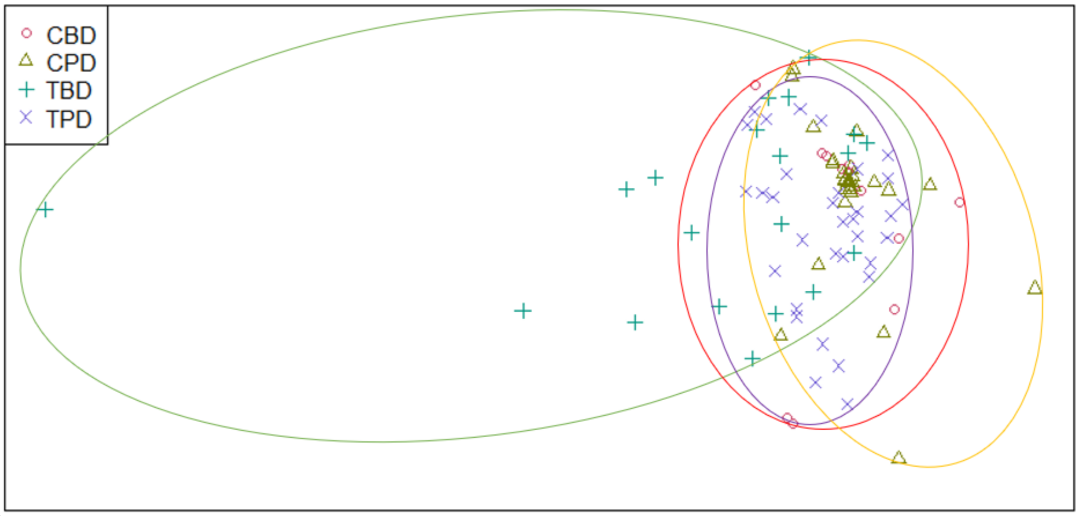

Benthic Bivalve Abundance vs Treatment: Overall
35000
30000
25000
20000
15000
10000
5000
0
Abundance m⁻² (+/- 1 StErr)
B
A
A
A
A
A
A
A
CBD:Seagrass
CBD:Muck
TBD: Seagrass
TBD:Muck
CPD: Seagrass
CPD: Muck
TPD: Seagrass
TPD: Muck
Treatment

nMDS Figures:

