OCEANWATCH
AUSTRALIA

Brisbane Waters Living Shorelines Monitoring Project

2020

OCEANWATCH AUSTRALIA'S LIVING SHORELINE PROJECT

OCEANWATCH AUSTRALIA

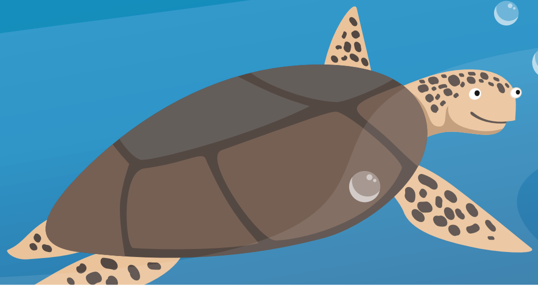
OUTCOMES SOUGHT

① **Establish a viable environmental approach to shoreline protection** that balances ecological and engineering outcomes, whilst being practical and aesthetically acceptable

② **Restore shellfish reefs,** and the associated benefits that these ecosystems provide change

③ **Enhance biodiversity** restored reefs which provide structural habitat for invertebrates and the fish that feed on them

RESEARCH QUESTIONS AND ANSWERS



	Question		Answer
Q1	In 12 months, can we expect dead shell to attract juvenile spat starting the process of cementing the structure together?	**A1**	**Yes, but highly dependent on site location & time of deployment.**
Q2	Can a natural fibre used in an intertidal marine environment provide predator control and structure long enough for the above to occur?	**A2**	**Yes for the first 12-16 months but results vary widely.**
Q3	Within 5 years, will the coir fibre decompose leaving a 3D matrix of living shell and therefore a functional oyster reef?	**A3**	**No, at sites in Sydney Harbour the coir decomposed too rapidly.**
Q4	Does shell in coir fibre bags provide wave attenuation, thereby reducing natural shoreline erosion?	**A4**	**Yes, this was confirmed through flume tank trials.**
Q5	Does the provision of shell in coir mesh bags enhance the ecological values of the project sites?	**A5**	**Yes in the short term.**

LIMITATIONS

Availability of **non-plastic, biodegradable materials** and background knowledge surrounding the use of these natural materials

Knowledge base on how the **coir fibre bags** would perform in an intertidal, marine environment, and in Sydney's climate

Short term project funding of 1 to 2 years, when reef formation and functioning may take longer, i.e. multiple years to decades

Timeframes for the deployment of structures influenced by **funding deadlines** as opposed to peak periods for **oyster settlement**

Red-tape for approvals and restrictive policy frameworks are a major disincentive to trial novel, blue-green innovation in the field. Drawn-out and cumbersome approval processes make for an economic challenge at small scale

OceanWatch Australia would like to thank all the project supporters for their time, funding, and participation in working to solve a problem that we feel as Australian's, we can lead the world in smarter, more productive, greener foreshore solutions. Greater Sydney Local Land Services funded this monitoring. The following organisations and departments also played a big part in project development.

NSW GOVERNMENT | Local Land Services Greater Sydney

NSW GOVERNMENT | Department of Primary Industries

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Contents

Summary

The global loss of oyster reefs, through overharvesting, habitat destruction and disease has led them to become functionally extinct in many parts of the world. Once a dominant ecological component of many bays and estuaries, these reefs provide many ecosystem services that are now reduced due to their decline. These services include water filtration and nutrient cycling, provision of habitat for invertebrates, nursery and feeding grounds for fish, and shoreline stabilisation. In the past, shoreline protection has focussed on predominantly manmade, hard structures with little consideration on their overall environmental effect. Following a growing interest in Blue-Green “eco-engineering” solutions, the installation of living, natural protective structures has been proposed as a more environmentally friendly option. These structures are called “living shorelines”. This relatively new approach combines shoreline protection with habitat creation.

OceanWatch had the aim of creating a 100% natural, biodegradable living shoreline structure using old oyster shell destined for landfill, not only to create an eco-friendly shoreline stabilisation option, but also to repurpose a waste product. The project started with the design of the living shoreline structure, which consisted of custom-made coir mesh bags filled with dead oyster shell. After the Sydney trial, using some adaptations and lessons learned throughout, a further installation was planned for the Brisbane Water Estuary on the Central Coast NSW. In the interim, the Brisbane Water Monitoring Project was designed and undertaken with experimental design and methods formed in collaboration with NSW Department Primary Industries (DPI), Fisheries. The aim of this monitoring project was to assess the ecological enhancement properties of the living shoreline structures and establish monitoring in the context of NSW estuaries.

A treatment site was constructed with three structures consisting of 5 m replicates of 2-tiered living shoreline structures on a patch of substrate in a disused oyster lease in the Brisbane Water Estuary. Reference sites were chosen to reflect ‘natural’ oyster

reef and control sites of bare substrate/sand. 2 monitoring events were undertaken to include invertebrate and fish abundance and species richness. Invertebrate data was collected using a combination of removal of oyster clumps from bags approximating 30 x 30 cm and placing a 30 x 30 cm quadrat over reference sites. Fish data were collected using a mini Baited Remote Underwater Video system (mini-BRUV). A small sample of oysters at the site was also opened to assess for the presence of the Pacific Oyster.

Overall, the living shoreline structures had a positive effect on invertebrate abundances and species richness compared to both oyster reef and bare substrate reference sites. Fish response was inconsistent among treatments, however the species richness and abundance appeared to be greatest at the oyster reef reference sites. It is expected, that over longer monitoring periods, assemblages of both invertebrates and fish at living shoreline sites would resemble that closer to natural oyster reefs. The results of this study have added to the little and slowly growing knowledge of the use of natural materials for living shorelines and demonstrated that with further research it could become a viable option for coastal protection.

1. Introduction and Background

1.1. Loss of Oyster Reefs

Shellfish reefs were once a dominant ecological component of many temperate and subtropical estuaries. While small populations of these reefs remain in most bays and estuaries, they are only a small proportion of what they were prior to European settlement (Gillies et al. 2017). Through overharvesting, habitat destruction and disease, the abundance of reef-forming oysters has diminished extensively over the past century (Manley et al. 2010). It is estimated that globally over 80% of these once productive natural reefs have been lost (Beck et al. 2011, Hoellein et al. 2015). Such a significant decline has led to their functional extinction in many bays around the world (Beck et al. 2011).

Figure 1.1. The global condition of oyster reefs in bays and ecoregions (Beck et al. 2011).

In Australia, there is a long history of decline in oyster reefs due to destructive fishing practices and over-harvesting. Soon after European settlement in NSW, large scale gathering of native oysters, Sydney Rock Oyster (*Saccostrea glomerata*) and the Flat Oyster (*Ostrea angasi*), began. These oysters were harvested not only for food but for use in mortar for Government buildings, churches, and private residences due to their high lime content (Roughley 1925, Nell 1993, Schrobback et al. 2014). Both common, native species of oyster, Sydney Rock & Flat oysters once formed large sub-tidal reefs within estuaries along the east coast; however, these reefs are now absent (Roughley 1925, Ogburn et al. 2007, Schrobback et al. 2014). Despite the early introduction of regulations in the oyster fishery (one of the earliest regulated fisheries in Australia), natural reef establishment continues to be impeded by other pressures such as disease outbreaks, water quality issues and habitat destruction and availability (Ogburn et al. 2007, Schrobback et al. 2014).

1.2. Ecosystem Services Provided by Oysters

Oysters and other bivalves provide critical ecosystem services such as turbidity reduction (Manley et al. 2010, Beck et al. 2011), reduction of toxic blooms (Paerl 1988, McComb and Davis 1993, Jackson et al. 2001, Bricker et al. 2008), nutrient cycling and overall water filtration. They also create important, complex physical structures and are considered ecosystem engineers because of this. An ecosystem engineer is an organism that creates and/or alters the availability of habitat and resources to other species, by causing a physical change in biotic or abiotic materials (Jones et al. 1994, Wright et al. 2002, Gutiérrez et al. 2003). Oysters provide habitat and protection for invertebrates, particularly in soft-sediment areas where complexity is lacking (Minchinton and Ross 1999, Coen et al. 2007), as well as nursery habitat and feeding grounds for fish (Coen and Luckenbach 2000, Coen et al. 2007, Dumbauld et al. 2009), overall enhancing biodiversity. For these, and other reasons, oyster reefs have been referred to as the temperate water equivalent of coral reefs (Beck *et al.* 2011).

