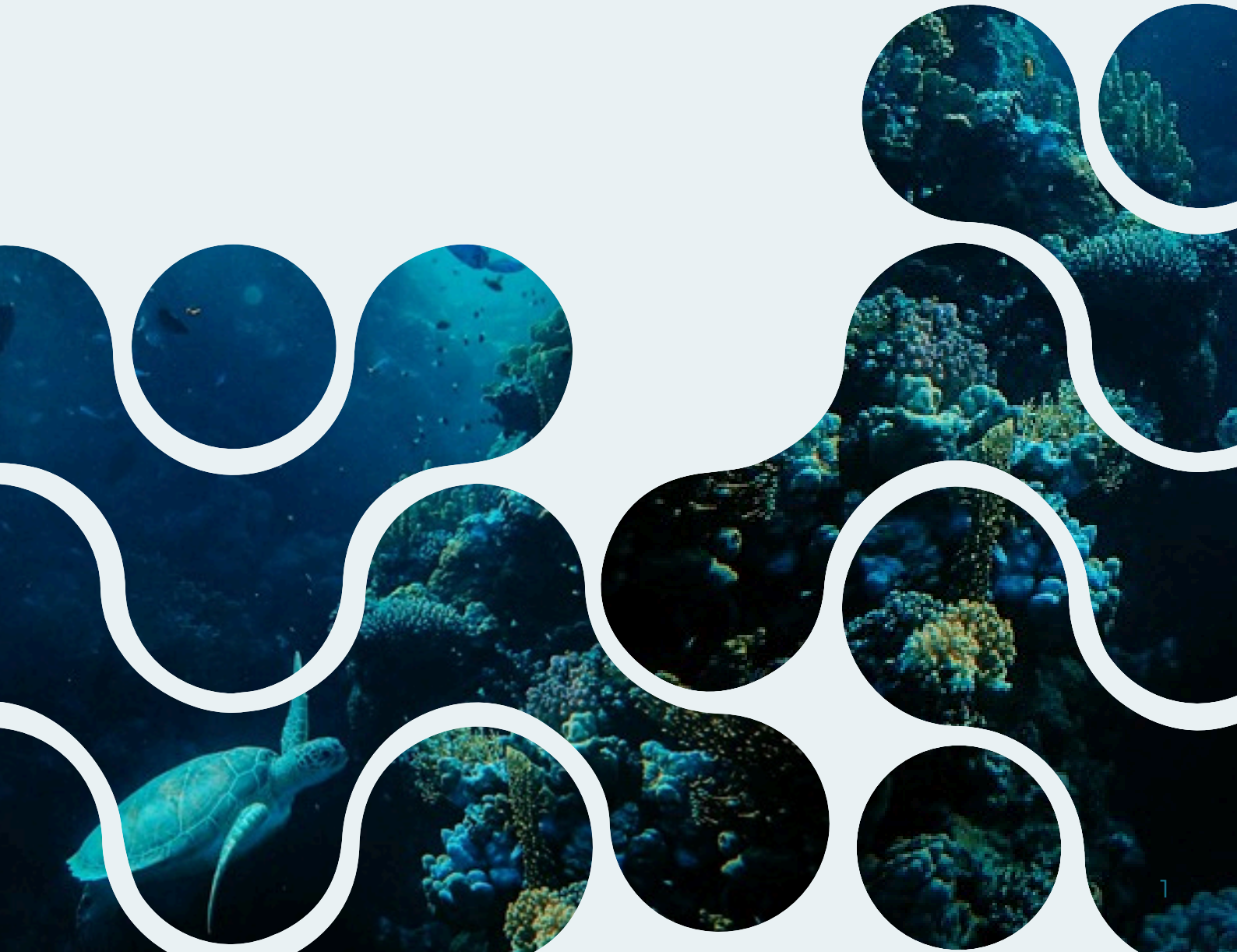
Research Report

Re-designing Coastal Protection Systems to be More Nature Inclusive

Written By: Emi Pienaru



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.

AI Use Statement

I have utilised Generative AI in this report (ChatGPT) to assist in various ways. The way I have used AI includes to assist reducing word counts, initial coding of interview findings and analysis (pulling key words form transcript extracts)

Name: Emi Pienaru

Date: 11/09/26

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EXECUTIVE SUMMARY

Climate change is causing sea-level rise, increasing coastal erosion and placing pressure in coastal environments and communities. Traditionally, the design of coastal protection systems has been focused on engineering performance and durability, limiting opportunities for marine colonisation and habitat formation. In partnership with In-Depth Innovations, this report explores how ecological centred design principles could be incorporated into coastal infrastructure so that it balances shoreline defence with habitat values for intertidal and submerged marine organisms.

A triangulation research method was implemented using surveys, interviews and secondary research to gather a holistic view for the ecological, structural and practical requirements for this system. Existing product benchmarking was conducted against existing coastal protection and habitat enhancement products. Industry and community perspectives were gathered though expert interviews and a public survey. These methods allow for reoccurring opportunities, limitations and design considerations to emerge.

The research consolidated the existing divide between engineered solutions prioritising structural protection and solutions focusing on ecological performance. Habitat complexity, such as varied surface textures, crevices, shelter and differences in environmental exposure, emerged as an key considerations for successful marine colonisation. While geometry and arrangement were identified as opportunities where a design could simultaneously influence wave energy and create protected habitat spaces. However, structural stability, weight, lifting, manufacturing, installation and site conditions were found to be valuable constraints that impact the practicality and scalability of coastal infrastructure. Moreton Bay was identified as the most appropriate context for future nature-inclusive intervention within Southeast Queensland, supported by both existing coastal management organisations and public responses.

These findings establish 8 guiding opportunities for the final design solutions; multifunctional geometry, habitat complexity, interlocking modularity, structural stability, efficient deployment, site adaptability, bio receptive materials and scalable manufacturing. These final opportunities provided a foundation for developing a coastal protection system in which coastal protection and ecology integrated together rathat than treaded as separate requirements.



PROJECT STRUCTURE



1 **ACADEMIC RESEARCH**
Secondary research & Identifying Problem Area

PRODUCT BENCHMARKING
Identifying gaps in existing market

2 **PRIMARY RESEARCH**
Survey of public & Interviews of experts in industry

ANALYSIS & FINDINGS
Address gaps & Analyse primary data through code/graphical format

3 **DISCUSSION**
Design Implications & Problem areas

OPPORTUNITIES
Identifying opportunities for Design Intervention



01

Introduction

Part 1

Introduction

Project Structure

Background

Benchmarking

INTRODUCTION

Coastal environments are dynamic, consistently being shaped by waves, sediment movement and weather conditions. Approximately 40% of the world populations lives withing 100km of any coast, where ports, cities and tourism and economic action account for over 70% of global production (UNDP, 2024). With the increase in rising sea levels, “4.62 mm per year between 2013 and 2022” (UNDP, 2024), combined with more powerful tides, storms and waves as resulted in an acceleration of coastal erosion and inundation (Pang et al., 2023, Saunders et al., 2019).

These impacts extend beyond just land loss and infrastructure damage, coastal ecosystems and species that are dependent on these environments are facing greater threat due to climate change (National Centers for Coastal Ocean Science, 2017).

Australian coastal habitats, including estuaries, wetlands, coral reefs, and saltmarshes, are vulnerable to sea-level rise as “deepening waters cause changes in distribution of environmental conditions...influencing the distribution and extent of suitable habitat for coastal marine species.” (Saunders et al., 2019).

The need to protect coastlines as led to a widespread use of engineered systems. However, these structures are introduced into existing environments altering natural sediment transport pathways while providing less opportunities for habitat growth for marine life (Geoscience Australia, 2025). In response to this challenge, this project works in partnership with In-Depth Innovations to explore a nature-inclusive coastal protection system that integrates coastline defence with productive intertidal and submerged habitats.

RESEARCH AIM

How can eco-engineering principles inform the design of a coastal protection system that combines the structural function of conventional defence units with habitat value for intertidal and submerged marine ecosystems?



BACKGROUND

The impact of climate change and the acceleration of coastal erosion is placing pressure on both natural and developed coastlines. In areas like Moreton Bay, habitats and urbanised foreshores are increasingly exposed to erosion, flooding and storm damage, thus, coastal protection and management have become a critical consideration (City of Moreton Bay, n.d., Geoscience Australia, 2025).

Current Coastal Protection Strategies

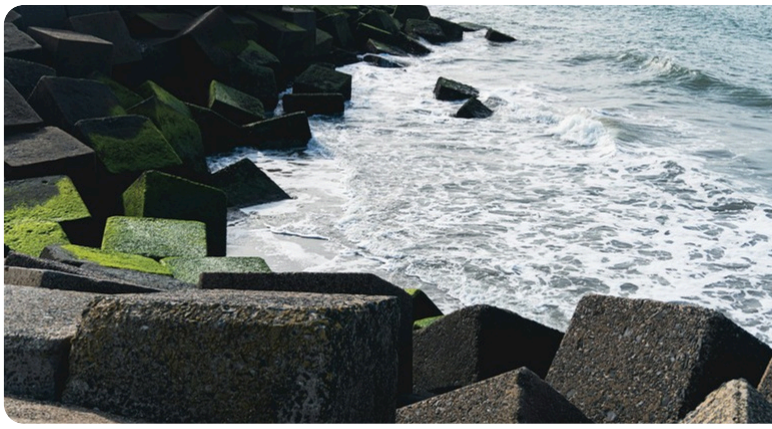
Hard and soft solutions are the two categories of solutions for conventional coastal protection systems (Geoscience Australia, 2025, Salyer, 2022). Hard solutions such as seawalls, revetments and breakwaters protect coastlines by being physical barriers to resist, redirect or dissipate wave energy. These structures provide long-lasting and efficient protection, especially in areas that are subjected to high wave energy. However, they can alter the movement of waves and sediment and cause the beach material in front of the structure to disappear (Salyer, 2022a).

