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Kia mau te moana: a review of artificial aquatic habitats in Aotearoa New Zealand

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Kia mau te moana: a review of artificial aquatic habitats in Aotearoa New Zealand

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Executive summary

In the face of ongoing habitat degradation and biodiversity loss across the aquatic domains of Aotearoa New Zealand, the deployment of artificial aquatic habitats (AAH) has emerged as an increasingly popular tool for restoration. However, despite the widespread use of AAHs across Aotearoa New Zealand, little work has been done to evaluate their current ecological value, particularly their capacity to restore indigenous biodiversity, deliver nature-based solutions and support ecosystem services at a national scale.

Report scope

This report provides the first national assessment of purposeful and incidental AAHs in Aotearoa New Zealand, focusing on those AAHs that support ecological communities and restoration. It examines how AAHs are currently defined, implemented and understood across freshwater and marine systems. Next, it brings together insights from a horizon-scan survey of practitioners and experts, a comprehensive review of Aotearoa New Zealand–focused literature and project documentation, and relevant international examples. Finally, the report evaluates the ecological roles and impacts of AAHs, compares their use and design across systems, and explores the costs and benefits associated with their implementation. Furthermore, it identifies priority knowledge gaps and considerations to guide future research, planning and management of AAHs in Aotearoa New Zealand.

Horizon-scan survey and literature review

Our evaluation of AAHs was primarily underpinned from information obtained through two key approaches:

- **Horizon-scan survey:** This was conducted with 16 subject matter experts (freshwater and marine) representing regional councils, public research organisations, universities, community groups and consultancies from Aotearoa New Zealand. Its aim was to gather insight into definitions, guidelines, preferences, national and local resources, concerns and perceived challenges relating to AAH implementation and management.
- **Systematic literature review:** This involved a comprehensive screening of the literature on AAHs in Aotearoa New Zealand based on an a priori list of search terms generated to cover structures deployed as purposeful habitat (e.g. large woody material, artificial habitats, artificial reefs) and infrastructure that functions as incidental habitat (e.g. breakwaters, jetties, revetments, shipwrecks). The review was complemented by grey literature and resources made available by subject matter experts involved in the survey.

We identified and reviewed a range of literature, including peer-reviewed articles, books, conference proceedings, grey literature (e.g. technical reports) and popular / public-facing media. This systematic review and subject matter survey resulted in a final dataset of 120 relevant publications spanning from 1945 to 2025, with the majority published after 2000. Most articles (76.7%) were about AAHs in marine systems, with just 23.3% from freshwater systems. The majority of articles from both systems reviewed AAHs as habitats, with a significant portion relating to the use of AAHs in a restorative context (68% of all freshwater articles, 34% of all marine articles). From this information, we generated a map to demonstrate the distribution of shipwrecks and purposeful AAHs around Aotearoa New Zealand. This revealed a larger concentration of AAHs around the North Island / Te Ika-a-Māui compared with the South

Island / Te Waipounamu, where most were concentrated in the Top of the South region / Te Tauihu o Te-Waka-a-Māui.

Evaluation of AAHs in Aotearoa New Zealand

Our evaluation suggests that AAH impacts on habitats, biodiversity and the physical environment in Aotearoa New Zealand were largely consistent with examples from the global literature. For example, AAHs in Aotearoa New Zealand reliably attract and support a range of native and non-indigenous fauna, including birds, algae, invertebrates and fish, much like AAHs globally. Across contexts, the information shows that AAHs can enhance habitat availability, biodiversity and local physical processes (hydrodynamics and sediment transport), with the strongest ecological gains reported where complex habitats have been lost. However, performance is often assessed without natural reference comparisons and long-term monitoring, and the Aotearoa New Zealand literature remains sparse for whole ecological community responses. Taken together, the evidence indicates that AAHs are best treated as complementary tools within broader restoration strategies – i.e. most effective when goal driven, site specific and monitored over time, and not substitutes for intact natural habitats.

Our evaluation further revealed a distinct divergence in the application and material composition of AAHs in freshwater and marine systems:

- **Freshwater:** Freshwater AAH interventions were predominantly small in scale and used natural materials such as wood, debris clusters, rock mounds and hay bales. These projects were primarily driven by restoration and rehabilitation objectives, specifically aiming to enhance habitat for native species such as īnanga / whitebait, freshwater koura / crayfish, giant kōkopu, kanakana / lampreys and tuna / eels.
- **Marine:** Marine AAHs were typically larger in scale than those in freshwater systems and composed of more durable materials, including boulder mounds, concrete and steel. While there is growing interest in leveraging AAHs to support native habitat-forming species (e.g. hururoa / horse mussels, kūtai / green-lipped mussels), the primary drivers behind their adoption to date have been recreational amenities (e.g. artificial surf breaks, dive sites) and fisheries enhancement, or they have resulted from coastal engineering.

Costs vs benefits of AAH implementation

AAHs can deliver ecological, cultural, social and economic value, but only when full life cycle costs are recognised and funded. True costs extend far beyond the 'sticker price' of modules or shipwrecks, and include planning and consenting, te Tiriti o Waitangi–grounded partnership and co-design with mana whenua, site surveys and engineering design, material acquisition and preparation (including decontamination for repurposed vessels), deployment logistics, and long-term funding for monitoring, maintenance, risk management and end-of-life remediation. Case studies in Aotearoa New Zealand and overseas show that acquisition or fabrication is often only a fraction of the total upfront investment, and that underestimating complexity has contributed to project failures (e.g. surf reefs). Benefits can be substantial (e.g. some tourism, recreational fisheries, biodiversity gains where complex habitats have been lost) and early projects in Aotearoa New Zealand report promising faunal colonisation and biodiversity responses. Yet the ecological and habitat-restoration benefits remain comparatively underevaluated in Aotearoa New Zealand, reinforcing the need for clear objectives, natural reference comparisons, robust baselines and long-term adaptive monitoring. In short, this review recommends that AAHs should be pursued when they are goal driven, site appropriate and supported by dedicated long-term funding; otherwise, they risk becoming liabilities rather than assets.

Knowledge gaps and challenges

Despite the large amount of infrastructure present in aquatic systems across Aotearoa New Zealand, there remains a lack of understanding in how these structures interact with native biodiversity and surrounding ecosystems. Furthermore, the use and consideration of AAHs to support management and restoration is constrained by several critical knowledge gaps:

- **Limited understanding of how to design and retrofit nature-positive aquatic infrastructure:** There is limited evidence on how to effectively integrate ecological principles into the design or retrofitting of aquatic infrastructure in Aotearoa New Zealand. This includes a lack of knowledge around which materials, structural features and eco-engineering methods best support long-term ecological function to support native fauna.
- **Limited ecosystem-scale understanding for strategic AAH planning:** Understanding of how AAHs operate within wider ecosystem processes – such as ki uta ki tai (mountains-to-sea) connectivity, species movement and interactions with endemic flora and fauna – remains sparse, limiting the ability to plan and site structures in ways that genuinely support ecosystem restoration.
- **Limited evidence on material performance and design innovation for Aotearoa New Zealand environments:** Emerging materials and fabrication techniques show promise, but their durability, safety, ecological performance and suitability in Aotearoa New Zealand's dynamic environments are poorly understood, with little comparative testing to guide evidence-based design decisions.
- **Insufficient regulatory clarity for restoration-focused AAHs:** Aotearoa New Zealand lacks clear regulatory pathways tailored to habitat-restoration AAHs, creating uncertainty for practitioners and making it difficult to distinguish restorative projects from commercial or extractive developments within current consenting frameworks.
- **Lack of governance, coordination and standardised monitoring across AAH projects:** AAH projects are often implemented in isolation, with inconsistent monitoring and no national standards for design or evaluation. This has resulted in limited understanding of their biodiversity outcomes and increases the risk of poorly planned interventions that fail to deliver long-term ecological benefits.

1. Introduction

1.1 Defining artificial aquatic habitats

The term artificial aquatic habitat (AAH) refers to any human-made structure that functions as a habitat within an aquatic environment (Frehse et al. 2025). Historically, AAHs have been predominantly classified as 'artificial reefs'; however, this terminology is insufficient for capturing the diversity of modern aquatic structures, particularly those in freshwater systems or those that function as habitat only inadvertently (Figure 1). For example, the *London Convention and Protocol / UNEP guidelines for the placement of artificial reefs* (UNEP 2009) defines artificial reefs as:

> a submerged structure deliberately constructed or placed on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating, and / or enhancing populations of living marine resources.

This definition excludes the vast array of infrastructure that exists within or adjacent to aquatic systems. Consequently, to capture the full scope of human structures in aquatic environments, this report adopts a broader definition that evaluates AAH structures based on two distinct functional roles:

- **Purposeful habitat:** Structures deployed with the explicit intent of creating or enhancing habitat, such as artificial reefs, intentional shipwrecks or living shorelines.
- **Incidental habitat:** Infrastructure established primarily for civil engineering or stabilisation purposes (e.g. seawalls), which, while not designed for supporting biodiversity, is recognised for supporting ecological communities.

Aquatic environments across Aotearoa New Zealand currently host numerous AAHs that include woody material, boulders, shipwrecks and purpose-built artificial reefs. In addition, a wide array of infrastructure incidentally functions as AAHs, including breakwaters, groynes, jetties, revetments, seawalls and marine farms (Figure 1).

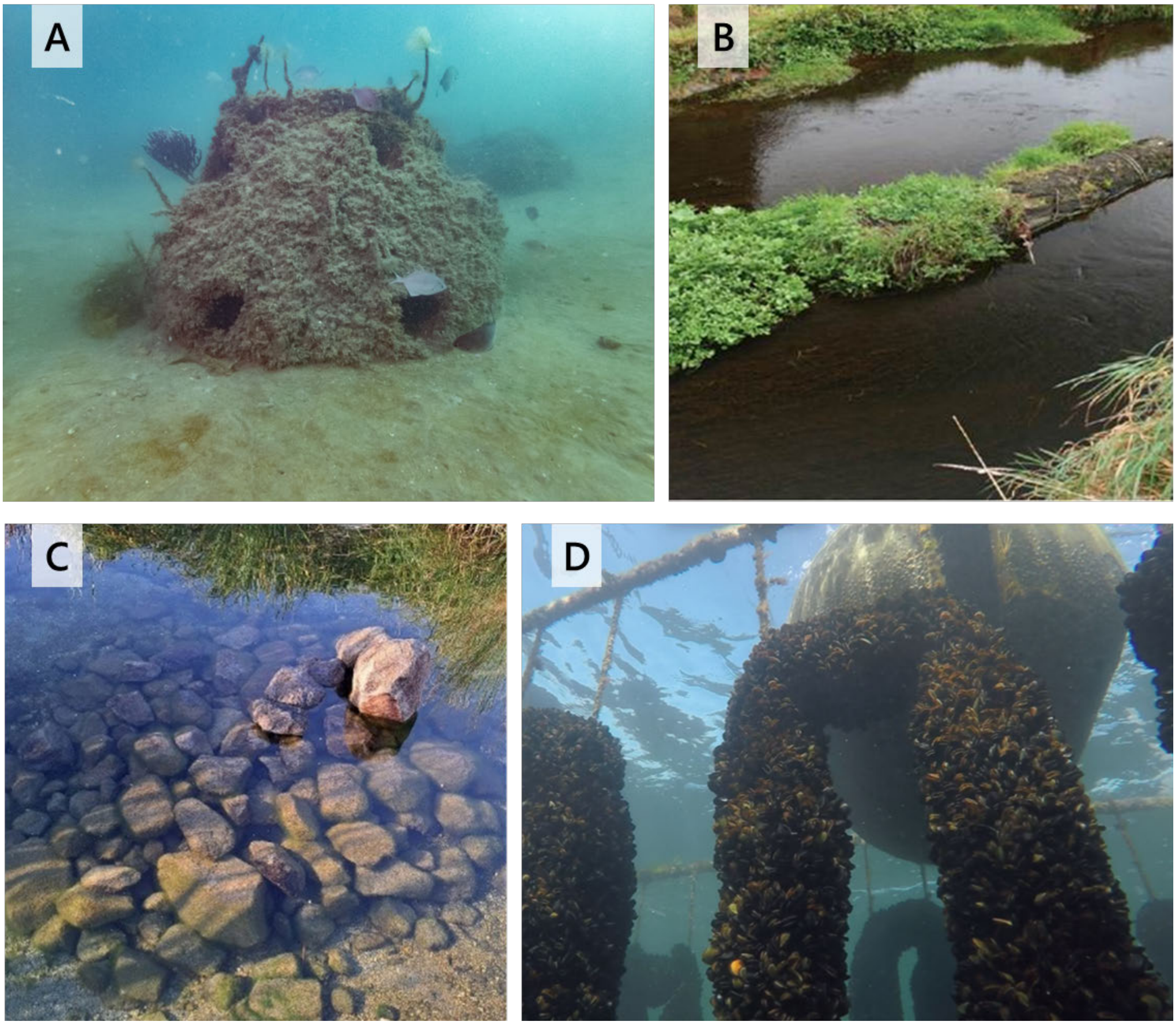

Figure 1. Examples of artificial aquatic habitats (AAHs) in Aotearoa New Zealand. (A) Structures deployed for the purposes of enhancing available habitat to provide refuge for native species, e.g. reef balls in the coastal environment in Long Bay, Auckland. (B) Woody material in river systems. (C) Rock piles in lakes. (D) Marine farms and other aquatic infrastructure that incidentally functions as habitat. Photo credits: (A) Shaun Lee, (B) the authors, (C) Ian Kusabs, (D) Javier Atalah.

1.2 Environmental context

In the face of ongoing habitat degradation and biodiversity loss across terrestrial and aquatic domains globally, the use of artificial habitats is an increasingly popular conservation management and restoration tool (Pratt 1994; Booth and Cox 2003; Seaman Jr. and Sprague 2013; Watchorn et al. 2022; Bracho-Villavicencio et al. 2023). While the focus on leveraging artificial habitats for ecological recovery is relatively recent in aquatic systems (Seaman 2007), understanding of the relationship between structures and biodiversity has a long history (Seaman Jr. and Sprague 2013; Frehse et al. 2025). For instance, coastal communities in the Philippines have long recognised the benefit of deploying simple floating structures such as payao (bamboo rafts) to attract pelagic species, including bigeye tuna (*Thunnus obesus*; Babaran 2006). More recently, localised interventions have given way to complex engineering and the deployment of large structures (e.g. for fresh water, Beechie et al. 2010; for marine, Pan et al. 2022 and Paxton et al. 2024a). Globally, there was a proliferation of AAH deployments in the mid-20th century to establish habitat for restorative and fisheries enhancement purposes, and the physical footprint of these structures has continued to expand significantly alongside the expansion of aquatic infrastructure that incidentally functions as AAHs (Baine 2001; Seaman Jr and Sprague 2013; Frehse et al. 2025). This has been particularly evident in North American waters, where the seafloor area covered by AAHs (i.e. artificial reefs) increased approximately 21-fold between 1970 and 2020 (Paxton et al. 2024a).

1.3 Risks and issues

Despite their popularity, AAHs carry significant risks and critical knowledge gaps remain with respect to their restorative potential, especially in understudied regions. One of the most significant risks limiting restorative applications of AAHs is the potential to create 'social–ecological traps' (Chong et al. 2024). For example, AAHs attract both fish and anglers, increasing catch rates (and thus angler satisfaction) in the short term, but this masks biological decline and can lead to hyperstability (i.e. catch rates remain high while fish populations crash), ultimately exacerbating regional overfishing (Chong et al. 2024). This exemplifies the 'attraction vs production' debate, which is a key theme relating to AAH implementation, management and research – i.e. do AAHs simply concentrate existing taxa from surrounding habitats (attraction), or do they genuinely increase the ecosystem's total biomass (production) (Bortone 1998; Smith et al. 2016; Layman and Allgeier 2020)? In regions where AAHs attract more fish than they produce, this can pose severe, cascading consequences for the surrounding ecosystem (Cinner 2011).

