Artificial Habitat Panels Best Management Practice

Description

In these guidelines, the term "artificial habitat panels" refers to the installation of specially designed panels that mimic natural habitats such as rockpools, crevices and overhangs on relatively flat seawalls and other marine infrastructures. These panels, like those developed by The Living Seawalls and Reef Design Lab (RDL) (Living Seawalls | REEF DESIGN LAB), aim to increase habitat complexity, thereby supporting marine and riverine biodiversity and improving ecosystem functions.

Artificial habitat panels are effective in areas where natural habitat complexity is low and can be used to mitigate the loss of habitat from the installation of some hard-engineered structures, such as seawalls. They can provide a basis for critically important habitats to establish (Bishop et al. 2022), resulting in the recruitment of other marine species, including shellfish, crabs and fish (Vozzo et al. 2021; Bone et al. 2024).

The installation of artificial habitat panels on other infrastructures (i.e. seawalls, pylons etc.) is relatively cost-effective compared to other marine habitat restoration techniques (Paxton et al. 2025). These panels are engineered for durability, with an intended lifespan of at least 20-years and may even continue to provide benefits for much longer as they become established habitats (Paxton et al. 2020; Vozzo et al. 2021). However, they can require regular monitoring and maintenance, especially in the first 6-months (Strain et al. 2018), to ensure long-term success. Panels should be monitored periodically to assess their condition, placement on the infrastructure and the biodiversity they support.

When implemented and maintained appropriately, artificial habitat panels can enhance marine and riverine biodiversity and ecosystem services over time, providing increasing benefits to these environments.

Case studies and examples

Successful artificial habitat panel projects often result from strong partnerships between government agencies, research institutions, and local communities. There are several examples from around the world, and within Australia, which demonstrate the effectiveness of these projects at promoting biodiversity. The below examples demonstrate the importance of thoughtful design, effective installation, and ongoing maintenance of habitat panels to achieve positive outcomes.

1) **Derbal Yerrigan, East Fremantle, Western Australia, Australia** (Figure 1): This Living Seawalls project along Derbal Yerrigan (Swan River) foreshore in East Fremantle was the first artificial habitat panel project to occur in Western Australia. This project involved the installation of panels that mimic "microhabitats" on seawalls and was intended to increase marine biodiversity and abundance when compared to a blank seawall across the sites. The chosen panels, flat (the control), honeycomb, swim-through, ridges and rockpool formations, provide habitats for

various marine species, including filter feeding species, such as mussels and scallops, to promote better water quality.

Figure 1: Swan River, East Fremantle Living Seawalls project.

2) **Sydney Harbour, New South Wales, Australia**: This project in Sydney Harbour is the flagship initiative for the Living Seawalls projects conceptualised and funded by the Sydney Institute of Marine Science. An increase of species coverage was found, up to 36% compared to plain seawalls, with 115 different colonising species found over the first two years of the project when compared to natural rocky reefs. All habitat tile designs in the Living Seawalls module types were used here (Living Seawalls Products — Living Seawalls).

3) **Boston Harbour, USA**: This pilot project from The Stone Living Lab at the University of Massachusetts aimed to increase marine life along barren seawalls in Boston Harbour. 240 habitat panels were installed in late 2024, with monthly surveys conducted over the first year of installation to monitor the panels for growth and assess their ecological impact Stone Living Lab.

4) **Lavendar Bay, New South Wales, Australia**: The Living Seawalls project expanded to Lavendar Bay, where habitat modules known as "Living Boulders" (Figure 2) were integrated into existing revetments and breakwaters that had limited habitat complexity. These modules were designed to enhance local biodiversity by providing habitat that mimics natural rock formations, demonstrating an alternative to the panel design Reef Design Lab - Living Boulders.