Soft solutions such as beach nourishments, dune restorations and mangrove planting, work with naturally occurring processes restoring coastal habitats gradually. After storms and erosion, these solutions help stabilise sediment and promote coastal recovery. However, their effectiveness is reliant on local environmental conditions, space and severity of coastal forces (Salyer, 2022).

Another approach is the use of artificial reefs and submerged structures. Reefs are natures form of breakwaters, made to reduce wave energy while creating a unique ecosystem for marine life (Guannel et al., 2016). By mimicking these structures, artificial reefs can be positioned offshore to reduce wave-induced coastal erosion while helping rebuilding ecosystems that have been lost due to climate change.

Within Moreton Bay region, artificial reefs, seawalls and offshore breakwaters have been identified as potential erosion management options by Moreton Bay's Regional Council (City of Moreton Bay, 2026).

As a result, designs for marine infrastructure are also beginning to combine these functions, with In-Depth Innovation's BioReef™ designed to enhance marine habitat and dissipate wave energy through subsea infrastructure.







Images: Top (Houwing, 2022), Middle (Bong, 2026), Bottom (Biorock Indonesia, 2020)

Intertidal Habitats & Ecosystems

The Intertidal zone is the transitional area between land and sea. It is regularly exposed and submerged by tides, resulting in fluctuating water level, temperatures and salinity (NOAA, 2024). These changing conditions support various organisms that specifically adapt to the demands of the intertidal environment (NOAA, 2024).

Rocky shores, mangroves, and mudflats are among the many intertidal habitats found in Moreton Bay that offer marine life refuge, hunting, and breeding opportunities (Department of Environment, Tourism, Science and Innovation, n.d., Rocky Shore - Qld.Gov.Au, 2018). Rocky shores are particularly complex, containing various surface textures, elevation, crevices and sheltered spaces, creating a range of microhabitats within the one area (Queensland Government, 2018).

Small differences in exposure and surface conditions support different species and communities, making the physical complexity an important characteristic of intertidal ecosystems (Rocky Shore - Qld.Gov.Au, 2018).

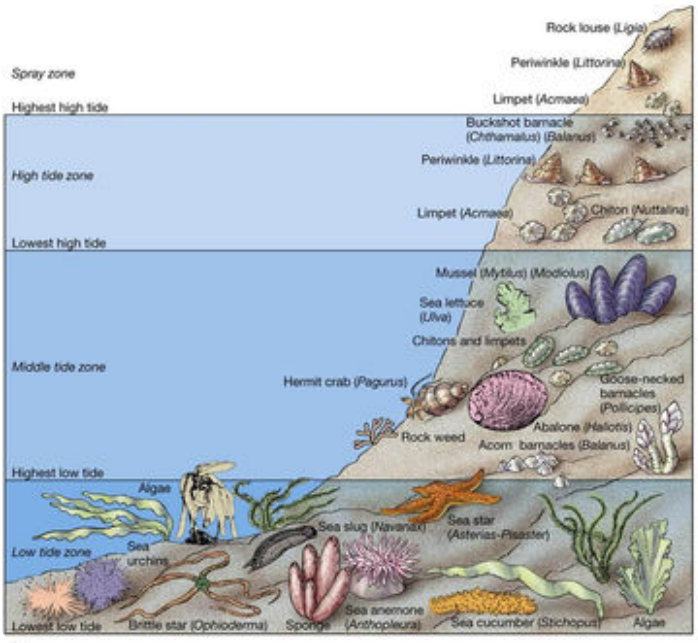


Figure 1: Diagram of Intertidal zone (feng, 2019)



Image: San Diego, 2026)

Coastal Infrastructure & Intertidal Habitat

The development of hard coastal protection solutions has resulted in the loss of natural shorelines and intertidal habitats. Naturally, marine habitat forming species can respond to rising sea-levels through various methods like, moving shoreward, building the seafloor upwards by trapping sediments and biological materials (Saunders et al., 2019). However coastal infrastructure can block an ecosystem's ability to naturally respond to changing sea levels through a process known as coastal squeeze (DCCEEW, 2021).

Natural forms and textures are often replaced by smooth and uniform concrete reducing the surface complexity available for marine organisms to colonise (Salyer, 2022). Marine infrastructure can also alter local hydrodynamics and sediment processes influencing the natural surrounding intertidal environment. Therefore, these insights highlight the need for continued development of hard solutions to maintain Moreton Bay's ecological function.

BENCHMARKING

In the existing market, there are a variety of coastal protection solutions, each approaching coastal protection or ecological opportunities differently. These solutions will be benchmarked across coastal protection, manufacturability, deployment, ecological performance, sustainability and adaptability. This will help identify strengths, limitations and gaps within existing approaches. By understanding these existing solutions, it will help inform the development of a coastal defence system that combines protection and habitat value.

The chosen products range from conventional protection systems to more modern solution with integrated ecosystem potential. CORE-LOC, XblocPlus and ShoreJax primarily focus on erosion control, wave attenuation and structural stability through interlocking concrete units. Reef Arches, Living Seawall Boulders, EMU and ECOncrete combine habitat complexity into coastal protection structures, while Living Seawalls and 3D Printed Seawalls integrate habitat opportunity directly into existing infrastructure.

Criteria									
	CORE-LOC	XBLOC PLUS	SHOREJAX	REEF ARCHES	LIVING SEAWALLS	LIVING SEAWALL BOULDERS	EMU	3D PRINTED SEAWALLS	ECONCRETE COASTALOCK
Erosion Protection + Wave Attenuation	5	5	4	4	1	2	5	4	5
Durability + Stability	5	5	4	4	4	4	4	3	5
Ecological Performance	1	1	2	3	5	5	5	5	5
Modularity + Adaptability	4	3	4	3	4	5	4	5	4
Manufacturability	5	5	5	4	4	4	4	3	4
Installation + Deployment	4	5	5	4	4	5	3	3	4
Environmental Sustainability	3	2	3	4	4	4	5	4	4

Table 1: Erosion Mitigation systems on the current market (Refer to Appendix 1 for a full analysis and benchmarking criteria information)

Benchmarking Analysis

Table 1 compares nine products against seven criteria covering structural, practical and ecological performance. Figure 2 displays the highest scoring results through a combined radar graph, allowing their performance to be compared simultaneously.

Figure 2 shows that the radar profiles of EMU (30/35) and ECOncrete (31/35) extend significantly across to both ecological performance and erosion protection. While EMU combines wave attenuation and erosion mitigation with habitat-forming geometry, COASTALOCK integrates habitat opportunities into an interlocking armour units. However, both present opportunities for further development, with EMU's form limiting application in harsher or non-flat environments and COASTALOCK offering marine life limited protection from environmental exposure.

CORE-LOC (27/35), XblocPlus (26/35) and ShoreJax (27/35) demonstrate strong structural and practical performance but are limited in ecological integration. CORE-LOC and XblocPlus 's smooth concrete surfaces provide little grip for organisms to colonise, while their large difficult-to-handle forms can complicate installation. ShoreJax allows for greater modularity but requires additional fasteners for stability.

In contrast, products focused on ecological enhancement, have limited coastal protection. Living Seawalls (27/35), Living Seawall Boulders (29/35) and 3D Printed Seawalls (27/35) provide strong habitat potential but rely on existing infrastructure and offer limited wave attenuation and erosion resistance. Their ecological performance can also depend on surrounding environmental conditions.

Therefore, there is a divided market as seen across table 1 and 2, where recurring limitations include minimal habitat value within conventional armour, insufficient protection within habitat forming products, dependence on specific site conditions and challenges associated with installation and adaptability.

Key Findings

- Solutions favour either structural protection or ecological benefits.
- Conventional armour lacks ecological complexity and shelter.
- Ecological solutions often rely on existing defence infrastructure.
- Many solutions are restricted to specific coastal conditions or infrastructure.
- Installation and adaptability remain limitations across existing systems.

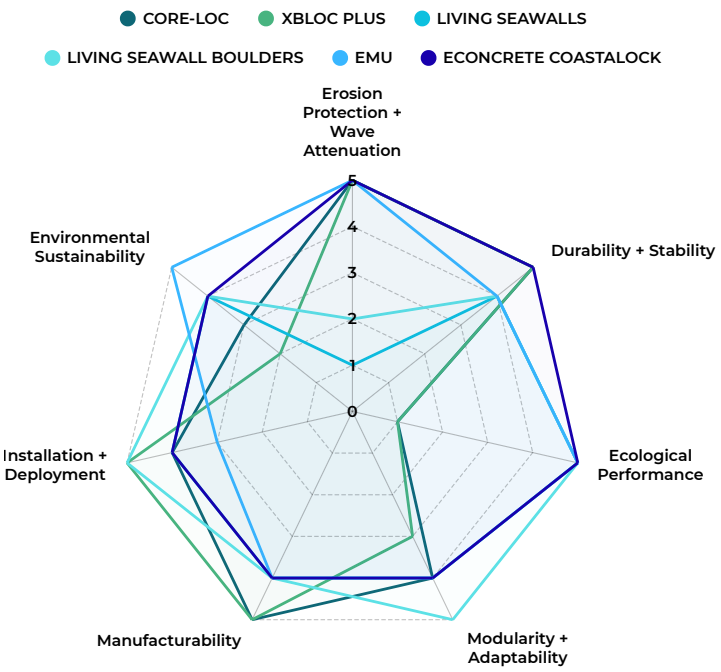


Figure2: Radar Graph benchmarking the highest ranking products identified in Table 1

Market Summary

The benchmarking presents a market progressively shifting from structural coastal defence towards multifunctional systems, but a clear opportunity remains to better integrate these approaches. The strongest products demonstrate that ecological function can coexist with structural protection, yet compromises remain across deployment, site suitability, adaptability and habitat performance.

