OCEANWATCH AUSTRALIA

Living Shorelines Project Report

2020

Sydney

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

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 solving a problem that we feel as Australian's, we can lead the world in a smarter, more productive, greener foreshore solution. The following organisations and departments played a big part in getting the project to where it is.

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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 minimised 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.

This study 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 main outcome of the study, that eventually, the dead oyster shell will become a living functional oyster reef, providing not only shoreline stabilisation but other valuable ecosystem services provided by oysters. Considering multiple research questions, aims and limitations, the project also provided numerous opportunities for scientific research and engagement with the community along with a multitude of other key stakeholders.

The project started with the design of the living shoreline structure, which consisted of custom-made coir mesh bags filled with dead oyster shell. Prior to any field installations, preliminary modelling was undertaken by the Water Research Laboratory (WRL), at the University of New South Wales in Sydney, to assess the

stability and wave attenuation ability of the structure. Recommendations on appropriate configurations, shore height and stabilisation of the structures were then made. Following the WRL assessment, OceanWatch conducted a field study across 5 sites throughout Sydney Harbour, which were chosen in collaboration with local councils and other agencies to represent a range of different features. The bags were arranged along the shorelines in tiered structures of different heights and lengths depending on individual site characteristics, WRL recommendations and shell availability. These living shoreline structures were then monitored for oyster recruitment, durability and degradation of the coir bags, associated biodiversity changes, and continued shoreline erosion.

Despite the limitations of this study, i.e. initial short-term funding and limited capacity to collect fine scale scientific data, key information was collected throughout the study. The methodology was also adapted throughout the project to reflect lessons learned from experience. Although changes in methodology throughout makes scientific analysis difficult, this study was goal orientated, therefore opportunities like this were taken to increase the chances of success.

The key findings in this study were 1) although there was evidence of recruitment, the coir mesh bags used disintegrated too fast for the settlement of oysters to cement the loose shell together, 2) the structures provide adequate wave attenuation in low energy areas, 3) some ecological enhancement was noted across multiple sites and 4) some findings were quite site specific the structures provide adequate wave attenuation in low energy areas.

The knowledge gained throughout this study will inform the adaptations required for future living shorelines deployments, and to guide further research on this subject. Future considerations should involve site choice and shoreline position, availability of natural oyster recruitment combined with environmental conditions, and kickstarting reef formation by way of seeding and/or adding live adult oysters. In conclusion, we believe that with further research, living shorelines, through intertidal oyster reef formation, could become a viable option in the future for protecting coastlines and reducing the effects of shoreline erosion.

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. 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).

