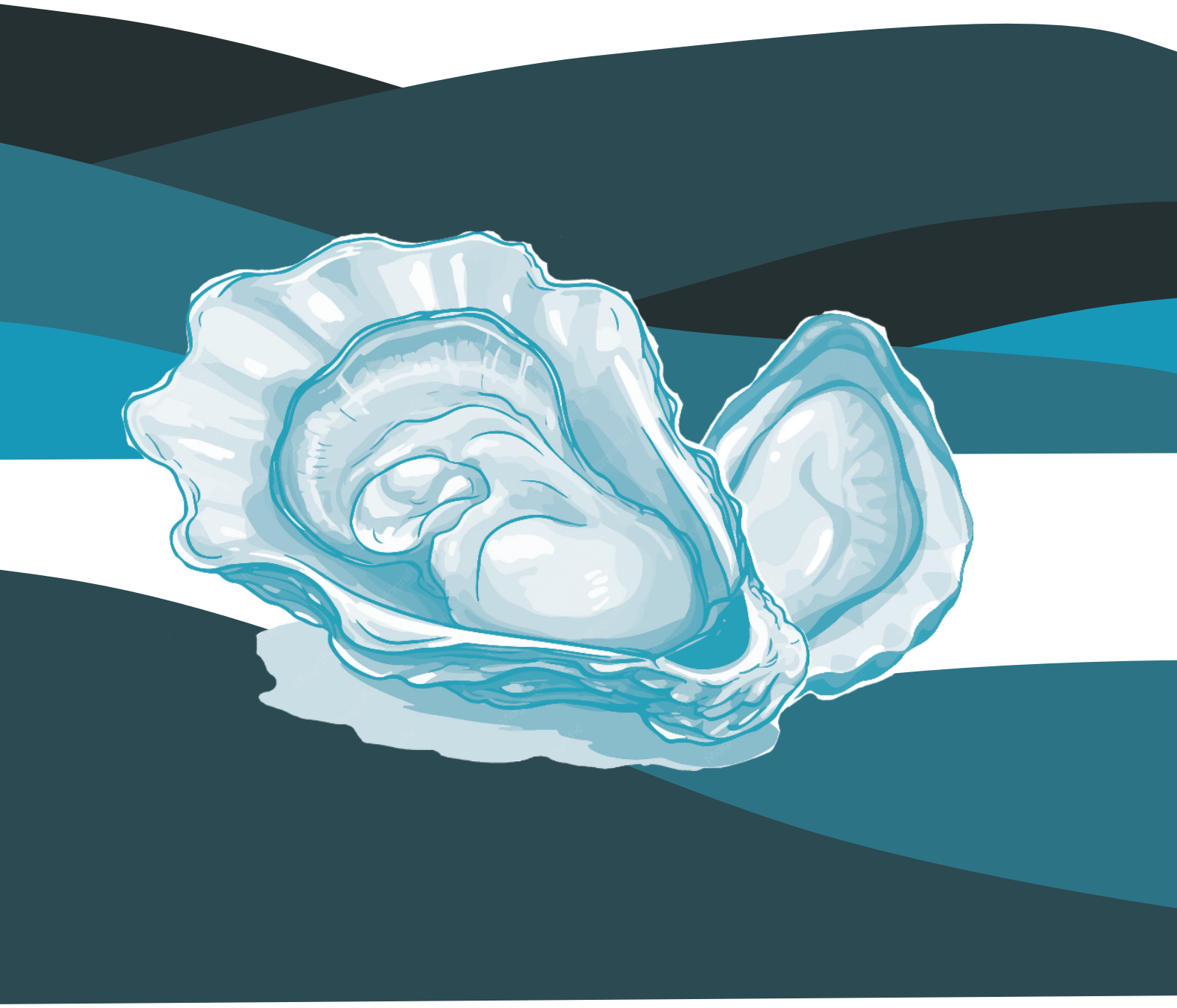
ID 7 - CAPSTONE RESEARCH REPORT



Authenticity Statement
This is to certify that to the best of my knowledge, the content of this report is my own work. This report has not been submitted for any subject or for other purposes. I certify that the intellectual content of this report is the product of my own work and that all the assistance received in preparing this report and sources have been acknowledged.
Your name: Isabella Warne
Student number: N11540711
Date: 07/09/2026

AI Use Statement
I have not utilised Generative AI in this report to assist in any ways.
Your name: Isabella Warne
Student number: N11540711
Date: 07/09/2026

Executive Summary:

This report explores the need for an implementation of oyster reef restoration modules in Australia.

Oyster reefs are a rapidly decreasing habitat in the Australian water ecosystem, utilised for farming, water filtration, and increased biodiversity. The loss of this habitat is attributed to an increased sediment baseline within estuaries, the natural location of oyster reefs, and due to this a steady and fatal spread of QX disease.