The opportunity for this project is therefore to combine structural performance of conventional coastal armour with the ecological complexity of habitat-focused systems, while improving manufacturability, deployment and adaptability. Rather than adding habitat to an existing defence, the design can treat coastal protection and marine habitat creation as integrated requirements from the beginning.



3: Market Gap

02

Research



Part 2

Research Overview

Methodology

Methods - Surveys

Methods - Interviews

Methods - Archival Research

Analysis and Findings

RESEARCH

To strengthen the precision and credibility of the research, a triangulation approach was used to investigate the research problem through complementary research approaches. Triangulation involves using multiple methods to investigate the research question, allowing findings to be considered from different perspectives (Carter et al., 2014). In this research, two complementary methods were explored: semi-structured expert interviews and a public online survey. The interviews were primarily qualitative, drawing on the detailed perspectives and experiences, while the survey generated both qualitative insights and statistical data. Together, these methods provided complementary perspectives and supported a more robust understanding of the research problem.

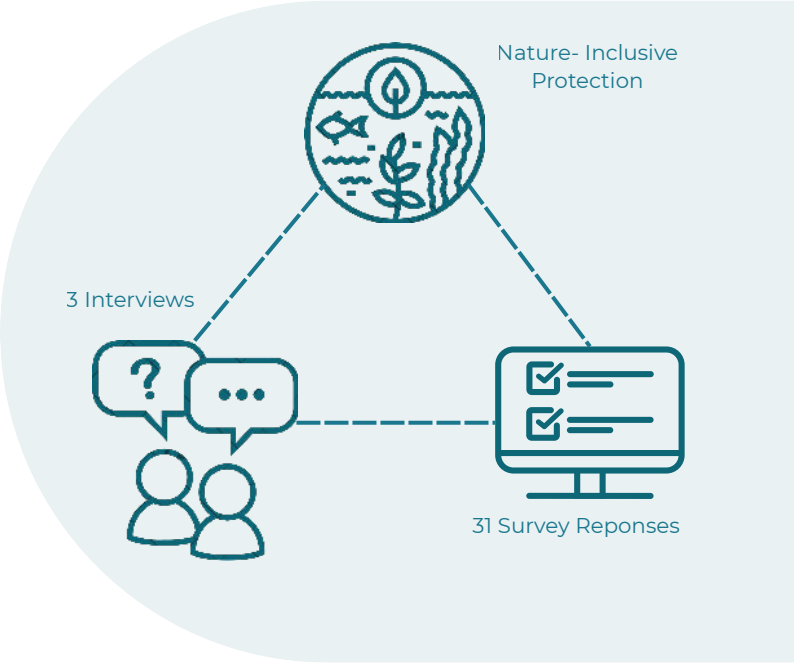


Figure 4: Triangulation Method for data collection

RESEARCH DESIGN

Interview

- Interview Questions were developed
- Interviewees were recruited
- Interviews were conducted in a semi-structured way over video call and transcribed

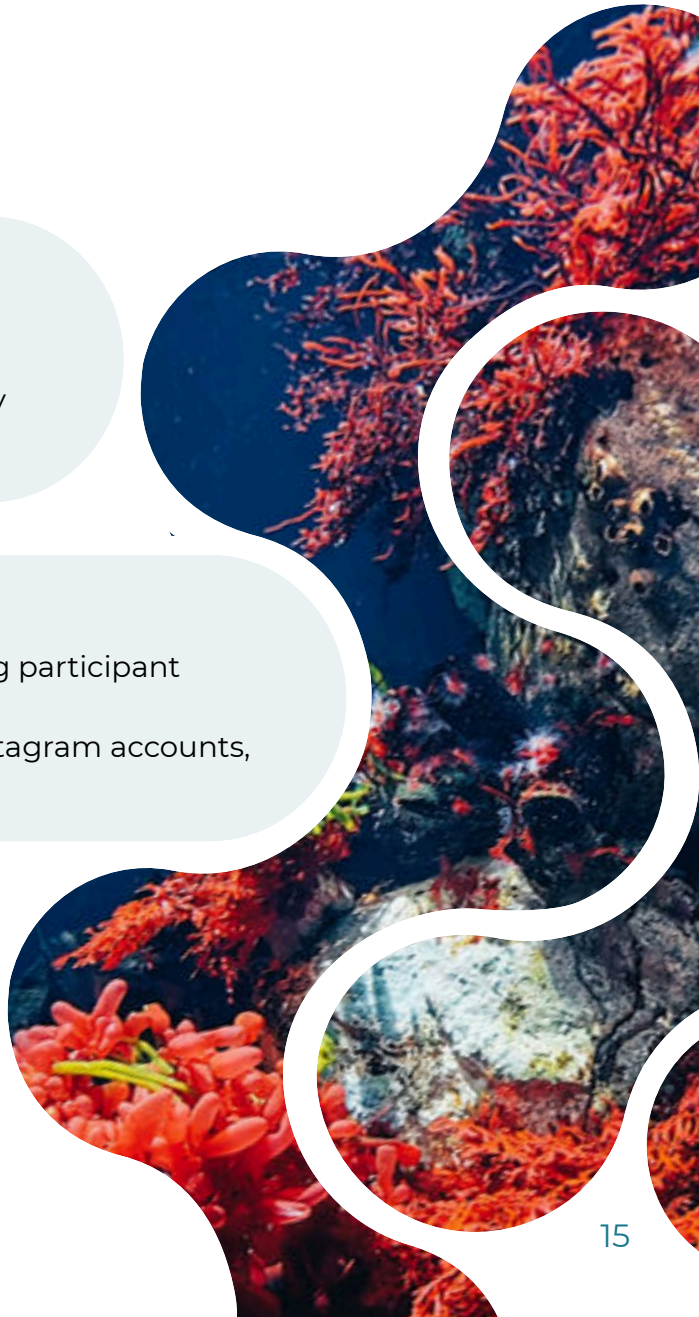
Survey

- Survey was designed using Microsoft forms ensuring participant confidentiality
- Shared on Facebook groups, posted on multiple Instagram accounts, and promoted through LinkedIn advertising

Data & Analysis

- Qualitative and Quantitative data was analysed and combined to compare results
- Thematic coding and statistical analysis were utilised

Figure 5: Research Design



INTERVIEW METHODOLOGY

Methods

Each interview followed a semi-structured approach to gather comparable information through predetermined questions. This allowed for spontaneous follow-up questions to explore relevant topics in greater depth. This approach was selected as it allows adaptability for discussion based on the participant's area of expertise and the information they provided.

To develop a broader understanding of the ecological, technical and practical considerations involved in designing and implementing coastal protection systems, experts from different areas were engaged. Three industry experts were interviewed, each bringing different professional perspectives relevant to the development of nature-inclusive coastal infrastructure.

The interview questions were developed from gaps and opportunities identified throughout the secondary research and were tailored to each participant's expertise (Figure 7). The main topics explored included ecological needs & habitat, environmental & physical performance, design & adaptability and implementation & viability. This allowed the interviews to explore the market gap presented in the benchmarking by investigating both the ecological opportunities and practical constraints associated with developing a new coastal protection system.

Question for Structural Engineer: Which load cases are the most significant? Would you look at wave impact, uplift, scour, tides?

Questions for Operations Manager: Do you have standardised machines or tooling that you use when you install? Does it change based on what you're placing into the water?

Question for Managing Director: What physical characteristics do you believe make a coastal structure more or less attractive or useful for marine organisms?

Figure 7: Example of tailored quetsion for interview participants



Interview 1: Operations Manager - InDepth Innovations
Length: 35min
Questions: 12 question asked
Format: Recorded Zoom meeting
Type: Semi-Structured



Interview 2: Structural Engineer - Marine
Length: 35min
Questions: question asked
Format: Recorded Zoom meeting
Type: Semi-Structured



Interview 3: Managing Director - InDepth Innovations
Length: 35min
Questions: 15 question asked
Format: Recorded Zoom meeting
Type: Semi-Structured

Figure 6: Interview and participant details

Limitations

While the interviews provided detailed specialist perspectives, the relatively small number of participants limited the range of professional viewpoints represented. The tailored nature of the interviews meant that not all participants discussed every topic to the same depth, hence their responses may reflect more depth in experiences associated with their individual fields. Additionally, the semi-structured nature of the interview allowed the direction of conversations to vary, which could have led to differences in the type and quantity of information collected between interviews.

SURVEY METHODOLOGY

Methods

Survey research can incorporate both quantitative and qualitative approaches, allowing measurable responses to be considered alongside individual perspectives. A public online survey was selected to broaden the research beyond specialist perspectives and explore public understanding and perceptions of coastal protection infrastructure. The survey was informed by findings from the secondary research and benchmarking, particularly the need to understand public awareness of existing structural and ecological approaches to coastal protection.

In total, the survey consisted of 15 questions that were a combination of multiple-choice, yes/no, ranked and short-answer questions to generate both quantitative and qualitative data. Questions progressed from participants' existing awareness of coastal protection towards their perceptions of its purpose, ecological considerations and potential applications of alternative approaches. The survey was open for 2 weeks and participation was open to the public, with 31 responses collected through social media, LinkedIn, and personal networks.

Existing coastal protection systems were used as scenario-based examples, with Living Seawalls and EMU modules introduced through images and brief descriptions. Participants were then asked to consider whether similar approaches could be implemented in areas near them. This introduced ecological coastal protection approaches while allowing participants to consider their potential application within familiar environments.

How familiar are you with coastal protection infrastructure, like the previously mentioned structures? 1 being no understanding, and 10 being strong understanding.

Figure 8: Example Likeart Scale question

The Living Seawalls is a design initiative created by Reef Design Labs, installed in Sydney. The system is composed of several interlocking hexagons that are installed on existing concrete infrastructure along Sydney's coastlines.