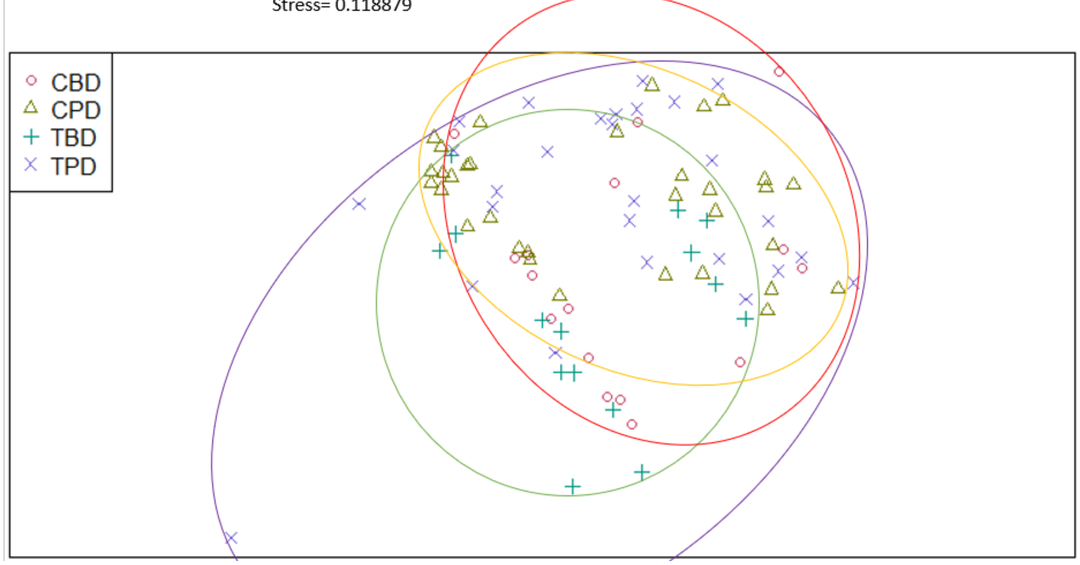




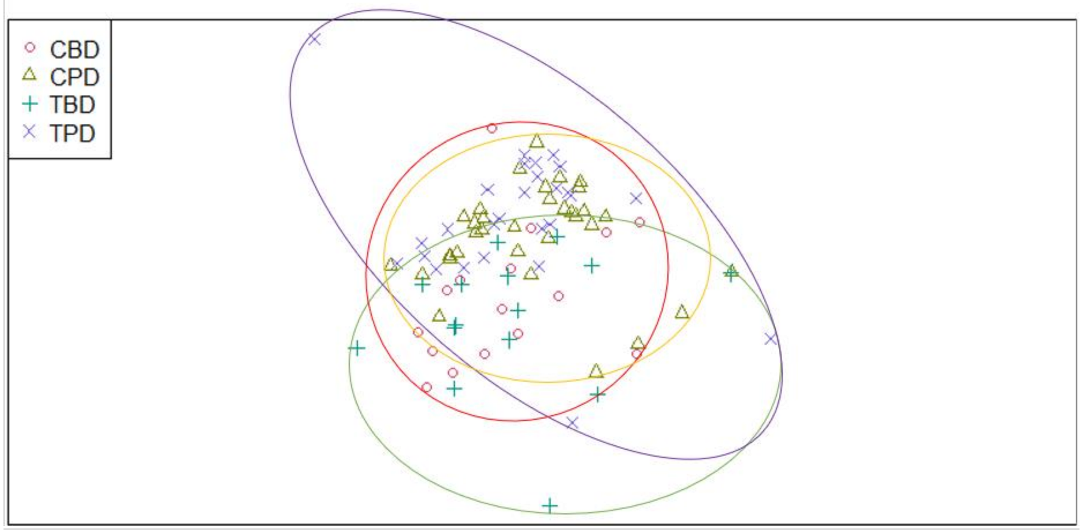
nMDS: MDM and MCM Bivalve: Abundance
Stress= 0.09502711



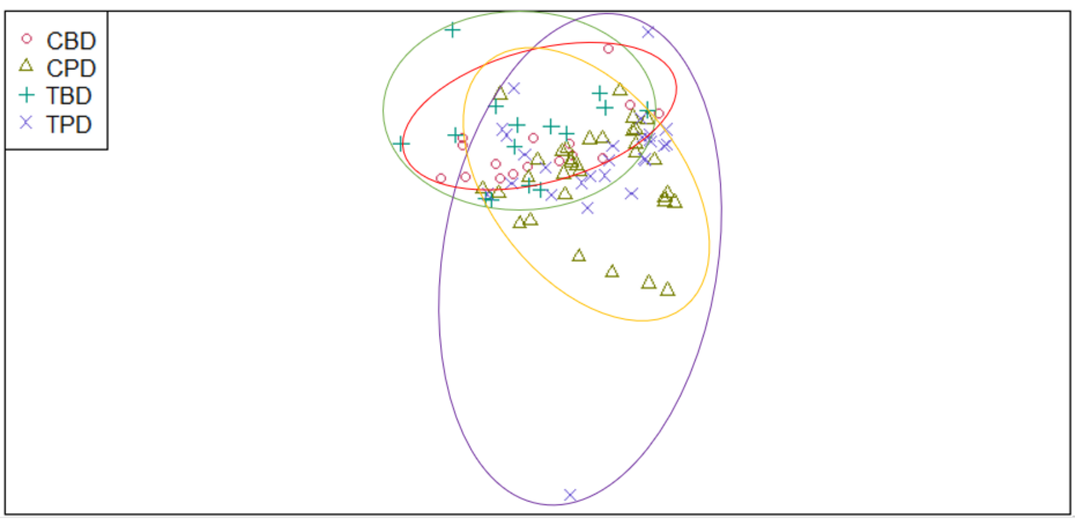
nMDS: MDS and MCS Bivalve: Biodiversity
Stress= 0.118879



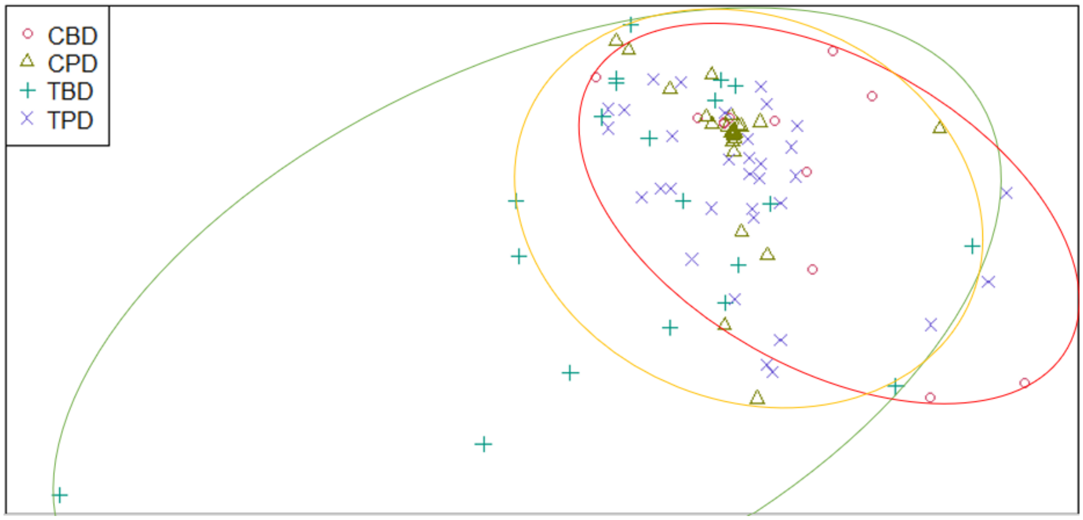
nMDS: MDS and MCS Bivalve: Species Richness
Stress= 0.1409883