5) **Port of San Francisco, America**: The Port of Francisco is currently piloting the implemented of textured tiles to promote biodiversity. Installed in 2022, the first set of preliminary results have shown that the textured surfaces do promote biodiversity and support native species, with the reintroduction of many oyster and seaweed species occurring along the three port locations Living Seawall Pilot | SF Port.

6) **Lake Macquarie, New South Wales, Australia**: In collaboration with Lake Macquarie City Council, this project used cobble stones of various sizes to stabilise

and protect coastal lake shorelines. This “soft” engineering approached aimed to enhance biodiversity while protecting the shoreline from erosion, demonstrating that using natural materials can effectively support marine life and improve ecosystem functions Walpole et al., 2009.

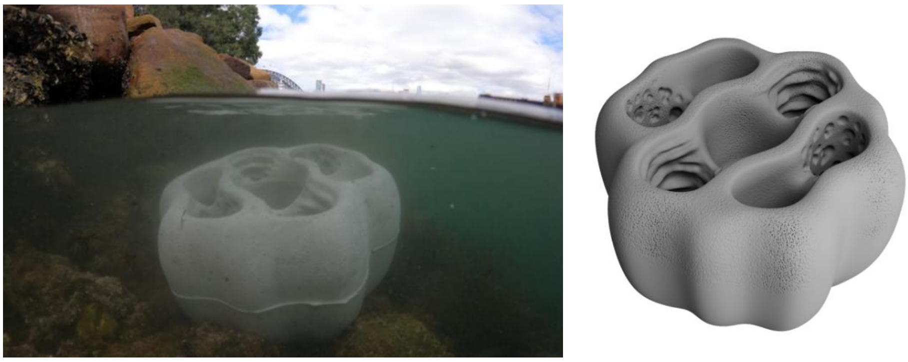

Figure 2: Living boulders. A) Underwater photo of the living boulders in Lavendar Bay, Credit: Aria Lee. B) Schematic of the living boulder design, Credit: Living Seawalls.

Purpose and application

The primary purpose of artificial habitat panels is to increase biodiversity and improve habitat quality in areas where hard-engineered infrastructure has replaced the natural environment. These panels can be installed on seawalls and other marine or riverine structures, such as pylons, piers and docks.

There are four specific ways that artificial habitat panels can benefit marine and riverine environments:

1) **Habitat complexity**. Habitat panels provide a variety of microhabitats that support different marine and riverine species, helping to offset the loss of natural habitats due to urban development.

2) **Biodiversity enhancement**. Increased habitat complexity leads to higher biodiversity and abundance of aquatic species.

3) **Ecosystem services**. Habitat panels can potentially reduce wave impact to shorelines and, by promoting the settlement of filter feeding species, can improve water quality.

4) **Community engagement**. Projects often involve local communities, raising awareness and fostering stewardship of aquatic environments as well as opportunities for citizen science.

Conditions where practice applies

Artificial habitat panels can be used in variety of aquatic settings, however, environmental factors (exposure, wave energy, temperature, etc.) need to be considered when implementing these practices. Additionally, the potential for biofouling, the durability of materials used, and the need for regular monitoring and maintenance need to be considered. Panels should be designed to withstand local environmental conditions and provide long-term benefits to aquatic ecosystems.

Artificial habitat panels can be used in marine and riverine environments where enhancing biodiversity and ecosystem functions is the desired outcome. In particular, they are most effective in locations that have low natural habitat complexity or in areas where urban development has removed habitats along foreshores. They are ideal for installation on seawalls, breakwaters, and other aquatic structures where natural habitats are scarce.

These panels are designed to withstand high-energy environments, such as areas with strong wave action, tidal currents or frequent boat traffic (Salauddin et al. 2021). These conditions often pose significant challenges to aquatic species, as natural habitats can be eroded or damaged by constant movement and force of water. Designs of these habitat panels contribute to wave attenuation by breaking up wave energy and protecting shorelines from erosion. This dual function of promoting biodiversity and reducing the risk of erosion makes them particularly valuable in high-energy environments where wave actions are a significant concern.