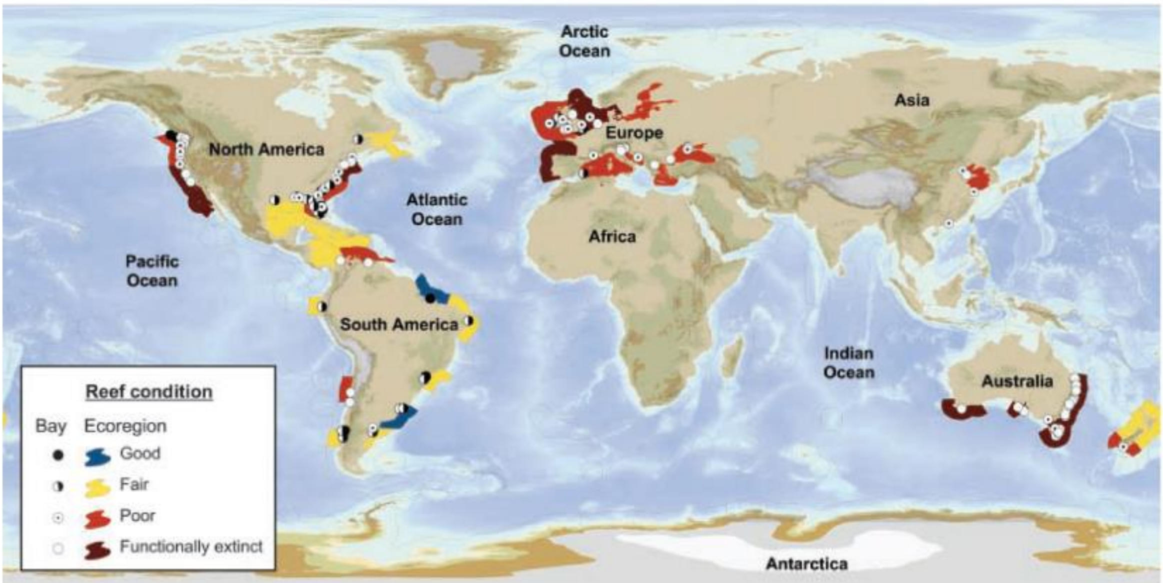


Figure 1.1. The global condition of oyster reefs in bays and ecoregions (Beck et al. 2011).

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 Sydney Rock & Flat oysters once formed large sub-tidal reefs within estuaries along the east coast; however, these reefs are now largely 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 has been 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.

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).

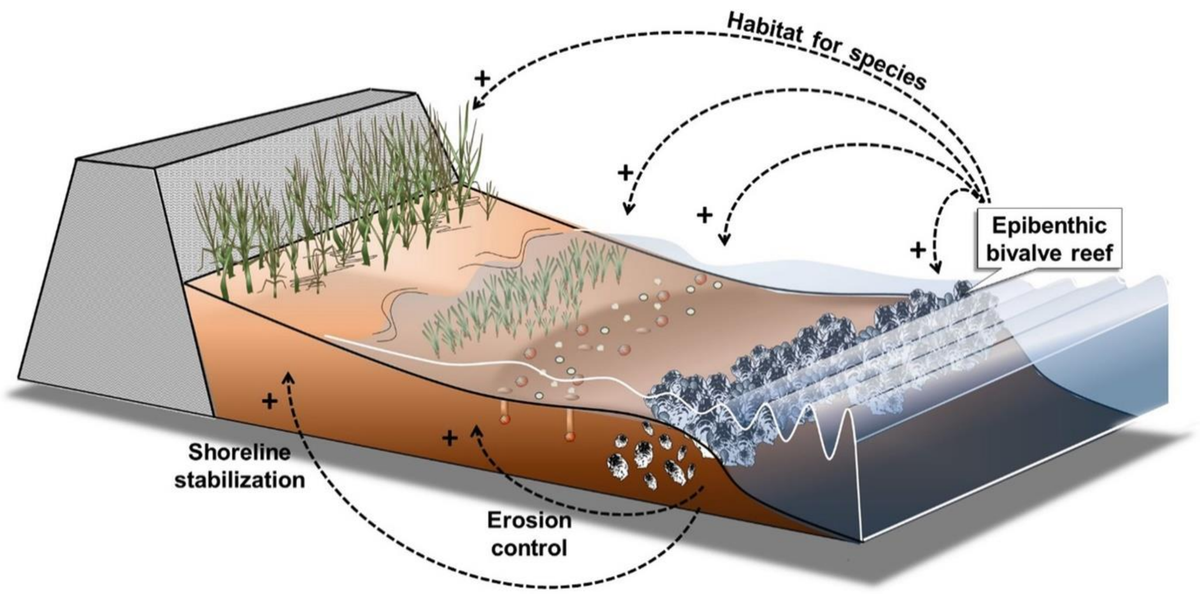


Figure 1.2. Visualisation of the ecosystem services delivered by epibenthic bivalve reefs. Reefs provide erosion control, shoreline stabilisation and create habitat for other species (Ysebaert et al. 2019).

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) mesh 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 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 (dead 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. A multitude of organisations and stakeholders were engaged in the trial including professional fishermen, oyster farmers, landholders, state governments agencies, local councils, hospitality groups and indigenous stakeholders.

2.2. Outcomes Sought

1. Establish a viable environmental approach to shoreline protection which balances aesthetics and practicality through ecological and engineering outcomes.
2. Restore once-abundant shellfish populations and the associated benefits that these reefs provide.
3. Enhance biodiversity at restored reefs which provide structural habitat for invertebrates and the fish that feed on them.