Explain what location Living Seawalls could be introduced, and how it could benefit from something similar to the Living Seawalls

Figure 9: Example Scenario Questions (see appendix 2 for all Survey Questions)

Limitations

While the survey allowed both quantitative and qualitative perspectives to be collected, the relatively smaller number of participants and broad recruitment approach limited control over the range of perspectives represented. Distribution through social media, LinkedIn and personal networks also meant participation was voluntary and may have attracted respondents with greater interest or familiarity with the topic.

Furthermore, self-rated questions relied on participants accurately assessing their own knowledge, while short-answer responses limited the opportunity to explore individual perspectives in greater depth. By introducing participants to specific nature-inclusive approaches before considering their potential application, the use of existing systems within scenario-based questions may have also influenced responses.



SURVEY ANALYSIS & FINDINGS

Survey Analysis

The survey was conducted on Microsoft Forms over two weeks, with responses displayed in basic graphics and raw data extracted for detailed analysis. Quantitative data was analysed through descriptive statistics and while short answer responses were thematically coded to identify common perceptions, opportunities, and concerns about coastal protection and ecological opportunities.

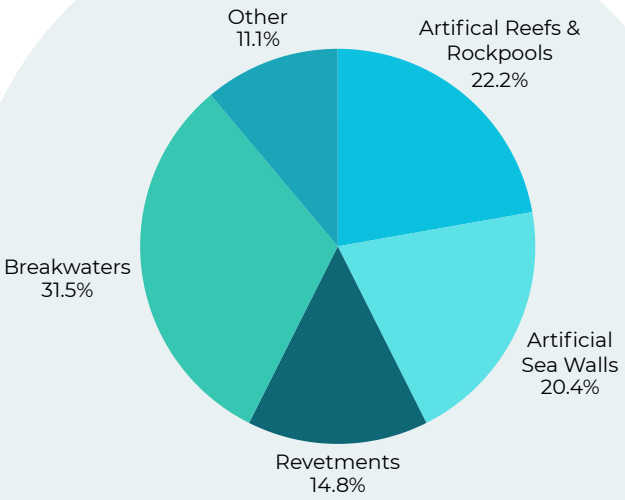


Figure 10: General Public awareness of existing coastal protection infrastructure

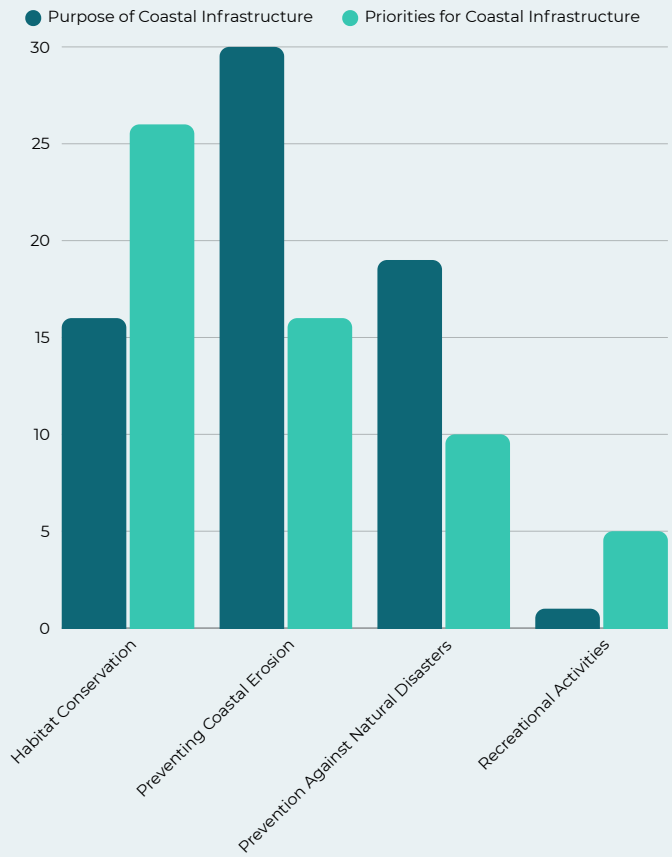


Figure 11: Graph comparing purpose and priorities for coastal protection system by general public

Quantitative Results & Findings

31 responses were received, with 93.5% of respondents from Southeast Queensland. Respondents rated their familiarity with coast protection infrastructure as moderate, with breakwaters recognized by 54.8%, followed by artificial reefs and rockpools at 38.7%, and artificial seawalls at 35.5%. This indicates that while coastal protection infrastructure was generally familiar, detailed technical understanding was limited.

A distinction emerged between the perceived purpose of coastal infrastructure and priorities for preserving coastal areas. Preventing erosion was identified as the primary purpose of coastal infrastructure by all respondents (100%), yet habitat conservation was the strongest priority for preserving coastal areas (87.1%), ahead of erosion prevention (51.6%). This reveals a distinction between the perceived protective function of infrastructure and respondents' ecological priorities.

Moreton Bay emerged as the strongest location opportunity, with 11 respondents (35.5%) identifying locations across the broader Brisbane and Moreton Bay region, particularly Wynnum (12.9%). This concentration suggests that the Moreton Bay region represents a particularly relevant context for integration for nature-inclusive coastal infrastructure.

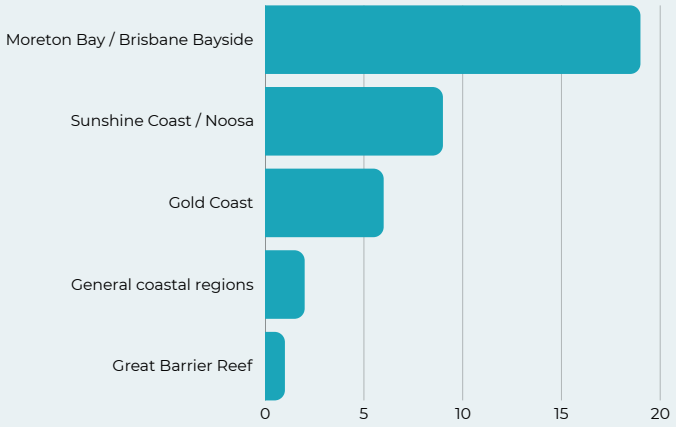
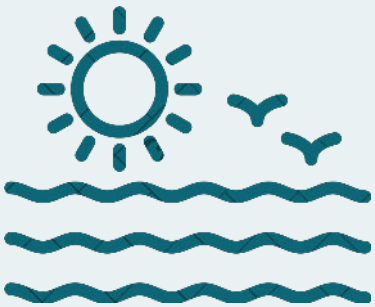


Figure 12: Frequency of locations mentioned by general public



Figure 13: Treemap represents frequency of coded mentions across qualitative survey responses. (see appendix 4 for full thematic analysis)



Qualitative Results & Findings

Qualitative responses were analysed through thematic coding, grouping recurring responses into broader themes related to understanding of coastal protection with code frequencies representing references rather than individual respondents (Figure 13).

Existing hard infrastructure, particularly seawalls, piers and developed waterfronts, emerged as the clearest implementation opportunity, with Brisbane and Moreton Bay frequently identified (48) (Figure 12). Living Seawalls and EMU modules were associated with habitat creation, shelter and species colonisation, reinforcing habitat complexity as a key consideration for ecological coastal infrastructure.

However, these opportunities were not universally applicable. Respondents mentioned environmental and practical constraints, including wave and cyclone exposure, impact on recreational activity, and durability. Some expressed concern that interventions could alter or displace existing ecosystems. Thus, site selection emerged as an important consideration, with ecological enhancement needing to respond to existing conditions.

Respondents also viewed infrastructure as part of broader coastal management, alongside habitat restoration, pollution reduction, vegetation protection and public education. This positions the opportunity within a broader nature-inclusive approach to coastal management, rather than as a standalone engineering solution.

Key Findings

- Strong support emerged for infrastructure combining coastal protection and habitat creation.
- Habitat conservation was the highest environmental priority.
- Existing infrastructure and Moreton Bay present opportunities for site-specific nature-inclusive intervention

INTERVIEW ANALYSIS & FINDINGS

Interview transcripts were analysed using inductive thematic analysis. The initial coding was assisted by generative AI and manually refined to combine recurring themes and record frequency counts (see Appendix 4).

Ecological Habitat Design

Ecological habitat design emerged strongly, with participants consistently associating marine colonisation and habitat use with physical complexity. Surface texture, crevices, shelter and varied environmental exposure were repeatedly identified as characteristics of productive natural habitats. Fish behaviour is an important indicator of habitat success, noting that smaller organisms and habitat-forming species can establish the foundations needed to support larger fish populations. Material characteristics through rough concrete and naturally derived materials, like oyster shells improved marine growth and bio receptivity. Varied textures, shelter, spatial complexity and bio receptive surfaces were consistently associated with more deliberate and productive habitat formation.

> “Flat concrete surface is definitely not biomimicry...structures that mimic the natural environment where a lot of these organisms, these colonisers, would be, is where I'd be focusing my design around.” - Managing Director

> “You need something that houses the small fish... the little invertebrates and baitfish that school up...and then large fish will come in to hunt those guys.” - Operations Manager

Installation, Scalability & Cost

Weight requirements were consistently identified as a major constraint on practical deployment and scalability. Heavier modules can improve stability but require larger vessels, cranes and supporting infrastructure, while lighter modules are easier and cheaper to handle but may be unsuitable for more exposed conditions.

Lifting was also recognised as a critical stage of installation, with participants emphasising the importance of structurally reliable lifting points capable of supporting modules under dynamic movements. Offshore vessel time, diver involvement, underwater assembly were also identified as contributors to installation cost.

Manufacturing showed a similar pattern, with 3D printing offering greater geometric complexity while pre-casting remained more economical at scale. From these findings, weight, manufacturing complexity and installation emerge as requirements that strongly influence how many structures can realistically be deployed.