In Derbal Yerrigan, the success of habitat development and species settlement onto the panels is dependent on the depth of the seawall and the amount of time the panels spend out of the water during low tide periods. During the pilot trial in East Fremantle (Figure 3), it was found that panels that were placed higher on the seawalls were less effective at promoting biodiversity than those placed lower on the seawall structure. Similarly, panels that were higher, were often exposed for longer periods, drying the material out. During summer months, panels that can retain water (i.e. rockpool formations), would be most applicable in Derbal Yerrigan environment, as their capacity to hold water provides refuge to species and continues to allow growth of benthic habitat.

Figure 3: Map showing the locations of the Living Seawalls panels at the three sites in East Fremantle. Site 1: Left hand side of the parking area on Riverside Drive, Site 2: After Dome Café on Riverside Drive; and Site 3: Next to the Marine Operations Centre on Riverside Drive.

Complexities and sensitivities

The design and installation of artificial habitat panels involve several complexities and sensitivities that must be considered to ensure their effectiveness and sustainability. By considering the below factors, practitioners can design and implement artificial habitat panels that enhance biodiversity whilst minimising potential negative impacts.

Factors affecting complexity include:

- **Wave and tidal action**: High-energy environments with strong wave action or fetch require robust panel design that can withstand these forces. Panels must be securely attached to prevent dislodgement and ensure long-term stability. This includes, using the triangle-style attachment (see Design Guidelines), marine-grade, heavy duty bolts and screws and being as flushed to the seawall or infrastructure as possible (see Design Guidelines).

- **Material selection**: To promote biodiversity, the panel's material should incorporate an eco-blend concrete, formulated with supplementary or recycled materials (e.g. fly ash, crushed glass or oyster shell) to reduce environmental impact and provide a textured surface that supports the settlement of benthic species. Eco-blend mixes can include up to 5% wood ash replacing cement, 20-50% recycled aggregates and silica fume around 32-34% (Rupasinghe et al.; Gerges et al. 2022), while Reef Design Lab uses low energy concrete blended with recycled oyster shell for marine habitat structures. The texture and complexity of the panel surface should mimic natural habitats to encourage colonisation of aquatic organisms. Marine-grade stainless steel (e.g. SS 316) should be used for fixings to increase durability and corrosion resistance when attaching the panels to the seawalls.

- **Installation techniques**: Proper installation methods are crucial to ensure the panels are securely attached and positioned to maximise their ecological benefits (see Design Guidelines).

Some sensitivities in design include:

- **Species interaction and invasive species**: Artificial habitat panels have the potential to attract species which may outcompete or predate on native species. Monitoring and adaptive management plans are essential to mitigate these impacts.

- **Climate change**: The panels should be designed to accommodate changes in sea level and increased storm intensity due to changes in climate. This may involve adjusting the height and positioning of the panels, so they are not exposed for long periods (see Design Guidelines). Additionally, changes in water temperature can affect the species that colonise the panels. Panel designs should take this into consideration and provide microhabitats that offer thermal refuge.

- **Human interactions**: Panels that are installed in areas with high human traffic may be at risk of accidental damage or vandalism. Protective measures such as signage may help to mitigate this risk. Public engagement through the installation and monitoring process may assist with reducing accidental damage and increase awareness of the projects.

Design guidelines

A comprehensive plan is essential for any artificial habitat panel project. The plan should outline objectives, design specifications, installation methodology, timing, monitoring procedures and maintenance plans. During the design phase, careful consideration should be given to the panel design and placement. These notes mostly relate to panels designed by The Reef Design Lab as part of The Living Seawalls initiative and for panels that are placed along seawall infrastructures in Derbal Yerrigan.

Loading

Loading on artificial habitat panels is produced by waves and tidal currents in Derbal Yerrigan, resulting in pressure on the attachment structures.