Other major risks include the potential for AAHs to be co-opted as 'greenwashing' to justify the impacts of extractive practices (Firth et al. 2020; Allgeier and Griffith 2025), or used as a pretext for waste disposal under the guise of habitat creation (UNEP 2009; DCEW 2023). Furthermore, structures that are poorly planned and managed can facilitate the spread of invasive species (e.g. Sheehy and Vik 2010; Frehse et al. 2025) and release contaminants from the degradation of unsuitable materials such as tyres (e.g. Collins et al. 2002).

1.4 Aotearoa New Zealand context

Aotearoa New Zealand's aquatic realms are characterised by remarkable biodiversity, featuring a high proportion of endemic species (e.g. for fresh water, Joy and Death 2013; for marine, Gordon et al. 2010). These unique ecosystems face significant challenges stemming from habitat degradation in the surrounding biomes (e.g. land-based effects for fresh water, Larned et al. 2020; for marine, Morrison et al. 2009) and within the systems themselves, all of which threatens their inherent biodiversity (e.g. habitat loss in freshwater systems, Weeks et al. 2016; and in marine systems, Turner et al. 1999). In response to these challenges, AAHs using natural materials (e.g. woody installations; Barrett et al. 2024) and purpose-built (i.e. intentional) artificial reefs (e.g. Te Ohooho o Parapara, Napier;[1] Artificial reefs 2021; RNZ 2021; Te Ara

[1] No easy task: Two artificial reefs created in Hawke's Bay – NZ Herald

Tupua enhanced reef habitat, Wellington[2]) are increasingly being considered as tools to support aquatic habitat restoration and native biodiversity recovery. The addition of structures to support native biodiversity has a long history across Aotearoa New Zealand – for example, the addition of brush (debris clusters) to river systems by Māori to harvest native species such as freshwater kōura / crayfish (e.g. *Paranephrops planifrons*; Noth et al. 2008).

Since the implementation of AAHs in a restorative context is relatively recent, the ecological ramifications of AAHs within the unique contexts of Aotearoa New Zealand's freshwater and marine environments require additional scrutiny. Despite the ubiquitous presence of AAHs across the country, little work has been done to evaluate their current ecological value, including assessing their capacity to restore indigenous biodiversity, deliver nature-based solutions and support ecosystem services at a national scale. Previous work has provided guidance for habitat construction in freshwater (e.g. Barrett et al. 2024) and marine systems (e.g. Morrison 2018; Sea et al. 2023) or briefly supported the consideration of artificial reefs for habitat enhancement (e.g. Morrison 2021; Handley 2022). However, these have been mostly focused on specific types of structures (e.g. woody material, shipwrecks) to provide options for restoration or to guide future AAH implementation.

1.5 Report purpose and scope

The purpose of this report is to support guidance for a more informed and sustainable approach to AAH implementation in Aotearoa New Zealand. To achieve this, the report reviews the use of AAHs in Aotearoa New Zealand to characterise the range of purposeful and incidental structures and the ecological benefits they confer, with a focus on AAHs that create habitats, support indigenous taxa and facilitate aquatic habitat restoration. The scope involved:

- Carrying out and summarising responses from a horizon-scan survey of subject matter experts across Aotearoa New Zealand on:
  - definitions, guidelines preference, national and local resources, concerns, and challenges for AAH development and implementation.
- Conducting a literature review of AAHs in Aotearoa New Zealand to:
  - compile and assess the number of articles related to AAHs in Aotearoa New Zealand from peer-reviewed literature, grey literature and popular / public-facing media
  - classify and visualise publications according to system, location, theme and publication date.
- Evaluating and contextualising AAHs in Aotearoa New Zealand based on horizon-scan survey responses and Aotearoa New Zealand articles with examples from international literature to assess:
  - ecological impacts of AAHs on native fauna
  - AAHs in Aotearoa New Zealand's freshwater and marine systems
  - costs and benefits of AAH implementation
  - knowledge gaps for AAH implementation and management.

[2] Te Ara Tupua: Ngā Ūranga ki Pito-One section enhanced reef habitat factsheet – February 2024

2. Horizon-scan survey

2.1 Survey methods

We conducted a horizon-scan survey with subject matter experts from various sectors that included central and local government, public research organisations, environmental consultancies and community groups to gather perspectives and information on the implementation of AAHs across Aotearoa New Zealand. All survey invitees were identified as actively involved in AAH development in Aotearoa New Zealand's freshwater and marine systems, either via management (e.g. government), implementation (e.g. environmental consultancies, community groups) or expertise related to aquatic habitat restoration (e.g. public research organisations, universities). A representative cohort of those experts that indicated interest in participating were invited via email to complete the survey using a Google Docs link. The survey was administered online and was conducted in accordance with the human research ethics approval CAW-ETH-250305.

The survey consisted of 12 main questions designed to capture a broad spectrum of views on the definition, principles, concerns, and implementation of AAHs (referred to in the survey as 'Artificial reefs'; see Appendix 1.1 for a full list of survey questions). The survey was structured into six key thematic sections:

- **Artificial reef [AAH] definitions:** Respondents were asked to select their preferred definition from a broad international context (*London Convention and Protocol / UNEP guidelines for the placement of artificial reefs* [IMO / UNEP 2009]) to a more recent version within the Australasian context ([Australian] *National artificial reef guidelines* [DCEW 2023]). Respondents were also given an open-ended opportunity to suggest modifications to suit the Aotearoa New Zealand context.
- **Artificial reef [AAH] guidelines preference:** Respondents rated the importance of 15 potential guiding principles on a five-point Likert scale (1 = not important to 5 = very important).
- **National and local resources:** Respondents were asked via open-ended questions to provide specific information regarding monitoring protocols, regulatory documents, technical criteria, costs and relevant case studies of AAHs.
- **Artificial reef [AAH] concerns:** Respondents rated their level of concern regarding 11 potential issues (e.g. biosecurity, pollution, fishing pressure) on a five-point Likert scale (1 = not concerned to 5 = very concerned).
- **Common challenges:** A final series of open-ended questions sought to identify implementation issues, communication preferences for AAH projects and knowledge gaps.

A thematic summary of respondent answers to each survey question is provided in Section 2.2, while a comprehensive breakdown of all response data is available in Appendix A1.2. Insights from the survey responses were then used to contextualise the available literature and assess diverse perspectives on the implementation of AAHs in Aotearoa New Zealand's aquatic systems (Section 4).

2.2 Horizon-scan survey results

In total, 16 subject matter experts from regional councils, government agencies, environmental consultancies, research institutions and community groups responded to the survey. The respondent cohort was predominantly marine-focused (*n* = 14), with only two representatives from the freshwater sector. This skew is likely attributable to the survey's initial framing around the term 'artificial reefs' – nomenclature rarely applied in freshwater management. A thematic summary of survey responses is provided below.

Artificial reef [AAH] definitions

Survey responses revealed a critical tension between the established definitions of 'artificial reefs' and the evolving reality of aquatic management in Aotearoa New Zealand. While there was strong support for the focus on structures that 'emulate some functions of a natural reef' in the *London Convention and Protocol / UNEP guidelines for the placement of artificial reefs*, respondents raised concerns that existing definitions were too broad regarding intent and too narrow regarding structure. Specifically, participants feared that definitions including 'human recreational activities' as the primary intent could lead to unintended consequences such as overfishing. However, submissions also highlighted that the field is evolving beyond standalone purpose-built infrastructure, such as seawalls and breakwaters. Respondents noted that traditional definitions focused on structures 'deliberately constructed' for habitat purposes might inadvertently exclude valuable shoreline interventions, which are increasingly being 'engineered to incorporate ecological features'. Respondents agreed that to fit the definition to the Aotearoa New Zealand context, the focus should be on local ecology and explicitly prioritise 'restoring or promoting settlement of indigenous biodiversity … as opposed to pest species'. Furthermore a national definition would need to integrate a Te Ao Māori worldview that connects whakapapa and taonga species to reef purpose.

Artificial reef [AAH] guidelines preference

Analysis of survey responses largely revealed a consensus (13 of 16) on the need for national guidelines concerning AAH implementation. Survey respondents viewed guidelines as essential for ensuring ecological effectiveness, mitigating environmental risks, building stakeholder confidence in using AAH within a restorative context and moving beyond the current ad hoc approach to implementation. Respondents viewed these guidelines as the primary mechanism to mitigate risk – specifically preventing the ocean from being used as a 'dumping ground' – and to build the stakeholder confidence needed to overcome implementation roadblocks. While a minority argued for regional flexibility to avoid imposing onerous monitoring costs on community groups, the prevailing view was that guidelines must be science led and purpose driven. Crucially, participants cautioned against rigidity, arguing that the framework must be a 'live', adaptable document that fosters innovation and requires proponents to justify AAHs as a specific tool within an integrated marine management toolkit.

National and local resources

Survey respondents detailed a wide array of national and local resources essential for the effective management and deployment of AAHs. These contributions were synthesised into key operational sub-themes covering monitoring protocols, technical standards, regulatory frameworks, cost considerations and relevant case studies.

Monitoring, technical standards and regulation

Survey respondents emphasised that robust, long-term monitoring and strict technical standards are foundational for successful AAH implementation and management in Aotearoa New Zealand. There was a consensus that monitoring must begin before installation to establish solid baselines, using methods ranging from traditional visual censuses to leveraging more modern approaches such as eDNA. Respondents suggested that monitoring should extend beyond biodiversity metrics and include invasive species, contaminants and physical sedimentation impacts. To standardise this effort without imposing a rigid 'one-size-fits-all' burden, respondents proposed a centralised national database to share data and facilitate cross-project learning. There was a strong call for guidelines to enforce rigorous material standards ensuring non-toxicity and durability, while encouraging innovation of eco-friendly materials and designs that account for local hydrodynamics. This technical rigour was underpinned by a variety of examples related to the complex regulatory landscape, with respondents identifying a broad suite of relevant statutes, including the Resource Management Act 1991, the Biosecurity Act 1993 and various regional coastal plans.

Cost considerations and case studies as existing precedents

Respondents agreed that implementation of these high standards faces significant barriers in terms of financial investment. Financial constraints were identified as the primary hurdle for AAH projects, with expenses spanning the entire life cycle – from initial consultation to design, deployment and long-term monitoring. Respondents highlighted a paradox, whereby the necessary rigorous standards for design and monitoring create a financial burden that often prevents projects from proceeding, especially given limited funding streams. The identified challenges were partially informed by an array of existing projects to serve as valuable case studies, including large-scale mitigation projects such as Te Ara Tupua reef and iconic shipwrecks (e.g. *Rainbow Warrior*, HMNZS *Canterbury*), community-led restoration initiatives (e.g. Ōpōtiki Community REAF Trust) and incidental habitats (e.g. Aramoana Mole). A selection of survey respondents also provided case studies for AAH projects currently underway across the country (Appendices 2 and 3).

Artificial reef [AAH] concerns

Respondents provided a key hierarchy of concern, with the most acute threats to implementation (rated as 'high risk') including pollution from inappropriate materials, mismanagement through poor site selection and regulatory challenges. Overarching these risks were concerns that artificial reefs could become a distraction from addressing the root causes of marine degradation, such as poor water quality and habitat loss. Respondents expressed strong fears that without strict material standards, reefs could introduce harmful substances to the marine environment, while poor planning could lead to ecological imbalances whereby reefs 'overcrowd certain areas and leave others barren'.

While issues such as invasive species and environmental impact were rated as 'moderate' concerns, respondents offered nuanced perspectives on their management. For example, rather than viewing reefs simply as attractors of pests, respondents noted that they facilitate the settlement of invasives already present in the system, suggesting this risk could be mitigated through adaptive management and citizen science removals. Overarching these operational risks, however, was a profound strategic concern: that artificial reefs could become a ‘distraction’ or perceived ‘quick fix’ for biodiversity declines. Respondents warned that such projects might ‘draw attention and funding away from restoring natural environments’ and hinder efforts to address the root causes of degradation, such as poor water quality.

Common challenges

Survey respondents detailed a consistent set of challenges facing AAH development, which we synthesised into three primary sub-themes: implementation issues (focusing on regulatory hurdles and cost), communication (strategies for public and cultural engagement) and knowledge gaps (the need for Aotearoa New Zealand–specific research). These responses collectively outline the operational friction points that currently stifle innovation.

Implementation issues

The primary impediments to implementation indicated by survey respondents were a restrictive regulatory environment and significant financial barriers. Respondents consistently described the consenting process as ‘onerous’ and ‘complex’, citing regional plans that restrict seabed structures as major roadblocks. Consequently, the high cost of compliance acts as a significant barrier to entry, preventing many potentially beneficial projects from ever getting off the ground.

Communication and knowledge gaps

To overcome existing barriers, respondents emphasised the need for tailored communication strategies that use social media for public outreach, professional channels for practitioners and face-to-face wānanga to build genuine partnership with mana whenua. Respondents also highlighted a need to bridge local knowledge gaps. Most were sceptical about applying international findings directly to Aotearoa New Zealand’s unique context and called for a structured national research programme focused on domestic ‘pilot studies’ to test materials and efficacy. Respondents suggested this research is required to answer a fundamental strategic question of whether ‘we actually need artificial reefs, and [whether] they ultimately benefit commercial interests or the environment’.

3. Literature review

3.1 Literature review methods

Peer-reviewed literature

Peer-reviewed articles relating to AAHs in Aotearoa New Zealand were compiled from the Web of Science (all years, all databases) and the search engine Google Scholar following a systematic literature review approach. Only literature and articles from the period up to and including December 2025 were considered. A search string was generated of the different structures common to freshwater and / or marine systems based on an a priori selection of terms developed from expert judgement (Table 1). A number of terms relevant to AAHs were excluded or specifically included for varying reasons:

- The terms 'marine farm', 'dock', 'riprap', 'and 'gabion basket' were excluded as the authors considered they were accounted for by 'artificial reef', 'artificial habitat', 'jetties', 'revetments' and 'groynes'.
- Terms such as 'weir' and 'dam' were excluded as literature in these domains is usually related to 'fish passage' (also excluded) and does not explicitly evaluate structures as habitats.
- The term 'shipwreck' was considered sufficient to account for additional descriptors such as 'sunken' or 'scuttled vessels'.
- The term 'fish passage' was excluded because, although such structures may inadvertently create habitat and support the recovery of mobile fish species, their primary function is the modification of hydrodynamics rather than the provision of habitat.
- The term 'fish aggregating device' was included to account for any structures deployed for the intention of enhancing fisheries and to address concerns posed by subject matter experts about structures being deployed for extractive purposes.

For Web of Science, the following query was used and constrained to Aotearoa New Zealand:

> TS=(('artificial reef' OR 'living seawall' OR 'seapod' OR 'econcrete' OR 'shipwreck' OR 'aquatic habitat enhancement' OR 'seafloor enhancement' OR 'reef ball' OR 'pre-fabricated concrete module' OR 'rock pile' OR 'rubble mound' OR 'living shoreline' OR 'rock sill' OR 'breakwater' OR 'groyne' OR 'jetty' OR 'revetment' OR 'seawall' OR 'lobster house' OR 'lobster casita' OR 'fish aggregating device' OR 'artificial habitat' OR 'wood installation' OR 'engineered log jam' OR 'single log' OR 'single rootwad' OR 'log vane' OR 'log groyne' OR 'rock riffle' OR 'little underwater neighbourhood keepers for eager roamers' OR 'LUNKERs' OR 'spawning riffle' OR 'floating island' OR 'biohaven' OR 'debris cluster') AND (New Zealand))

For the review using Google Scholar, the term 'New Zealand' was included in addition to the search term in question to constrain results to literature from Aotearoa New Zealand. As an example, the search was conducted along the following lines: 'New Zealand' and 'artificial reef'. Prior to inclusion, literature was screened to check that terms were used in relation to aquatic systems, as certain interventions (e.g. rock piles) are also used to create artificial habitats in terrestrial domains. A maximum of 300 article abstracts were reviewed for each term in the Google Scholar search. This constraint was placed based on expert judgement, as articles beyond this limit were found to generally fail to meet the criteria relating to article themes (see Table 1) for review. A prior search showed that no literature existed from Aotearoa New Zealand on 'artificial aquatic habitats'; therefore, this term was excluded from the search. To maintain consistency with the scope of this report, literature was considered only if at least one of the article themes was presented in the text as a focus of the study in addition to the search terms (see Table 1 for a list of article themes).