> “Mass or weight is really important for these artificial reefs...we want them to perform and sustain for the design life, so we really don't want structures too light.” - Structural Engineer

> “You've got to make sure the point you're picking up is nice and solid, with a safe working load...want to limit the amount of time on the water, because the boat is the most expensive thing in any operation.” - Operations Manager

> “3D printing gives you that ability to, on demand, create new structures and shapes and habitat... [but] 3D printing is still expensive and not cost-effective at this stage.” - Managing Director

Erosion–Habitat Balance

The relationship between coastal protection and habitat creation emerged as a distinct theme rather than two entirely separate objectives. Participants described how unit geometry and arrangement can influence wave behaviour and energy dissipation, while gaps and voids created between units can simultaneously provide shelter and habitat for marine organisms. Interlocking configurations could additionally create sheltered spaces resembling natural rocky habitats. This suggests that the physical features responsible for coastal protection could also contribute to ecological performance, with both functions influenced by geometry and arrangement of the overall system.

> “In erosion management you want to disturb the wave... by putting anything in the seabed, you're shortening the water depth... that causes the wave to then go into breaking condition... [and] as the wave breaks, it dissipates its energy...When they stack they have gaps between them, which create nice little hidey spots for fish to congregate. - Structural Engineer

Structural Durability

Long-term stability and strength were identified as essential conditions for maintaining marine infrastructure performance. Extreme environmental loading was a recurring concern, with the 100-year storm condition associated primarily with in-place stability and required mass. Stability was associated with sufficient mass and a low centre of gravity, while concrete was considered suitable for long-term subsea use. Marine growth was also identified as increasing mass and hydrodynamic loading over time. Although alternative aggregates and recycled materials were viewed positively for ecological performance, participants noted that changes to conventional concrete mixes could reduce compressive strength. Structural performance was therefore linked to long-term environmental exposure and changes occurring throughout the structure’s service life.

> “The most significant load cases to consider for artificial reefs are generally offshore lifting, and the 100-year storm condition..want these reefs to have a low centre of gravity, so that they're stable... a wide base.” - Structural Engineer

Site & Regulation Considerations

A consistent finding was that marine infrastructure performance is highly dependent on site-specific conditions. Participants emphasised the need for site investigation and environmental data, with wave conditions, water depth, sediment and seabed characteristics as important factors influencing placement and erosion management. Regulatory requirements further influenced where and how marine structures could be installed. Approvals depend on whether projects were located within state or Commonwealth waters and if they are classified as artificial reefs or coastal protection infrastructure. These findings demonstrate that both environmental conditions and regulatory frameworks have an influence over how marine structures are implemented across different locations

> "We want to build specific habitat for each site... [but] build habitat that is multi-purpose, scalable, productive." - Managing Director

> “There's quite a bit of permitting just to go and put it in the ocean.” - Operations Manager

TREE MAP - THEMATIC ANALYSIS



Figure 14: TreeMap diagram display most significant codes found in the thematic analysis categorised by frequency (see appendix 6 for full thematic analysis)

03

Discussion



Part 3

Discussion

Design Implications

Conclusion

DISCUSSION

Overall, the research identified how nature-inclusive coastal protection can move beyond simply adding habitat features to conventional infrastructure. The primary research reinforced market gaps found through the secondary research and benchmarking, while adding detail around how ecological, structural, practical and community considerations interact within coastal protection design.

Integrating Coastal Protection & Ecological Function

Across all the research, a consistent trade-off emerged between structural protection and ecological performance. Conventional armour systems performed well in durability, stability and erosion protection but generally offered limited habitat value, while habitat-focused systems often depended on existing infrastructure or provided less primary coastal protection. Interview participants added greater insight by explaining how structure height, volume, spacing and arrangement can influence wave behaviour while also creating sheltered areas for marine organisms. This extends the identified research gap by shifting the focus away from adding ecological features to existing armour forms and towards designing geometry and configuration so that both functions are considered together from the beginning.

Habitat & Ecological Performance

Habitat complexity emerged consistently across the secondary research and interviews, with physical variation in surface texture, shelter, elevation and environmental exposure associated with improved habitat potential (Queensland Government, 2018, Rocky Shore - Qld.Gov.Au, 2018). Primary research gave specificity to habitat design, suggesting that physical variation should be deliberately incorporated into the surface and form of the system. This provides clearer direction for translating natural habitat characteristics into design features capable of supporting colonisation and ecological diversity.

Practical & Structural Constraints

Interviews introduced practical considerations that were less prominent within the literature but critical to whether a nature-inclusive system can be realistically implemented. Weight, lifting, vessel requirements, manufacturing methods and installation costs were identified as major influences on deployment and scalability. Benchmarking reinforced these limitations, demonstrating that habitat complexity must remain compatible with structural reliability, manufacturability and efficient deployment for the system to remain viable at scale.



Images: BioReef by Indepth Innovations (Leslie, 2026)

Site Responsiveness & Adaptability

Site-specific performance was strongly supported across the research. Secondary research and interviews highlighted wave exposure, depth, currents, sediment and seabed conditions as environmental factors to consider when determining site suitability (Paxton et al., 2025). Survey respondents raised concerns around cyclone exposure, recreational use and ecological disturbance, with Moreton Bay was repeatedly identified as an area that could benefit from future intervention. This aligned with existing local coastal management initiatives, further supporting its relevance as a context for nature-inclusive infrastructure (City of Moreton Bay, 2026). Moderate public familiarity with coastal infrastructure also suggests an opportunity for future projects to involve coastal communities and support education around erosion, climate change and marine habitat conservation.

DESIGN IMPLICATIONS

Following the discussion of the research findings, eight opportunities emerged for the design of nature-inclusive coastal protection. These opportunities focus on integrating structural, ecological and practical requirements within one system, rather than treating coastal defence and habitat creation separately.

Multifunctional Geometry

Geometry should contribute simultaneously to wave attenuation and habitat creation, using form, spacing and arrangement to dissipate energy while generating sheltered areas for marine organisms. Ecological and protective performance can be developed through the same physical form.

High Habitat Complexity

The research consistently highlighted the importance of physical complexity for productive marine habitats, thus habitat complexity should be created through varied textures, crevices, cavities, ledges and sheltered spaces, using biomimetic principles to replicate the physical variation of natural rocky intertidal habitats.

Interlocking and Modularity

Repeatable units could connect, stack or overlap to create stable arrangements while generating ecological and protected spaces between modules. Different configurations could also vary habitat conditions without requiring multiple specialised products.

Form-Driven Structural Stability

Structural stability remains essential for long-term coastal performance, thus stability should be embedded into the form through necessary mass, wide bases, low centres of gravity and complementary interlocking geometries, to reduce movement underwater and current forces. This could reduce reliance on increasing unit weight.

Efficient Deployment

Integrated safe lifting points and simplified placement could reduce vessel time, diver involvement and underwater assembly. Hence, modules that are designed for direct crane placement with minimal secondary machinery would improve installation efficiency and support larger-scale implementation.

Site Adaptability

Configurations could respond to site-specific conditions including wave exposure, seabed type and surrounding ecology. Moreton Bay provides a relevant context for development due to its combination of intertidal habitats and developed coastlines. Future implementation could also involve coastal communities in education around erosion, climate change and marine habitat conservation.

Bioreceptive and Durable Materials

Unit materials could promote marine colonisation without compromising structural durability. Rough concrete surfaces and natural or recycled aggregates could improve bio-receptivity, provided required strength and long-term coastal performance are maintained.

Scalable Manufacturing

Precast production would provide a scalable foundation, while additive manufacturing (3D printing), could introduce complex ecological features through moulds, inserts or specialised habitat components. This hybrid approach could provide geometric freedom without while maintaining practical and economic considerations to manufacture at scale

CONCLUSION

Developed in response to a project brief provided by In-depth Innovations, this report demonstrates how eco-engineering principles can inform the design of coastal protection systems. Insights from the literature, benchmarking, survey and interviews identified that habitat complexity, geometry, structural stability and efficient deployment were key considerations for a nature inclusive protection infrastructure. Furthermore, Moreton Bay emerged as a strong context for future interventions by both literature and the public, alongside opportunities for more community engagement around ecological awareness.

The report findings demonstrate that habitat opportunity and coastal protection should be considered together, rather than as separate priorities. For designers, this creates an opportunity to reposition coastal infrastructure as a multifunctional system that protect shorelines while contributing habitat value for intertidal and submerged marine ecosystems. These findings provide a clear foundation for the development of a nature-inclusive coastal protection solution that responds directly to the project brief and identified research opportunities.



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APPENDICES

Appendix 1: Benchmarking Criteria

1. **EROSION PROTECTION + WAVE ATTENUATION**
   How effectively does the system mitigate coastal hazards and reduce wave energy/erosion?
2. **DURABILITY + STABILITY**
   How well does the system maintain structural and functional performance in the marine environment?
3. **ECOLOGICAL PERFORMANCE**
   How effectively does the system create and support marine habitat?
4. **MODULARITY + ADAPTABILITY**
   How easily can the system be configured, expanded, replaced or adapted to different coastal conditions?
5. **MANUFACTURABILITY**
   How effective can the system be manufactured at a required scale?
6. **INSTALLATION + DEPLOYMENT**
   How easily can the system be transported, deployed and integrated into coastal environments?
7. **ENVIRONMENTAL SUSTAINABILITY**
   Is the product environmentally responsible across its lifecycle?