Environmental conditions

The capacity of artificial habitat panels to withstand erosive forces from waves and tidal currents in Derbal Yerrigan is determined largely by their design and the materials used.

In the exposed areas of Derbal Yerrigan, waves are generally wind generated, particularly in areas with a large south-west fetch (Damara 2007). However, there are many areas of the river where boat wake is the more significant than local wind waves.

Water levels to consider include tides, storm surges and river flood levels (Damara 2007). For artificial habitat panels projects in Derbal Yerrigan, design guidelines should account for site-specific hydrodynamic forcings, including wave exposure, boat wake, tidal range and potential extreme events to ensure structural stability and ecological functionality.

The lifespan of the river wall will also need to be considered.

Considerations for detailed design

The detailed design for artificial habitat panels is relatively straightforward, provided the structural design loadings, site-specific environmental conditions and ecological objectives have been considered. A multidisciplinary approach involving marine ecologists, engineers and site managers is recommended.

- **Site planning and mapping:** A site plan should be developed using either aerial imagery, on-ground observations, GIS or other mapping software. The plan should include the location and extent of the panel installation, substrate type and complexity (i.e. rockpool formations, swim-throughs etc.), tidal range and wave exposure, existing marine life and adjacent habitats, access points for installation, monitoring and maintenance. If required, different zones for different panel designs can be marked to reflect where placement will occur.

- **Work Schedule:** A detailed work schedule should be included specifying appropriate installation times (preferably during low tide and calm weather conditions to allow the marine-grade epoxy to set). This should also include pre-installation site preparation (i.e. drilling and cleaning holes where panels will be attached and epoxy set), and post-installation monitoring and maintenance (see Monitoring and Maintenance).

- **Site preparation:** The site should have been scoped, with the seawall or substrate checked for structural integrity. Biofouling or loose debris should be removed from the structure before applying the epoxy (this will limit risk of the panels detaching). Wave energy should be assessed to inform whether the panels will need 3 or 4 marine grade rods for installation to the structure. Benthic assessments should be taken to make sure that any species already growing on the structures are not negatively impacted. If removal of some species is required, this should be assessed with a breakdown of the pros and cons.

- **Anchoring and installation:** Panels should be attached using marine-grade stainless steel M16 threaded rods, nylon nuts and washers (see Materials and Equipment). For areas with high wave energy 4 rods should be used in all anchoring points, in low – medium wave environments a triangle anchoring system can be used (see Materials and Equipment). Panels should be attached at times where low tides will be expected for at least two days to allow to appropriate amount of curing time for the epoxy to set (this will be based on the epoxy manufacturing specifications).

- **Panel design and placement:** Panel designs should be selected based on 1) the ecological goal of the project; 2) the hydrodynamic exposure to the site; and 3) the depth, orientation and light availability the panels will be exposed to. In intertidal systems, like Derbal Yerrigan, the panel designs should incorporate a "rockpool" formation (Figure 4a), as this design is able to retain water in the pools during the low tides. Areas in high wave impact areas will need greater anchoring system to ensure stability (Figure 3). For Derbal Yerrigan, if panels are placed westward facing, consider designs that retain water, especially in summer months as often the high temperatures coupled with low tides will dry-out the panels. Panels can be placed modular or scalable to accommodate future expansion or sea level rise. The height of the structure in relation to tide height should be taken into account when deciding placement of the panels.

- **Ecological considerations:** Artificial habitat panels are designed to allow the settlement of macroalgae and sessile organisms, creating an environment for other species, such as invertebrates, filter feeding species to settle and fish to take up possible residence. Targeting native marine assemblages is key and can be done using reference points from natural rocky shorelines or nearby reefs to guide the panel design and placement.

- **Protection from damage:** Panels may require protection from damage including boat traffic, mooring activities, vandalism, and sediment abrasion. Clear signage and community engagement are essential to raise awareness and should be easily accessible to inform and involve the public.