1.3. Shoreline Protection

In the past, shoreline protection has predominantly been addressed through the construction of hard manmade structures, with little consideration of ecological values. One of the major issues of these hard structures is that the wave energy is often reflected into the water body, rather than absorbed (Scyphers et al. 2011). This "bounce" effect subjects adjacent shorelines to increased wave energy and can cause vertical erosion (Scyphers et al. 2011), the downdrift of sediment and the accelerated erosion of nearby shores (Swann 2008). In recent years there has been heightened interest to in more eco-friendly, 'softer' engineering solutions (Scyphers et al. 2011, Pontee et al. 2016).

The “living shorelines” approach focuses on balancing shoreline protection and habitat creation. Living shorelines are living, natural structures that support rather than degrade the surrounding ecosystem, by not only stabilising the shoreline, but also providing many other ecological functions enhancing the ecosystem. Living shoreline projects often involve the restoration of naturally occurring habitats or the planting of these biogenic habitats which have many ecological benefits (Scyphers et al. 2011). Using oyster shells in the creation of breakwaters is becoming more popular as historically natural oyster reefs protected coasts (Allen and Webb 2011).

1.4. Biodiversity Enhancement

As previously stated, oysters as ecosystem engineers provide structure and habitat for other organisms, the impacts of which are particularly pronounces in areas where there is minimal hard substrate (Ruesink et al. 2005). Many studies have shown that structurally complex oyster reefs have greater associated species richness than in habitats where complexity is lacking (Coen *et al.* 2007). Coen *et al.* (2007) states that the abundance and species richness of finfish is higher in oyster reefs than unstructured estuarine habitats. Particularly some taxa, such as gobies and blennies which are obligate reef residents throughout most of their life (Coen *et al.* 2007).

Oysters are also important in terms of their interactions with other organisms in estuaries (Underwood and Barrett 1990, Minchinton and Ross 1999). Underwood and Barrett (1990) found a greater abundance of the gastropod, *Bembecium auratum* in areas where there were oysters present. Likewise, Minchinton and Ross (1999) reported the distribution of the limpet, *Patelloida mimula* to be influenced by *S. glomerata*, rarely finding limpets in the absence of oysters. In addition, in the harsh habitat of intertidal shores oysters provide refuge for small organisms at risk from desiccation (Underwood and Chapman 1995, Crowe 1996, McAfee *et al.* 2016), and protect them from being carried away by the tide (Underwood and Chapman 1995, Minchinton and Ross 1999). Furthermore, many species of invertebrates, such as some polychaete worms, are present only in oyster habitats (Cole *et al.* 2007).

2. The OceanWatch Living Shoreline Project

2.1. Project Overview

With engineers and ecologists working alongside each other, the focus of this project was to test the efficacy of living shorelines in Sydney, NSW. A major philosophy of OceanWatch is to work towards a reduction in the use of plastics in marine rehabilitation, which is why this study aimed to use 100% natural biodegradable materials. In NSW alone, it is estimated that the hospitality sector generates over 3000 tonnes of oyster shell per year which is destined for landfill. Additionally, a considerable volume of oyster shell is produced by oyster farms due to natural mortality during cultivation.

The living shoreline concept starts by taking this disused oyster shell and bagging it in coir (coconut fibre) bags. These are then placed on eroded shorelines, providing habitat for other marine animals, and a surface on which free-swimming oyster larvae (spat) can settle. The ultimate goal is that, over time, the spat settlement and growth cements the dead shell together, the coir mesh bags decompose, leaving a functioning oyster reef as the result.

This OceanWatch program poses a great opportunity to start developing a process through which a waste product (disused shell) can be treated, bagged, and used to enhance the environment rather than contribute to landfill. It also provides universities and other organisations with research opportunities and it is an excellent way to involve local communities in environmental works. Indeed, a multitude of organisations and stakeholders were engaged in the trial including professional fishermen, oyster farmers, landholders, state government agencies, local councils, hospitality groups and indigenous stakeholders.

2.2 Brisbane Waters Monitoring Project

The Brisbane Waters Monitoring Project is a continuation of the living shorelines project, using some of the adaptations learned throughout the Sydney trial. It is a trial intended for assessment of the ecological enhancement component of the structures, rather than the erosion mitigation properties. It aims to establish ecological monitoring procedures for living shorelines in the context of NSW estuaries. It is a pilot to installing further living shoreline structures at another site within the Brisbane Water estuary, the Elfin Hill Rd Project. This monitoring project will further assess the features of the living shoreline structures including their ecological enhancement properties and their erosion mitigation properties.

2.3. Outcomes Sought

1. Establishing a viable environmental approach to shoreline protection which overall enhances the biodiversity of the site by providing structure and habitat for invertebrates and fish.
2. Establish some ecological monitoring for living shorelines in the context of Brisbane Waters.

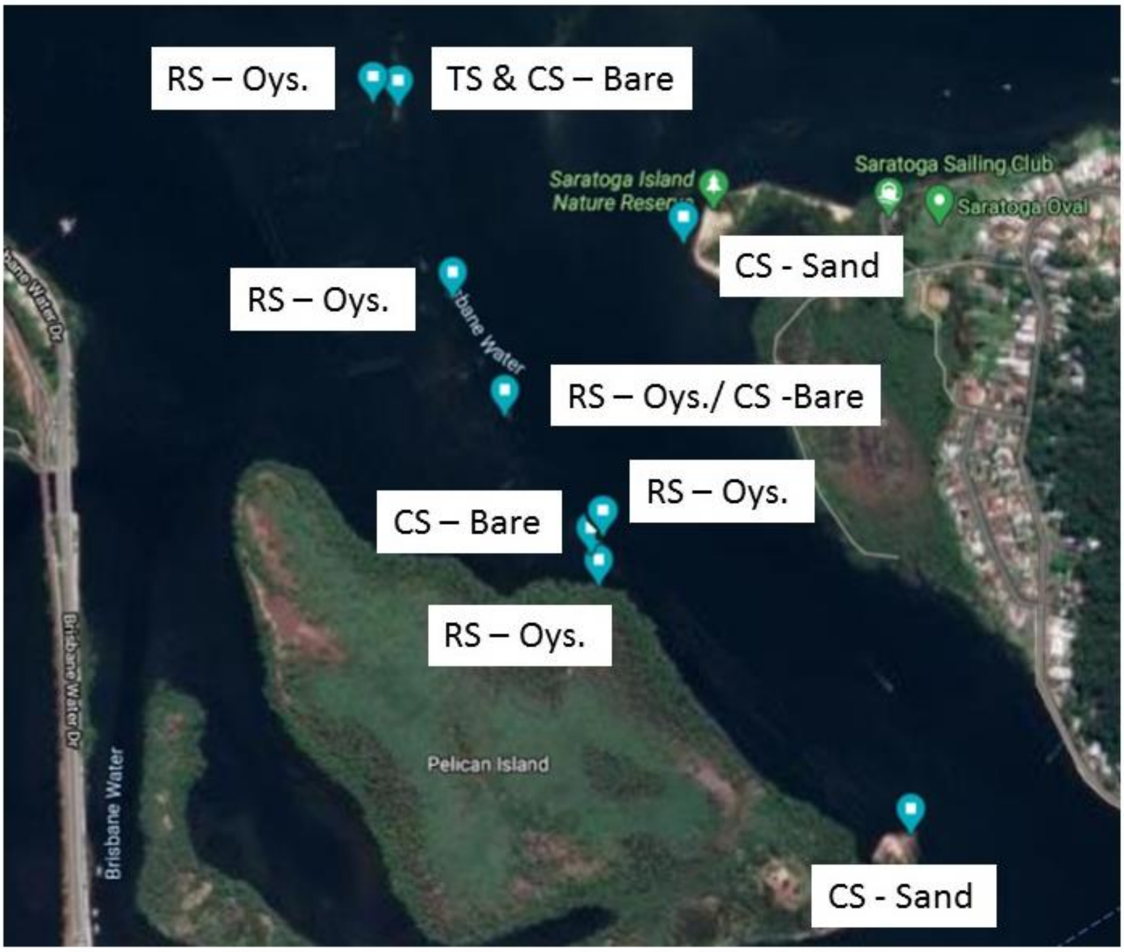
2.4. Research Questions

1. Will the OceanWatch living shoreline structures provide/increase habitat available for invertebrates?
2. Will there be a difference in number of and/or fish assemblages surrounding the structures compared to different reference sites, oyster reef and control sites, sand?