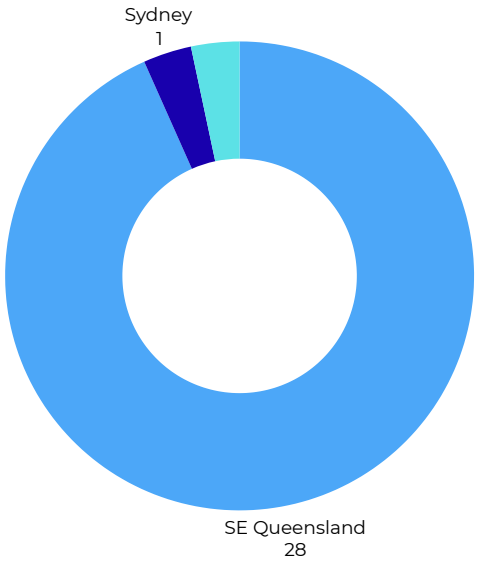
Criteria	1 — Poor	2 — Limited	3 — Moderate	4 — Strong	5 — Excellent
1. Erosion Protection + Wave	Provides little/no protection	Provides limited protection	Provides moderate protection	Provides strong protection	Provides highly effective protection
2. Durability + Stability	Easily degrades/moves	Limited durability or stability	Adequate durability/stability	High durability and stability	Highly durable and stable in harsh
3. Ecological / Habitat	Little/no habitat value	Limited habitat opportunities	Provides some habitat	Creates diverse habitat	Actively supports diverse and productive
4. Modularity + Adaptability	Fixed/non-adaptable	Limited configuration	Some configuration options	Easily reconfigured or expanded	Highly adaptable to different sites and changing conditions
5. Manufacturability	Difficult/impractical to manufacture	Requires specialised manufacturing	Manufacturable with some challenges	Easily manufactured at scale	Highly efficient and scalable manufacturing
6. Installation + Deployment	Very difficult to install	Difficult installation	Moderate installation requirements	Relatively easy to deploy	Simple, efficient and highly adaptable deployment
7. Environmental Sustainability	High environmental impact	Limited sustainability measures	Moderate environmental performance	Low environmental impact	Strong lifecycle sustainability and environmental benefits

Appendix 2: Survey Questions

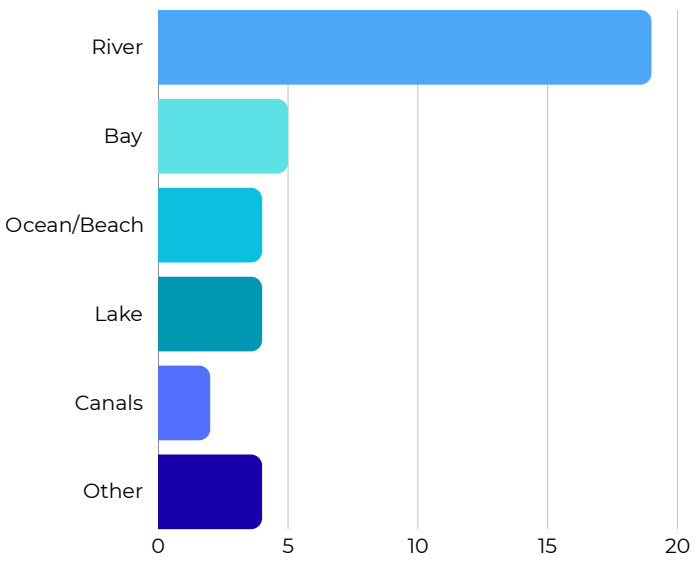
	Question	Answer Type
1	Do you live in SE Queensland, Sydney, or elsewhere in Australia?	Multiple choice (Checkbox, multi-select)
2	Do you live close to a body of water? If so, what type?	Multiple choice (Checkbox, multi-select)
3	Are you familiar with any coastal protection infrastructure near you?	Multiple choice (Checkbox, multi-select)
4	How familiar are you with coastal protection infrastructure, like the previously mentioned structures? 1 being no understanding, and 10 being strong understanding.	Likert scale
5	Explain your answer to the above question.	Short Answer
6	What do you think the primary purpose of coastal protection infrastructure is?	Multiple choice (Checkbox, multi-select)
7	Explain your answer to the above question.	Short Answer
8	In terms of preserving coastal areas, what is of most importance to you?	Multiple choice (Checkbox, multi-select)

	Question	Answer Type
	In recent years, coastal and aquatic environments have increasingly faced challenges such as rising water levels, erosion, lack of biodiversity, and habitat loss. In response to this, there is a growing interest in eco-engineered solutions such as artificial reefs and living sea walls. These initiatives aim to provide coastal protection while supporting biodiversity, helping preserve Australia's rich natural environment for years to come. The Living Seawalls is a design initiative created by Reef Design Labs, installed in Sydney. The system is composed of several interlocking hexagons that are installed on existing concrete infrastructure along Sydney's coastlines, with the intended goal of inviting marine life to repopulate the area, as well as algae and other habitat-forming organisms.	
9	Do you believe something similar to the Living Seawalls could be introduced in an area near you?	Yes/No
10	Explain what location you were thinking of, and how it could benefit from something similar to the Living Seawalls	Short Answer
	Another design initiative by Reef Design Labs is the EMU, a series of specialised wave break modules installed in the city of Greater Geelong. The modules were created to reduce the force of waves, help prevent erosion, and act as a habitat for colonising species. Additionally, they serve as a living art piece the public can explore.	
11	Do you believe something similar to the EMU modules could be introduced in an area near you?	Yes/No
12	Explain what location you were thinking of, and how it could benefit from something similar to the EMU Modules.	Short Answer
13	Is there an area of coastline in SE Queensland specifically that you believe could benefit from an installation like the Living Seawalls or the EMU modules?	Short Answer
14	Do you have any suggestions for helping preserve Australian coastlines and marine life?	Short Answer
15	To what extent do you think coastal animals and habitats should be considered when constructing new coastal infrastructure? 1 being no consideration, and 10 being a strong consideration.	Short Answer

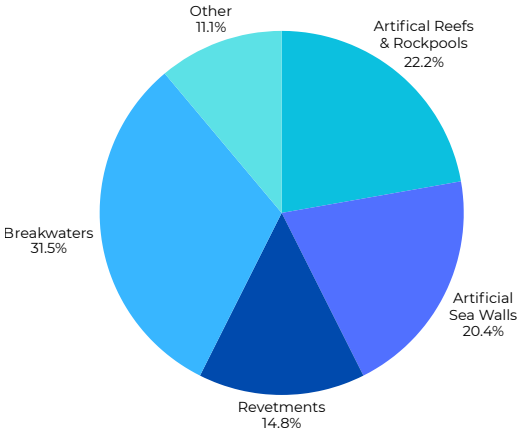
Appendix 3: Quantitative Survey Data



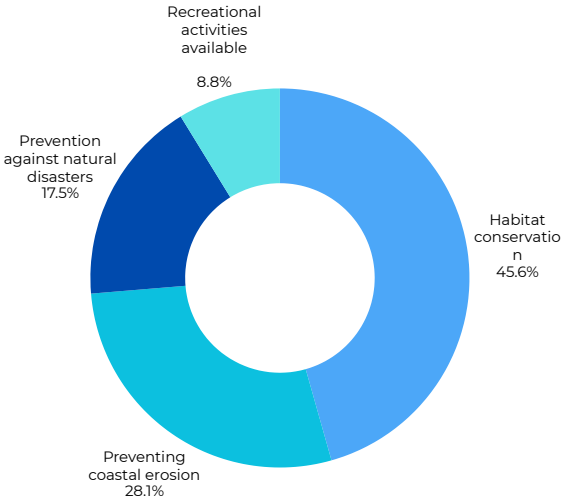
Q1: Do you live in SE Queensland, Sydney, or elsewhere in Australia?



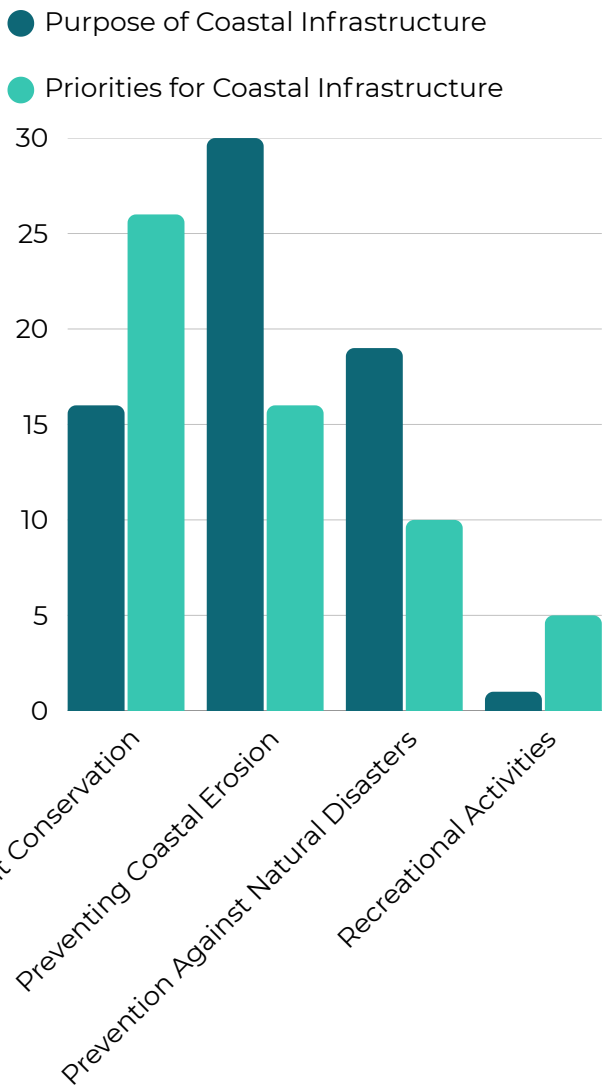
Q2: Do you live close to a body of water? If so, what type?