Grey literature

Peer-reviewed articles from the systematic review above were supplemented by grey literature (e.g. technical reports and popular / public-facing media) provided by survey respondents and sourced from regional councils, Earth Sciences New Zealand, Cawthron Institute and community-led projects. In addition, articles published by news agencies and magazines were included following an ad hoc approach via personal communication and an internet search.

Article classification and data visualisation

To assist with visual interpretation, each literature article was catalogued according to metadata attributes: date published, system (fresh water, marine), structure type and article type (peer-reviewed scientific literature, grey scientific literature, popular / public-facing media). AAH structure types were classified as:

- **Highly modified (engineered)** structures were purpose-built structures designed to achieve specific ecological or physical outcomes, including shipwrecks, prefabricated reef modules, living seawalls and any form of infrastructure (e.g. breakwaters, groynes, jetties).
- **Moderately modified** substrates referred to any structures deliberately arranged or altered to enhance habitat, such as boulders.
- **Minimally modified or opportunistic** structures were those used largely in their existing form with minimal manipulation, including woody material, hay bales, rock piles and shell debris.

Article themes were then evaluated to characterise the relative contribution of each theme to the literature base for each system (fresh water, marine). Theme contribution was calculated as a proportion based on the sum of articles, with a given theme divided by the total number of articles for that system. Where articles were assigned multiple themes, contributions were weighted equally, with each theme contributing an equal fractional share to the system totals. For example, if an article was assigned 'Research habitat' and 'Species', then both would contribute equally (i.e. each count as 1) to the overall totals for both themes.

A Sankey diagram was used to visualise the percentage contribution of freshwater and marine systems, the individual terms and article types to the literature base reviewed. Polar plots visualised thematic differences between systems and bar plots demonstrated temporal trends in publication. An additional map was generated to visualise the spatial distribution of AAHs across Aotearoa New Zealand based on a shapefile of shipwrecks and general locations of artificial reef projects identified in this review. All plots were generated using R Studio and the map was created with ArcMap Pro.

Content synthesis and analysis

A qualitative synthesis of the content of articles identified during the literature review was undertaken to address the broader research scope. Findings from the literature were extracted and synthesised to characterise the ecological role AAHs play in Aotearoa New Zealand's aquatic systems, identify gaps in domestic understanding, and highlight crucial considerations for future research and management. This synthesis formed the foundation of the review of AAHs in Aotearoa New Zealand (Section 4), where domestic findings were contextualised against the broader international literature to provide a comprehensive evaluation of AAHs where local data were otherwise absent.

To support the development of a preliminary cost–benefit framing for AAH implementation, a targeted synthesis was undertaken using the same body of literature identified through the systematic review and results from the horizon-scan survey described above. Cost and benefit information was extracted from international guidelines, peer-reviewed case studies, programme reports and relevant Aotearoa New Zealand examples encountered during the review. Recurrent life cycle cost categories (e.g. planning / consenting and cultural engagement, material acquisition and preparation, deployment, monitoring and maintenance, and risk / remediation / end of life) and benefit streams (e.g. fisheries enhancement, tourism, ecological service and cultural outcomes) were assessed qualitatively and consolidated into a full-life-cycle framework to be contextualised for Aotearoa New Zealand. Because few AAH projects in Aotearoa New Zealand have complete life cycle records, this synthesis provides a conceptual structure rather than a quantitative cost–benefit analysis.

Table 1. Search terms for systematic review of peer-reviewed literature of artificial aquatic habitats (AAHs) in Aotearoa New Zealand. Literature collated (both peer-reviewed and grey) was included in the report synthesis if at least one of the article themes was presented in the text.

Search terms
artificial reef
living seawall
living shoreline
seapod
econcrete
shipwreck
aquatic habitat enhancement
seafloor enhancement
reef ball
pre-fabricated concrete module
lobster house
lobster casita
kelp anchor
fish aggregating device
artificial habitat
engineered log jam
little underwater neighbourhood keepers for eager roamers
LUNKERs
floating island
biohaven
debris cluster
rubble mound
rock sill
rock pile
breakwater
groyne
jetty
revetment
seawall
wood installation
single log
single rootwad
log vane
log groyne
spur
rock riffle
spawning riffle

Article themes (for all search terms)	Theme description where articles specifically stated that:
Habitat	AAH functioned as some form of aquatic habitat or evaluated the structure as a potential habitat, such as engineering interventions with explicit aims to generically provide habitat.
Research habitat	AAH was used temporarily for experimental purposes pertaining to biology or ecology, such as to study some aspect of an organism's life history or the relationship with an ecological community.
Species	AAH functioned as a habitat for a specific taxon, e.g. the use of breakwaters as nesting sites or as substrates facilitating the spread of non-native species such as the seaweed *Undaria pinnatifida*.
Biodiversity	AAH supported or impacted biodiversity, such as a shipwreck influencing the establishment of a marine community.
Restoration	The main objective of AHH was a form of habitat restoration, i.e. structures were placed to recover a lost habitat.
Reef	AAH was referred to as a form of reef.

3.2 Literature review results

From the systematic and grey literature searches, we compiled 120 articles consisting of peer-reviewed journal articles, technical reports and popular media articles that met the criteria for inclusion in the literature review (see Section 3.1). Of the literature reviewed, 92 were marine based (76.7% of all articles) and 28 were fresh water based (23.3% all articles; Figure 2). Of the terms searched, articles with the term 'artificial reefs' had the highest representation, with 51 articles (42.5% all articles), followed by 'artificial habitats' (18 articles, 15.0%), 'fish aggregating devices' (7 articles, 5.8%), 'revetments' (6 articles, 4.9%), and 'shipwreck' (6 articles, 4.9%; Figure 2). The remaining 12 terms accounted for 27.1% of the articles reviewed. Of the literature reviewed, the majority comprised peer-reviewed journal articles (51 articles, 41.8%), reports (28 articles, 23.0%) and conference proceedings (14 articles, 11.7%; Figure 2). Additionally, most articles were published after 2000, with only a small number (13 articles) published earlier (i.e. between 1945 and 2000; Figure 3).

While peer-reviewed journal articles comprised the majority of the literature reviewed (41.8%), a significant portion of the knowledge base existed as grey literature, including monitoring reports (23.0%) and conference proceedings (11.7%; Figure 2). This distribution suggests that much of the operational data on AAHs in Aotearoa New Zealand may currently sit outside standard academic databases.

Article components demonstrated key differences between marine and freshwater systems. Habitats, as an article theme, were ubiquitously represented between both systems and featured in most of the articles reviewed (habitat: 86% of all marine articles, 93% of all freshwater articles; Figure 4). Freshwater systems had a higher proportion of articles representing the use of AAHs in a restorative context (restoration: 68% of all freshwater articles) when compared to marine systems (restoration: 34% of all marine articles). This may have resulted from a more species-specific focus in freshwater systems (species: 43% of all freshwater articles, 12% of all marine articles) rather than the recovery of biodiverse communities in marine systems (biodiversity: 11% of all freshwater articles, 48% of all marine articles). Unlike habitats in fresh water, habitats in marine systems are often referred to as 'reefs' (reefs: 0% of all freshwater articles, 58% of all marine articles), which explains a current lack of articles with a reef component in freshwater systems, despite ongoing work in this space (Appendix 2).

A map of key AAH projects and shipwrecks demonstrates that AAHs are a ubiquitous feature of Aotearoa New Zealand's coastline, with sites conspicuously more dense around Te Ika-a-Māui / North Island (Figure 5). These were largely concentrated within Te Tai Tokerau / Northland, Tīkapa Moana / Te Moananui-ā-Toi / Hauraki Gulf, Te Tara-o-te-Ika-a-Māui / Coromandel Peninsula, and Te Whanganui-a-Tara / Wellington regions, while Te Waipounamu / South Island features fewer examples, with activity largely confined to Te Tauihu o Te-Waka-a-Māui / Top of the South. However, this mapping provides a conservative estimate of the true extent of AAHs, as it excludes the vast network of incidental infrastructure (such as marine farms, breakwaters, jetties, etc.) and temporary experimental habitats used for academic research.

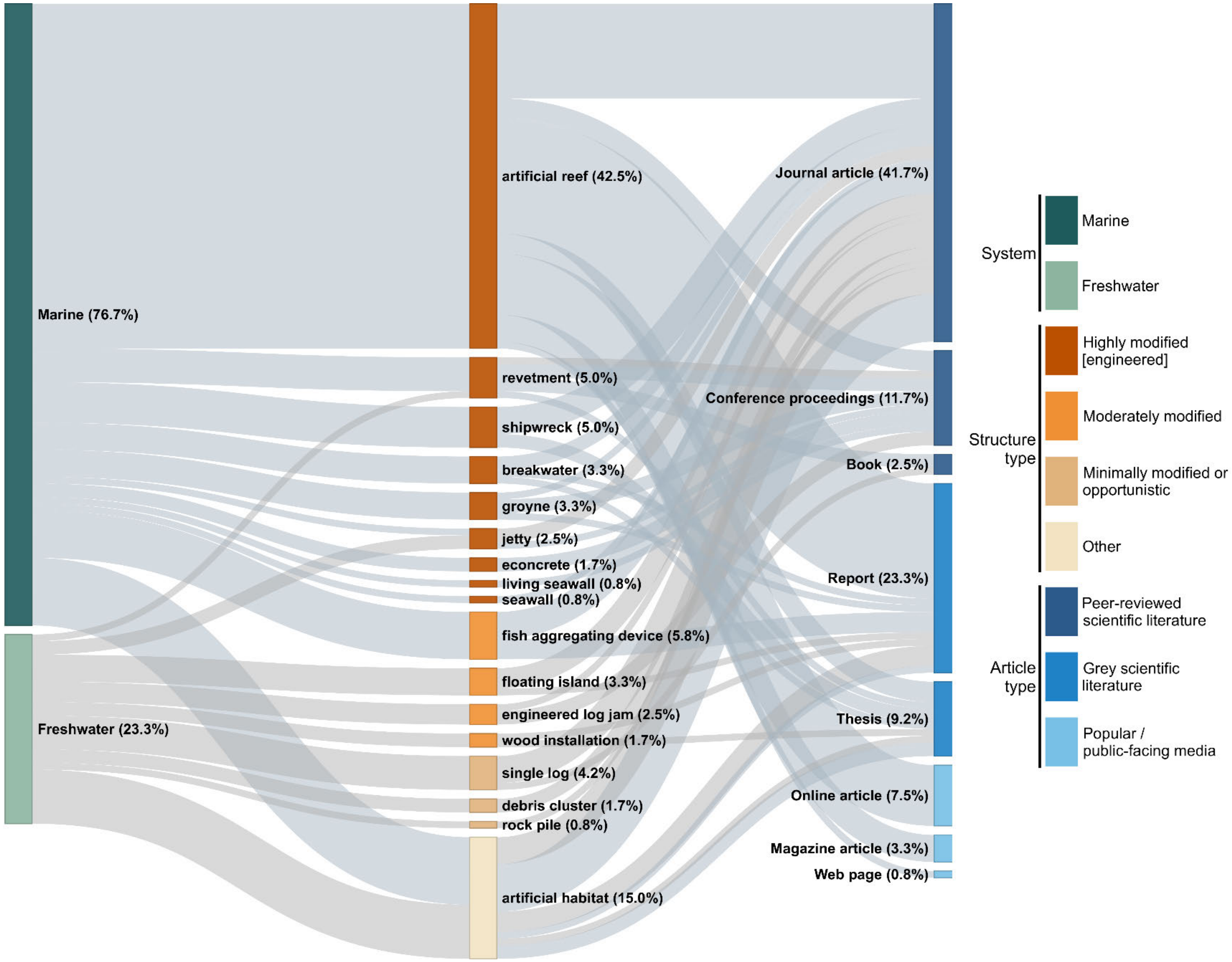

Figure 2. Sankey diagram of search terms (centre) used to carry out the systematic literature review for artificial aquatic habitats in Aotearoa New Zealand. Terms were grouped according to system (left-hand side), structure type (centre) and article type (right-hand side). Percentages refer to the percentage contribution of terms and article types to the overall total for each grouping term (system and type), respectively. Colour grading for terms refers to structure types

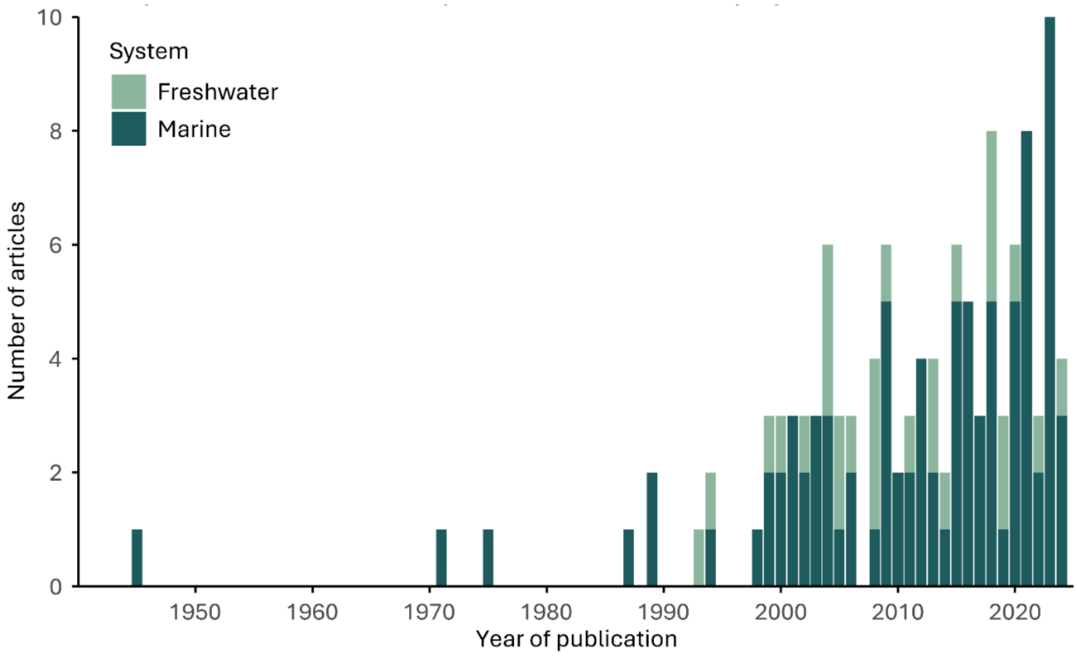

Figure 3. Number of articles compiled for the literature review of artificial aquatic habitats in Aotearoa New Zealand showing year of publication. Dates range from 1945 through to July 2025.