It was determined through primary research, that there is an extreme lack in research and action within oyster reef restoration due to legal barriers presented in marine water ways across Australia. Current modules utilise concrete and recycled shells as their main substrates, making them inexpensive and easier to implement on larger scales globally *(refer Appendix A).* However, these modules are oversimplified, and hard to install, requiring large boats and cranes, adding to the obstacle of cost already identified by existing companies working within this space *(refer Appendix G&C).*

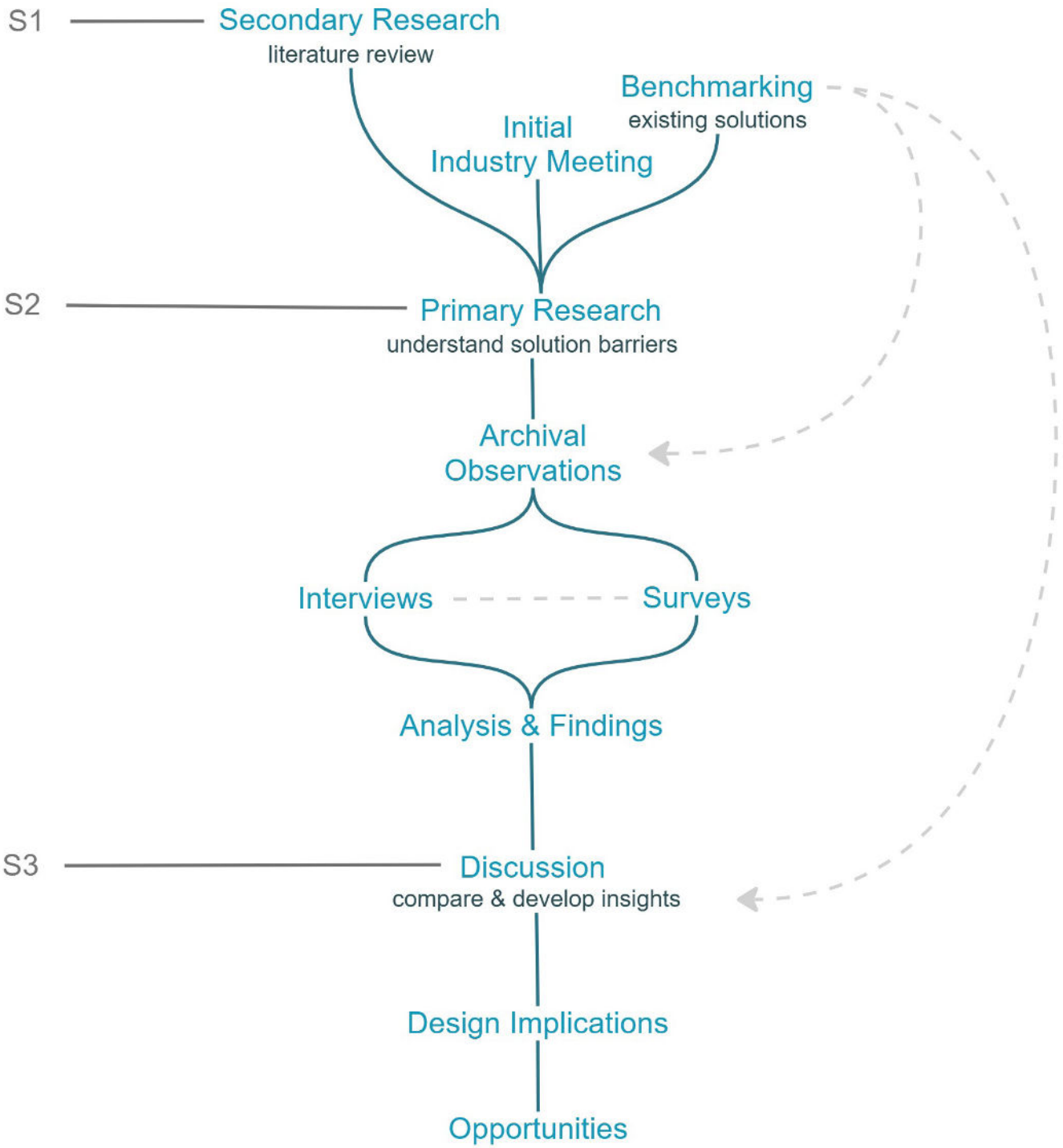
Manual spat adhesion is stated as a desirable method to get an initial boost in oyster population, outside of the short natural oyster reproduction window *(refer Appendix D2).* It is conducted in aquaculture tanks and has been trialled and then dropped by existing restoration companies such as OZ Fish due to their experience with disease spreading due to inefficient cleansing of spat filtered through the tanks *(refer Appendix D1).* Disease is also known to be spread through insufficient sanitisation of recycled oyster shells, which are collected from restaurants and other establishments and then sanitised via UV by being left in the sun for up to a year.

Maintaining a clean and hard surface is crucial for natural spat adhesion, which is hard to maintain for more than two months unless design methods such as increased water flow speed and decreased sunlight exposure are used. Additional ways to supply an increased usable surface area is to maximise internal and overhang spaces as these have been identified as the last spaces to be covered and or filled with sediment. Making future restoration modules interconnectable with allow for variations in reef designs and implementations, catering to both intertidal and subtidal locations, while also supporting other organisms such as fish, shrimp, and crabs.

Creating future modules utilising this expert biological knowledge will allow for a constant and steady growth in oyster populations instead of a sharp spike that will not maintain long-term.

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SECTION 1

Introduction:

85% of the globe's oyster reefs have been destroyed by dredging, pollution, coastal development, and destructive harvesting (Wet Tropics Waterways, 2025). In fact, in some areas in Australia "up to 90% of oyster reefs have been lost", making oyster reefs a listed critically endangered habitat (Australian Environmental Education, 2026).

An oyster reef is defined as a "dense cluster of oysters that grow on hard surfaces such as rocks or even other oysters in shallow waters" (Wet Tropics Waterways, 2025).

Oyster reefs and oysters biproxy play a crucial role in the ocean's ecosystem. Providing habitat and nurseries for marine wildlife, filtering water and improving water quality, helping to create storm and erosion protection for coastlines, and storing carbon (Australian Environmental Education, 2026). This makes oyster reefs a clear potential solution and mitigation technique for the climate change our world is currently experiencing.