3. Methods

3.1. Study Location and Sites

This field trial was undertaken in Brisbane Water, a wave-dominated barrier estuary located on the Central Coast of New South Wales (NSW) (Roy et al. 2001, OzCoasts 2015, Central Coast Council 2020). The treatment site, a small area of substrate is situated within a disused oyster lease, among currently operating oyster leases. The site receives moderate wave exposure from boats and ongoing tidal exchange (Central Coast Council 2020). Reference and control sites sites were chosen based on available substrate and access during low tide combined with distance from the treatment site. 3 reference sites with ‘natural’ (either naturally occurring or oyster lease) oyster reef (photos. 3.1.1) were selected and 3 control sites of ‘bare’ substrate (similar to the treatment site for invertebrates and sand for fish) (photo. 3.1.2).



Map 3.1. Map of data collection/monitoring sites within the Brisbane Water estuary (TS = Living shorelines treatment site, RS – Oys. = reference site of oyster reef, CS – Sand = control sites of sand (BRUVs), and CS – Bare = control site of bare substrate (inverts.)).

Photo 3.1.1. Example of reference sites reflective of 'natural' oyster reefs where invertebrate data was collected – August 2020.

Photo 3.1.2. Example of control sites reflective of 'bare' substrate, similar to what the treatment site was installed on where invertebrate data was collected – August 2020.

3.2. Structure

The structure consisted of custom-made coir (coconut fibre) mesh bags filled with a mixture of oyster clumps and lose shell collected from the site to approximately ¾ full. The bags were arranged in a 2-tier structure parallel to the 'shoreline' in 3 replicates of 5m structure and secured in place using hardwood stakes and coir rope (photos 3.2.1 and 3.2.2).

Photos 3.2.1 and 3.2.2. Living shoreline structures installed at treatment site - July 2020.

3.3. Monitoring/Data Collection

Monitoring/data collection was undertaken during August and September 2020. Abundance and species richness of both invertebrates and fish were recorded. During these monitoring events, a small sample of 10 oysters from the site were collected and opened for presence of Pacific Oysters (*Magallana gigas*) (photo 3.3). They were identified by the presence of hinge teeth inside the upper shell which is a feature of only the Sydney Rock Oyster (*Saccostrea glomerata*) (DPI, NSW).

Photo 3.3. Opening oysters to identify between Sydney Rock and Pacific oysters – August 2020.

3.3.1. Invertebrates

For the treatment site, x3 randomly selected bags on each replication were opened and an amount approximating a 30 x 30cm area was removed, this was done to resemble the quadrat size used for reference sites (photo 3.3.1.1). A visual identification and count of macro-invertebrates was recorded for later analysis. For those that could not be identified on site, photographs were taken for later identification. 6 reference sites were used for comparison, x3 of oyster reef and x3 of bare substrate. 30 x 30 cm quadrats were placed randomly on the reference site and a visual identification and count of macro-invertebrates was recorded for later analysis (3.3.1.2). For those that could not be identified on site, photographs were taken for later identification.

Photo 3.3.1.1. Identifying and counting invertebrates within randomly selected bags on the living shoreline structures – August 2020.

Photo 3.3.1.2. Identifying and counting invertebrates within 30 x 30 cm quadrat within oyster reef reference site – September 2020.

3.3.2. Fish

A mini Baited Remote Underwater Video (mini-BRUV) system (photo 3.3.2.1) was used to survey the relative abundance and species richness of fish. This is an adapted, compact method of the larger BRUV which is impractical for use in intertidal habitats (Harasti et al. 2014). The compact mini-BRUV utilises small high definition GoPro HERO7 underwater cameras incorporated onto a 30 cm baited arm which is weighted with two 2 kg weights with a mesh bag at the end containing x2 pilchards (photo 3.3.2.2). Due to the mobile nature of fish, they were sampled at the site scale, rather than at the bag scale as with invertebrates. Cameras were placed randomly from a boat at each site with 3 replicates, with an attempt made to ensure the field of vision captured the treatment site of bags, oyster reef or sand. Footage was processed to 30 min of footage each replicate for a total of 90 min at each site, after which a MaxN (relative abundance) and species richness was recorded for analysis.

Photo 3.3.2.1. Mini-BRUVs setup on boat ready for deployment (DPI, 2020).

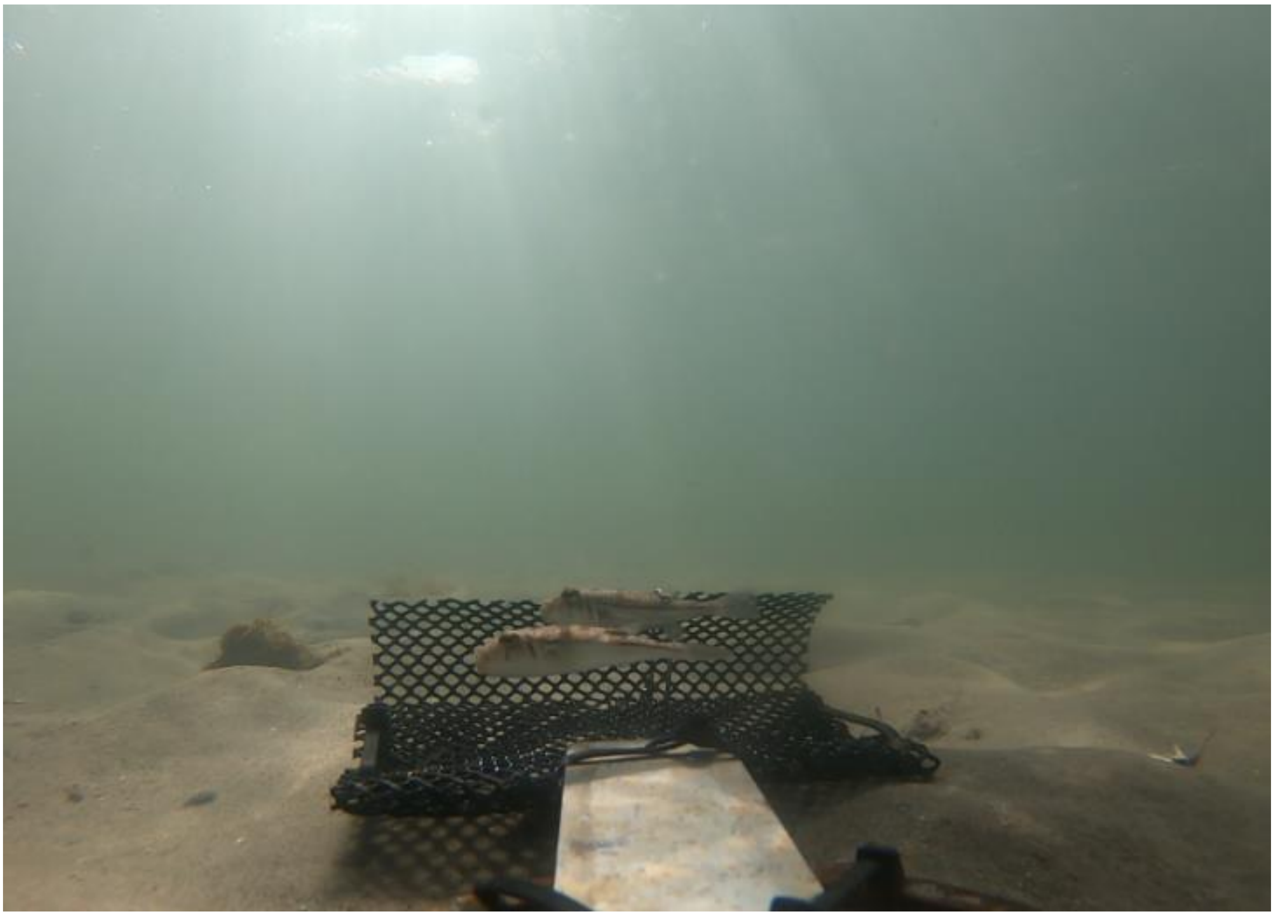


Photo 3.3.2.2. Screenshot of mini-BRUV footage from sand control site showing Tetractenos hamiltoni – August 2020.