2.3. Research Questions

1. In 12 months, can we expect dead shell to attract juvenile spat starting the process of cementing the structure together?
2. Can a natural fibre used in an intertidal marine environment provide predator control and structure long enough for the above to occur?
3. Within 5 years, will the coir fibre decompose leaving a 3D matrix of living shell and therefore a functional oyster reef?
4. Does shell in coir fibre bags provide wave attenuation, thereby reducing natural shoreline erosion?
5. Does the provision of shell in coir mesh bags enhance the ecological values of the project sites?

2.4. Limitations

1. Availability of non-plastic, biodegradable materials and background knowledge surrounding the use of these natural materials.
2. Knowledge base on how the coir fibre bags would perform in an intertidal, marine environment, and in Sydney's climate.
3. Short term project funding of 1 to 2 years, when reef formation and functioning may take longer, i.e. multiple years to decades.
4. Timeframes for the deployment of structures influenced by funding deadlines as opposed to peak periods for oyster settlement.

5. 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.

3. Methods

3.1. Structure

The living shorelines structure built for this project consisted of custom-made, 1 m long coir mesh bags sourced and designed to order from overseas, both India and Sri Lanka. These bags were then filled ¾ full/roughly 16kg of dead oyster shell consisting of approximately 99% Sydney Rock Oyster shell. Due to the risk of pathogen translocations with the use of oyster shell from outside the local area, the shell was “treated” before filling the bags. OceanWatch worked closely with the biosecurity unit of NSW Department of Primary Industry (NSW DPI), and was provided with the following protocols for shell treatment and biohazard security before use:

- Boiling shells at a minimum of 80^{0}C for a minimum of 5 minutes
- No whole oysters are to be included
- Following the treatment, all shells must be placed in a clean bag away from all equipment and non-treated shells

Photo 3.1. Custom-made coir (coconut fibre) bag filled with lose, dead oyster shell.

3.2. Two-Dimensional Physical Modelling of Oyster Shell Filled Bags

Prior to any deployment of the living shoreline structures into field sites, the Water Research Laboratory (WRL) of University of New South Wales, Sydney, designed and undertook preliminary two-dimensional (2D) physical modelling of oyster shell-filled bags to understand their behaviour in response to wave attack. The trials were carried out to assess the stability and wave attenuation potential of the bags under different water levels and wave conditions.

The modelling tests were not site-specific, however as this approach is not suitable for exposed coastlines, only relatively low-energy scenarios were tested. The trials were therefore reflective of the typical wave conditions and water levels the bags could be exposed to at selected project sites (photo 3.2).

Several combinations of variables were undertaken for the physical modelling phase tests including depth of water at the structure, wave period, wave height at the structure, bag arrangement and numbers, and bags anchored and tethered together. For full methods and experimental conditions see Coghlan et al. (2017).

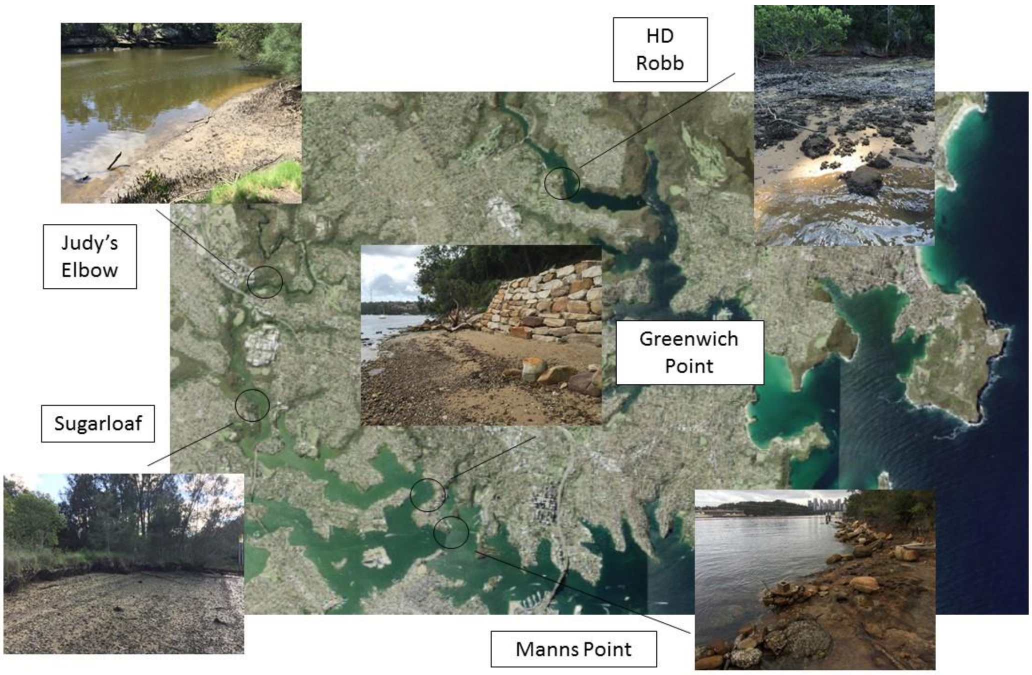
Photo 3.2. Example of wave attacks on oyster filled bags in WRL (Coghlan 2017).