Existing solutions are variations on an oyster reef restoration module, backed off the in-depth work of coral reef restoration modules. However, these modules, are ineffective (in terms of biology), expensive, and hard to install, limiting their impact radius greatly. Therefor the aim of this project is to explore the lifecycle of oysters, and reef restoration module manufacturing to determine how best to redesign these solutions to maximise the positive impact they could be having.

Background:

A vast amount of research has been conducted on oysters, specifically on their current and potential impact on our environment. Oysters have been noted to have many positive impacts in our world, as mentioned previously however there are two that are most of interest in terms of research.

Firstly, is their positive effect on biodiversity. Oyster reefs provide; nurseries, homes, and food to a wide variety of organisms including; crabs (blue, stone, mud, oyster, hermit, and fiddler), fish, shrimp, and worms (Oyster Reef & Benthic Community, n.d.) (Kimbro et al., n.d.).
Research has also been conducted into whether oyster reefs can be used as storm protection for coastlines. In coastal areas that face increasing natural dilemmas including storms, sedimentation, erosion, and pollution it has been concluded that the best nature-based option is to combine a 'living shoreline', defined as reefs or mangroves, with hard structures, such as rock stills. Using oyster reefs as this "living shore" with wave attenuation has been proven as effective, especially when emergent oyster reefs are used, however some erosion may still occur (Fergel et al., 2026). Other sources have found that oyster reefs only function as low-crested breakwaters but are more able to respond dynamically to sea level rise compared to hard structures (Oyster Reef Shore Protection - Coastal Wiki, n.d.).

Research based on the degradation of oyster reefs is clear that it is closely tied to global warming and climate change. As the ocean absorbs "90% of excess heat and 30% of atmospheric carbon dioxide" (Stéphane & Stéphane, 2021) the surface of the ocean (defined as 0-300m) has warmed 0.11 degrees in the last decade. Alongside this ocean acidification is contributing, with CO2 interacting with sea water and forming carbonic acid, overall lowering the pH of the ocean. According to the IPCC; RCP 8.5, the most pessimistic climate model, an ocean temperature increase of 4 degrees and 110% increase in ocean acidity can be expected in the next century.
Although oysters initiate their reproduction, producing spat oysters, at 17-19 degrees (Flat oysters and Pacific oysters), the rising sea temperature means milder winters which allows more pathogens to survive making oysters more fragile.

The increase in ocean acidity also causes problems as it reduces the amount of calcium carbonate readily available for oysters to build their shells with. Especially due to oysters being found in foreshore bodies of water, known for more variable water pH and higher acidity. Mature oyster growth has been found to only be affected at a pH below 7.1 whereas the larvae stage can be greatly affected as soon as the pH drops below 7.6, which is already found in areas around the world (refer Figure 1).

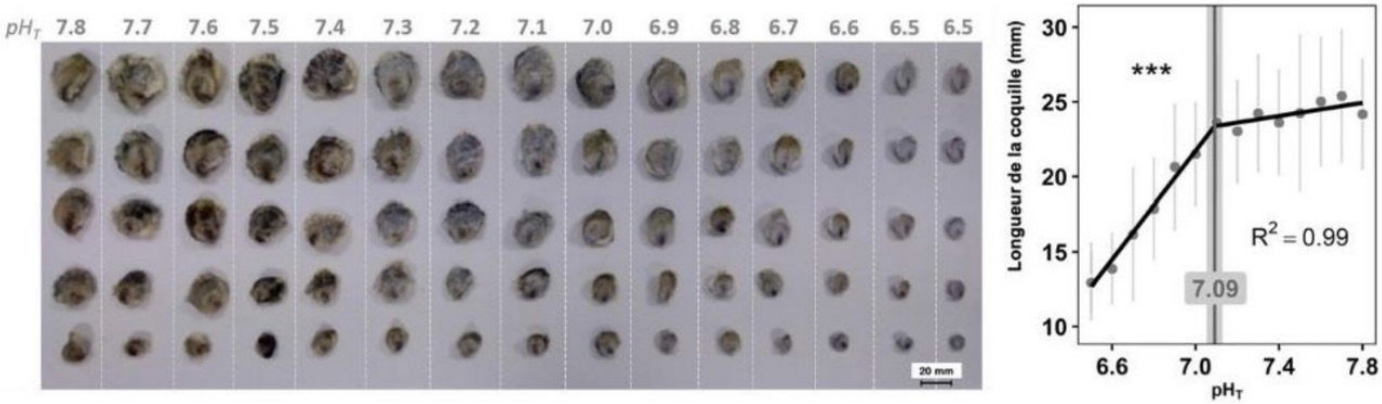


Figure 1: Impact of different pH conditions (full scale, pHT) on the length of Pacific oyster shells exposed for 23 days.

Research into the restoration of oyster reefs however is sparser. Though many studies concluded that reef restoration designs that were the most successful in terms of establishment and long-term survival were complex 3-dimensional structures incorporating providing multiple small spaces for oyster larvae to settle free from currents, sediment, and predation (This Simple Design Could Save Oyster Reefs Worldwide, 2026) (Esquivel-Muelbert et al., 2026).

Other barriers to current manmade and natural oyster reefs include most importantly QX disease. QX disease (also known as Marteiliosis) which is defined as a “protozoan parasite (that) infects the digestive system of Sydney rock oysters and mud dwelling polychaete worms.” (Australian Government, Department of Agriculture, Water and the Environment, 2020).

Benchmarking:

In terms of solutions within this field, there is a lot of innovation in the reef restoration field, however, oyster reef restoration specifically is lacking. Below are the descriptions and analysis of existing solutions in either field.