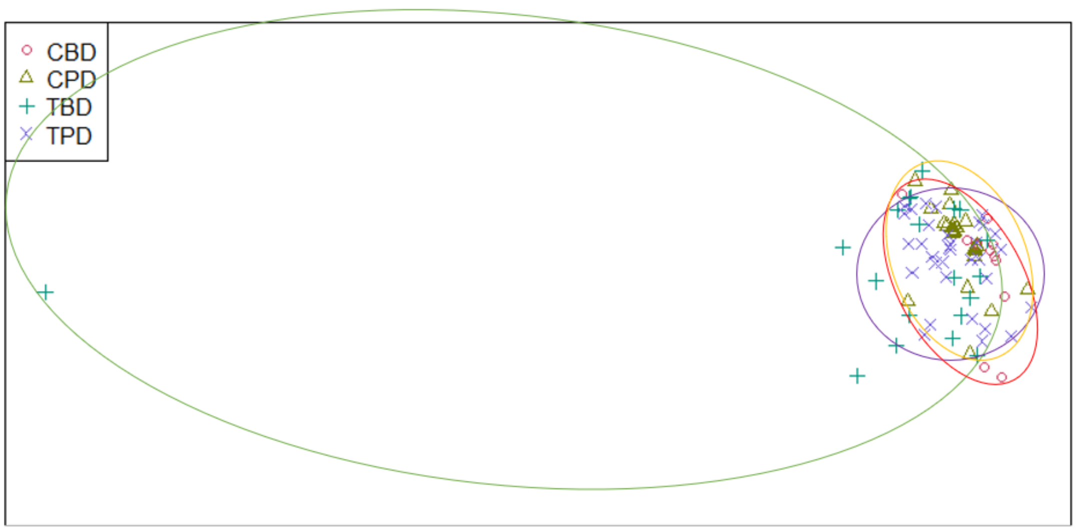
nMDS: MDS and MCS Bivalve: Abundance
Stress= 0.131298



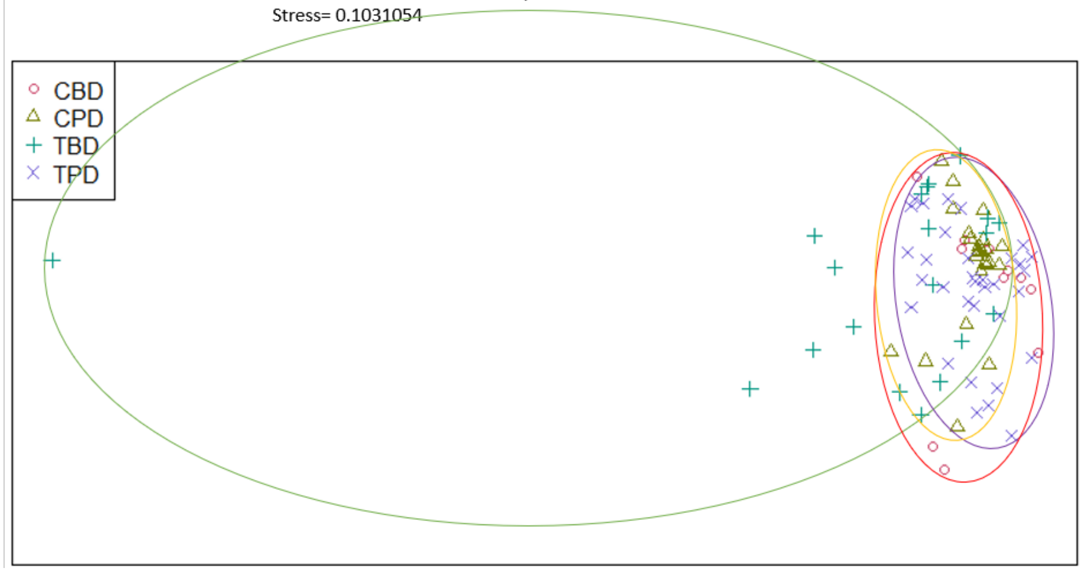
nMDS: MDM and MCM Gastropod: Biodiversity
Stress= 0.1034328