After the preliminary modelling trials were completed, recommendations on the appropriate configuration of bags and placement height on the shoreline, bags were made in preparation for field trials. This included recommendations on how to best secure the bags both together and to the shoreline to reduce displacement of the structure when under wave attack (photo 3.3).

Photo 3.3. Complete displacement of an unsecured crest bag after wave attack (Coghlan 2017).

3.3. Study Locations

The study was undertaken across 5 sites in the Sydney region. The sites were selected in collaboration with key stakeholders based on several factors, including substrate, aspect, shoreline profile, active erosion, salinity, wave exposure, and community access. The living shoreline structures were deployed across the sites during 2017 and 2018. Bags were arranged in either 2 or 3-tiered structures, consisting of 3 or 6 bags every metre, secured in place using hardwood stakes and coir rope (photos 3.4 – 3.8). At some sites, the structures were placed among rocks to further provide security. The arrangement of structures was not consistent across the sites due to available space, shoreline height, shell availability and wave exposure of the site, combined with the recommendations made by the WRL.



Map 3.1. Location and images of the five study sites across the Sydney Harbour estuary.

3.3.1. Judy's Elbow

This site is situated on the upper Lane Cove River (map 3.1). This site was selected by Willoughby City Council with a northern aspect and muddy substrate. It has a steep gradient, ongoing erosion and there is evidence of some limited oyster recruitment and growth on mangrove pneumatophores. The site has been used in the past as an entry and exit point for kayaks. Willoughby City Council were interested to explore soft options to control erosion and deter direct public access to the river via this location. Structures at this site were deployed in May 2017 (photo 3.4).

Photo 3.4. Structures installed at Judy's Elbow Site.

3.3.2. Sugarloaf

The Sugarloaf site, situated mid Lane Cover River (map 3.1), was selected in conjunction with National Parks. It was chosen as it experiences ongoing wave generated erosion with an exposed southerly aspect on a medium gradient consisting of sand and dead cockle and oyster shell. The site was a priority due to the high value of the park and the ongoing effort by volunteers to rehabilitate it. The structures were deployed at this site in July 2017.

Photo 3.5. Structures installed at Sugarloaf Site.

3.3.5. HD Robb

HD Robb is an eastern aspect site situated in a different tributary, located in Middle Harbour (map 3.1). This rock shelf was selected in conjunction with Willoughby City Council because of erosion and limited public. There is significant evidence of oyster recruitment and growth at the site founded on dead oysters. Living shorelines structures were installed at the HD Robb site in May 2017 (photo 3.8).

Photo 3.8. Structures installed at HD Robb Site.

3.3.3. Greenwich Point

This site, situated at the Lane Cove River's entrance to Sydney Harbour (map 3.1), was selected in conjunction with Lane Cove Council as a site of active aggressive erosion. The site is subject to high boat wash from passing larger vessels contributing to the erosion of a valuable shoreline track which needed protection. The substrate consisted of rock and pebbles with a high presence of active oyster growth and recruitment on a shallow gradient with a western aspect. Greenwich Point structures were deployed during November 2018 (photo 3.6).

Photo 3.6 Structures installed at Greenwich Point Site.

3.3.4. Manns Point

Situated adjacent to the Viva energy fuel import terminal wharf, the Manns Point site (map 3.1) sees frequent freighter use and associated boat traffic. It is also a site of active erosion with a substrate of sandstone rock shelf and boulders, a shallow gradient and little public access. Despite the location being adjacent to an oil terminal, there is a high presence of oyster growth and recruitment. The structures at Manns Point were also installed during November 2018 (photo 3.7).