Nine existing reef restoration products/ solutions were analysed throughout this benchmarking process, they are named and described in the table below *(refer Table 1).*

Table 1: Existing Reef Restoration Solutions and Their Descriptions

Company:	Existing Reef Restoration:	Description:
Reef Design Lab	Mars 2	Modular coral reef rstoration tower, allows for assembly to maximise stability up slopes
	Emu	Made of concrete and recycled shell aggregate, it mimicks rock pool's water retention abilities
Reef Ball Foundation	Reef Ball	Oyster restoration, In clusters of 5 balls, Manual installation via floating bouy
Reef Innovations	Oyster Reef Ball	A hollow concrete aggregate dome filled with interconnecting holes
	Oyster Layer Cake	A tiered module made of offset layered oyster shells
Noosa River	Reef Builder Project	Rocks with cured/dried oyster shells attached, seeded wirh hatchery reaered spat and layed 50cm above sediment
OZ Fish	Robust Oyster Basket	Recycled and cured oyster shells contained within welded steel baskets, noted to be faster than other methods
Chesapeake Bay Foundation	Oyster Garden Reef Balls	modules with seeded oyster shells attached, each shell has approx. 10 spats adhered. Also run their own shell recycling program
Reef Arches	Reef Arches	Hexagon patterned arches, using pH neutral concrete, connected in groups of 11-13 via brackets, installed by being wheeled out into water

A vast majority of the modules use a pH neutral concrete as their main substrate/aggregate, though few utilise recycled shells (oyster or seashells) (Weinhofer, 2026) (Klerck, 2026) (Oyster Restoration Chesapeake Bay Foundation, 2026). Additionally, it can be identified that the predominant shape/form used by these modules is a hollow dome with interconnecting holes, the modules that use this form are known to be cheaper, easier to construct and transport as well (Reef Innovations, 2025).

Other shapes and forms vary between hyper simplified modules using rocks and steel baskets e.g. ‘Reef Builder’ and ‘Robust Oyster Baskets’ (Frequently Asked Questions: Noosa Oyster Ecosystem Restoration Project, n.d.) (Ecological Service Professionals, 2024), and complicated tiered structures e.g. the ‘Mars 2’ and ‘Oyster Layer Cake’ (Reef Innovations, 2023) (Modular Artificial Reef Structure II (MARS II) | REEF DESIGN LAB, n.d.).

Interestingly, other technology such as erosion mitigation, water retention, and the absorption of wave energy is integrated into these existing solutions as well. For example, the ‘EMU’ module mimics rockpools to allow for water retention while preventing further shore erosion (Erosion Mitigation Units (EMU) | REEF DESIGN LAB, n.d.). The ‘Reef Arches’ are a more extreme example of this however, focusing mainly on wave energy absorption with a secondary focus on reef restoration (Justin Breckenridge For Hometown News, 2024).

Throughout the analysis of existing research in this field and of what worked in existing products, fourteen benchmarking criteria were created. First off; stability, constituting a wide stable base and even weight distribution, Habitat complexity, replicating the natural structure of the reef, accelerated water flow and elevated settlement from the seabed to prevent sediment build up smothering juvenile oysters. Additionally, recycled oyster shells are used as part of the substrate material, design for seeding specifically; making sure the module is Handel able, stackable, and seedable in a hatchery. The module should be cheap and simple to produce, and should preferably allow for placement by hand, and finally, the modules should interlock or cluster *(refer Appendix A).*

Each of the above-mentioned products were then critiqued based on these criteria and were given a score of '1' if they did have the required benchmark and '0' if they did not. The products were then given total scores with the top four; 'Reef Ball', 'Reef Builder", and 'Mars 2' along with 'Oyster Garden Reef Balls' being further analysed via radial diagrams *(refer Appendix A).*

These four radial diagrams were then overlayed on top of one another to create an overview of the benchmarking criteria best covered by existing products and to highlight the criteria that were being missed in the design of existing solutions *(refer Figure 2).*