3.4. Analysis

Univariate data were analysed with analysis of variance (ANOVA) with the package GAD (Sandrini-Neto & Camargo 2011) in R version 3.5.1 (The R Foundation for Statistical Computing 2018), as was the case for invertebrate species richness and number of individuals. A 2-factor analysis was performed that tested for an interaction of the factors time and treatment. Sites were pooled for a stronger test. For significant sources of variation identified by the ANOVAs, *post-hoc* Student-Newman-Keuls (SNK) tests were performed to identify the direction of differences. Due to unbalanced data sets for MaxN and species richness of fish, although univariate, were analysed using the permutational multivariate analysis of variance (PERMANOVA) add-on in PRIMER6 (Clarke and Gorley 2006), routinely used for these types of unbalanced univariate designs (Anderson *et al.* 2009). PERMANOVA analyses were based on Euclidean Distance measures with 999 permutations (Anderson *et al.* 2009). Pair-wise tests were performed for significant sources of variation to determine the pattern of differences. Multivariate analysis was done using PERMANOVA for assemblages of invertebrates and fish, and non-metric multidimensional scaling (nMDS) ordinations were performed to visualise differences in assemblages between treatments.

4. Results

4.1. Invertebrates

16 taxa were identified, with 15 in bags, 9 in oysters and 4 on bare (table 4.1.1). Mussels (*Trichomya hirsuta*), small crabs, and brittle stars (Ophiuroidea) were found predominantly in the living shoreline structures, with only a small number found occasionally in the reference and control sites and encrusting bryozoan and colonial ascidians found only in bags (photos 4.1.1 and 4.1.2, table 4.1.1). For both the times of sampling, there appeared to be a greater species richness in bags than oysters then on bare sediment (figure 4.1.2). This was found to be significant with a significant Time x Treatment effect when the SNK was performed (table 4.1.2). For number of individuals, in August the SNK was unable to detect a clear difference among treatments, whereas in September there was a greater abundance in bags then oysters then bare (figure 4.1.2, table 4.1.3). The nMDS shows clear separation of assemblages among treatments different treatments (figure 4.1.3). In the analysis (PERMANOVA), there was a significant Time x Treatment effect (table 4.1.4). Despite the interaction, the pair-wise test showed that at both times there was a significant difference among assemblages from the 3 treatments (bags, oysters and bare) (table 4.1.4). In reference to the presence of Pacific Oysters, all of the sampled oysters opened were identified as Sydney Rock Oysters.

Photo 4.1.1. Encrusting bryozoan only found in bags – August 2020.

Photo 4.1.2. Colonial ascidian only found in bags – August 2020.

Table 4.1.1. List of invertebrate taxa, X denotes taxa present.

	Bags	Oysters	Bare
Agnewia tritoniformis	X	X	X
Bembicium auratum	X	X	X
Lasaea australis	X		
Onchidiidae	X		

Patelloida minula	X	X	X
Trichomya hirsuta	X	X	
Grapsidae	X	X	
Chthamalus antennatus	X	X	X
Ophiuroidea	X		
Polychaeta sp. A	X		
Polychaeta sp. B	X	X	
Sipuncula		X	
Watersipora sp.	X		
Styela plicata	X		
Botryllus sp.	X	X	
Porifera	X		

Table 4.1.2. ANOVA of invertebrate species richness comparing treatments (bags, oysters and bare). Cochran's test C = 0.41. Post-hoc SNK tests were performed for significant sources of variation (P < 0.02).

Source	*d.f.*	*M.S.*	*F*	*P*
Time	1	2.241	1.3789	0.2461
Treatment	2	72.463	8.0349	0.1107
Time x Treatment	2	9.019	5.5499	0.0068
Residual	48	1.625		
SNK	Aug & Sep Bare < Oys < Bags			

Table 4.1.3. ANOVA of invertebrate abundance comparing treatments (bags, oysters and bare). Cochran's test C = 0.32. Post-hoc SNK tests were performed for significant sources of variation (P < 0.21).

Source	*d.f.*	*M.S.*	*F*	*P*
Time	1	96.0	0.3497	0.557
Treatment	2	4437.6	1.5979	0.384
Time x Treatment	2	2777.1	10.1164	0.000
Residual	48	274.5		
SNK	Aug Bare = Oys = Bags			

Sep
Bare < Oys < Bags

Table 4.1.3. PERMANOVA of invertebrate assemblages comparing treatments (bags, oysters and bare). Pair-wise tests were performed for significant sources of variation (P < 0.05).

Source	df	MS	Pseudo-F	P(perm)
Time	1	2224.5	1.8077	0.093
Treatment	2	25042	10.449	0.062
Time x Treatment	2	2396.5	1.9475	0.039
Residual	47	1230.6		
Total	52			
Pair-wise	Bags ≠ Oysters ≠ Bare			

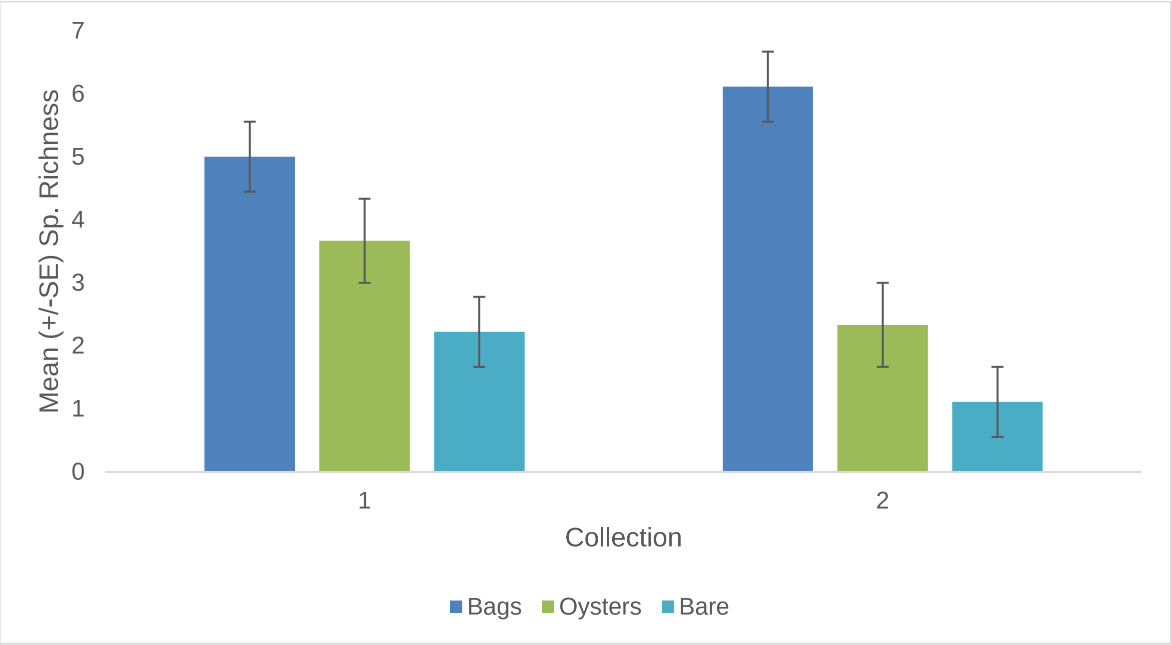


Figure 4.1.1. Average (±S.E.) species richness comparing treatment site (bags, dark blue bars), reference sites (oysters, green bars), and control sites (bare, light blue bars).