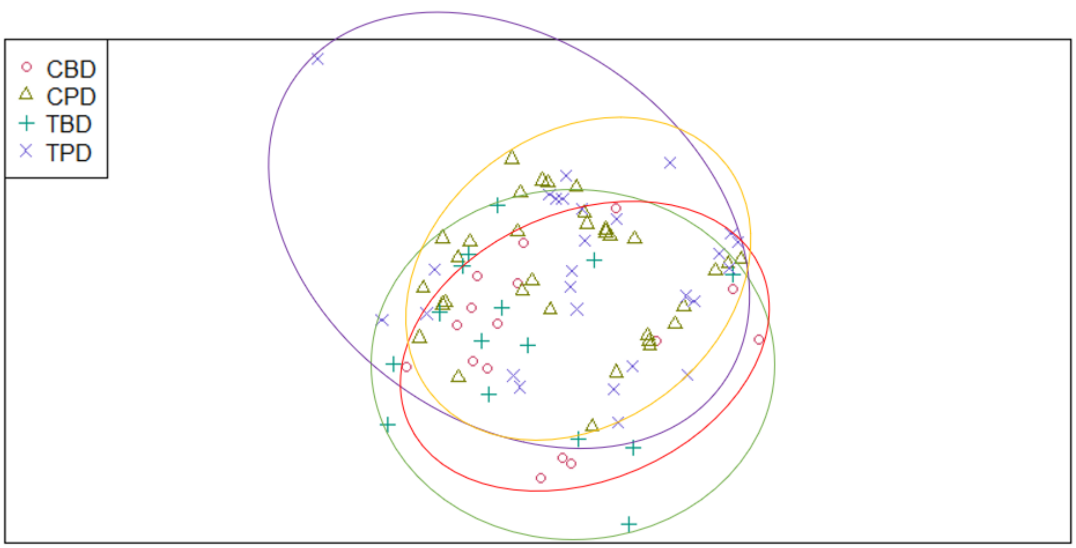
nMDS: MDM and MCM Gastropod: Species Richness
Stress= 0.1102413



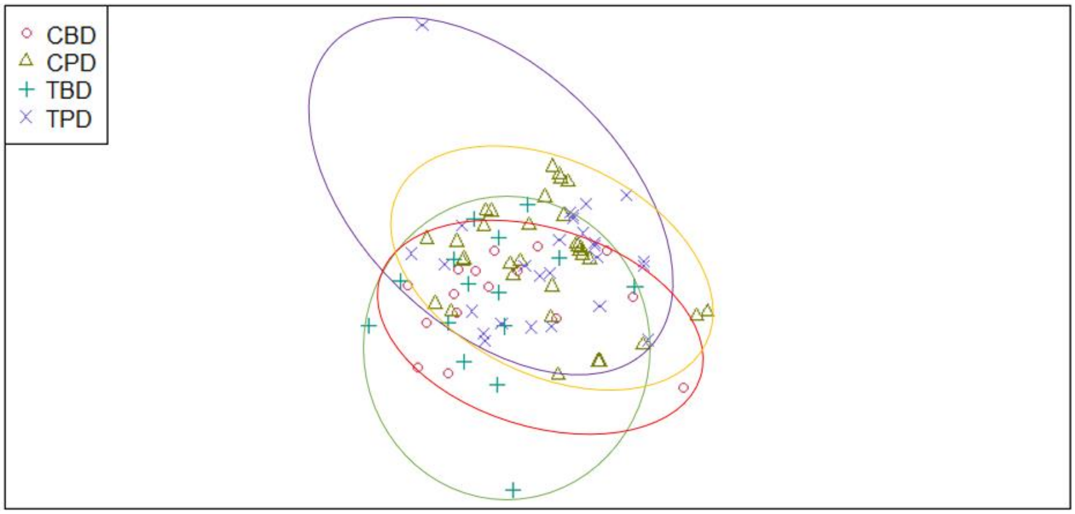
nMDS: MDM and MCM Gastropod: Abundance
Stress= 0.1031054



nMDS: MDS and MCS Gastropod: Biodiversity
Stress= 0.1327984



nMDS: MDS and MCS Gastropod: Species Richness
Stress= 0.139741



nMDS: MDS and MCS Gastropod: Abundance
Stress= 0.1516374