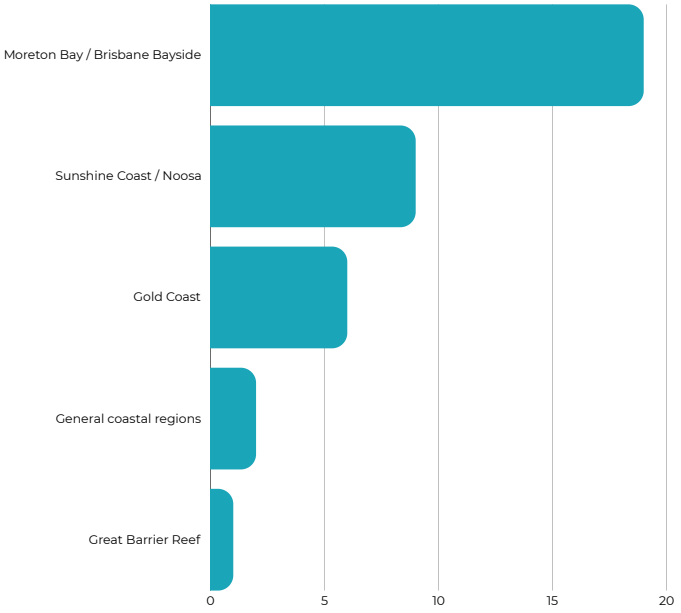
Q3: Are you familiar with any coastal protection infrastructure near you?



Q8:In terms of preserving coastal areas, what is of most importance to you



Comparison between priority and purpose identified by general public



Q13: Is there an area of coastline in SE Queensland specifically that you believe could benefit from an installation like the Living Seawalls or the EMU modules?



Thematic Analysis Break down

Appendix 4: Qualitative Thematic Analysis

Overarching Theme	Code / Idea	Mentions	Key Quote(s)
Community Knowledge & Engagement	Basic / general understanding	19	R8: "I have a basic conceptual understanding of what they do and how they work." R6: "I am familiar with the general purpose of structures such as seawalls, groynes and breakwaters, but I have limited knowledge of their design, construction and effectiveness in managing coastal erosion and hazards."
	Knowledge gaps & uncertainty	31	R6: "I am familiar with the general purpose of structures such as seawalls, groynes and breakwaters, but I have limited knowledge of their design, construction and effectiveness in managing coastal erosion and hazards." R15: "I understand that these things may prevent eroding of shore lines and some shell animals such as oysters find home on them. But other than that, my understanding is quite low."
	Formal, professional & policy exposure	7	R2: "I am familiar with these coastal protection infrastructure because I did 2nd year class called oceans coast and climate change at usyd. In this class, we looked at wave morphology and coastal erosion." R28: "Former marine biologist. Worked in oceanography departments"
	Personal / local observation	4	R23: "Knowledge only to the extent of observing as a tourist, vegetation planting and several rock structures at Coolangatta, Currumbin, and Main Beach Gold Coast Queensland." R9: "I'm pretty familiar with coastal protection because I grew up on a beachside town"
	Public education, awareness & responsibility	7	R18: "Better education, maybe if something like this is implemented, how can we make it attar give to the average population and have them know why it's important or what it does? how do they know where they are and why?" R2: "Investing into science and innovation like this. The more we understand systems the better they can be conserved."
Coastal Protection & Hazard Reduction	Erosion prevention / reduction	25	R15: "I do feel that its main purpose is to prevent erosion." R5: "I have answered yes as I think its a good idea, but probably not near where I live. But there are numerous opportunities for something like that on the Sunshine Coast where beach erosion has been a major issue for many communities"
	Shoreline / sand stability & protection	5	R23: "I have assumed that planting projects were designed to hold the soil/sand together to maintain stability during exceptional tidal/storm conditions. Similarly, the placement of boulders and rock breakwaters I have assumed were to reduce/influence sand migration particularly resulting from extreme weather events." R16: "Bullock Beach Caloundra. To protect beaches along Golden Beach and to minimise the break which has been made through the northern end of Bribie Island."
	Wave attenuation / impact	4	R2: "Hard to choose just one, but a lot of these structures, including artificial reefs, serve to buffer wave energy or impact."

	Flooding, storm surge & tidal hazards	9	R22: “The answer about the protection of the against flooding and natural disasters is Sewalls of predominantly become this little bit of a fight from what I understand against rising sea levels and intensifying storm climates, and they’re used to help stop like sand and banks eroding because we’ve stupidly built too close to the water in the first place, and then the other part is it does inherently make a habitat by itself that is similar if they’re done right to natural habitats so creates more habitats for a different kind of I would assume sometimes different than the species that used to be there if there wasn’t rock formation and wall formation their previously, so in that case, it could have a downside of changing the environment so I know that there’s positive and negative with all these things”
	People, assets & infrastructure protection	6	R6: “I think preventing coastal erosion is one of the most important issues to consider because it can contribute to displacement and mass migration. As a social worker, particularly in how the loss of homes, communities and livelihoods can affect people’s wellbeing” R4: “My interpretation is that it provides an effective means of protecting "assets and infrastructure". Unfortunately, it is typically hard engineered..”
Habitat & Biodiversity Enhancement	Habitat creation / enhancement	21	R19: “Well I think purpose built areas to provide shelter and reintroduce important ecosystems features could be done in local creeks I don’t see why not” R19: “Well I think a lot of it is to provide more habitat for eco systems whilst providing additional benefits in terms of protection”
	Marine life & biodiversity	25	R25: “I do not live in an area with waves. But in ocean environments where ocean life could use these as a home or protection would be incredibly beneficial” R1: “Obviously coastal protection involves physical protection from erosion and protecting infrastructure near the beach, and also coastal protection would involve artificial habitats to support marine life too”
	Colonisation, shelter & refuge	5	R4: “These could work at the base of Oliver's hill to create a marine sanctuary and a safe designated recreational area. There are already artificial reefs off the Frankston pier, but these are utilised by scuba divers and are too far off-shore for a safe family-friendly snorkel zone.” R27: “EMU modules could be introduced around the Cleveland and Moreton bay in general, as there exists a wide variety of colonising species, particularly corals.”
	Habitat restoration & conservation	11	R29: “Cease the development of human habitats in mangrove areas.” R25: “Reducing human impact, rehabilitating impacted areas, helping rebuild homes for animals”
Infrastructure & Location Opportunities	Existing hard infrastructure	9	R4: “We have an expanse of existing sea wall in Frankston, which could benefit from additional biodiversity.” R6: “Sandgate or Redcliff piers”
	Urban / developed waterfronts	5	R14: “Moreton bay - Wynnum/lota waterfront as it is a highly frequented area. The boat club waterfront could be ideal”
	Moreton Bay / sheltered waters	3	R27: “EMU modules could be introduced around the Cleveland and Moreton bay in general, as there exists a wide variety of colonising species, particularly corals.”

Site Suitability & Environmental Context	Aquatic, marine & freshwater settings	12	R28: “Live a fair way from coast. Near a river, but I'm not sure about habitat for centric freshwater creatures. Where I see the benefit of those for marine environment easily” R25: “I do not live in an area with waves. But in ocean environments where ocean life could use these as a home or protection would be incredibly beneficial”
	Existing ecological conditions	7	R15: “Same as stated previously. The whole area could use it. It’s not an overly wavy space though and you would want something that crabs and other creatures could inhabit when the tide is very far out.” R25: “I don’t think the living seawalls would be beneficial near me as the area I live in does not have much aquatic wildlife. However, I do believe these would be beneficial along coast lines that have been altered due to human impact.”
	Local physical conditions & exposure	6	R15: “Anywhere on the wynnum waterfront area could benefit. I have seen many animals dwelling in the area so offering more habitat opportunity could help support the life there. Areas such as the marina and mangrove spaces are in less need of this support as they already offer habitats, so places where the sea wall is bare would be best.” R5: “This is an interesting idea, but I think trickier in QLD. There are a LOT of sharks present in open waters as well as mangroves in many esturies. From a fishermans perspective, waves are required to create gutters and opportunities for fish to come into the shore (both to breed and to be caught!). While these installations may survive in Geelong, I am unsure of their viability in more cyclone prone Queensland.”
Human Use & Accessibility	Recreation & accessibility	3	R9: “I don’t think you can be introduced into my area because the body of water near me is a recreational sporting area. Where a lot of people tend to swim, kayak and jet ski” R4: “These could work at the base of Oliver's hill to create a marine sanctuary and a safe designated recreational area. There are already artificial reefs off the Frankston pier, but these are utilised by scuba divers and are too far off-shore for a safe family-friendly snorkel zone.”
	Human-use & recreational conflicts	4	R9: “I don’t think you can be introduced into my area because the body of water near me is a recreational sporting area. Where a lot of people tend to swim, kayak and jet ski” R5: “Stricter monitoring of 4WD use on beaches - too many permits granted and not enough police enforcement to prevent 'idiots' driving on sand dunes and inappropriately. Remove some commercial fishing operations from popular tourist areas to allow more opportunity for recreational fishing. In return, implement an annual QLD fishing licence - we are one of the few states that does not require this which suggest we place no value on our fish stocks. I believe the biggest way to get people interested, valuing and protective of something is to allow them to enjoy it, not to lock it away. But needs to be a balance - with access comes respect and responsibility.”
Environmental Responsibility & Nature-Based Management	Nature-based systems, restoration & planting	9	R11: “Through human removal of natural supports, it is critically important that either we replant water dwelling flora (mangroves) or find man made alternatives to allow for our water ways to stay clean, biodiverse and prevent any severe erosion.” R15: “Building around mangrove spaces and similar natural spaces and then building out from that. Support the natural ecosystems first.”