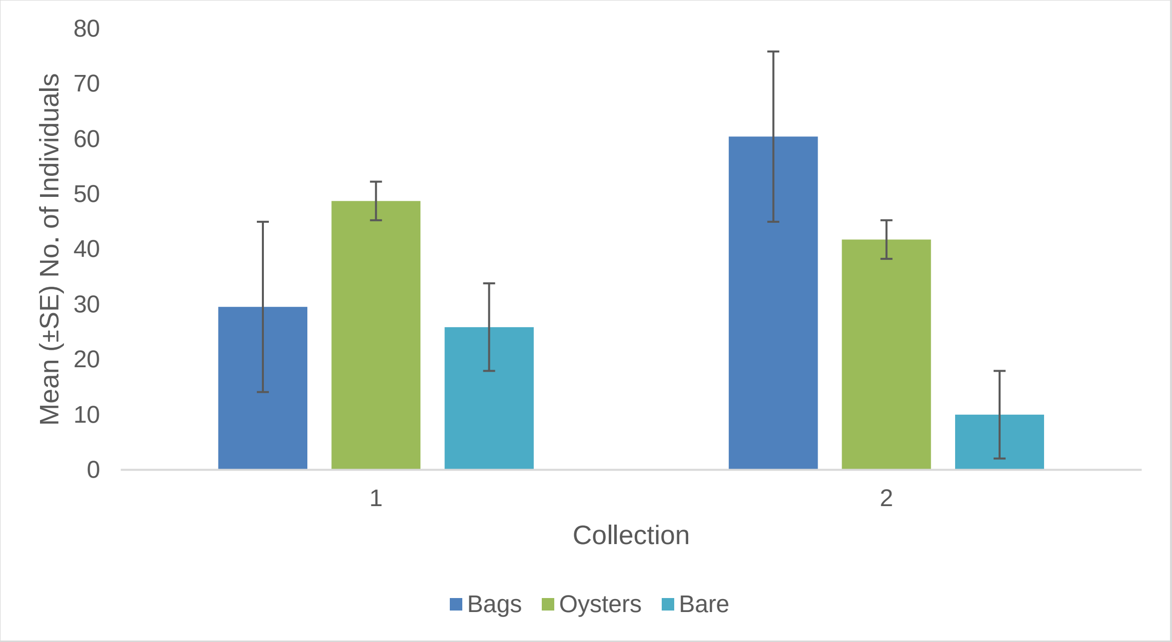


Figure 4.1.2. Average (±S.E.) abundance of invertebrates comparing treatment site (bags, dark blue bars), reference sites (oysters, green bars), and control sites (bare, light blue bars).

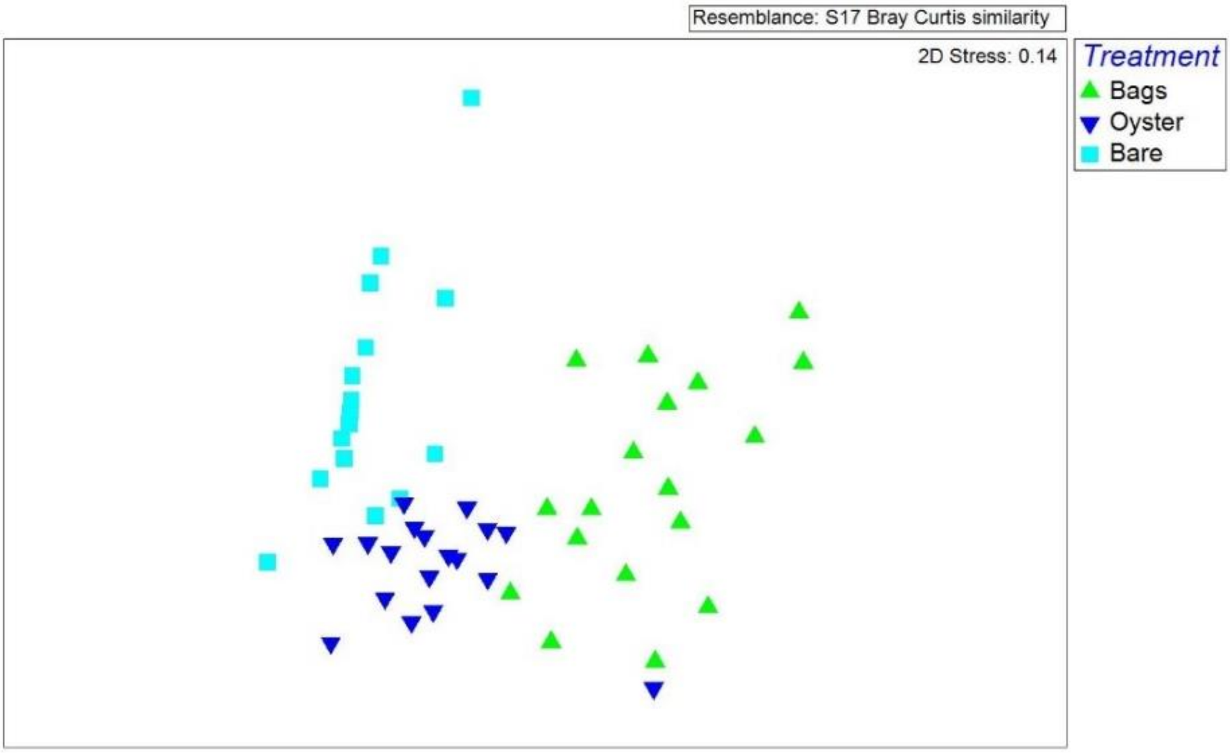


Figure 4.1.3. Non-metric multidimensional scaling ordinates of macroinvertebrate assemblages comparing treatment site (bags, green triangles), reference sites (oysters, blue triangles), and control sites (bare, blue squares).

4.2. Fish

9 taxa were identified, with 6 in bags, 6 in oysters and 6 on sand (Table 4.2.1). For both collection periods the average species richness and MaxN appeared to be greater for oysters than both the treatment site (bags) and the sand cotrol site (figures 4.2.2 and 4.2.3). However, when analysed, pair-wise tests found the differences between all 3 treatments to be inconsistent (tables 4.2.2 and 4.2.3). There were differences in assemblages seen among the treatments, with the sand sites mainly dominated by toadfish (*Tetractenos hamiltoni*) with only occasional other species seen throughout the footage (photo 3.3.2.2 and table 4.2.1). Whereas footage of both the oyster sites (bags and reef) showed mostly bream (*Acanthopagrus australis*) and glassfish (*Ambassis* sp.) throughout (photos 4.2.1 and 4.2.2, table 4.2.1) and mullet (*Mugil cephalus) seen only at treatment sites* (photo 4.2.3, table 4.2.1). The nMDS plot shows these differences in the composition of assemblages between all treatments (figure 4.2.3), with the pair-wise test showing this difference to be significant (table 4.2.4).