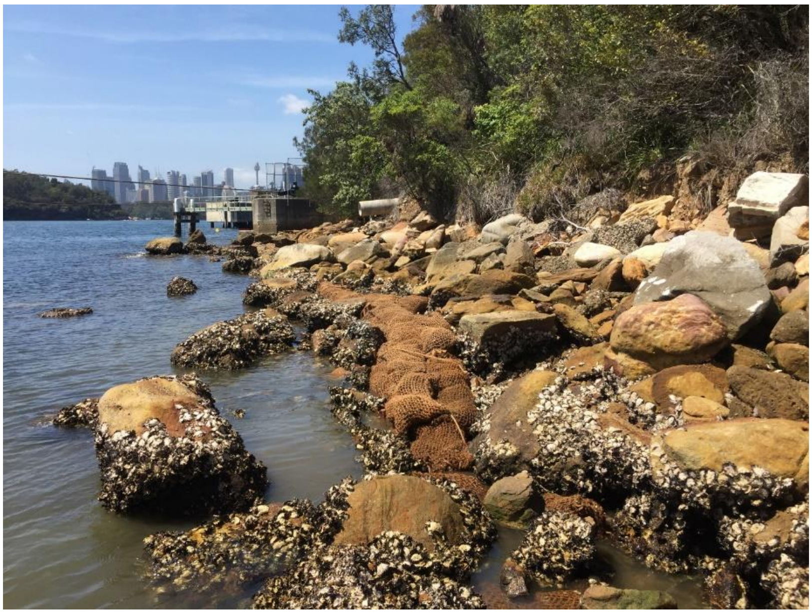


Photo 3.7. Structures installed Manns Point Site.

3.4. Monitoring and Maintenance

Monitoring of the sites occurred every 5 – 6 months, with the final visit attended on 21st August 2020. The monitoring consisted of photographs taken of the structures to include level of displacement and degradation of the bags, recruitment of oysters, associated biodiversity present in and around the structures, and level of continued shoreline erosion. Maintenance was undertaken at the first 3 sites installed, i.e. Sugarloaf, Judy's Elbow and HD Robb, during June and August 2018. This maintenance involved raking the dead shell at these sites and replacing the bags that had degraded with bags which had been previously deployed in a Shoalhaven River oyster lease to seed them. A further attempt was made to provide structural rigour to the bags with cement drizzle added to the bags containing loose shell in an attempt to artificially create a 3-D structure (photo 3.8).

Photo 3.8. Photos of bags with concrete drizzle applied to bags of loose shell.

4. Findings and Discussion

4.1. Spat Recruitment and Settlement

There was some evidence of recruitment seen within the structures at some sites (photos 4.1 and 4.2), however, within the limitations of this study there was limited capacity to collect in-depth data on spat settlement and recruitment. Ideally, deployment of the living shoreline structures would correlate with peak oyster spawning periods; the timing of which was not established until this project was well underway. Even if this data was available at project commencement, the short-term nature of project funding contracts, would have made precise deployment of bags quite difficult.

Photos 4.1 and 4.2. Photos evidence of recruitment at HD Robb Site and Sugarloaf Site.