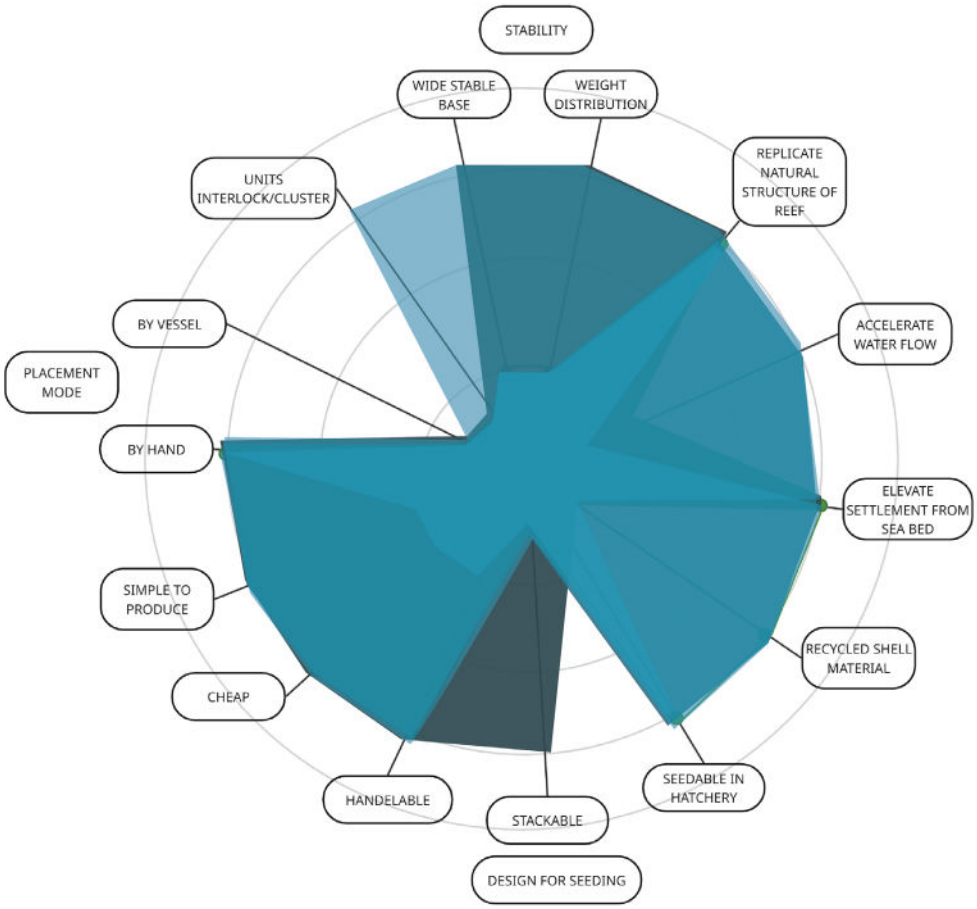


Figure 2: Combined Radial Diagram of Top 4 Existing Solutions

Using this analysis method, it can be clearly identified that the criteria most often unsolved by existing products are; that unit's interlock or cluster (1/4 of solutions accomplish), are stackable (1/4), use recycled shells as a substrate material (2/4), and that they accelerate water flow (2/4) *(refer Figure 2).*

Although placement mode by vessel is unchecked by all of these existing products it is not the main goal of this final solution and therefore this data can be ignored. It should be noted that though many modules claim to be handleable the exact details of how these modules are installed needs to be further researched.

SECTION 2

Research:

A triangulation approach was utilised within this report, defined as “investigating the same phenomenon through multiple sources, methods, researchers, or theories” (Hassan & Hassan, 2026) specifically in this case three research data collection methods were used; archival observations, interviews, and surveys.

Two separate surveys were conducted for this research project, the first was intended for end users of water ways, such as, kayakers, swimmers, fishers, boat drivers, etc. with a focus on how the installation of an oyster reef module would obstruct and limit their activity in the water ways and therefore inhibit installation. This survey received 25 responses from a variety of users, and utilised short response and multiple-choice questions *(refer Appendix B)*. The second survey was intended for companies currently undertaking reef restoration module installation, to collect data regarding how modules are currently installed, what tools are required for this, and how many modules are installed. Additional questions regarding the primary material choice for the restoration modules and the main barrier negatively effecting the installation of said modules were also posed *(refer Appendix C).*

Secondly, interviews, two of these were conducted, each tailored to the interviewee and the desired information outcome. The first was with a marine biologist working with OZ fish (a company currently installing reef restoration modules around Australia), with a focus on the installation of their modules, and how these modules are manufactured; material choice, manual spat adhesion etc. The final interview was with a professor leading the research field in oysters, mainly focused on the spat adhesion phase of oyster’s lifecycles, and additionally, on what poses the biggest threat to oyster reef restoration efforts. Interviews were chosen, as a research method, to allow for clarification and discussion of the complex biological terminology and topics required to understand and research this topic. Both interviews were conducted online via ‘Zoom’ and were recorded using the recording feature in the program, they were then transcribed using ‘TurboScribe’.

The third and final research method used was archival observations, defined as “the process of searching for and extracting information and evidence from original archives” (Science Direct, n.d.). This method was used to collect data on the process of installing reef restoration modules, to note the pain points and future opportunities. Archival observations were used due to the inaccessibility of real-time observations of reef restoration module installation, which requires travel, dive certification and other parameters unachievable within this time frame.

Analysis:

Three different forms of primary research were undertaken throughout this report, each utilising a different analysis method best tailored towards the data collected.

The data collected via the two interviews was analysed using affinity mapping, defined as “a collaborative technique used in UX research to organize and prioritize ideas, insights, or data by grouping them based on shared themes or similarities.” (Hassan, 2025). Here, inductive coding was used, via analysis of the interview transcripts *(refer Appendix D)*, to create the categories, codes and sub-codes necessary. Quotes were then analysed and sorted into subcode labelled groups, often overlapping, to determine the occurrence and concurrence of the coded themes and therefor, quantify their relative importance *(refer Appendix E).* Two separate inductive codes were used, one for each interview. This decision was reached due to interview one being much shorter and having different themes noted when creating the inductive code *(refer Appendix F).*

Data collected via the two surveys were analysed using graphical representations of the quantitative data, however for the short-written response questions a smaller scale version of affinity mapping was used, to allow for the connection of themes across respondent’s answers *(refer Appendix B&C).*

Finally, the archival observations, in the form of videos, were viewed multiple times and then graphically represented in colour blocked timelines *(refer Appendix G).* Each colour used on the timeline indicates a different activity or action being undertaken. These coloured bars are then placed on the timeline, which represents the length of the observation, to illustrate the length of each activity and its placement in the overall order of the installation. Additional notes were taken underneath the timeline, collected from the narration of the archival observations.

Findings:

Interviews:

Interviewee one, notes that the most important quality for a restoration module is its ability to biodegrade (occurrence 3 times, *refer Appendix F)* as the “ideal product would last about three to four years” just long enough to provide support for the foundation of an oyster reef (refer Appendix D1). However, during the second interview, it was stated that leaving any form of module, in our current environment, uncleaned or adjusted for “longer than two months” would be too dirty to allow for productive settlement of spat *(refer Appendix D2).*

One of the ways to tackle this issue is to increase the speed of the water flow/current as it goes through and over the restoration module *(refer Appendix D2)* as “anywhere the water speeds up it doesn’t drop sediment”.