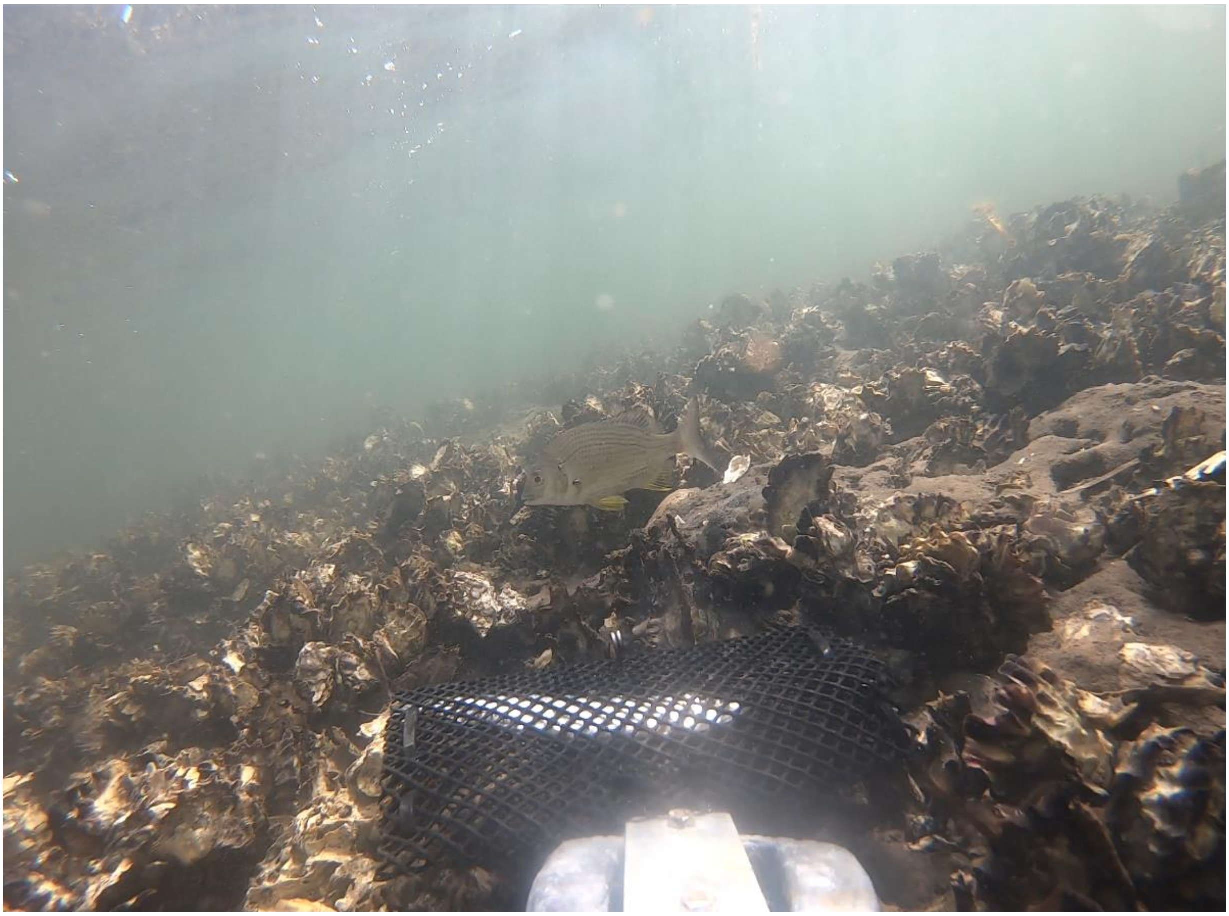


Photo 4.2.1. mini-BRUV footage of Acanthopagrus australis at oyster reef reference site – August 2020.

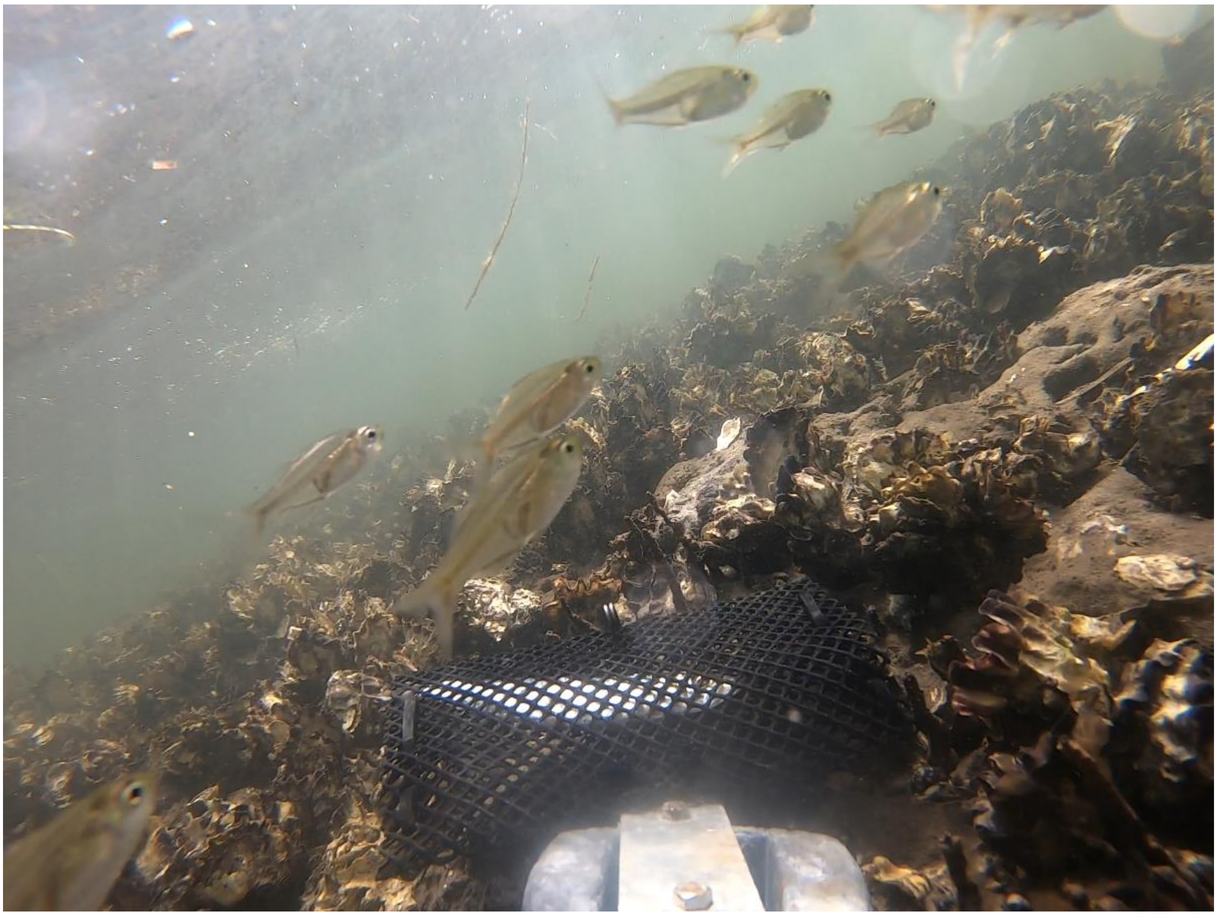


Photo 4.3.2. mini-BRUV footage of Ambassis *sp. at oyster reef reference site – August 2020.*