Nevertheless, the ability of these living shoreline structures to attract spat is however supported by another study undertaken in the Noosa River, QLD. The School of Science and Engineering University of the Sunshine Coast used the OceanWatch custom-made living shoreline bags and found oyster settlement and growth at each of their sites throughout the Noosa River. Gilby et al. (2020) found that the growth of oyster reefs was correlated with placement of the structures within the River in terms of proximity to available sources of oyster larvae and to the mouth of the estuary. This is consistent with farming practices in the Sydney rock oyster aquaculture industry, who typically collect spat from leases in the lower reaches of coastal estuaries. This may have bearing on findings shown by the 2 sites situated on the Lane Cove River furthest from the mouth of the estuary (Sugarloaf and Judy's Elbow). Although some recruitment was seen, overall growth of the reef may be inhibited by distance from the mouth and limited flushing through tidal exchange. It is reported that the Lane Cove tributary of the Sydney Harbour estuary has limited tidal flushing causing poor quality water to remain in the estuary for longer periods of time (Freewater 2018). This creates a more freshwater environment and inhibits the dilution of any water pollution issues. Further data collection of water quality, and suspended sediment levels at each study site should therefore be included in the future to assess the effects on these parameters on the growth of the reefs. Moreover, Dr Maria Vozzo, a Postdoctoral Research Associate at Sydney Institute of Marine Science conducted research on settlement onto sampling units comprised of live and/or dead oyster shell at one of the OceanWatch living shorelines sites in Sydney, Sugarloaf. Dr Vozzo observed spat settlement on her oyster shell structures within 12 months of deployment (Maria Vozzo, pers. comm.). While Dr Vozzo's structures were different to the ones used by OceanWatch, and they were deployed at a lower intertidal level (Maria Vozzo, pers. comm.), this is further evidence that spat can begin to settle within 12 months on structures of dead oyster shell commencing the reef-forming process into a living structure. Other studies have emphasised the importance of intertidal position or tidal emersion to obtain maximum reef growth (Ridge et al. 2015, Walles et al. 2016, Salvador de Paiva et al. 2018). As this is an essential factor for the recruitment and growth of oysters, it is also a crucial factor in establishing functional reefs. The longer the reef/structure is submerged, the more available it becomes to free-swimming spat (Bartol and Mann 1997). However, the longer they are immersed many of these newly settled oysters will likely be picked off by predators during early stages of development, as is further discussed in section 4.2 with post-settlement morality. Finding the balance between an optimal engineering outcome and optimal ecological outcome can be challenging in these types of studies and these considerations require further research.

4.2. Structural Integrity of the Coir Mesh Bags

For the structure to cement together creating a 3D matrix of living reef, the coir mesh bags must be able to provide predator control and structural integrity long enough for this to occur. This study showed that the chosen coir mesh bags and the way they were secured do not perform sufficiently in Sydney's intertidal marine environment, with displacement and degradation occurring before the reef could adequately form (photos 4.3 and 4.4). Continued physical disturbance of the structure (habitat) affects negatively on spat settlement (La Peyre et al. 2014), as oysters prefer settling in shaded, protected areas of low flow within the microhabitat of the reef (Bartol and Mann 1997). This is likely the main reason we did not see the structures forming a solid 3D matrix of living reef.

Photo 4.3. Photo of Judy's Elbow Site showing structure displacement - February 2019.

Photo 4.4. Photo of structures at HD Robb Site showing bag degradation - April 2018.

Further research using the OceanWatch living shoreline bags was conducted as part of an Honours project of the University of New South Wales, Sydney. It involved wave flume trials using combinations of sandbags and coir bags to further stabilise the structures. Several configurations of shell-filled coir mesh bags and sandbags were tested under wave conditions broadly consistent with those used previously by the WRL (Dunlop et al. 2017). This research concluded that the addition of the sandbags enhanced the stability of the structure preventing displacement and therefore field implementation would reduce shoreline erosion (Dunlop et al. 2017). Sandbags are however constructed using geotextiles, and their use would deviate from the projects philosophy to only use natural, biodegradable materials. Previous studies, mainly in the USA, have also added a covering to reef structures; however, these are also primarily made from plastics and/or other non-biodegradable materials. Scyphers et al. (2011) suggested the use of a ridged backbone structure which could be removed or would disintegrate, to reduce movement and enhance the stability of the structure. Considerations such as this in the future would be beneficial, however a balance between using natural materials and delivery of structural integrity would need to be addressed.

At the Sugarloaf site, there were two rows of living shoreline structure deployed in the intertidal zone (photo 4.6). The bags deployed at the highest point on the shoreline lasted considerably longer than those deployed lower on the intertidal zone, most likely due to the amount of time they spent submerged and the wave action received. This demonstrates the limitations and difficulties with using natural materials and why these structures are frequently constructed overseas using non-biodegradable materials, namely plastic. Further research into the application of natural materials to this setting is required due to the general lack of knowledge surrounding their use in these environments. This finding also shows possibility for the bags themselves to be used in terrestrial application, or even freshwater environments. Prior to the design of these bags for this study, coir was only available in large rolls. The bags, which are much more user friendly, could be beneficial for small scale and volunteer studies in the future.