QX Disease and Manual Settlement:

Making the restoration module removable was discussed five times throughout the 30 minute first interview, specifically in relation to the legal issues surrounding oyster reef restoration *(refer Figure 3).*

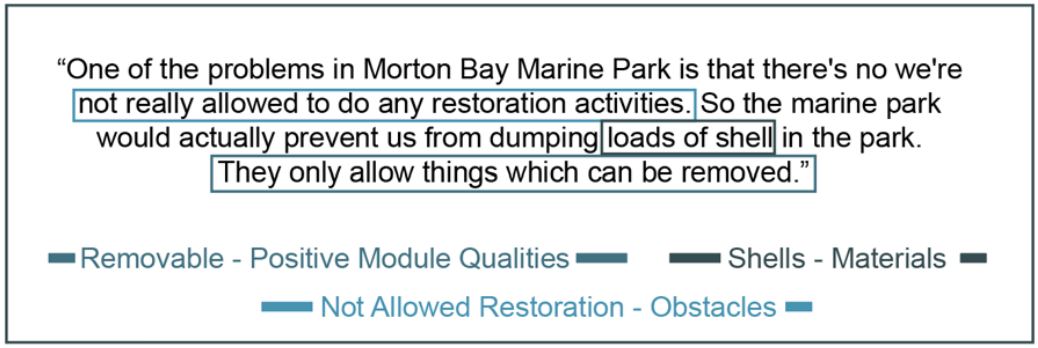


Figure 3: Quote 2 from Interview OZfish Representative

This concern is justified by the potential for restoration modules to carry diseases such as QX disease (also known as Marteiliosis). This spread is due to the ineffective sanitisation of recycled oyster shells used as a substrate but also the manual settlement of diseased spat on to the modules in aquaculture tanks *(refer Appendix D).*

Interviewee two, states that spreading of disease via manual adhesion in aquaculture tanks is easily avoidable with the right risk management strategies *(refer Appendix D).*

Sedimentation:

Sedimentation is affecting the settlement of spat/larvae (mentioned 27 times in interview 2)*(refer Appendix F)* due to the larvae phase of the oyster's lifecycle being much more fragile than its fully grown counterpart with a very short window in which to settle, states interviewee two *(refer Figure 4).*

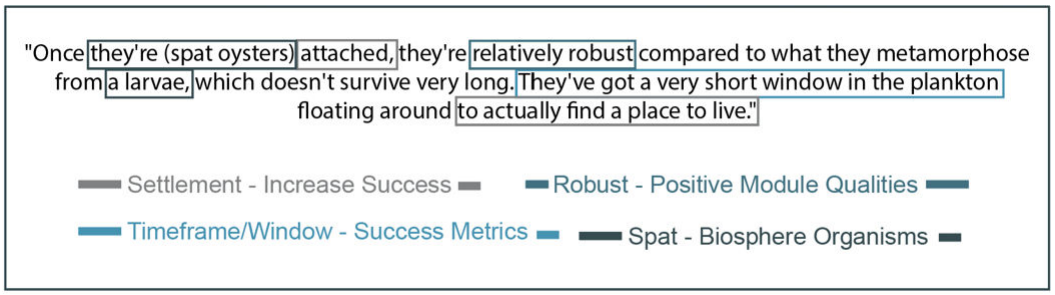


Figure 4: Quote 2 from Interview with Oyster Professor

There a much higher background sediment rate in the current ecosystem, and this, combined with, the existing high light penetration, allows for the growth of algae turf (occurs 10 times in interview two) *(refer Appendix F).* Which in turn traps silt and sediment while preventing the existing currents from clearing the surfaces *(refer Appendix D).*

This soft mud-covered surface blocks the calcium carbonate signal required by the spat/larvae to signal them to settle on said surface states interviewee two. If this happens enough in one area, the spawn phase in the December to February window will end without any new spat settling, interrupting the oyster's natural lifecycle *(refer Appendix D).*

This calcium signal, can, however, be magnified or increased, it is stated that concrete as a material choice has the possibility to enhance this signal, making it a preferred material choice to others such as steel, soft materials, and plastic, as "you've only got a period of one to two months in these degraded systems where you'll get that effect out of those other suboptimal materials." *(refer Appendix D2).*

New Module Recommendations:

Interviewee two noted that this phenomenon only occurred on the top surfaces of the modules. Stating that new module design should be focussed on increasing internal and overhang spaces, as these are the most productive spaces for oysters, while also increasing the "rugosity" and "interstices" of the modules *(refer Figure 5).*

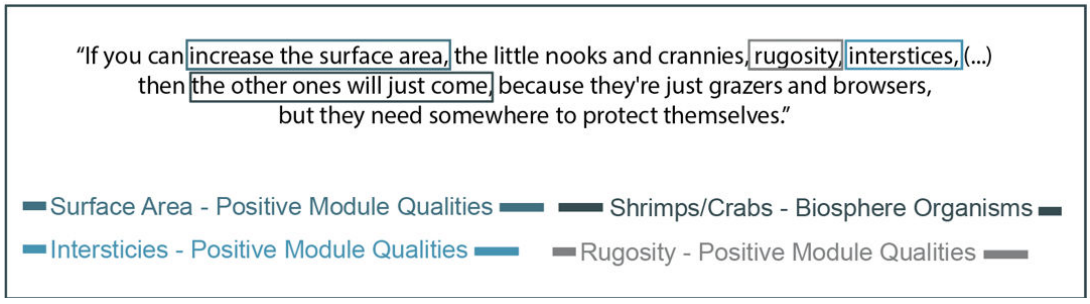


Figure 5: Quote 3 from Interview with Oyster Professor

Making the restoration modules interconnectable was also highly recommended, by the oyster professor *(refer Appendix D)*, especially vertically so one design can supply both intertidal and subtidal reefs. Other benefits mentioned include; making the device lighter for installation and manual seeding and allowing for the creation of tunnels up to 30cm in size to provide shelter for fish communities as well.