- **Monitoring and maintenance** — A monitoring and maintenance plan should be integrated into the design phase (see Monitoring and Maintenance). A cost breakdown has been provided (see Costs), however a budget allocation should include structural inspections, ecological surveys and panel replacements or upgrades.

Design life/expected lifetime

Artificial habitat panels have an intended lifespan of at least 20 years. Due to being a relatively new technology, few projects have reached that intended lifespan, however, with the correct application and installation, ongoing monitoring and maintenance, artificial habitat panels can offer a long-term option for improving habitat coverage on seawalls. Life cycles and recruitment of benthic species, invertebrates and fish onto or near the panels will vary with seasonal changes and tide heights. Therefore, location and placement of the panels on the seawall or other infrastructure, is a vital component to enhance the longevity of these applications.

Materials and equipment

The following materials and equipment are required for artificial habitat panel projects.

- **Habitat panels**: Available in a variety of designs, shapes and sizes that can be 3D printed using moulds. Designs previously used in Derbal Yerrigan area are from The Reef Design Lab and can be printed on the east coast of Australia and shipped or moulds sent to WA to be produced using local materials. Panels from RDL are 553mm x 525mm x <100m (Figure 4) and weigh between 23kg – 30kg per panel. All designs can be cast into larger prefabricated modules. If using the Living Seawall panels, there are currently 10 designs (Appendix 1), however, the most suitable for Derbal Yerrigan area has found to be the Rockpool and Swim-through formations (Figure 5). Different designs offer unique benefits for various aquatic organisms, and when combined, they can create a more complex habitat that supports a diverse and resilient community structure.