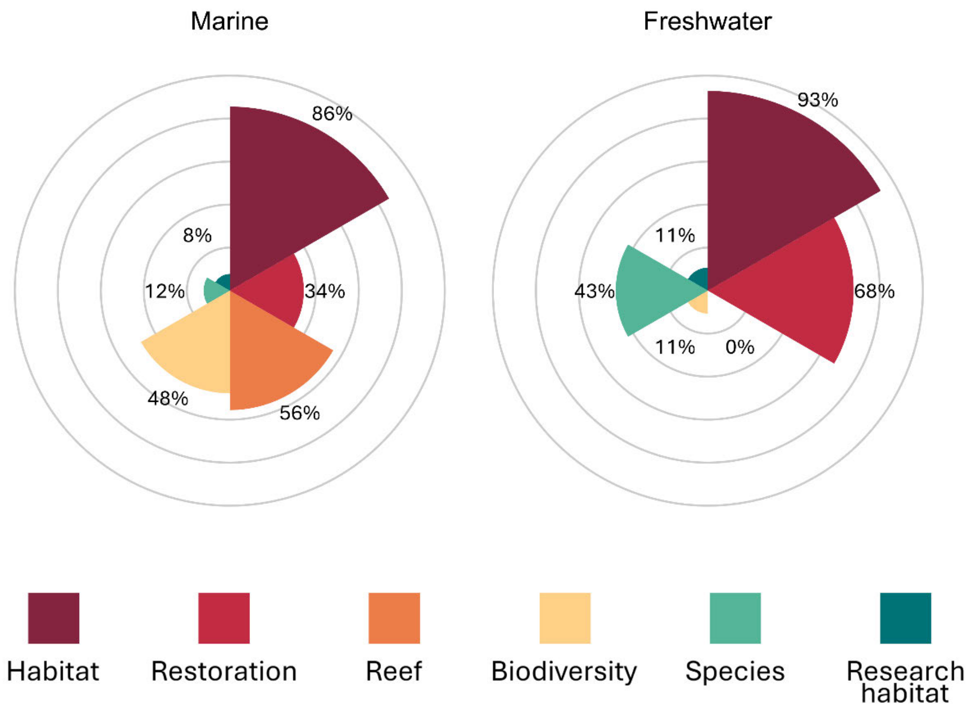

Figure 4. Polar plot of article themes used as selection criteria in the literature review for artificial aquatic habitats in Aotearoa New Zealand, by aquatic system (marine, freshwater). Article themes are represented by the coloured key at the bottom of the plot. Percentage indicates the proportion of articles catalogued according to specific themes. Where an article was assigned multiple themes, each theme contributed equally to the respective totals for all articles in either freshwater or marine systems. Grey lines represent 20% increments.

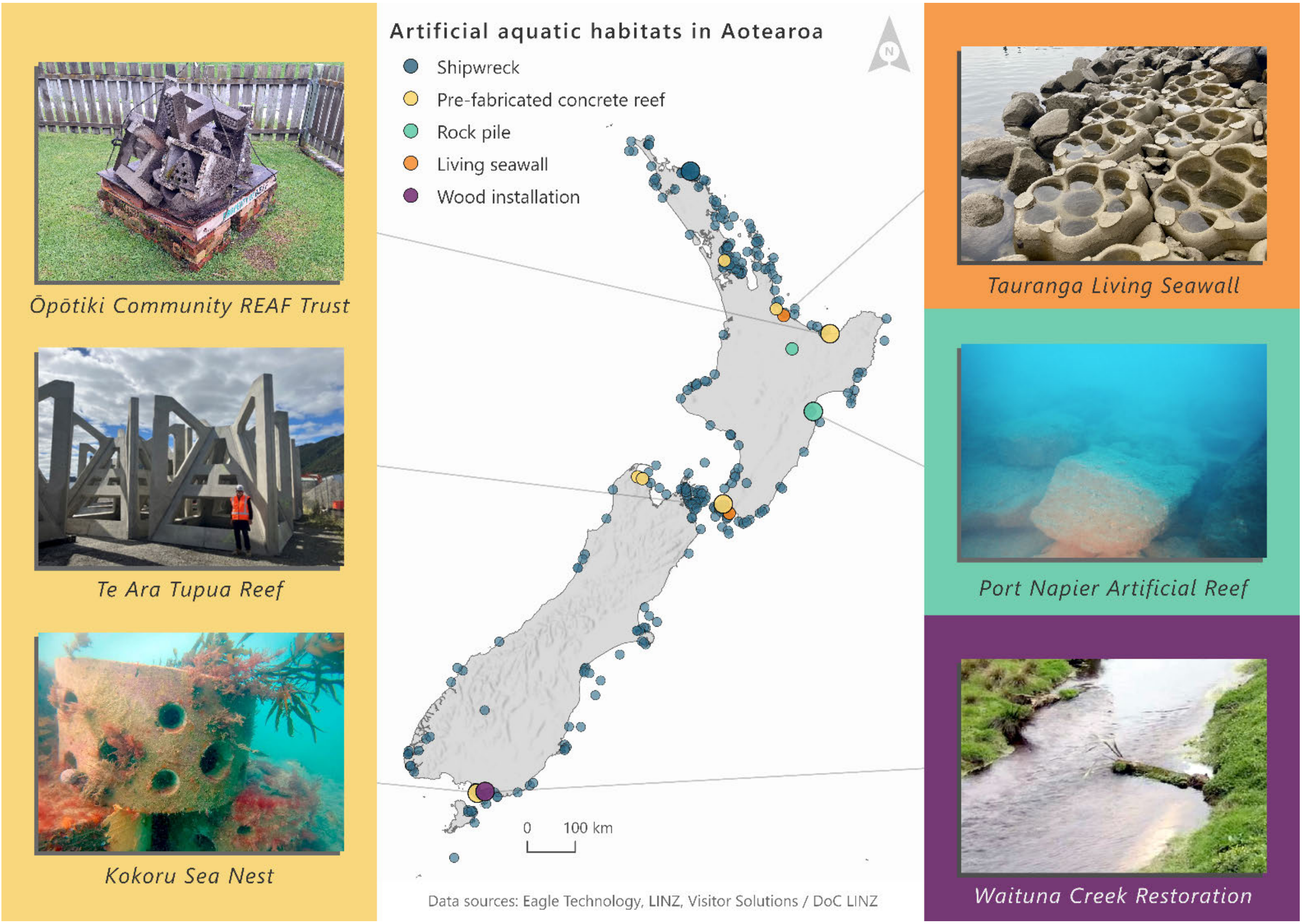

Figure 5. Artificial aquatic habitats (AAHs) in Aotearoa New Zealand. Note that additional AAHs exist (e.g. marine farms, jetties, breakwaters) but are not presented, and that many of the wrecks presented here have likely been salvaged, degraded or destroyed, limiting or removing their use as habitat. Similarly, several small-scale interventions, such as temporary additions of small-scale AAHs for research or additional woody material projects, are not displayed. Photo credits: the authors (Ōpōtiki Community REAF Trust and Waituna Creek Restoration), Josie Crawshaw and Rigoberto Sanchez Medina (Tauranga Living Seawall), Ross Sneddon (Port Napier Artificial Reef), Marcus Cameron and Te Ara Tupua Alliance (Te Ara Tupua Reef), Bryony Miller and Sea Nest (Kokoru Sea Nest).

4. Evaluation of artificial aquatic habitats in Aotearoa New Zealand

We combined insights from the horizon-scan survey, Aotearoa New Zealand-based literature and international research to evaluate AAHs in Aotearoa New Zealand. This revealed significant variability between freshwater and marine environments, with AAH structures differing in scale, material composition and intent (Figures 1 and 5). Within freshwater systems, AAH interventions in Aotearoa New Zealand tend to be deployed purposefully (i.e. for habitat recovery), are relatively small scale and predominantly use minimally modified or opportunistic structures to recover lost ecological functions (e.g. wood in streams; Evans et al. 1993; Meleason et al. 2005; Meleason and Hall 2005). In contrast, AAHs in Aotearoa New Zealand's marine systems are typically larger in scale, use moderately to highly modified materials with a variety of designs, and more broadly encompass both purposeful and incidental habitats (Figure 5). This contrast between freshwater and marine systems provides the organising framework for interpreting both the review literature and the system-specific applications discussed below.

4.1 Impacts on habitats, biodiversity and physical environment

Decades of research have demonstrated that AAHs significantly alter aquatic systems by enhancing available habitat, supporting biodiversity and altering local hydrodynamics and sediment transport (e.g. Dafforn et al. 2012; Seaman Jr. and Sprague 2013; Fariñas-Franco and Roberts 2014; Perkol-Finkel et al. 2018; Pondella et al. 2022). This work has shown that AAHs consistently support enhanced taxa density, biomass, richness and diversity (e.g. for fresh water, Holmes and Goodwin 2021; for marine, Paxton et al. 2020). This is especially apparent in systems where complex habitat features have been lost (e.g. Seaman 2007; Schulze et al. 2020). However, while AAHs can provide localised increases in species diversity, community composition may still differ significantly from natural, unimpacted reference sites (Folpp et al. 2014; Bracho-Villavicencio et al. 2023).

Consistent with AAHs reported in the global literature (e.g. Seaman Jr and Sprague 2013; Bonnici et al. 2018; Paxton et al. 2025), the introduction of structure to Aotearoa New Zealand's aquatic environments creates habitat that is readily exploited by a diverse range of native and exotic taxa. Selected examples for Aotearoa New Zealand include:

Birds

- Pacific reef heron / matuku, *Egretta sacra* (Wodzicki and Eyles 1945)
- little penguin / kororā, *Eudyptula minor* (Koneski and Huteau 2023)
- New Zealand dabchick / weweia, *Poliocephalus rufopectus* (Bell et al. 2003; Bright et al. 2004).

Algae

- *Lithothamnion* sp. (Fish Forever 2012)
- *Undaria pinnatifida* (Hay and Luckens 1987; Stuart 2004; Russell et al. 2007).

Invertebrates

- broad squid / ngū, *Sepioteuthis bilineata* (*S. australis*; Larcombe and Russell 1971)
- tunicates, e.g. *Didemnum vexillum* (Forrest et al. 2013)
- kōura / red rock lobster, *Jasus edwardsii* (Booth et al. 1998; Skelton and Jeffs 2021; Sneddon 2023).

Fish

- short-finned eel / tuna, *Anguilla australis* (Jellyman and Chisnall 1999; Noth et al. 2008)
- īnanga / whitebait, *Galaxias maculatus* (e.g. Hickford and Schiel 2013; Orchard et al. 2018)
- giant kōkopu, *Galaxias argenteus* (Bonnett et al. 2000, 2002; Joshua et al. 2022)
- snapper / tāmure, *Chrysophrys auratus* (Lohrer et al. 2018; Parsons et al. 2018)
- common triplefin / kokopara, *Forsterygion lapillum* (Shima et al. 2012)
- blue cod / rāwaru, *Parapercis colias* (Wade 2020; Wade et al. 2025).

A single-species focus was particularly evident for AAHs in freshwater systems, for which the literature often evaluated habitat features for specific species and life stages. Conversely, only a small number of academic studies and theses explored the broader ecological communities associated with AAHs in freshwater environments, which was more common in marine systems (e.g. Russell 1975; Blakely et al. 2006; Morrisey et al. 2006; Funnell 2019; Underwood 2023; Underwood and Jeffs 2023; Gallagher 2025). Assessments of ecological communities were more commonly found in the grey literature via project monitoring reports (e.g. Long Bay reef balls, Jaffrey et al. 2001, 2002; HMNZS *Canterbury* wreck, Robertson and Jacobs 2011, Fish Forever 2012, Booth 2020; SS *Taioma* and SS *Taupo*, Robertson 2012; Napier Reef, Rose 2020, Napier Port 2021, Jeffares 2023, Sneddon 2023) and popular literature (e.g. magazine articles, Szabo and Grace 1994, Grzelewski 1999). Conversely, the peer-reviewed literature assessed for this report predominantly covered observational and experimental research that employed artificial habitats, such as artificial seagrass units (Parsons et al. 2018) and artificial canopies (Shima et al. 2012), to understand life history traits of species.

The literature indicates that increases in biodiversity are most pronounced in systems that have been impacted by multiple, sustained stressors, such as rivers modified by channelisation (Roni et al. 2008; Holmes and Goodwin 2021) or nearshore coastal environments homogenised by bottom-contact fishing (Handley 2006; Paul 2012; Schulze et al. 2020; Appendices 2 and 3). A similar pattern is emerging within the field of restorative aquaculture, where the ecological benefits of farm structures are highly context dependent and greatest in areas where ecosystems are degraded or key ecological functions have been diminished (TNC 2024). This suggests that AAHs may hold significant potential for enhancing native biodiversity or supporting the recovery of depleted species (e.g. blue cod, Wade 2020, Wade et al. 2025; freshwater kōura / crayfish, *Paranephrops planifrons*, Appendix A2.2) across Aotearoa New Zealand, particularly in regions that have experienced the loss or degradation of complex reef habitats (e.g. as suggested internationally, Seaman 2007, Bracho-Villavicencio et al. 2023). In areas where natural hard-bottom habitats are scarce or damaged, the introduction of AAHs has been shown to result in substantial increases in biodiversity and to provide habitat for a wide range of marine taxa (e.g. Becker et al. 2017; Folpp et al. 2020). A compelling example is the use of habitat-mimicking horse mussel / hururoa (*Atrina zelandica*) reefs in Tauranga Harbour designed to replicate both the structure and ecological functions of historical mussel beds, including their role in supporting biodiversity (Appendix A3.5; Ellis-Smith et al. 2025). This project has demonstrated promising outcomes, with increased diversity and biomass of marine organisms observed in the vicinity of the structures, underscoring the potential value of AAHs as a restoration tool in appropriate contexts. However, consistent with perspectives expressed in the horizon-scan survey, it is important to emphasise that AAHs should not be viewed as substitutes for intact, functioning natural habitats, but rather as complementary measures within broader conservation and restoration strategies (e.g. as discussed internationally, Walker and Schlacher 2014, Paxton et al. 2020, Higgins et al. 2022).

Within the broad system-level context, several articles provide high-level syntheses of planned engineering interventions intended to create or enhance habitat, often drawing on examples from Aotearoa New Zealand alongside international case studies (e.g. Booth and Cox 2003; Norman 2018; Pomeroy and Burmeister 2022; Koneski and Huteau 2023; Hale et al. 2024). Across systems, these reviews focus on the role of built structures as habitats within aquatic environments. In freshwater contexts, the literature commonly centres on relatively small-scale AAHs constructed from natural materials such as wood or debris clusters (e.g. Hicks and Reeves 1994; Roni et al. 2008; García-Rama et al. 2015; Norman 2018; Joshua et al. 2022). In contrast, marine-focused reviews tend to emphasise larger or pre-existing structures, including shipwrecks (e.g. Ilieva et al. 2019), marine farms (e.g. Gibbs 2004; Morrisey et al. 2006; Stenton-Dozey and Broekhuizen 2019; Atalah et al. 2020), and emerging infrastructure such as offshore wind farms (e.g. Hale et al. 2023). More recent work also reflects a growing emphasis on ecological considerations in coastal infrastructure design, particularly the interactions between structural complexity and surrounding biological communities (e.g. Jackson and Corbett 2007; Hancock et al. 2009; Weppe et al. 2009; Foster and Burke 2015; Reinen-Hamill et al. 2015; Jackson et al. 2022; Bell et al. 2023). Paxton et al. (2025) highlight that, globally, more work is needed to understand how standard built infrastructure can be better employed to increase available habitat and support biodiversity in aquatic systems, a gap that remains prevalent in the Aotearoa New Zealand context.