	Pollution, waste & runoff reduction	6	R14: “Active trash collection such as the Seabin” R17: “Reduce pollution”
	Reducing human impact & development	4	R25: “Reducing human impact, rehabilitating impacted areas, helping rebuild homes for animals” R29: “Cease the development of human habitats in mangrove areas.”
	Fisheries & marine protection management	3	R7: “Banning gill netting and tunnel netting completely, higher fisheries presence enforcing bag limits and closures.” R20: “not off the top of my head unfortunately, getting rid of shark nets, investing in mangroves are probably the two i’m best versed on”
	Ecological caution & unintended impacts	4	R22: “The answer about the protection of the against flooding and natural disasters is Sewalls of predominantly become this little bit of a fight from what I understand against rising sea levels and intensifying storm climates, and they’re used to help stop like sand and banks eroding because we’ve stupidly built too close to the water in the first place, and then the other part is it does inherently make a habitat by itself that is similar if they’re done right to natural habitats so creates more habitats for a different kind of I would assume sometimes different than the species that used to be there if there wasn’t rock formation and wall formation their previously, so in that case, it could have a downside of changing the environment so I know that there’s positive and negative with all these things” R26: “Make sure it doesn’t encroach on the existing wildlife”

Appendix 6: Interview Thematic Analysis

Themes	Count	Code	Sub-Code	Quote Example
Ecological Habitat Design	21	**Habitat Design and Biomimircy**	Biomimetic reference	"flat concrete surface is definitely not biomimicry — structures that mimic the natural environment where a lot of these organisms, these colonisers, would be, is where I'd be focusing my design around"
			Texture	"Definitely texture so they can attach — smooth surfaces have been proven not to be as effective, but texture and the actual structure of it, the complexity built into that structure"
			Natural habitat characteristics	"concept taken from diving, seeing where fish would sit on a structure — a lot of the time they're tucked under a ledge where the oncoming current is bringing food to them, they can ambush it, but they've also got protection from predators from above and behind..., they're looking for that protection"
			Assisted colonisation	We're doing it with our oyster restoration modules as well — basically seeding them with oyster larvae is one way of doing it. Seeding them with coral plugs, frags, is another way...""
			Ecosystem considerations	"If we can develop really optimised habitat at scale, that's going to future-proof the ocean—extra resilience... food security, coastal protection, it all ties in."
			Food-web succession	you need something that houses the small fish — the little invertebrates and baitfish that school up — and then large fish will come in to hunt those guys...focus in on one of the key attributes that will start the food chain — start more from the bottom and then build up."
			Managing unwanted growth	"Generally algae... will be one of the first things to actually colonise, and what it does is outcompete a lot of the other organisms that you want...generally we'd be trying to get other organisms colonising first and giving them a head start."
			Microhabitat complexity	"Complexity built into that structure — different angles, protection from waves and currents and sun"
			Purposeful habitat design	"On the seabed, when it's completely flat, it's not conducive to developing a fish habitat — whenever you put anything on the seabed, whether purposeful or unpurposeful, it creates a node, and fish are instantly attracted...But ideally, if you're going to create it artificially, you want to make it as purposeful as possible "
			Post-installation ecological management	"it's become a living organism...to end up with basically a piece of reef, and every time you rip that up you're just resetting a lot of things"
Deployment, Scalability and Cost	19	**Weight & Instalation Logistics**	Site-selection data	"I'll go out and do a drop-camera survey — underwater video — grab samples for density analysis, an ROV survey to see the seafloor, and a multibeam survey, so we get a full picture of what's actually down there...Met Ocean data — peak wave heights, peak velocity of current, depth of water, sediment type, how it'll be anchored"
			Weight	"...Mass or weight is really important for these artificial reefs — we want them to perform and sustain for the design life, so we really don't want structures too light"
			Lifting Points	"you've got to make sure the point you're picking up is nice and solid, with a safe working load — because if we pick it up and it falls off the hook, that's a big incident... grooves and holes and all that sort of stuff [shouln't matter] as long as there's a strong lifting point, it's fine."

Deployment, Scalability and Cost			Moving heavy modules	"We do build large modules — around 11 tonnes — which I consider extremely large. They take really big infrastructure to put in, they're expensive, and we still struggle to find a boat for them.That's about our upper limit on practicality "
			Boat instilation Logistics	"an installation method, we generally use a vessel with a crane...make it economical, you want to limit the amount of time on the water, because the boat is the most expensive thing in any operation"
			Tooling + Transport	"the truck, in this case, may drive to the site and get craned from the truck into position"
			Land-based assembly	"On land, at any stage. You're trying to eliminate the use of divers at any stage..."
Erosion–Habitat Balance	**18**	**Erosion–Habitat Consideratioans**	Interlocking Capabilities	"they're concrete blocks, and it's just the mechanism of linking and stacking them togethe...when they stack they have gaps between them, which create nice little hidey spots for fish to congregate"
			Multi-functional	"Sometimes there are artificial reefs that are purposely placed in position just to protect against erosion — they may have a dual function...aim for erosion management as your main driver, and have fish habitats and tourism as secondary drivers"
			Wave-energy reduction	"...in erosion management you want to disturb the wave — this wave energy is hitting the beach or the coastline and causing erosion, so you want to basically dissipate all that energy by using these concrete or steel structures on the seabed...by putting anything in the seabed, you're shortening the water depth — that causes the wave to then go into breaking condition...wave breaks, it dissipates its energy"
			Form + Water Flow	"Certain objects, such as sharp-edged rectangular shapes, disturb that wave pressure a lot, and generate vortexes and eddy currents behind it, so those shapes are high in drag loads and high inertia loads"
			Surface area	“More surface area does mean more habitat can grow. Cryptic habitat might increase growth speed, but if that limits how many you can get in, I’m not sure which wins out.”
			Specialised vs scalable	“We want to build specific habitat for each site… specialised habitat generally costs more, generally isn’t as scalable… [the balance is] habitat that is multi-purpose, scalable, productive.”
			Scour considerations	"look at how the scouring happens around the concrete blocks, and whether putting curves in them might help minimise it"
			Geometry	"Generally you want rounded structures — a vertical standing cylinder would be preferred, because those shapes are less likely to disturb the wave current as it passes over... you want them to be fully open structures, no enclosed air, rounded, with a low profile and a wide base."

Structural Durability	16	**Structural Performance & Stability**	Long-term performance	"Design life is basically a specific engineering term to say that they are guaranteed to last that 50 years—there's nothing to say they can't last longer. "
			Stability	"We want these reefs to have a low centre of gravity, so that they're stable… a wide base"
			Durability	"Durability too — it's well known that high strength marine concrete, around 40 to 50 MPa, is about right for the strength characteristics needed for that 30 to 50 year lifespan"
			Wave loading	“Tidal or ocean waves… are low frequency, so they carry a lot of energy… [and] can carry energy down to the seabed and affect these artificial structures.”
			100-year storm	“The most significant load cases to consider for artificial reefs are generally offshore lifting, and the 100-year storm condition.”
			Vessel wakes	“If these large tankers are causing wakes… they’re similar to ocean waves, and they can cause wave loading on your structure.”
			Base stability	"I wouldn't look to reduce weight around the lift points, or around the base, because we want these reefs to have a low centre of gravity, so that they're stable"
Site and Regulation Considerations	10	**Site-specific design**	Placement Optimisation	"You really want to get these waves to break early, before they come to the shore… you want to find the sweet spot"
			Customisation	"We want to build specific habitat for each site… [but] build habitat that is multi-purpose, scalable, productive."
			Site exposure conditions	"There's nothing easy about installation, because of the marine environment — that's the big factor"
Deployment, Scalability and Cost	9	**Manufacturing, Scalability and Cost**	Additive Manufacture Considerations	"3D printing gives you that ability to, on demand, create new structures and shapes and habitat, whereas traditionally with moulding, precasting … could be used to enhance current modules "
			3D Printing limitations	"3D printing is still expensive and not cost-effective at this stage…not it's going to be robust enough in that sort of environment …"

Deployment, Scalability and Cost			Scalable habitat customisation	"where you can build a really specialised habitat, that generally costs more, generally isn't as scalable — yes, it's effective, but it balances somewhere in between, where you can build habitat that is multi-purpose, scalable, productive"
			Cost	"start increasing your time to install your reef...it increases the time you need for your installation vessel, and that can drive your budget up"
			Funding	"going into the commercial industry and securing funding from large companies to really make a difference in the industry...they want to look after the community they impact...Getting big companies behind it is how we get real scale"
Ecological Habitat Design	7	**Material and Bio-enhancment**	Alternative aggregates	"Anything we can do to make them more bio-friendly, the faster the microorganisms are going to attach, the faster that ecosystem kicks off, and the more productive the reef i"
			Fast-setting concrete	"concrete mix needs to set fast, so we can produce them every single day — so our mix is designed to be fast-setting and extremely hard"
			Mixed concrete limitations	"general concrete is generally cement, sand, and stone aggregate... start incorporating anything outside of that, I think you do have a knock-on effect on strength...detrimental to the structure"
			Bioreceptive materials	"...natural substrate gives off a chemical signature in the water, which fish and crustaceans can actually sense... Anything that encourages growth and improves bioreceptivity, so we can get the ecosystem going.."
			Material durability	"Concrete structures generally have a life of 50 years due to their good protection against corrosion...they're very good in subsea environments"
Site and Regulation Considerations	7	**Regulation and Permit requirments**	Regulations	"So you've got to meet all the criteria — it also depends on where you're deploying. Normally in state waters we need to get state approvals — fisheries, and we have to lease the seafloor. ... Australian [Commonwealth] side, sea dumping regulation, under the Commonwealth. There's quite a bit of permitting just to go and put it in the ocean"
			Success measure + monitoring	"we're trialling and prototyping, monitoring it regularly and documenting successes and failures and everything in between."
			Artificial reef instalation limitations	" national artificial reef guideline that stipulates that any new reefs need to be more than a kilometre from an existing habitat...But in the case...building nature-based design into rock walls and ports and things like that is determined by the location of the actual infrastructure...dosent transfer "