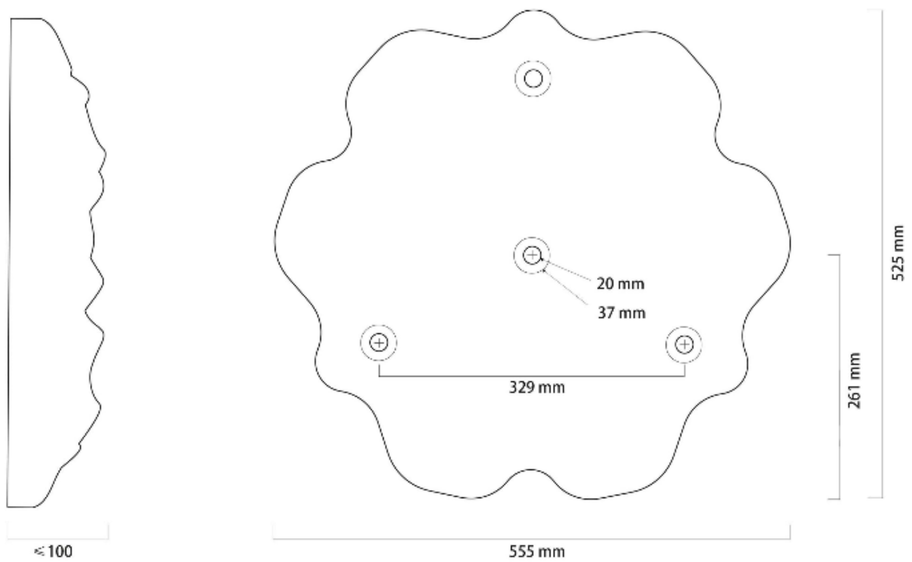

Figure 4: Dimensions for RDL Living Seawall habitat panels

A B

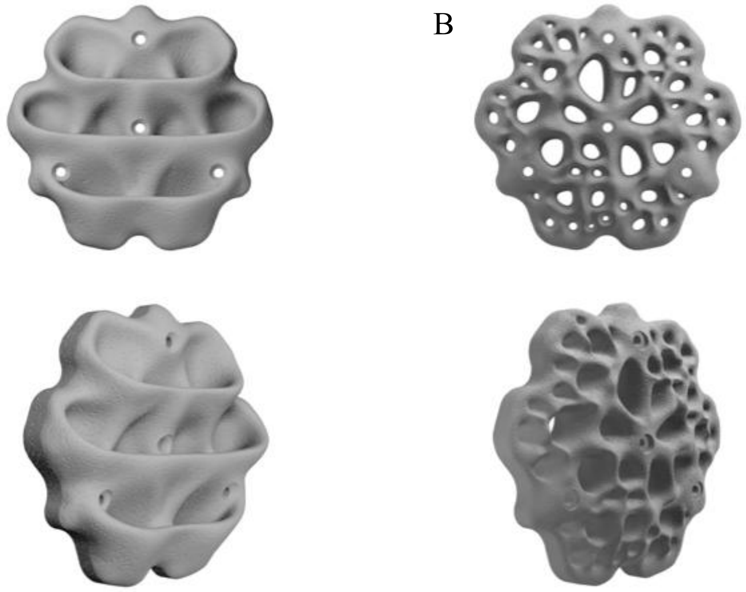

Figure 5: Examples of RDL Living Seawall habitat panels. A) Rockpool formation; B) Swim-through formation.

- **Anchoring system**: M16 SS 316 Threaded rods, M16 SS 316 Nyloc nuts, M16 SS 316 Nuts and M16 36mm SS 316 Washers. It is recommended that panels be attached using either the triangle anchoring system or all four rods depending on wave energy in the installation area (Figure 6). **N.B.** M refers to metric thread and SS refers to Stainless Steel.

- **Epoxy**: Marine-grade chemical epoxy anchor to fix the mounting rods into the seawall. Recommendation is to use Hilti Hit Re 500 Mortar.

- **Dispenser**: For ease of application of epoxy.

- **Drill**: For making holes in the seawall. Recommended to use a hammer drill or core drill with a M18 Masonry Drill bit.

Construction/installation

Site preparation should be planned and undertaken in advance of any construction or installation of artificial habitat panels. Site preparation may involve, testing the stability of the seawall (or intended infrastructure if not newly installed), assessing if there are any benthic species already established on the seawall (or intended infrastructure if not newly installed) and determining the best placement and spacing strategies.

In the East Fremantle study, the Reef Design Lab was used to fabricate the units as they work directly with the Living Seawalls initiative, however, there are various eco-engineering companies that can also be used to 3D print moulds of various artificial habitat panel designs. Most of the time, panels can be designed and printed in house, or moulds of desired designs can be sent direct to the area for construction of panels to be done using local materials.