Photo 4.6. Photo taken at Sugarloaf Site showing the difference in the degradation of structures on the low-mid and high intertidal zone – April 2018.

When considering the aspect of predator control provided by the structures, links should be made to the biodiversity found in, on and around the structures. Although these are further reported and discussed in section 4.6, they also require mention here. With the presence of predators noted at the sites, including *Morula marginalba*, a predatory whelk (photo 4.7) and crabs (photo 4.8), post-settlement mortality could be a restricting factor on the growth of the reef (Bartol and Mann 1997). Therefore, despite the evidence of recruitment seen in this study, the bags may not have provided adequate predator control to overcome this and begin the reef-forming process. They do however provide protection from larger scavengers such as fish during the 12 to 18-month period the material remains viably intact.

Photos 4.7 and 4.8. Photos taken at Manns Point (August 2020) and HD Robb (April 2018) showing the presence of predators at sites.

4.4. Remaining Oyster Reef

Within 2-3 years, the coir bags decomposed almost completely across all sites, with only small amounts of material still present. However, there was little evidence of a 3D matrix of oyster shell left (photos 4.9 and 4.10).

Photos 4.9 and 4.10. Photos taken at Greenwich Point Site showing little evidence of structure remaining - August 2020.

Because of these findings, we conclude that the likelihood of the coir bags decomposition leaving a 3D matrix of living oyster shell is small. Without assumptions 1 (12-month spat settlement) and 2 (predator control and structural integrity) met, it is not possible for assumption 3 (within 5 years, the coir fibre will decompose leaving a 3D matrix of living shell) to occur. However, the duration of studies involving close and intensive monitoring and maintenance of oyster reefs is usually several years, with some monitoring studies being performed over decades, as in the case of Ridge et al. (2015). Ridge et al. (2015) constructed reefs oyster from 1997 – 2011 and continued monitoring and researching them until 2014. Despite the maintenance that occurred throughout this study, due to the continued displacement and break down of the coir bags, it is unlikely that adequate settlement would have been able to occur before the coir mesh bags disintegrated. Therefore, for a 3D matrix of living, functional reef to remain, increased maintenance of structures should be considered a high priority.

Other considerations for the future include the use of live oyster clumps or promoting spat recruitment through seeding. Using the same coir mesh bags, OceanWatch installed the living shorelines in Brisbane Water Estuary using live clumps of oysters from the site in 2017 (photo 4.11). When further installation and monitoring at the site occurred in July 2020, there is some evidence of a 3D matrix of shell remaining while most of the coir mesh has degraded (photo 4.12). Past research suggested that the establishment of an adult population would provide increased structural complexity that may better protect spat and allow them to grow (Bartol and Mann 1997, La Peyre et al. 2013). It is also reported from both laboratory studies and field experiments that the presence of chemical cues from adult oysters increase spat settlement (Geraldi et al. 2013, Ridge et al. 2015).

Photo 4.11. Photo taken at Brisbane Water Estuary Site - 2017.

Photo 4.12. Photo taken at Brisbane Water Estuary Site - July 2020.

Furthermore, in areas that are lacking adequate natural recruitment, seeding may provide a head start to the reef-forming process (Geraldi et al. 2013). This was attempted as revised methodology as a solution after the realisation that natural spat-fall alone would not be enough with seeded bags incorporated into the structure with the maintenance at Sugarloaf, Judy's Elbow and HD Robb. Concrete drizzle was also added to the bags to an attempt to artificially create a solid 3D matrix. Although these were not successful solutions throughout the Sydney sites, likely due to other factors; such as, post settlement mortality, continued disturbance and environmental factors (i.e. water quality, temperature, and nutrient availability), in future studies this may be applied in the methodology.

4.5. Wave Attenuation and Erosion Reduction

Through the preliminary research conducted by the WRL of the stability and wave attenuation of the oyster shell filled coir bags, it was concluded that, due to the dissipation of wave energy, the wave-driven foreshore erosion process would be mitigated immediately landward of the shell filled coir bags. Due to the limitations of this study, testing this in the field was difficult. Although some shoreline profiles were measured, the decomposition of the bags in such a short time made it difficult to ascertain if the living shoreline structures had any impact on the erosion across the sites.