It is stated that subtidal modules are much more productive, compared to intertidal, in terms of increasing fish population. Additionally, subtidal modules are known to in the process of nocking the tops from waves provide sheltered and cleaner biomes behind themselves, ideal for seagrass and therefor dugong grazing.

Surveys:

End User Survey:

Many survey respondents, 60.7%, stated that they interact with water ways such as rivers and estuaries *(refer Appendix B),* with 68% also stating that they normally encounter obstacles such as underwater rocks during their interaction *(refer Figure 6).*

Although the number of respondents that have interacted with natural or manmade reefs is 75%, only 64% of respondents feel positively towards an oyster reef being constructed in their local waterways *(refer Figure 6).*

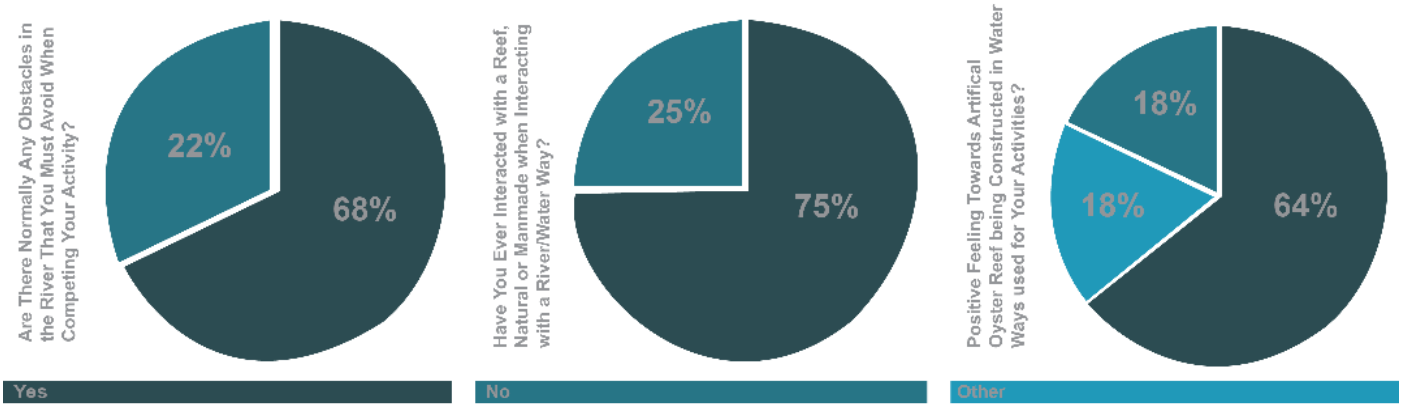


Figure 6: Affirmative or Negative Survey Response's Pie Charts

Provided reasonings for this lack of positive support were, lack of information, and stipulation on the placement/width/depth of the reef instalment *(refer Appendix B).* In terms of said obstacles impacting their interaction/activity, 71% of respondents state they must adjust, but it does not impact them, and only 1% said it would make them avoid that water way *(refer Appendix B).*

Restoration Module Installation Survey:

60% of respondents listed concrete as the primary material used in their restoration modules, with assorted rocks and other materials accounting for the other 40%. The most common number (60%) of restoration modules installed per installation round was less than 5, with 60% also stating that they install their modules via a vessel, specifically a large boat. Respondents cited weight and cost as two of the greatest barriers to installation *(refer Appendix C).*

Observations:

All 3 of the archival observations conducted involved balloons to float out the modules, although in some cases the modules are bolted together prior to this stage *(refer Figure 7)* whereas in other they are attached (bolted together) while submerged *(refer Appendix G).*