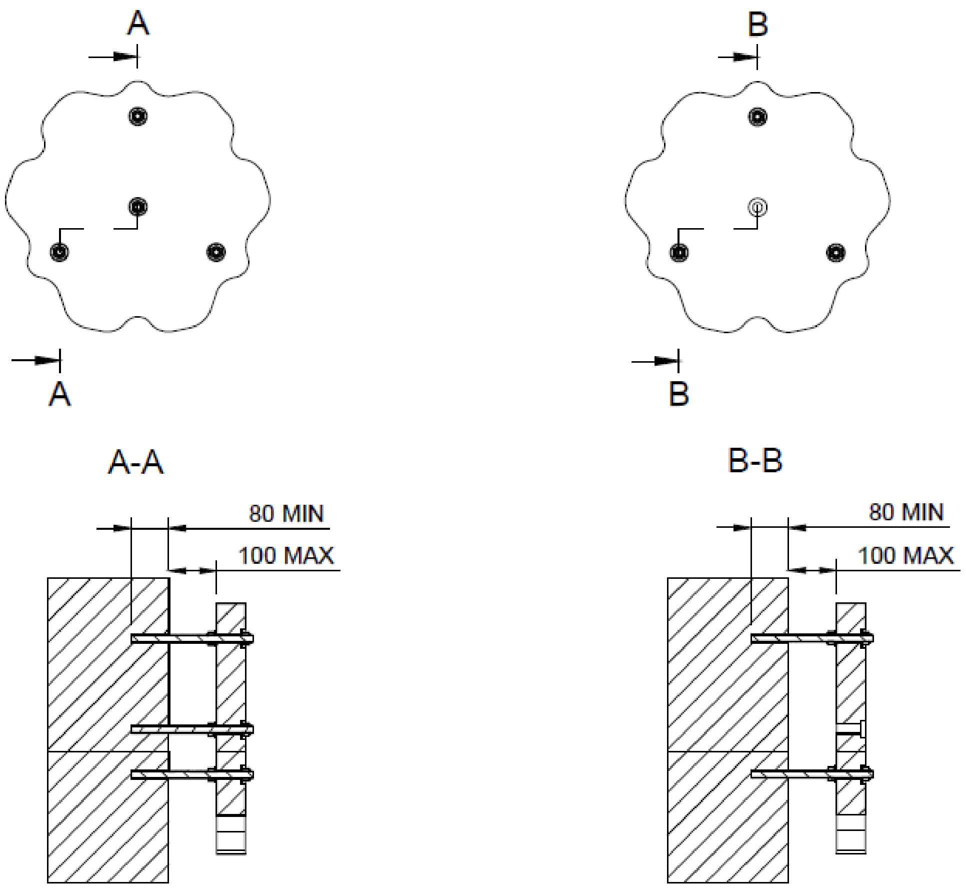

Figure 6: A) Installation of the habitat panels using all four installation points. B) Installation of the habitat panels using the triangle formation, with the top and outside installation points used.

Living Seawalls habitat panels are attached to the walls using M16 SS 316 threaded rods. There are four connection points per panel; the recommended number will depend on the wave energy at the installation site. It is recommended for Derbal Yerrigan, three rods in a triangle formation or four rods in all points be used. There should be a minimum of 80mm of threaded rod drilled into the seawall.

When attaching the panels to the rods and setting, it is advised to keep them as close to the seawall as possible. There should be no more than 100mm gap between the back of the panel and the seawall when attaching the panels to the rods. This will reduce the risk of the panels becoming loose and falling off due to wave impacts. If on a new seawall, panels can be placed closer to the seawall, at a minimum distance of 80 mm. **N.B.** If pre-existing benthic species are occurring on the intended seawall where the panels are being placed, place the panels at a greater distance than 80 mm.

For retrofitting panels in intertidal locations, such as parts of Derbal Yerrigan, it is recommended that work is completed during low tide times. This will allow adequate curing time for the epoxy to occur. As mentioned, three – four attachment points are recommended for this system. Drill holes need to be properly cleaned before epoxying the rods into the wall, and it is advised that rods be allowed to cure in dry conditions for the required time before placing the panels onto the rods.

For new seawall constructions, mounting rods or frames with artificial habitat panels can be integrated into the construction. The panels can be attached flush to the walls using epoxy, set to cure, and depending on the wave energy of the area, fewer rod attachment points per panel can be used.

For Derbal Yerrigan, placement of the panels should occur as low on a seawall as possible. Due to the system being intertidal, low tides result in shallow areas being exposed for long periods of time. Growth on the panels will be dependent on time in and out of water, direction the panels are facing (i.e. into the sun or in shaded areas) and height above the tide. Panels can be placed interlocking to each other or spaced apart, growth onto the panels is not dependent on this factor. It is recommended to consult with the Living Seawalls team before installation.

Experienced contractors with specialised equipment and training may be required for installation of the panels.

Failure mechanisms

Common reasons for failure of artificial habitat panels works include instability in the installation of the panels to the seawall, not allowing adequate curing time for the epoxy and panel design has not been constructed in line with the system they are being installed i.e. placed too high in a low tidal system. Common reasons for fluctuations in species growth on the panels includes orientation of the panels into direct sunlight for prolonged periods, panels being out of the water for longer periods than they are submerged.