Previous studies have reported that living shorelines structures have mitigated shoreline erosion. For example, similar structures installed in Alabama mitigated shoreline retreat by more than 40% over 3 years (Scyphers et al. 2011). However, structures created from shucked oyster shell deployed in a Louisiana lake reported that while shoreline retreat was reduced in low-energy areas, in high-energy areas the structures had little effect (Piazza et al. 2005). This suggests that these solutions to shoreline stabilisation may only be effective in areas of low wave energy. Further research into the capacity of similar living shoreline structures to mitigate shoreline erosion in different areas of wave energy is required.

4.5. Enhancement of Ecological Values of Sites

Ecological enhancement was observed across the sites throughout the study. At the Manns Point site there was large recruitment of gastropods (snails and whelks) to the external surface of the coir mesh bags (photo 4.13).

Photo 4.13. Photo taken of Living Shoreline Structure at Manns Point Site showing gastropod recruitment - February 2019.

There was also evidence of bivalve recruitment shown at the Sugarloaf site (photo 4.14) along with evidence that the structure provides refuge for small mobile invertebrates, as when the structure was lifted numerous small crabs were noted moving underneath. We also found that the structures attracted small fish (photo 4.15) and larger predators to the site, particularly we observed a ray remarkably close to the bags deployed at the Judy's Elbow Site (photos 4.16 and 4.17). Further research to incorporate the presence and behaviour of fish and other aquatic predators at the living shorelines sites would be beneficial to further explore this attraction. Furthermore, reef age is an important factor when studying the interactions between fish and other animals (Powers et al. 2003, Farinas-Franco and Roberts 2014, Walker and Schlacher 2014). Although algae and invertebrates often colonise new structures quite quickly (Bohnsack and Sutherland 1985), fish populations can take a few months to reach maximum population numbers, and it can take considerably longer to reach an equilibrium of community structure. This demonstrates the need for future studies to conduct research over longer periods of time.

Photo 4.14. Photo taken at Sugarloaf Point Site showing recruitment/settlement of bivalves to the dead oyster shell within the coir mesh bags - February 2019.

Photo 4.15. Screenshot of footage taken at Sugarloaf Site showing small fish swimming past structure.

Photos 4.16 and 4.17. Judy's Elbow Site showing ray at the living shoreline structure - July 2017.

Mangrove shoot growth was also evident shoreward of the low-mid level structure at Sugarloaf (photo 4.18). This is further evidence of the ability of the structure to enhance ecological values of sites, and mangroves are also a natural shoreline stabiliser (Morris et al. 2018). This is reflective of the ecosystem services provided by oyster reefs, showing the protection they provide to other valuable habitats such as sea grass, saltmarshes, and mangroves (Ysebaert et al. 2019). As the bags were found to not be enough for shoreline stabilisation in the long-term, they could provide short-term protection for riparian vegetation ie. mangrove seedings to grow and therefore form living shoreline structure.

Photo 4.18. Photo taken at Sugarloaf Site showing mangrove shoot growth shoreward of the low-mid intertidal living shoreline structure - February 2019.

5. Conclusions

The concept of the "living shoreline" as a solution to mitigate the effects of shoreline erosion while enhancing the ecological value of an area is very appealing. It also a concept that is becoming more popular with shifts away from hard unfriendly structures to softer natural solutions.

While the study reported here faced many limitations due to its short-term funding, it has nonetheless contributed to expanding our knowledge on living shorelines. Furthermore, it has contributed to the little knowledge base surrounding the use of natural materials, and how they perform in intertidal estuarine environments, pioneering their use in this capacity.

The findings of this study have shown that oyster reef restoration could be a viable option for coastal protection, with evidence of oyster settlement, recruitment of other invertebrates, enhancement of biodiversity and wave attenuation properties. However, more applied application and further adaptive management is required. Taking into consideration the lessons learned throughout this study, future endeavours should focus further on site choice and shoreline position, availability of natural recruitment combined with environmental conditions, and possibly kickstarting reef formation by way of seeding and/or adding live adult oysters. Further innovations in keeping the shell still and permitting recruitment over a number of years while still being visually appropriate on high value shorelines are also required.

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