Similar to projects globally, a primary concern shared in the horizon-scan survey is that AAH implementation has often occurred without clear, quantifiable goals or the long-term monitoring needed to assess its performance and ecological efficacy (Seaman 2007; Bartholomew et al. 2022). Furthermore, many studies lack comparisons to appropriate natural controls, limiting evaluation of their restorative potential (Bracho-Villavicencio et al. 2023). While evaluations of the performance of AAHs has largely focused on fish populations attracted to submerged structures (e.g. for fresh water, Roni et al. 2008; for marine, Brickhill et al. 2005, Frehse et al. 2025), emerging research is also considering this question from a broader ecological perspective. For example, AAHs can enhance a system’s production by alleviating resource limitation through the aggregation of fish that concentrate nutrients via excretion. This can create ‘biogeochemical hotspots’ that increase local primary production in surrounding habitats such as seagrass (Layman and Allgeier 2020). Studies on biodegradable AAHs also found that they enhanced food web complexity by supporting species from lower trophic levels (Nauta et al. 2023). However, more work is needed to understand how these biogeochemical hotspots form around AAHs in Aotearoa New Zealand.

This understanding could be supported by research demonstrating how AAHs can be designed to modify their surrounding physical environment. For example, AAHs interact with physical processes in aquatic environments that fundamentally alter local hydrodynamics (e.g. Young et al. 2004; Faltinsen 2015; Da Silva et al. 2022; Nielsen et al. 2022; Chan et al. 2023) and sediment transport (e.g. White and Healy 2001; Smith et al. 2011), which together have cascading effects on the distribution of surrounding flora and fauna (e.g. Brook and Grace 1981; Hancock et al. 2009; Burt et al. 2010). While not explicitly reviewed for this report, this context parallels the considerable body of research evaluating engineering interventions for fish passage in Aotearoa New Zealand's freshwater systems. For example, research into retrofitting culverts with ramps and baffles has consistently demonstrated how manipulating physical flow dynamics can facilitate the migration of indigenous species such as īnanga and bullies (Baker 2003, 2014; Baker and Boubée 2006; Franklin and Bartels 2012; Franklin and Gee 2019; Baker et al. 2024). Although these engineering-focused studies (e.g. Pomeroy and Burmeister 2022) rarely evaluate structures explicitly as habitat, they offer critical insights for future AAH implementation by defining the physical parameters that help drive ecological interactions and the potential for using AAHs as an intervention within a restorative context.

4.2 Freshwater systems

Our evaluation of AAHs in freshwater systems found that projects generally focused on habitat rehabilitation or restoration via species-specific support using biodegradable, low-impact materials (Ellery and Hicks 2009; Joshua et al. 2022). Notable examples include the use of hay bales to facilitate īnanga spawning (Hickford and Schiel 2013; Orchard et al. 2018), and the strategic placement of debris clusters, woody material or small boulders to provide critical habitat structure for species such as freshwater kōura / crayfish, kanakana / lamprey (*Geotria australis*), eels and native galaxiids (Appendix A2.1; Kusabs et al. 2018; Parata 2019; Holmes and Goodwin 2021; Barrett et al. 2024).

The ecological function of constructed woody habitats in waterbodies – often referred to as large woody debris (LWD) in the literature – is now widely recognised as a common mitigation and restoration action across Europe and North America. Numerous studies have demonstrated the benefits of LWD for habitat complexity, sediment retention and fish populations. For example, Roni et al. (2015) reviewed restoration projects across North America and Europe, finding consistent improvements in salmonid habitat and population metrics. Beechie et al. (2010) further advocate for process-based restoration approaches that incorporate LWD to restore natural river dynamics. Technical guidance from agencies such as the Natural Resources Conservation Service in the United States also supports the use of LWD for both ecological and engineering outcomes (USDA 2007).

Incidental habitat

Research evaluating AAHs or artificial reef-like structures in freshwater systems and focusing on biodiversity, restoration and habitat remains relatively limited compared with the extensive body of work in marine environments, especially for Aotearoa New Zealand. Furthermore, despite a widespread amount of freshwater infrastructure functioning as incidental AAHs (e.g. jetties, revetements), we identified little to no peer-reviewed research that evaluated existing freshwater structures as incidental habitats, aside from observations of jetties used as roosting habitat for dabchicks (Bell et al. 2003; Bright et al. 2004) and ongoing work focused on nature-positive lake shoreline modification (Appendix A2.2).

This contrasts sharply with marine systems, where highly and moderately engineered structures such as nature-positive revetments and seawalls are increasingly being considered as aids for habitat enhancement (see Section 4.3).

Purposeful interventions

A handful of large wood additions have been trialled in Aotearoa New Zealand, showing clear benefits for taonga species with high biodiversity value, such as longfin eel / tuna (*Anguilla dieffenbachii*) and giant kōkopu. These species rely on complex shaded habitats, often created by instream wood, undercut banks and debris jams. In particular, restoration efforts in the Waikato (DOC 2019; Livingstone et al. 2019) and Southland Regions have demonstrated increased habitat use by these native species (Holmes and Goodwin 2021). In Waituna Creek, Southland, the addition of large logs resulted in a 10-fold increase in eel biomass around the added logs and the immigration of giant kōkopu and juvenile lamprey to treatment reaches (Holmes and Goodwin 2021).

A small number of freshwater 'lake reefs' and constructed habitat initiatives exist that serve analogous functions to commonly deployed marine AAHs; however, these are rare and mostly documented in the grey literature. For example, ARC marine has developed modular reef systems designed to enhance habitat for the endangered white-clawed crayfish (*Austropotamobius pallipes*) in the United Kingdom (ARC marine 2023). In Aotearoa New Zealand, the use of constructed reef-like habitats represents a particularly novel approach to habitat enhancement and native species recovery. An ongoing trial of lake-edge and rock reefs was initiated in 2025 in Te Arawa Lakes in the Waikato Region, with multiple rock piles (known as pā kōura) installed in Lake Rotorua / Te Rotorua nui ā Kahumatamomoe (hereafter Lake Rotorua) supported by a monitoring programme to assess their effectiveness. It is hypothesised that the addition of rocky habitat to Lake Rotorua will provide critical refuge for freshwater kōura / crayfish, supporting population recovery following severe population declines associated with the invasion of the predatory brown bullhead catfish (*Ameiurus nebulosus*) in 2016. Catfish predation has reduced kōura biomass to less than 10% of pre-invasion levels (Kusabs et al. [In prep.]), underscoring the urgent need for novel habitat-based interventions. Importantly, these contemporary trials build on long-standing mātauranga Māori practices rather than introducing entirely new concepts. Te Arawa Lakes hapū have maintained the use of the traditional centuries-old tau kōura harvesting method, in which long lines of sunken whakaweku (bracken fern bundles) are used for both habitat enhancement and mātauranga-based monitoring (Kusabs et al. 2018). When old whakaweku bundles are replaced, they are deposited alongside harvest lines connected to new bundles, forming additional habitat piles (i.e. constructed habitats) that provide habitat refuge to support and maintain harvested kōura populations.

While not widespread, floating islands (aka floating wetlands) have been trialled in Aotearoa New Zealand and represent a distinct category of constructed aquatic habitat that functions at the interface of ecological restoration and water quality remediation. Unlike benthic structures, these systems use buoyant mats to suspend extensive root networks into the water column, creating complex vertical structure analogous to the root masses of riparian vegetation or hanging woody debris (Headley and Tanner 2006, 2012). This 'hanging biofilm' acts as a highly active biological filter; the dense root matrix physically entraps fine suspended sediments and facilitates the uptake of dissolved nutrients and heavy metals (e.g. zinc and copper), significantly enhancing the treatment performance of stormwater retention ponds (Borne et al. 2013; Tanner and Headley 2011). Consequently, floating island structures provide a dual benefit: they remediate degraded water quality and, simultaneously, they offer a unique, structurally complex habitat for microbial, invertebrate and bird communities in systems that may otherwise lack physical structure (Headley and Tanner 2006, 2012).

Available guidance

Aotearoa New Zealand's *Guidance for large wood installations in New Zealand rivers* (Barrett et al. 2024) provides a comprehensive framework for planning, designing and managing large wood material (LWM) additions to maximise ecological benefits while minimising risks such as flooding, bank erosion and navigation hazards. The guidelines complement the *National works in waterways guideline* (MfE 2021), which outlines best practices for civil works and habitat enhancement. Together, these guidelines emphasise that LWM interventions should primarily restore habitat complexity and ecosystem functions lost through historical deforestation and wood removal (e.g. Baille et al. 2008; Baille and Davies 2010), adding wood strategically to create critical microhabitats such as shelter, pools and nesting sites for species like longfin eels and kōkopu species, while also stabilising stream banks and trapping sediment.

To ensure successful AAH implementation, the guidelines require robust pre-feasibility assessments that evaluate key risk factors, including flow flashiness, channel width and proximity to infrastructure such as bridges and culverts. In addition, they offer design advice ranging from the placement of single 'key logs' to the construction of complex engineered logjams and root wads. Material durability is also emphasised, with decay-resistant species such as eucalypts or redwoods preferred over rapidly degrading softwoods, and stability treated as a core design consideration. Although gravity-based structures that use the mass of the wood or added ballast for stability are generally favoured for their natural function, higher-risk sites may necessitate anchoring methods such as burial, pinning or pile support. The guidelines further highlight the need for a long-term maintenance plan that anticipates natural wood decay and includes periodic replenishment to maintain habitat function and self-sustainability over time. Although focused on LWM, the guidelines' underlying principles – strategic design, risk assessment, material suitability, structural stability and ongoing maintenance – are broadly applicable to other habitat-enhancement interventions, including fish-friendly rock walls and similar forms of intentional or incidental AAHs.

4.3 Marine systems

Marine AAHs in Aotearoa New Zealand fall into two distinct categories: a vast network of incidental habitats (i.e. coastal infrastructure), and a small, localised collection of purpose-built habitats and intentional shipwrecks. Purpose-built AAHs range from small-scale experimental habitats deployed primarily for research purposes – such as those studying temperate rocky reef communities and species life histories (Russell 1975; Lohrer et al. 2018; Parsons et al. 2018, Morton and Shima 2013; Gallagher 2025) – to medium-scale structures such as modular concrete reefs. Examples of the latter include community group reefs (e.g. Ōpōtiki Community REAF Trust 2010; Fitzgerald and Guccione 2021; Appendix A3.1), reef balls (Cawker 2000; Spheres of influences! 2001; Taylor and Buckridge 2002; Jaffrey 2004), and pyramid reefs deployed as compensation for the removal of rocky reef (McLintock et al.

2023; Appendix 3.4). Shipwrecks such as the HMNZS *Canterbury* (Booth 2020), *Rainbow Warrior* (Szabo and Grace 1994; Viduka et al. 2020) and HMNZS *Wellington* (O'Neil 2015) serve as the largest single structures deployed for habitat enhancement and dive tourism (Ilieva et al. 2019).

In the early 2000s, there was additional interest in engineering coastal amenities using large sand-filled bags to create multi-purpose reefs and artificial surf breaks; however, these projects were largely frustrated by dynamic coasts, resulting in high-profile structural failures (e.g. Mead and Black 1999; Black 2001; Mead and Black 2005; Phillips et al. 2009; Taranaki Regional Council 2009; Weppe et al. 2009). More recently, marine projects have also repurposed coastal infrastructure, such as relocating limestone boulders from revetments to establish large reefs (e.g. Napier Reef, Sneddon 2023) or employed specially designed concrete retrofittings to create living shorelines (e.g. Tupua Horo Nuku, Appendix A3.6; Murray 2025; WSP 2025). This is also being trialled in freshwater lakes (Appendix A2.2).

Incidental habitat

Numerically, the dominant form of AAH in Aotearoa New Zealand is essential civil infrastructure. Most coastal structures are civil infrastructure such as jetties, breakwaters, seawalls, revetments and groynes that were not engineered to support marine communities. Consequently, it was noted during the review that the bulk of the literature regarding these structures evaluates them through physical parameters and not as habitats (e.g. see Comfort and Single 1997; Glassey et al. 2003; Watson et al. 2020; Nielsen et al. 2022). However, a shift is evident in recent years, with increasing attention being paid to how these structures can be designed or retrofitted to serve additional ecological functions (e.g. Foster and Burke 2015; Reinen-Hamill et al. 2015; Gordon 2017; McKenzie 2017; Norman 2018; Jackson et al. 2022; Bell et al. 2023; Foster and Shand 2023; Koneski and Huteau 2023). This is best exemplified by projects that retrofit existing infrastructure with nature-positive modules, and represents a transition from viewing infrastructure purely as coastal defence to acknowledging its role as a 'living shoreline' (Koneski and Huteau 2023; Appendix A3.6).

Purposeful interventions

In contrast to the ubiquity of infrastructure (see above), structures deployed to purposefully enhance habitat, such as shipwrecks (scuttled vessels) or prefabricated reef modules (e.g. reef balls), are rare. However, monitoring of these types of AAHs provides the clearest evidence of ecological utility. For marine systems, the development of ecological communities on monitored artificial reef structures appears to follow a predictable pattern of succession (e.g. as described by Paxton et al. 2024b). This process often begins with the creation of plankton-rich upwellings in the vicinity of the structure, which in turn attract small planktivorous fish. These smaller fish then draw in larger pelagic predators. Subsequently, creatures seeking refuge from the open ocean, including hole- and crevice-dwellers such as grouper / hāpuku (*Polyprion oxygeneios*), spotty / paketi (*Notolabrus celiodotus*) and conger eel / kōiro (*Conger verreauxi*), begin to colonise the reef, as seen with observations at the SS *Taupo* in the Bay of Plenty (Robertson 2012) and Sea Nest reefs in Southland waters (Appendix A3.2). Over longer periods, the reef structure becomes increasingly covered with encrusting organisms such as algae, tunicates, hard and soft corals, and sponges (e.g. as seen at the HMNZS *Canterbury*, Booth 2012).

The artificial reef in the Long Bay–Okura Marine Reserve provides a specific example of this successional process: initial colonisation was dominated by microfilamentous brown algae, cushion stars, hermit crabs and herbivorous gastropods. This was followed by the establishment of sciaphilic invertebrates and a notable increase in the populations of various fish species (Jaffrey et al. 2001, 2002, 2003). However, subsequent surveys have also indicated that these modules were colonised by the invasive Mediterranean fanworm (*Sabella spallanzanii*), providing a stark example of the risk AAHs can pose in aiding the spread of non-indigenous species (similar to marine farms, as indicated in Taylor et al. 2015 and Atalah et al. 2020; Figure 6).

Monitoring of key marine AAH sites has shown that purpose-built structures and shipwrecks support a diverse spectrum of temperate rocky reef fish that encompass a variety of trophic levels, ranging from encrusting biota to mobile fish:

- **Prefabricated reefs:** Reef ball installation at Long Bay–Okura Marine Reserve rapidly attracted a diverse fish assemblage, including snapper, trevally / araara (*Pseudocaranx dentex*), blue maomao (*Scorpis violacea*), sweep / hui (*Scorpis* sp.), goatfish / āhuruhuru (*Upeneichthys lineatus*) and parore (*Girella tricuspidata*; Jaffrey et al. 2001, 2002, 2003). This was similar to observations around reef units deployed in the Bay of Plenty (Ōpōtiki Community REAF Trust 2010; Appendix A3.1) and habitat mimics in Tauranga Harbour (Ellis-Smith et al. 2025; Appendix A3.5).
- **Boulder reefs:** Artificial reefs formed by relocated limestone boulders in Hawke Bay showed rapid biofouling by encrusting biota, followed by the recruitment of green-lipped mussels / kuku (*Perna canaliculus*), kōura / crayfish and finfish (Sneddon 2023).
- **Shipwrecks:** The intentional HMNZS *Canterbury*, HMNZS *Wellington*,[3] *Rainbow Warrior*, SS *Tui* and SS *Taioma* shipwrecks all supported a dense encrusting community of sponges, anemones and hydroids (Szabo and Grace 1996; Robertson and Jacobs 2011; Fish Forever 2012; Robertson 2012; Booth 2020; Rideout 2025). Critically, the *Canterbury* site provides one of the few comparative datasets in Aotearoa New Zealand benchmarking an AAH against natural reef systems. Booth (2020) noted that while the wreck supported a distinct assemblage, it held lower abundances of key species such as snapper compared to adjacent natural reefs. This finding aligns with international observations that AAHs often mimic, but do not perfectly replicate, natural ecosystems (e.g. Carr and Hixon 1997), although community convergence may improve as the structure ages (Paxton et al. 2024b). However, unintentional (i.e. incidental) wrecks such as the MV *Rena*, MS *Mikhail Lermontov* and RMS *Niagara*[4] also deliver cautionary examples of the environmental devastation that may supersede the development of aquatic habitat (e.g. Grzelewski 2009; Freeman 2014; Webby 2014; Battershill et al. 2016; Reihana 2016; Ross et al. 2016; Schiel et al. 2016; Faaui et al. 2017; Te Ūaka The Lyttelton Museum 2025).