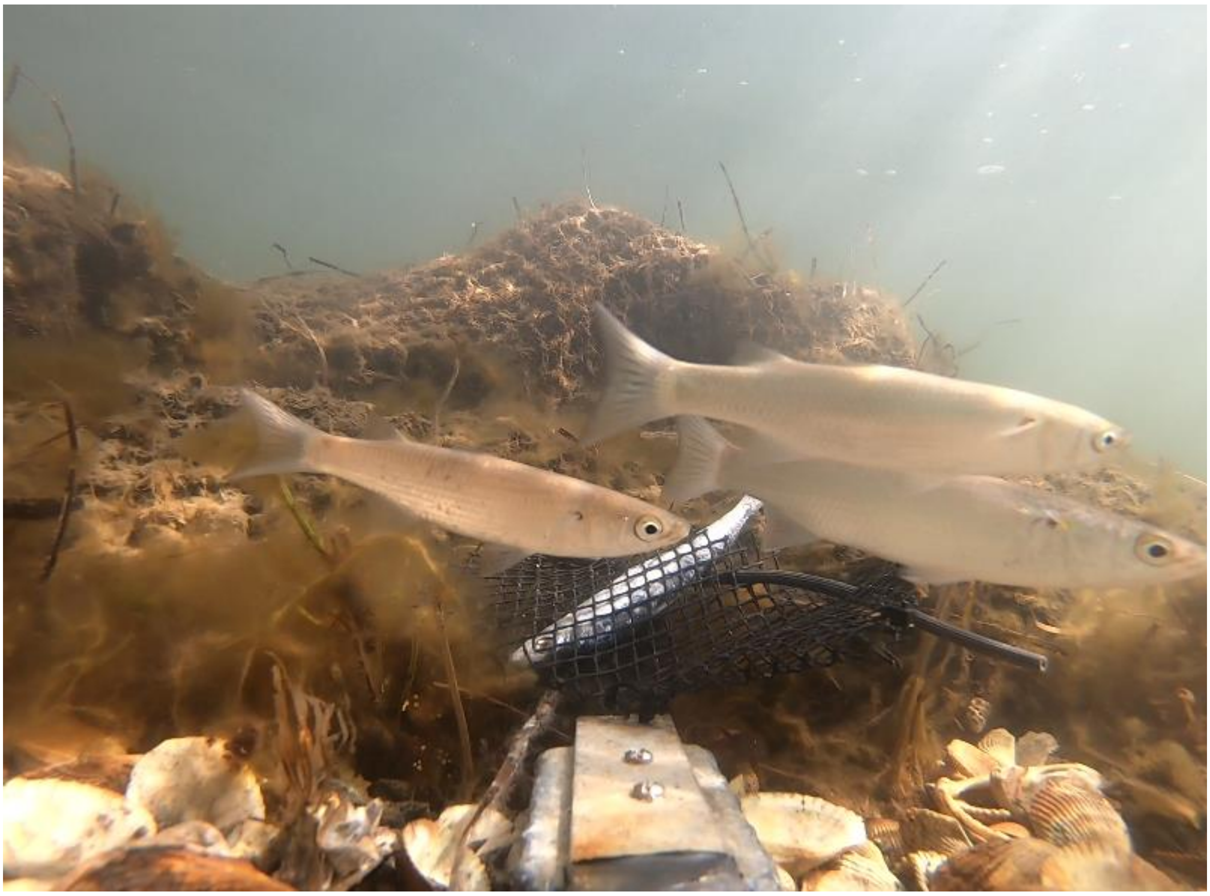


Photo 4.4.3. mini-BRUV footage of Mugil cephalus at treatment site – August 2020.

Table 4.2.1. List of fishes, X denotes taxa present.

	Bags	Oysters	Sand
Acanthopagrus australis	X	X	X
Ambassis sp.	X	X	
Girella tricuspidata	X	X	X
Gobiidae		X	X
Mugil cephalus	X		
Omobranchus anolius	X	X	X
Tetractenos hamiltoni			X
Sillago sp.	X		X
Tylosurus gavialoides		X	

Table 4.2.2. PERMANOVA of species richness of fish comparing treatments (bags, oysters and sand). Pair-wise tests were performed for significant sources of variation (P < 0.05).

Source	df	MS	Pseudo-F	P(perm)
Treatment	2	6.575	4.7929	0.021
Residual	21	1.3718		
Total	23			
Pair-wise	Bags = Oysters = Bare			

Table 4.2.3. PERMANOVA of fish MaxN comparing treatments (bags, oysters and sand). Pair-wise tests were performed for significant sources of variation (P < 0.05).

Source	df	MS	Pseudo-F	P(perm)
Treatment	2	141.1	3.389	0.041
Residual	21	41.634		
Total	23			
Pair-wise	Bags = Oysters = Bare			

Table 4.2.4. PERMANOVA of fish assemblages comparing treatments (bags, oysters and sand). Pair-wise tests were performed for significant sources of variation (P < 0.01).

Source	df	MS	Pseudo-F	P(perm)
Treatment	2	5.5167	5.0719	0.001
Residual	21	1.0877		
Total	23			
Pair-wise	Bags ≠ Oysters ≠ Bare			

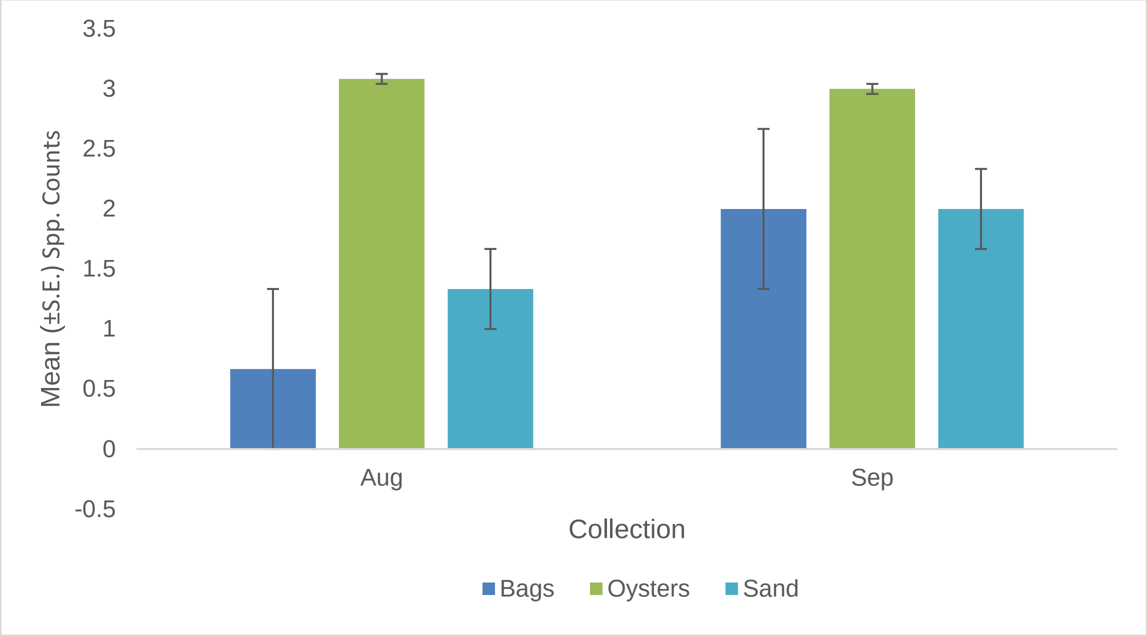


Figure 4.2. Average (±S.E.) species richness of fish comparing treatment site (bags, dark blue bars), reference sites (oysters, green bars) and control sites (sand, light blue bars).

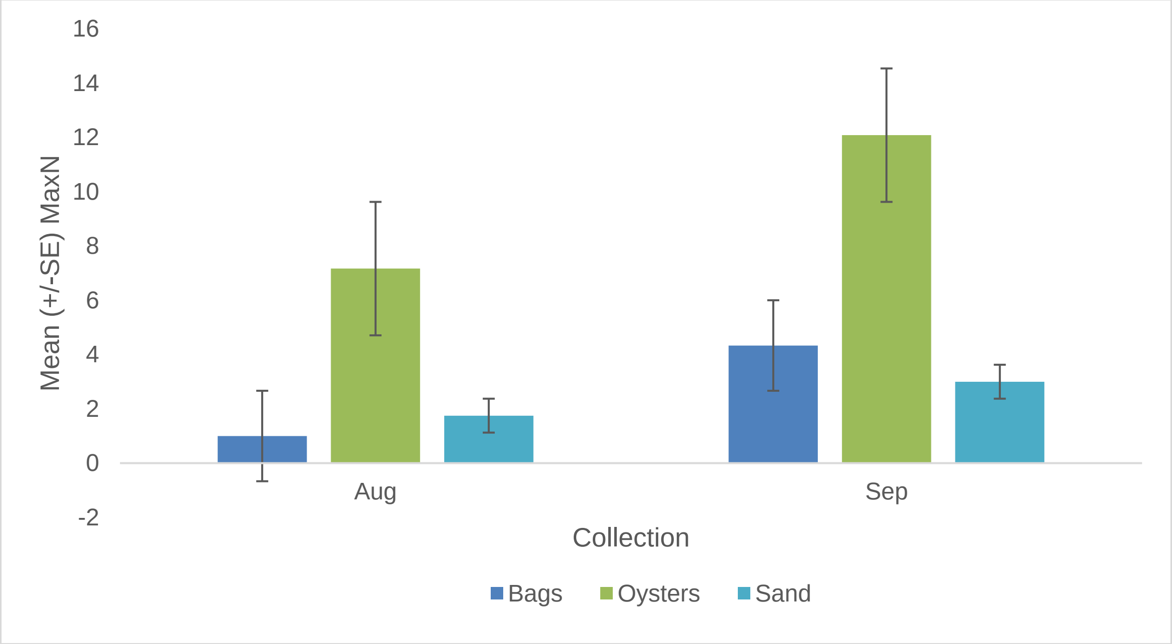


Figure 4.2. Average (±S.E.) MaxN of fish comparing treatment site (bags, dark blue bars), reference sites (oysters, green bars) and control sites (sand, light blue bars).