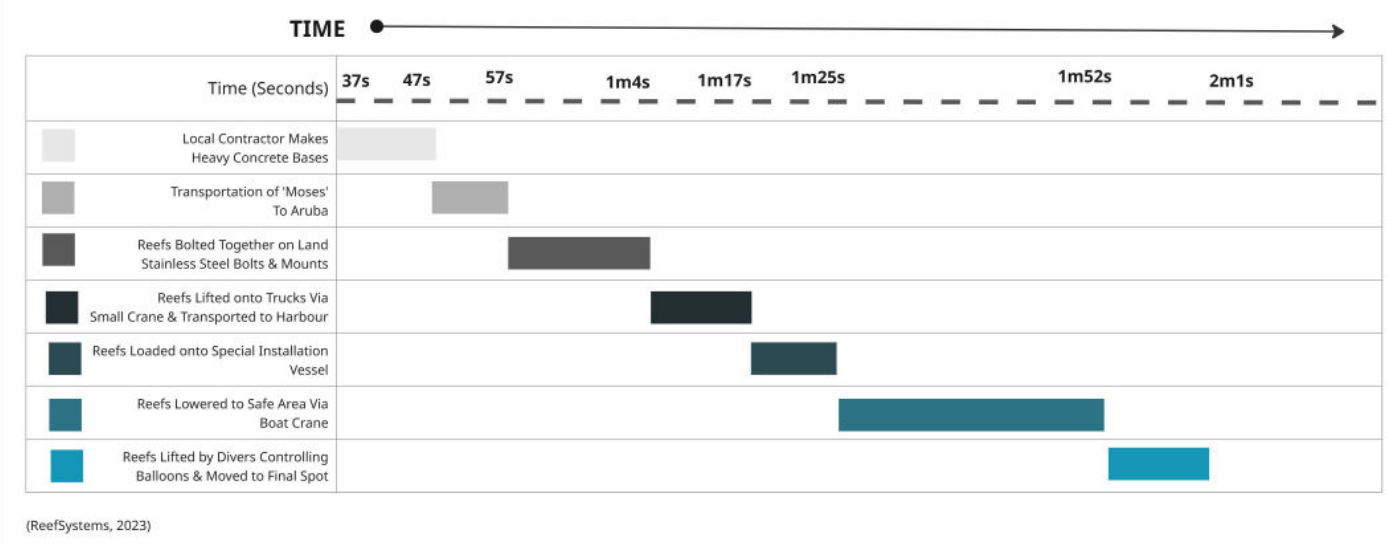


Figure 7: Observation of Reef Module Installation by ReefSystems

The inflatable balloons, used to float the modules out to their desired location, are inflatable bags which must be inflated in the water by a diver while also manoeuvring the heavy module *(refer Appendix G).*

SECTION 3

Discussion:

The primary data collected through the above interviews, surveys and observations both contradicted previous conclusions made by literature but also provided interesting additional insights.

For example, although pH was mentioned in the literature review as a serious barrier towards o yster reefs and their restoration, this was contradicted with the information that oysters can withstand large variations in pH, and are currently doing so, as stated in interview with a leading oyster professor. Instead, the main barrier is listed, as sedimentation, with an important addition of sunlight causing algae turf growth furthering the impact of built-up sediment limiting safe settling locations for spat oysters.

Comparing the two interviews showcased the extreme contradictions between what is most effective for oyster reef restoration, a product that biodegrades after 3-4 years, and what is plausible in the current environment, where any product left for over 2 months will be unusable. Additionally, it was noted, through both interviews, that the lack of research or implementation, into oyster reef restoration specifically, is due to the legal barriers in Australia regarding restoration efforts in marine waterways. Not, in fact, due to end user backlash, as seen in the survey with end users, where a majority state they feel positively towards a reef being constructed in their local water way, even though it would impact or obstruct their chosen water activity.

In terms of existing products, it's been identified that they prioritise easy installation and cost-effective manufacturing practices instead of expert identified increased success criteria. This was later confirmed via primary survey data with existing reef restoration companies, where the majority install their modules on large boats with cranes and list cost as their biggest barrier. Difficulty with installation was further detailed within the archival observations, where heavy, large, concrete modules, if attempted to be installed by divers, must be floated to their desired location using hand inflated balloon bags.

Design Implications:

Implications:

Existing oyster reef restoration modules, place a high focus on utilising oyster shells as their main substrate, which is backed up in research for their high calcium carbonate signal, high surface area, rugosity and overhangs. However, they give little to no attention to preventing sediment build up and thereby nutrient loading, which have been identified by professionals in the field to be the main barriers to be focussed on.

Modules utilise a basic and biologically subpar design, providing either small modules that are easy to install but provide no benefits for other surrounding organisms (such as fish which relied on the original reefs), or large, cavernous modules not at all replicating the natural reefs they aim to support.

Additionally, these modules are hard to construct, or hard to install, with initial boosts in oyster populations seeming to be the biased success metric, instead of long-term oyster reef restoration and growth.

Opportunities:
Placing the priority on long term growth of the oyster population allows for a broadening of the scope of the design, showing a clear need for sediment prevention. Making the modules interconnectable allows for smaller modules, which would be both easier and less costly in terms of installation, being by hand (via divers) instead of by cranes on boats. Overhangs and open spaces are already being utilised, but combining this with forms to block sunlight on the modules to discourage algae turf growth would further the usable surface area for spat settlement.

Designing with the potential for fish and other organisms to also interact with the reef while also preventing their access to the reef during the fragile and short reproduction period of the oysters, would boost oyster and various other organisms' populations. This can be achieved through subtidal reef forms potentially also with sloping fronts on the modules. This would help to increase the speed of the water flow over the module, minimising the sediment settling on its surfaces.

Making the interconnecting aspect of the modules possible while in its permanent position underwater has also been highlighted as a design opportunity. This would minimise the identified issues of installing heavy and large modules via floating devices discovered during archival observations.

Conclusion:

Oyster reefs are a rapidly disappearing, crucial part, of Australia's underwater ecosystem. This large loss in habitat is due to many causes, including; the spread of QX disease, nutrient loading and most importantly, sedimentation. This loss is detrimental as not only do these reefs provide benefits such as; coastline protection, water filtration, and biodiversity support; oyster reefs are also much more durable to rough weather, sun exposure and pH changes than their more popular counter parts, coral reefs.

The aim of this study was to combine an understanding of the intricacies of the oyster lifecycle with exploration into reef restoration modules current designs and installation, to determine how best to redesign these solutions to maximise their potential positive impact.
A triangulation research approach has been used within this study. Utilising existing literature, archival observations, interviews with biological and practical experts, and finally, surveys with both the end user of the product and companies currently installing reef restoration modules. The data collected throughout these methods was then analysed using an inductive code to create quantitative data from the qualitative raw information.

Combining the experience of leading biological researchers in the oyster field with the real-world experience of companies actively trying to solve the issue, will reduce the financial and physical barriers preventing effective oyster reef restoration around Australia. To reverse the damage of this loss of habitat, future module designs should implement internal spaces, rugosity and interstices while blocking sunlight to maximised usable hard, clean surface area for spat oyster settlement. With the goal of providing consistent oyster population growth instead of short-term spikes.

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