[3] https://www.stuff.co.nz/nz-news/360876102/world-class-shipwreck-dive-edge-city
[4] https://www.boxfishrobotics.com/shipwrecks/rms-niagara

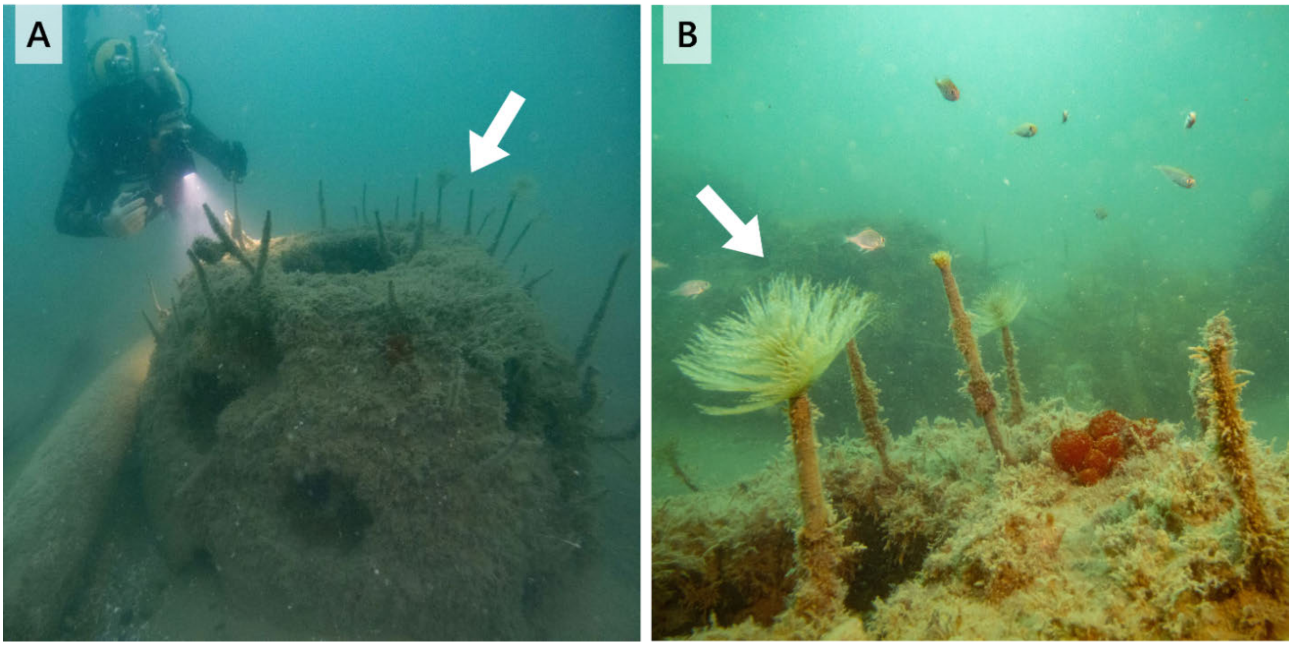

Figure 6. (A) Reef ball artificial reefs in Long Bay–Okura Marine Reserve, Auckland. (A, B) White arrows point to invasive Mediterranean fanworm (*Sabella spallanzanii*). Photo credit: Shaun Lee.

Use and knowledge of intentional AAHs in Aotearoa New Zealand is varied, offering scattered insights into what works in local conditions and highlighting critical management challenges. For example, the Ōpōtiki Community REAF Trust and Sea Nest projects are community-led efforts to create purpose-built structures designed to contend with local conditions, minimise environmental impact and provide localised enhancement to complex seafloor habitat (Appendices A3.1 and A3.2). In contrast, the *Rainbow Warrior* wreck suffered from souvenir-taking by divers before a greater sense of protection was established (Szabo and Grace 1994), and adherence to the voluntary no-take zone around the SS *Taioma* has been imperfect, as evidenced by the presence of discarded fishing line (Robertson 2012). Similarly, while artificial surf breaks were initially touted as 'multiple-use options' for coastal protection and marine ecology (e.g. Harris 2003; Mead and Black 2005; Moores 2006; Mead 2009), their failure underscores the significant risk posed by high-energy environments and the need for robust structural assessments prior to deployment (FOCUS 2013; Reid and Sumner 2021).

The inclusion of fish aggregating devices (FADs) in our review was driven, in part, by survey respondents emphasising that future AAH deployments must generate genuine ecological value rather than merely functioning as FADs that facilitate extraction. By definition, FADs are designed to modify species distribution and behaviour to increase catchability (Gershman et al. 2015). In Aotearoa New Zealand, these effects manifest in two distinct ways: as incidental coastal habitats, and through Aotearoa New Zealand's engagement with Pacific fisheries. Domestically, the extensive structures of the marine aquaculture industry have been recognised as a network of incidental, semi-permanent FADs (Gibbs 2004). Research from Aotearoa New Zealand and overseas indicates that bivalve farms (e.g. mussel lines) act analogously to traditional FADs by providing suspended structure that offers shelter, food and settlement surfaces for both commercial and non-target species (Gibbs 2004; Callier et al. 2017; Underwood and Jeffs 2023). Given the spatial scale of these farms, understanding their influence on fisheries dynamics is critical, as they effectively serve as large-scale artificial reefs that can modify coastal carrying capacity (Gibbs 2004). Crucially, however, the perception that these structures function solely by aggregating biomass is evolving; recent evidence suggests that they also assist with net production – for example, by supporting early-settlement juveniles (e.g. Underwood and Jeffs 2023).

In pelagic offshore systems, drifting FADs (dFADs) are not a primary feature of Aotearoa New Zealand's domestic tuna fishery, which relies largely on visual detection (Hill-Moana et al. 2025). However, Aotearoa New Zealand entities remain central to the management and study of dFADs across the wider Western and Central Pacific Ocean (WCPO). Research led by Aotearoa New Zealand scientists has been pivotal in deciphering the ecological mechanisms of these structures – such as the acoustic cues used by fish to locate them (Ghazali et al. 2013) – and in addressing the consequences of their design, including bycatch mitigation and marine pollution (Escalle et al. 2023; Peatman et al. 2023). Consequently, this literature can offer critical insights for future AAH implementation into the behavioural mechanisms of fish attraction, helping to bridge the gap between structural design, fish response and fishing pressure.

Available guidance

Several guidance documents are now available to support the implementation of AAHs in Aotearoa New Zealand's marine systems, offering important best practice recommendations for design, deployment and long-term management (e.g. Morrison 2018; Sea et al. 2023). These guidelines emphasise that AAHs should be planned with clear ecological objectives, rather than used to dispose of inorganic material, a point also raised by survey respondents in this report (Morrison 2018, 2021; Handley 2022; Sea et al. 2023). Successful projects are those designed to replicate natural habitat features or restore ecosystem functions that have been lost, such as providing complex hard surfaces in areas degraded by sedimentation or fishing pressure – as demonstrated in examples such as habitat mimics and shell-addition restoration (Benjamin et al. 2024; Ellis-Smith 2025; Appendix A3.5).

Material choice is central to project success. Durable and environmentally compatible materials such as concrete modules or natural boulders tend to be preferred, while 'materials of opportunity', including scuttled vessels, come with significant long-term risks such as storm-related movement, chemical leaching and structural failure. Site selection is equally important. AAHs should be placed where water quality and larval supply can support faunal recruitment, and where new structures improve habitat connectivity rather than create fragmentation. To avoid relying on simple fish aggregation, designs should aim to increase the ecological capacity of the environment by providing settlement surfaces, juvenile shelter or other forms of functional habitat. Finally, as with freshwater interventions, marine AAHs require thorough baseline monitoring before deployment and a long-term adaptive management plan to determine whether they are supporting genuine ecosystem recovery or acting primarily as FADs.

4.4 Costs vs benefits of artificial aquatic habitat implementation

A credible cost–benefit analysis requires a comprehensive and realistic accounting of all financial liabilities associated with an AAH project across its entire life cycle. Since there are few purposeful AAH projects available in Aotearoa New Zealand to consider this across the whole project life cycle, additional work (outside the scope of this report) is needed to provide a more comprehensive analysis. However, it is possible to take findings from international examples and a few national ones (e.g. the case studies presented in Appendices 2 and 3) to establish how this might be done.

In general, the initial investment to establish an AAH reef extends beyond the physical structure itself. For example, the 'soft costs' associated with planning, consenting and engagement are substantial and foundational to a project's viability. However, the tendency to focus on the visible 'sticker price' of materials or a vessel can lead to critical under-budgeting and project failure. The true cost encompasses a wide range of capital and operational expenditures that must be established from the outset.

Costs

Planning, consenting, cultural engagement and time

The implementation of an AAH is often a complex, multi-phase undertaking that requires significant investment in expertise and process. This includes carrying out initial feasibility studies, rezoning marine areas, undertaking detailed site selection surveys to assess environmental conditions (e.g. to avoid sensitive habitats), and securing the necessary resource consents and permits from regulatory bodies. The planning process itself, as outlined in comprehensive international guidelines (e.g. IMO / UNEP 2009) and national guidelines (e.g. Barrett et al. 2024), involves numerous steps, from conceptualisation to engineering design and risk assessment, each with associated costs.

In the unique context of Aotearoa New Zealand, subject matter experts suggested that a critical and non-negotiable component of this initial phase is genuine partnership and co-design with mana whenua. All discussions and strategies must be based on te Tiriti o Waitangi principles to ensure cultural values are respected, mātauranga Māori is integrated where possible, and social licence from the community is obtained. This process of meaningful engagement, including hui facilitation and collaborative planning, represents a significant and essential upfront cost. Additionally, projects that include a protective component, such as the establishment of a marine preserve or rāhui (as seen with the HMNZS *Canterbury*, Booth 2020), need to account for time to implement protection policies that may involve policy or plan changes as well as subsequent compliance monitoring.

Material acquisition and preparation

The choice of material is a primary driver of cost and can vary dramatically. Minimally modified or opportunistic natural materials such as wood and rock are often the most cost-effective and accessible options, particularly for small-scale freshwater or community-led projects where budgets are limited (e.g. Appendix 2). However, the logistical costs of transporting heavy materials such as boulders, or the potential for degradation of organic materials such as wood, must be weighed against their lower initial purchase price. Purpose-built modules made from concrete or steel offer high durability and can be designed for specific ecological objectives, as seen in the New South Wales artificial reef programme[5] and Te Ara Tupua artificial reef project (Bell et al. 2023; Appendix A3.4).[6] Alternatively, use of decommissioned vessels or oil rigs can require significant amounts of preparation, representing major

[5] https://www.dpi.nsw.gov.au/fishing/recreational/resources/artificial-reef

[6] https://nzta.govt.nz/assets/projects/te-ara-tupua/te-ara-tupua-enhanced-reef-habitat-factsheet-february-2024.pdf

costs towards projects (e.g. Morrison 2018; Sea et al. 2023). To prevent long-term pollution, vessels and oil rig components must be meticulously cleaned and stripped of all hazardous materials, including residual fuels, oils, toxic paints, asbestos and polychlorinated biphenyls (PCBs). This decontamination process is labour intensive, requires specialised handling, and is a legal and ethical prerequisite for deployment (IMO / UNEP 2009; DCEW 2023).

Acquisition and deployment costs

The direct costs of acquiring and deploying AAHs, especially for large-scale (i.e. ≥ 1 ha) projects, can be substantial. For example, the San Diego Oceans Foundation paid US$235,000 (approximately NZ$387,000) to acquire the 366 ft destroyer escort HMCS *Yukon*.[7] The subsequent additional costs for preparation, towing and sinking were significant. Comparable projects in Aotearoa New Zealand demonstrate similar financial magnitudes: Te Ara Tupua project cost approximately NZ$11 million (Appendix A3.4), the multi-function reef at Mount Maunganui cost around NZ$1.5 million and the artificial reef project at Ōpunake exceeded NZ$1.1 million before ultimately being abandoned (Reid and Sumner 2021).

These examples demonstrate that the acquisition cost is often only a fraction of the total upfront investment required to successfully establish large AAHs. In several cases – particularly the surf reefs – project failure was linked not only to underfunding, but also a broader underestimation of the project's total complexity. This underscores the need for budgets that treat planning, design and engagement as core, non-negotiable project costs rather than optional preliminary overheads. AAHs, whether intentional or incidental, are not static, one-time deployments. They function as dynamic, long-lived pieces of infrastructure that require ongoing investment to ensure their ecological performance, structural integrity and public safety (IMO / UNEP 2009; DCEW 2023). Failing to secure a dedicated, long-term funding stream for operational costs can rapidly lead to AAHs becoming liabilities rather than assets.

Monitoring and maintenance

Long-term monitoring is fundamental to determine whether an AAH is achieving its stated objectives and to enable adaptive management (IMO / UNEP 2009; DCEW 2023). This involves regular ecological surveys to track biological succession – similar to those undertaken for the Waituna Creek restoration project (Holmes and Goodwin 2021), the Long Bay–Okura Marine Reserve reef balls (Jaffrey 2004), and the HMNZS *Canterbury* (Booth 2012, 2020), SS *Taupo* and SS *Taioma* (Robertson 2012) wrecks – so that species composition and abundance can be assessed over time. Monitoring also requires structural integrity assessments to monitor for degradation or movement, and surveillance for the potential establishment of invasive species, which can be facilitated by the introduction of new hard substrate. Furthermore, associated infrastructure requires maintenance (DCEW 2023). Mooring buoys, which can be highly desired by user groups such as divers and anglers to prevent anchor damage and improve site access, must also be regularly inspected and replaced, representing a recurring cost.

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[7] https://abcnews.go.com/Travel/story?id=118328andpage=1#:~:text=Divers%27%20affection%20for%20the%20new,county%20to%20explore%20the%20site

Risk, remediation and end of life

A comprehensive financial plan must account for the risk of project failure and the potential costs of remediation. For example, the HMNZS *Wellington*, scuttled as a dive wreck off Wellington, broke up in storms, creating a debris field and altering the intended structure.[8] More dramatically, the failed Mount Maunganui surf reef was ultimately deemed a public hazard and had to be removed at a significant additional cost to the community (Reid and Sumner 2021). This demonstrates that a worst-case scenario involves not only the complete loss of the initial capital investment, but also significant additional expenditure on removal. A credible cost–benefit analysis should therefore project operational expenditure over the intended lifespan of the reef (e.g. 20–50 years) and include a risk-adjusted contingency fund for potential remediation or end-of-life decommissioning.

Benefits

The returns on an investment in AAHs can be multi-faceted, spanning quantifiable economic gains, vital ecological services (e.g. see Section 4.1), and significant social and cultural value. However, while the economic dimensions of AAH projects – particularly tourism and fisheries enhancement – are relatively well documented internationally (e.g. Pollard 1989), the ecological and habitat-restoration benefits are less consistently evaluated and remain understudied in Aotearoa New Zealand. International research demonstrates clear ecological gains in many contexts, including increases in fish abundance, habitat quantity and coral cover (Higgins et al. 2022). Meta-analyses also show that artificial reefs can support fish assemblages comparable to those of natural reefs, although outcomes vary by location and design (Paxton et al. 2020).