These factors have been discussed throughout this document and should be considered during design, implementation and monitoring.

Monitoring and maintenance

Regular monitoring and maintenance are essential for the success and longevity of artificial habitat panel installations. These activities help assess ecology outcomes, ensure structural integrity and guide adaptation management.

Monitoring

Monitoring should be aligned with the project's ecological and engineering objectives. A monitoring plan should be developed prior to the project starting and could include:

Ecological surveys: These can include various survey techniques including:

- **Benthic habitat surveys**: Assessing colonisation rates of algae, invertebrates and fish species. Techniques for measuring should include quadrat sampling, where species richness, abundance and diversity are collected and analysed.

- **Photo point monitoring**: Using fixed locations on the panel and seawalls for consistent visual documentation of how growth is changing over time.

- **Underwater photography and videography**: Placing underwater cameras near the vicinity of the panels to observe fish interactions.

- **Species-species surveys**: These panel designs give the opportunity for filter feeders and seahorse species to settle. Monitoring of the panels should include demographic measurements of invertebrates that are found. For example, to measure filter feeding species, such as mussels, the shell length from the hinge to the highest point should be measured, and for seahorses measuring the length of their bodies from base of tail to head.

Structural and environmental monitoring: These processes are solely focused on the structural integrity of the panels and other environmental parameters outside of the biodiversity surveys:

- **Panel integrity checks**: These checks should be done weekly or fortnight within the first one-two months to ensure the epoxy as set properly. After this point, monthly checks for the next 6-months will show any signs of early corrosion, dislodgment and damage to the panels. Once established, yearly checks will suffice.

- **Temperature and water quality monitoring**: This monitoring component is not essential but will provide data that assist in species growth and abundance onto the panels, especially in areas prone to heat stresses.

Maintenance

Maintenance should be factored into both the initial and ongoing budgets for the design life of the project. Key activities include:

- **Structural maintenance**: Replacement or reattachment of damaged or missing panels. Inspections and tightening of anchoring systems and reapplication of marine-grade epoxy if signs of degradation are observed.

- **Ecological maintenance**: Removal of invasive species or excessive biofouling if it impedes native colonisation.

All monitoring and maintenance activities should be recorded with dates, observations and measurements, photographic records and actions taken and material used logged. Further documentation and monitoring procedures can be found in the appendices and from the Sydney Institute of Marine Science Living Seawalls protocols.

Cost

Cost estimates are based on 2025 prices. This includes habitat panels sourced directly from The Reef Design Lab (eastern Australia) and other materials from various Western Australian suppliers (Table 1). These figures should be used as estimates only and quotes from suppliers should be obtained when producing final budgets. These cost estimates assume a 30m stretch of seawall with 50 panels in this space.

Note that many of the products below may be discounted if buying in bulk. This cost breakdown only covers materials and equipment. Labour, permits, and other contingencies would need to be considered on a case-by-case basis.

It is recommended that budgets include maintenance and monitoring costs, with funding requirements determined on a site-by-site basis.

Table 1: Costs estimates for key elements to implement artificial habitat panels.

Item	Quantity	Approx. unit cost (as of 2025)	Approx. total cost (as of 2025)
Artificial habitat panels (The Reef Design Lab)	50	$100	$5000
Transport of panels from Eastern Australia	Flat transport rate	$1200	$1200
Threaded rods - M16 SS 316	200 (up to 4 per panel)	$20 – $40	$4000 - $8000
Nyloc nuts -M16 SS 316	200	$1.50 - $3.50	$300 - $700
Nuts -M16 SS 316	200	$1 - $3	$200 - $600
Washers -M16 36mm SS 316	200	$0.75 - $1.25	$150 - $250
Epoxy - Hilti HIT RE 500	100 cartridges	$50 - $70	$5000 - $7000
Epoxy dispenser	1	$200	$200
Hammer/core drill	1	$300	$300

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Appendix

Living Seawalls habitat panels brochure