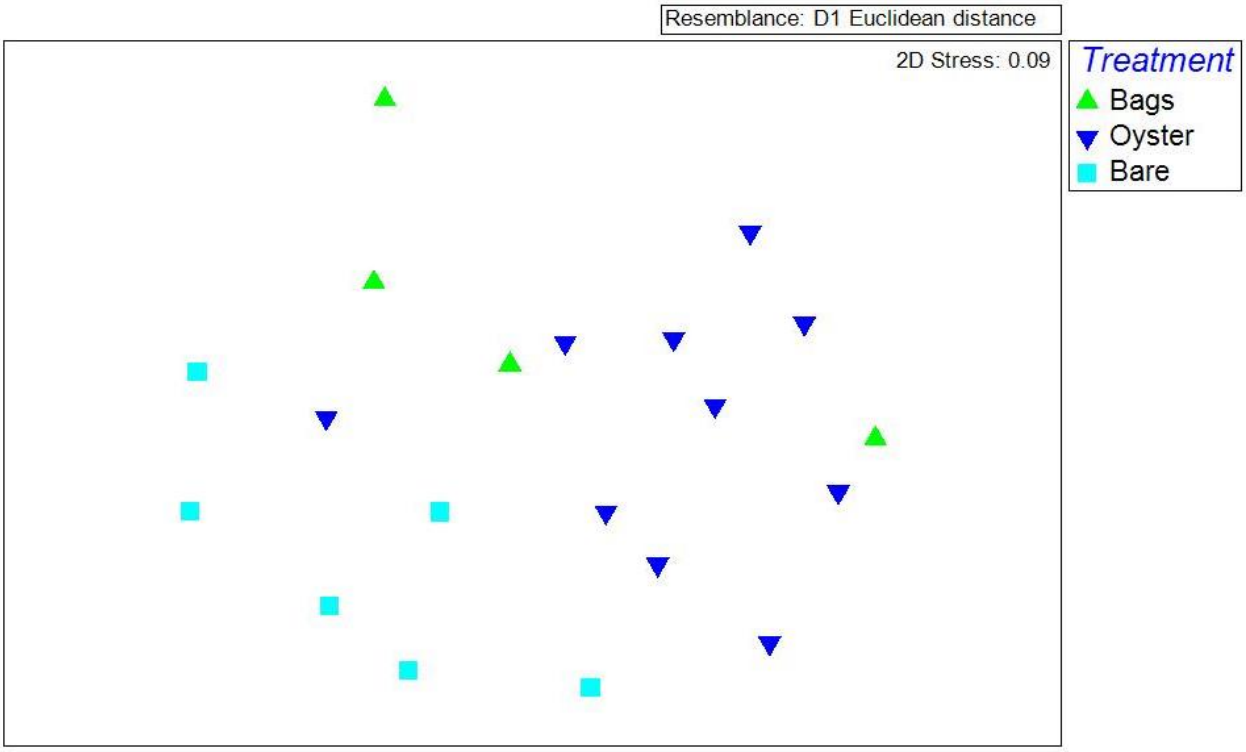


Figure 4.1. Non-metric multidimensional scaling ordinates of fish assemblages comparing treatment site (bags, green triangles), reference sites (oysters, green bars) and control sites (sand, light blue bars).

5. Discussion

5.1. Invertebrates

Overall, **invertebrate assemblages were positively affected by the presence of oysters in this study with oyster sites (bags and oyster reefs) having a greater abundance and species richness than the reference sites of bare substrate.** These results are comparable to numerous previous studies that report increases in abundance of taxa within oyster beds and the heterogenous structure they provide (Coleman and Williams 2002, Coen et al. 2007, Dumbauld et al. 2009, Beck et al. 2011). Furthermore, for both collections, the **species richness was greater in the living shorelines structures than the oyster reef reference sites** with the second collection also showing a greater abundance in the bags than reference sites. **This**

demonstrates that the bags may also provide additional properties than simply oysters alone, this could include increased protection from predators and greater protection from desiccation during low tide.

The abundance of invertebrates within the bags was greater on the second collection, with non-significant difference detected between treatment on the first. Previous studies have reported seasonal variation and length of deployment of artificial reef structures in assemblage, such that different deployment times and lengths will result in difference species compositions and abundances (Qiu et al. 2003, Krohling et al. 2006, Chapman et al. 2008). **Over time, likely years, we would expect the living shorelines to become similar to that of natural oyster reefs and remain different to bare substrate, absent of oysters**. Future studies, over longer periods of time to include a seasonal aspect should be considered for more detailed, significant results regarding invertebrate assemblages. Despite being more in bags, inverts can be more in disturbed environments so longer is needed to settle in to become like natural oysters.

5.2. Fish

While the differences in relative abundance and species richness were found to be statistically inconsistent, both appeared to be greater at the oyster reef reference sites than both sand reference sites and the treatment site (bags). This is reflective of numerous past studies and literature reporting that oyster reefs enhance habitat and effect fish presence and assemblages (Clynick et al. 2007, Coen et al. 2007, Scyphers et al. 2011, Folpp et al. 2013, La Peyre et al. 2013). **Reef age, however, is an important factor when considering biological enhancement of reef** (Powers et al. 2003, Farinas-Franco and Roberts 2014, Walker and Schlacher 2014). Although invertebrates usually colonise new structures relatively fast (Bohnsack and Sutherland 1985), fish often take months to possibly years to reach maximum populations and community structures. Over time, it is expected that these community structures would become more pronounced between treatments. Therefore, length of deployment of the living shoreline structures could have a significant effect on the assemblages of fish at the site requiring future endeavours to take place over considerably longer periods.

Furthermore, it has also been noted that fish response to artificial reef structures are inconsistent (Folpp et al. 2013), with some previous studies reporting that these structures failed to influence fish populations (Bohnsack and Sutherland 1985). **The School of Science and Engineering University of the Sunshine Coast used the OceanWatch custom-made living shoreline bags for a reef restoration project within the Noosa River in Queensland. Gilby et al. (2020) found that the structures supported an average of 1.4 times more fish species than control sites.** The difference in results may also have bearing on the available 'natural' oyster reef surrounding the treatment site. The living shoreline treatment site in this study was surrounded by operating oyster leases, providing uninhibited oyster reef and other structures, this is not a feature of the Noosa River. This is likely why the living shoreline structures had little effect on the presence or assemblages of fish in the study reported here.

Although not quantified, when bags were opened for collection of invertebrate data, small fish were noted to be in the oyster clumps, suggesting that the structures provide shelter and habitat for small fish. Similarly, past studies have found increases in small cryptic fish (Clynick et al. 2007) and obligate reef residents following oyster restoration efforts (Coen et al. 2007). This also reflects the fact that oysters provide 'nursery habitat' for fish, particularly those that will lay their eggs in recently dead oyster shells (Coen and Luckenbach 2000). In the future, inclusion of small and juvenile fish would be advisable, especially with the added protection assumed provided by the coir mesh bags.

6. Conclusion

While some of the results of this monitoring project appear inconsistent , it is expected that over longer periods of time more concise conclusions could be drawn. The information gathered here adds to the currently little and slowly growing knowledge of natural, living shoreline structures and their associated benefits within the context of Australian systems. The custom-made structures used here demonstrated an overall positive effect and ability for ecological enhancement within estuaries of New South Wales. With future monitoring, for longer time periods we can increase our knowledge of the performance of these structures and work our way to finding a viable, cost effective and aesthetically pleasing option for erosion control which enhances the environment rather than degrading it.

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