Aotearoa New Zealand has only recently (i.e. since 2000) begun to generate empirical evidence on the ecological performance of purposeful AAHs. The projects presented in Appendices 2 and 3 provide some of the best domestic examples that have systematically monitored (or are monitoring) long-term ecological outcomes. Projects such as the Sea Nest Kōhanga Moana Pilot Reef (Appendix A3.2) and Te Ara Tupua Reef Enhancement (Appendix A3.4) have reported rapid colonisation by indigenous species and measurable biodiversity gains within the first year of deployment (similar to the reef balls in Long Bay–Okura Marine Reserve, Auckland). These examples highlight a growing interest in using engineered structures to support ecological restoration, yet they also emphasise how sparse the evidence base remains relative to other countries where artificial reef deployment has a longer history.

From an economic perspective, the most compelling financial returns from international AAH projects arise through tourism and fisheries enhancement. In some regions, iconic shipwreck reefs function as destination attractions for recreational scuba diving, generating substantial local revenue. For example, the wreck of the SS *Yongala* near the Great Barrier Reef supports regional dive tourism that is estimated to generate more than AU$1 million AUD (approximately NZ$1.13 million) annually from organised dive trips, excluding secondary spending on flights, accommodation and other services (Viduka 2008). Fisheries enhancement represents a second major economic pathway, with several reviews recognising both the potential benefits and the need for careful site-specific assessment (Lima et al. 2019; Paxton et al. 2020). For example, in Australia, the New South Wales artificial reef programme is explicitly funded by recreational fishing licences to improve angling opportunities for key species such as snapper and

[8] https://www.nzherald.co.nz/nz/dive-wreck-frigate-ruled-off-limits/J6S5HRODCBUHFLEYU32HTLIBMI

kingfish.[9] However, the use of AAHs remains under debate and should be evaluated very carefully to avoid further overexploitation, especially for taonga fishery species throughout Aotearoa New Zealand.

The scale of economic returns is tightly linked to the type and visibility of the AAH. An AAH project in Aotearoa New Zealand would likely require a significant, marketable asset, such as a navy shipwreck (e.g. HMNZS *Canterbury* and HMNZS *Wellington*) capable of drawing domestic and international tourism. Alternatively, smaller, modular reefs targeted at local recreational fishers (e.g. Ōpōtiki Community REAF 2010; Gardiner 2022) can provide positive local economic impact, but its scale will be orders of magnitude smaller. Additionally, AAHs may provide indirect conservation benefits by diverting user pressure away from sensitive or overused natural reef ecosystems (e.g. Leeworthy et al. 2006), although further research is needed to quantify this effect in Aotearoa New Zealand.

4.5 Knowledge gaps for artificial aquatic habitat implementation and management

Given the immense number of structures submerged nationwide, AAHs undoubtedly provide a significant – yet undervalued and understudied – contribution to available aquatic habitats (e.g. Paxton et al. 2020; Salauddin et al. 2021). Recognising this undervalued resource presents an opportunity: designing purpose-built AAHs to assist with ecological recovery where appropriate, and leverage incidental structures for both their engineering functions and their capacity to provide habitat. Situated at the interface of whenua (land) and wai (water), incidental AAHs warrant additional consideration for their potential to reconnect and revitalise fragmented coastal ecosystems, including those that exist in the liminal margins between habitats that are often engineered out of existence (e.g. dunes, saltmarshes, estuaries) (Gesing 2016; Jenks 2018).

In general, all submerged structures will function as an aquatic habitat, although their ecological quality varies significantly. It is an ecological truism that any hard substrate introduced to the water column will eventually be colonised; however, not all colonisation equates to a functioning, productive ecosystem. Without deliberate design, incidental structures often lack the complexity required to support diverse life stages, acting instead as simple aggregation devices for adult fish or, in worse scenarios, as stepping stones for invasive species (Atalah et al. 2020; Paxton et al. 2020). Understanding the specific structural traits – such as rugosity, crevice availability and shading – that differentiate a productive reef from a simple 'bio-fouled wall' will be critical for transforming our existing infrastructure from passive occupants of the coastal zone into active contributors to marine biodiversity (Paxton et al. 2020).

Below, we outline five key knowledge gaps for AAHs in Aotearoa New Zealand identified from the survey responses and literature review that can be used to guide future research, implementation and management.

1. **Limited understanding of how to design and retrofit nature-positive aquatic infrastructure.** There is a major knowledge gap in how best to integrate ecological principles into the design of new and existing aquatic infrastructure. It remains unclear which design features, materials and

[9] https://www.dpi.nsw.gov.au/fishing/recreational/resources/artificial-reef

retrofitting methods are most effective in Aotearoa New Zealand's specific environmental conditions. Furthermore, little is known about how interventions such as tidepool retrofits or eco-engineered seawalls influence long-term ecological function, or how they can be scaled across diverse infrastructure types.

2. **Limited ecosystem-scale understanding for strategic AAH planning.** AAHs are often planned and assessed at the scale of individual structures, but there is limited knowledge about how they function within broader ecosystem processes, including ki uta ki tai (mountains-to-sea) connectivity. More research is needed to identify the ecological roles AAHs can play in habitat restoration and biodiversity support, and in facilitating the movement of native, rather than invasive, species. There are also gaps in understanding around how artificial structures interact with endemic flora and fauna, whether they promote or disrupt connectivity, and how Aotearoa New Zealand–specific site selection criteria should be developed.
3. **Limited evidence on material performance and design innovation for Aotearoa New Zealand environments.** Although new materials and fabrication techniques (e.g. 3D-printed concrete, shell-based substrates and other waste-derived components) are emerging, there is insufficient knowledge about their long-term ecological performance, durability and environmental safety in local conditions. Key uncertainties also remain around toxicity, pH alteration, colonisation suitability and structural longevity in high-energy coastal environments. Comparative testing of materials and design innovations remains a major gap that constrains evidence-based decision-making.
4. **Insufficient regulatory clarity for restoration-focused AAHs.** There is a clear gap in regulatory guidance for AAH projects whose primary aim is ecological restoration rather than commercial development. Current consenting frameworks treat restoration-focused AAHs similarly to large coastal developments, and the absence of specific policy pathways creates uncertainty for practitioners. Additional work is needed to determine how regulatory processes could differentiate between extractive, commercial and restorative interventions, what criteria would underpin streamlined approval pathways, and how ecological benefits could be formally incorporated into decision-making.
5. **Lack of governance, coordination and standardised monitoring across AAH projects.** AAH projects in Aotearoa New Zealand have largely been implemented on an ad hoc basis, with minimal coordination, inconsistent monitoring and limited connection to prior initiatives. As a result, there is a significant knowledge gap regarding how these structures support endemic biodiversity compared with natural habitats, and little ability to generalise outcomes across projects. In addition, there are no national standards for material selection, construction methods, siting or ecological monitoring. This creates a risk of 'social–ecological traps', where projects driven by short-term social or economic goals inadvertently undermine long-term ecological outcomes.

While evidence on the long-term ecological performance of AAHs in Aotearoa New Zealand is still emerging, an extensive international knowledge base provides valuable guidance for shaping best practice and avoiding unnecessary trial and error. In freshwater systems, global meta-analyses highlight the need to move beyond localised structural fixes towards process-based restoration that addresses the underlying drivers of habitat simplification (e.g. Roni et al. 2008). In the marine environment, rapidly advancing frameworks for nature-inclusive or nature-positive infrastructure offer practical pathways for embedding ecological principles into engineering design – from understanding fine-scale habitat complexity such as shipwreck ecology (Paxton et al. 2024b) to applying broader seascape-scale planning approaches (Paxton et al. 2020, 2024a). Drawing on these international insights and aligning them with Aotearoa New Zealand's unique biogeography and cultural context will be essential for designing AAHs that do more than offset impacts. When strategically planned, grounded in mātauranga and ecological science, and integrated into wider restoration efforts, AAHs have the potential to transition from reactive mitigation tools to active contributors in the recovery and long-term resilience of Aotearoa New Zealand's aquatic ecosystems.

5. Appendices

Appendix 1. Survey questions and summary of responses on the implementation of artificial reefs [AAHs] in Aotearoa New Zealand

A1.1 Survey questions

The survey consisted of 12 main questions designed to capture a broad spectrum of views on the definition, principles, concerns and implementation of artificial reefs [AAHs].

Section 1: Artificial reef definitions

1. Which definition do you support? [Possible responses included: Definition A, Definition B, both, neither.]

   Definition A – *London Convention and Protocol / UNEP: Guidelines for the placement of artificial reefs* (IMO / UNEP 2008):

   An artificial reef is a submerged structure deliberately constructed or placed on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating, and / or enhancing populations of living marine resources. Objectives of an artificial reef may include: the protection, restoration and regeneration of aquatic habitats, and the promotion of research, recreational use opportunities, and educational use of the area. The term artificial reef does not include: submerged structures deliberately placed to perform functions not related to those of a natural reef – such as breakwaters, mooring, cables, pipelines, marine research device platforms – even if they incidentally imitate some functions of a natural reef.

   Definition B – *National artificial reef guidelines. Version 1.0* (DCEW 2023):

   An artificial reef means a structure or formation placed on the seabed for the purpose of: Increasing or concentrating populations of marine plants and animals, or being used in human recreational activities. Artificial reef placement means the placement of any controlled material into the sea for the purpose of creating an artificial reef, being a placement that is not contrary to the aims of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972.

2. What changes, if any, would you make to your chosen definition were it to be used to guide artificial reef development in Aotearoa New Zealand?

Section 2: Artificial reef [AAH] guidelines

3. Do you support the development of standardised guidelines for the construction and management of artificial reefs [AAHs] in Aotearoa New Zealand?

4. If yes, why? If no, what are your reasons for not supporting guidelines for artificial reefs [AAHs]?

Section 3: Artificial reef [AAH] guidelines principles

[Respondents were asked to rate the importance of 15 potential guiding principles (and content) to be included in future guidelines for artificial reef [AAH] development on a scale of 1 (not important) to 5 (very important). This section also included space at the end to offer additional principles that respondents may have wanted to include.]

5. Guiding principles [and content]:

   (5A) *Honour te Tiriti o Waitangi*: Recognise the principles of partnership, protection and participation enshrined in te Tiriti. Engage with tangata whenua from the outset of any project, ensuring their full and active participation in all stages of the project.

   (5B) *Respect the mauri / health and well-being of the ecosystem*: Assess and prioritise, wherever possible, the protection of the marine environment. Ensure artificial reefs [AAHs] enhance, rather than diminish, the overall health and well-being of the ecosystem.

   (5C) *Embrace kaitiakitanga*: Uphold the principles of kaitiakitanga by prioritising the long-term sustainability of the reef and its surrounding environment. Consider the impacts on future generations of the whole community (man and nature).

   (5D) *Prioritise native species*: Design and construct reefs to specifically attract and support native Aotearoa New Zealand aquatic fauna. Promote biodiversity and the restoration of natural habitats and / or functions.

   (5E) *Minimise environmental impacts*: Conduct thorough environmental impact assessments before, during and after reef placement to identify and mitigate potential risks. DO NOT use this as an excuse to dump refuse. Use non-toxic, durable materials and avoid sensitive areas at all costs.

   (5F) *Optimise for functionality and site specificity*: Not all sites on the seabed or across Aotearoa New Zealand are equal! Design the reef to maximise ecological function suited to the environment of the specific site and ecological community. For example, what works in Wellington Harbour may not work in Auckland Harbour. Consider factors such as water flow, substrate type and habitat complexity. Monitor and adapt the design as needed.

   (5G) *Champion community engagement*: Foster open communication and collaboration with all stakeholders, including iwi, community groups, fishing communities and scientists. Share information and address concerns transparently.

   (5H) *Ensure accessibility for mahinga kai*: Consider the potential for the reef to enhance mahinga kai opportunities. Work with tangata whenua to ensure sustainable harvesting practices.

   (5I) *Commit to long-term monitoring*: Implement a robust monitoring plan to assess the reef's performance over time. Track ecological changes, evaluate success and adapt management strategies as needed.

   (5J) *Seek continuous improvement*: Stay informed about the latest research and best practices in artificial reef [AAH] development. Contribute to the growing body of knowledge and strive for ongoing improvement.

(5K) *Case studies*: Documented artificial reef [AAH] development case studies that show individual project aims, summary of learnings and advice for future work and approaches to community engagement. [Note: respondents were provided with space to list case study examples in the next section.]

(5L) *Technical information* related to artificial reef [AAH] materials and design. [Note: respondents were provided with space to list examples of technical information in the next section.]

(5M) *Regulatory*: National and local regulatory processes involved in consenting and monitoring of artificial reefs [AAHs]. [Note: respondents were provided with space to list regulatory examples in the next section.]

(5N) *Artificial reef [AAH] function-specific criteria* (i.e. what would be involved in reefs that focus on: biodiversity enhancement, fisheries enhancement, nature-based solutions, recreational).

(5O) *Additional information and resources*, including international guides, list of relevant literature, international examples.

6. Please add any further items that should be included or identify items that should not be included in future guidelines.

Section 4: National and local resources

[Respondents were asked to provide specific information on the following areas.]

7. (7A) *Monitoring*: Please list any relevant standardised monitoring protocols for aquatic habitats that you think could be used to monitor artificial reefs [AAH] (e.g. monitoring for state of the environment, contaminants, invasive / pest species, fisheries species, etc.).

(7B) *Regulatory*: Please list any statutory and / or non-statutory documents related to artificial reefs [AAHs] in Aotearoa New Zealand.

(7C) *Technical*: Please list any technical criteria (e.g. materials, design) that you believe would be crucial to include in the production of future guidelines.

(7D) *Costs*: Please list any relevant costs that you are aware of related to artificial reef [AAH] design, deployment and monitoring (e.g. divers' time, reporting time, permits / consents).

(7E) *Case studies*: Are there any examples of artificial reef [AAH] projects throughout Aotearoa New Zealand that you think deserve specific mention in the guidelines / subsequent appendices (e.g. Wellington Harbour, *Canterbury* wreck, *Rainbow Warrior*)?

Section 5: Artificial reef [AAH] concerns

[Respondents rated their level of concern related to the development of artificial reefs [AAHs] for the following on a scale of 1 (not concerned) to 5 (very concerned). This section also included space at the end for respondents to include any additional concerns they might have.

8. (8A) *Environmental impact*: There are worries that [AAHs] may disrupt local ecosystems, alter sediment patterns and negatively affect native species.

(8B) *Invasive species*: Artificial reefs [AAHs] can attract invasive species that may outcompete native organisms, potentially harming local biodiversity.

(8C) *Pollution*: If materials used for artificial reef [AAH]s are not environmentally friendly, they can introduce harmful substances into the water, affecting the surrounding marine life.

(8D) *Fishing pressure*: While artificial reefs [AAHs] can bolster fish populations, they may also lead to overfishing in those areas due to increased accessibility for anglers.

(8E) *Objections from fishing industry*: Fishing interests have traditionally been opposed to reef and aquaculture structures that potentially restrict commercial fishing methods.

(8F) *Structural integrity*: Concerns about the longevity and stability of artificial reefs [AAHs] arise as deteriorating structures can pose hazards to navigation and marine life.

(8G) *Mismanagement and over-placement*: Poorly planned placement of artificial reefs [AAHs] can lead to ecological imbalance, with reefs overcrowding certain areas and leaving others barren.

(8H) *Social and economic issues*: The benefits of artificial reefs [AAHs] may not be equally distributed among local communities, leading to conflicts over resource use.

(8I) *Regulatory challenges*: There are often inadequate regulations governing the construction and maintenance of artificial reefs [AAHs], which can lead to poorly implemented projects.

(8J) *Aesthetic concerns*: Some individuals and stakeholders may have aesthetic preferences against artificial structures, viewing them as unattractive or unnatural.

(8K) *Limited research*: A lack of long-term studies on the ecological impacts of artificial reefs [AAHs] makes it difficult to ascertain their effectiveness and consequences fully.

Section 6: Common challenges

[Respondents were asked open-ended questions to identify some of the core challenges of developing artificial reefs [AAHs].]

9. *Implementation issues*: Please list any implementation issues that you foresee restricting the development of artificial reefs [AAHs] in Aotearoa New Zealand.

10. *Communication*: In your opinion, what are the best mediums to convey information about artificial reefs [AAHs] in Aotearoa New Zealand?

11. *Knowledge gaps*: What do you believe are the main knowledge gaps regarding the development of artificial reefs [AAHs]?

12. *Research*: In your opinion, what additional research is needed to better understand the effects and efficacy of artificial reefs [AAHs] in Aotearoa New Zealand?

A1.2 Summary of survey responses

Section 1: Artificial reef [AAH] definitions

Responses revealed a consensus for a definition grounded in ecological purpose, while highlighting critical adaptations necessary to ensure cultural resonance, prevent misuse and accommodate innovation. Most of the respondents (10 of 16) supported Definition A from the London Convention. The focus on emulating ecological function was identified as a key differentiator. One respondent articulated this preference clearly, stating, 'I also like the use of "emulate some functions of a natural reef" in the London definition'. This preference is further illuminated by concerns raised around Definition B's inclusion of 'human recreational activities' as a potential purpose. The same respondent feared that this broader scope could lead to unintended consequences, where 'other things that are not intended to be artificial reefs [AAHs] could fall into that definition unintentionally'.

While Definition A provides a strong foundation for outlining what constitutes an artificial reef [AAH], respondents were clear that it requires significant adaptation to be fit for purpose in Aotearoa New Zealand. The proposed amendments for an artificial reef [AAH] definition for Aotearoa New Zealand would embed the definition within the nation's cultural context, address specific risks and broaden the scope to include modern eco-engineering practices. The most frequently mentioned recommendation was the need to integrate a Te Ao Māori worldview directly into the definition. One respondent stated that in the Aotearoa New Zealand context, there 'must be an emphasis on Māori cultural values and specifically the connection to atua (gods) and whakapapa (genealogy) and how that links to how the community and specifically mana whenua connect to the coastal environment where the reef will sit'. This has practical implications for every stage of a project, influencing the cultural suitability of a location, and the reef's intended purpose and its naming conventions. Another respondent echoed this by questioning how taonga species could be included in the definition, suggesting that the purpose of an artificial reef [AAH] should be explicitly stated as restoring culturally significant species.

The survey responses indicated that the concept of an artificial reef [AAH] is evolving beyond standalone, purpose-built structures. The adopted definition must therefore be forward-looking and flexible enough to accommodate innovation. For example, respondents signalled that it is becoming more common to 'eco-enhance' dual-purpose structures such as seawalls, breakwaters and piles, 'which are engineered to incorporate ecological features'. A broader definition could facilitate their recognition as valuable reef habitats that 'may act similar to an artificial reef, as well as distinguishing between different "offshore" subtidal reefs and other interventions performed along the shorelines (e.g. living seawalls, artificial tide pools, etc.)'. Definitions A and B, with their focus on structures 'deliberately constructed or placed', could inadvertently prevent the recognition of materials installed in the marine environment as artificial reefs [AAHs]. However, the respondents also signalled that care needs to be taken within the adopted definition so that artificial reefs [AAHs] are not co-opted for purposes that run counter to ecological enhancement.

Respondents called for a sharper definition with a specific focus on local ecology. This was reinforced by one participant, who suggested adding 'something about restoring or promoting settlement of indigenous biodiversity typical of the area, as opposed to pest species or species brought in that may not have occurred in an area'. Another respondent proposed a revised definition: 'An artificial reef is: a submerged structure deliberately constructed or placed on the seabed to emulate some functions of a natural reef such as providing habitat, protecting, regenerating, concentrating, and / or enhancing populations of living, indigenous, marine resources.'

Responses demonstrated a need for the definition to function as a critical gatekeeping mechanism for appropriate use of the guidelines. For example, one respondent warned that guidelines should include a section 'discussing conflicts of interest with the purpose of the AR [artificial reef], e.g. a fishing group purporting to install an AR for the purpose of increasing biodiversity but actually wanting a FAD [fish aggregating device]'. The concern is that without this clarity embedded at the definitional level, projects could be advanced under the guise of restoration while their true function leads to increased fishing pressure, a risk that was rated as a significant concern by several respondents. The strong desire for guidelines to 'avoid the ocean being used as a dumping ground' and to ensure people 'don't create FADs and manage pressures first' suggests that the definition is viewed as the first line of defence against misuse. By embedding core principles – such as ecological emulation, cultural connection and a focus on indigenous species – directly into the definition, the guidelines can immediately frame the national conversation around the acceptability of a project.

Section 2: Artificial reef [AAH] guidelines
The survey revealed a near-unanimous (13 yes, 2 no opinion, 1 no) and emphatic consensus on the need for standardised national guidelines for the development of artificial reefs [AAHs] in Aotearoa New Zealand. The hope expressed by one participant was that guidelines will 'encourage more deployments to rehabilitate many degraded / lost habitats' and add another well-defined tool for 'fast, large-scale solutions'. This mandate is not born from a desire for additional bureaucracy, but from a shared recognition of the risks from unguided approaches and the potential benefits of a coordinated, science-led framework.

A primary driver for the development of guidelines is the need to ensure the effectiveness and appropriateness of using artificial reefs [AAHs] for restorative purposes. Respondents were concerned with outcomes, and they see guidelines as the primary mechanism to prevent the creation of 'ineffective artificial reefs [AAHs] that don't enhance ecosystem services'. A closely related theme is the need for consistency and transparency. Multiple respondents described the current artificial reef development as following 'ad hoc approach[es]'. This lack of a standardised process leads to 'inconsistency in deciding what materials to use, locations, size and how to monitor success of structures'. Guidelines are seen as a partial solution to this fragmentation, providing a clear and transparent framework that can be applied consistently across the country, ensuring that all projects are held to the same high standard.

Perhaps the most urgent rationale was the imperative to mitigate risk and prevent harm. A number of respondents stated that, without clear rules, the concept of artificial reefs [AAHs] could be misused. The bluntest expression of this was the desire for guidelines 'to avoid the ocean being used as a dumping ground under the guise of "seabed restoration"'. This concern is echoed by others who state that it is important 'that they do not have adverse impacts on the marine environment' and that projects must have 'a clear purpose and be objective to avoid unforeseen negative effects'.

Survey respondents largely saw guidelines as a tool to build confidence and enable good projects. A well-structured framework would 'help clients, designers, engineers, ecologists, regulators, mana whenua and other stakeholders have more confidence in the methods, materials, approach and outcomes'. As one respondent noted, 'Having guidelines creates efficiencies and will help to overcome roadblocks for implementation'.

Respondents stressed the need for the guidelines to be evidence based and science led. They must be grounded in the best available science to ensure that the practices they recommend are robust and effective. This connects to the need for them to be purpose driven and objective led. The guidelines must also be flexible and adaptable – there was strong caution against creating a document that is overly prescriptive and stifles innovation. One participant warned that 'we also want to foster innovation and embrace advances in technology so any guidance should be "live", adaptable and not too prescriptive to allow for the best approaches to be used and support the best outcomes'. A key theme is that every artificial reef [AAH] project must have a clear, articulated purpose and measurable objectives against which its success can be judged. One respondent suggested the guidelines should include a 'flow chart or some way of assessing the requirement for an artificial reef', emphasising that natural reef restoration should be prioritised in the first instance.

One respondent answered 'No' to Question 3 around support. However, this was not out of opposition to standards, but based on a view of governance. This individual argued that 'management would likely be dealt with at a regional level which may lead to differences across Aotearoa', and suggested that 'a best practise guidelines for constructions would be [of] more use'. Another respondent from a different regional council expressed 'No opinion', stating that their support would 'depend on the scope of the guidelines'. This response was accompanied by specific concerns that poorly designed guidelines could inadvertently create barriers to progress. The participant noted they 'would not want to see prescriptive requirements for iwi or community engagement that hinder projects progressing when stakeholders have limited capacity to engage', and warned that 'realistically more onerous monitoring requirements … may be beyond the resourcing availability for some groups or projects'.

This implies that the national guidelines must explicitly position artificial reefs [AAHs] not as a panacea or a replacement for conventional marine management or native habitat restoration, but as one specific tool within a much larger, integrated toolkit. This framework must require proponents to demonstrate that they have considered and, where possible, addressed the systemic pressures on the marine environment (such as land-based sediment and nutrient run-off), and to provide a clear justification for why a purpose-built structure is the most appropriate intervention for a specific, well-defined ecological problem. Without this critical first step, the entire endeavour risks being perceived, rightly or wrongly, as a form of greenwashing that papers over, rather than addresses, underlying environmental issues.

Section 3: Artificial reef [AAH] guidelines principles

The survey presented respondents with 15 potential principles to be included in future guidelines. The ratings and comments offer a blueprint for the ethical, ecological and practical foundations of artificial reef development in Aotearoa New Zealand (Table A1.1). An analysis of this feedback reveals a clear hierarchy of priorities, such as those that involve Te Ao Māori and ecological integrity. There was less consensus around principles that seek to include technical and regulatory criteria. Ensuring access for mahinga kai and the inclusion of additional information / resources were also met with mixed perspectives. One respondent noted that these latter criteria (5K to 5O) needed to be 'articulated a bit better', but affirmed they were 'very relevant'.

Table A1.1. Summary of principles for guidelines of artificial reefs [AAHs] for Aotearoa New Zealand based on subject matter expert survey respondent ratings. Ratings were based on a scale of 1 (not important) to 5 (very important). For determination of consensus: 'Very high' = ≥ 75% of respondents gave the highest possible rating of 5, 'High' = ≥ 75% of respondents gave a rating of either 4 or 5, 'Mixed' = < 75% of respondents gave a rating of 4 or 5.

Principle ID	Principle description	Rating distribution (1 / 2 / 3 / 4 / 5 stars)	Average star rating	Consensus level
5A	Honour te Tiriti o Waitangi	0 / 0 / 0 / 6 / 10	4.63	High
5B	Respect the mauri / health of the ecosystem	0 / 0 / 0 / 1 / 15	4.94	Very high
5C	Embrace kaitiakitanga	0 / 0 / 0 / 1 / 15	4.94	Very high
5D	Prioritise native species	0 / 0 / 0 / 2 / 14	4.88	Very high
5E	Minimise environmental impacts	0 / 0 / 0 / 4 / 12	4.75	Very high
5F	Optimise for functionality and site specificity	0 / 0 / 0 / 2 / 14	4.88	Very high
5G	Champion community engagement	0 / 1 / 1 / 4 / 10	4.38	High
5H	Ensure accessibility for mahinga kai	1 / 2 / 3 / 4 /6	3.69	Mixed
5I	Commit to long-term monitoring	0 / 0 / 2 / 2 / 12	4.56	Very high
5J	Seek continuous improvement	0 / 0 / 2 / 5 / 9	4.31	High
5K	Include case studies	0 / 0 / 3 / 4 / 9	4.38	High
5L	Include technical information	0 / 1 / 1 / 4 / 10	4.38	High
5M	Include regulatory guidance	1 / 0 / 3 / 4 / 8	4.06	High
5N	Include function-specific criteria	0 / 0 / 2 / 7 / 7	4.31	High
5O	Include additional information and resources	0 / 0 / 5 / 5 / 6	4.06	Mixed

Section 4: National and local resources

Monitoring

A foundational principle emerging from the survey feedback was the necessity of baseline surveys. One respondent stressed that 'monitoring [programmes] should have a robust BEFORE installation component so that there is a solid baseline'. Respondents identified a suite of specific monitoring protocols and metrics that should be included in the framework. These range from established ecological survey methods such as underwater visual census (UVC) and baited remote underwater video (BRUVs) for fish populations, to benthic surveys using photoquadrats and invertebrate cores. Modern techniques such as eDNA analysis were also suggested as a possible monitoring approach. The monitoring should cover not just biodiversity, but also the presence of invasive species and contaminants, and physical impacts such as changes in sedimentation. To ensure consistency, respondents suggested leveraging existing frameworks where appropriate, such as:

- 'biodiversity and benthic quadrats'
- 'soft sediment ecological functioning'
- 'Auckland council monitoring … protocols for benthic ecology (soft sediment and rocky reef), water quality and sediment contaminants'
- 'ANZG, USEPA and CCME guidelines for water quality and contaminants'
- 'NZ fish monitoring protocols for wade-able streams; stream habitat assessment protocols'
- '[Society for Ecological Restoration] recovery wheel'
- 'reporting by reef users'
- 'Marine Cultural Health [programme]'
- 'DOC Marine Monitoring and Reporting Framework'.

However, there was also a strong recognition that a rigid, one-size-fits-all monitoring programme would be counterproductive. The guidelines must allow for flexibility, with monitoring requirements that are scaled to the size, complexity and potential risk of the project. A key idea that emerged to tie nationwide monitoring together is the development of a 'centralised database', where AAH practitioners can record and share monitoring data. This would create a national repository of knowledge, allowing for cross-project comparisons and facilitating the continuous improvement suggested by many of the respondents.

Regulatory

The survey respondents identified a wide range of regulatory documents and guidance materials relevant to artificial reef development in Aotearoa New Zealand (Table A1.2).

Table A1.2. Relevant regulatory and guidance materials for artificial reefs [AAHs] in Aotearoa New Zealand identified by survey respondents. Note that this is not an exhaustive list, and nor is it listed in any particular order; rather, it functions as a representation of survey responses.

Document	Description	Links and citations
Resource Management Act 1991	The primary statute governing environmental management, including activities in the coastal marine area.	https://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html
New Zealand Coastal Policy Statement 2010	National policy statement that guides local authorities in their management of the coastal environment under the Resource Management Act 1991.	https://www.doc.govt.nz/documents/conservation/marine-and-coastal/coastal-management/nz-coastal-policy-statement-2010.pdf
Maritime Transport Act 1994	Relevant legislation for the sinking of wrecks and navigational safety.	https://www.legislation.govt.nz/act/public/1994/0104/latest/DLM334660.html

Document	Description	Links and citations
Fisheries Act 1996	Relevant legislation for managing fishing activities on and around reefs, and for tools such as rāhui and mātaitai.	https://www.legislation.govt.nz/act/public/1996/0088/latest/DLM394192.html
Biosecurity Act 1993	The legislative framework for managing invasive species and biosecurity risks.	https://www.legislation.govt.nz/act/public/1993/0095/latest/DLM314623.html
Marine and Coastal Area (Takutai Moana) Act 2011	Legislation relevant to rights and interests in the common marine and coastal area.	https://www.legislation.govt.nz/act/public/2011/0003/latest/dlm3213131.html
Regional coastal plans	Statutory plans created by regional councils to manage the coastal marine area.	Various
Regional natural resources plans	Broader regional plans that can contain relevant provisions.	Various
Unitary plans	Combined plans, such as the Auckland Unitary Plan, that govern land and water use.	https://unitaryplan.aucklandcouncil.govt.nz/
Marine offsetting and compensation – summary of management guidance and policy	Greater Wellington Regional Council's guidance for marine offsetting and compensation. Contains additional regulatory documents that pertain to nature-based solutions.	Wilson and Oliver (2023)
Ecological impact assessment (EcIA). EIANZ guidelines for use in New Zealand: terrestrial and freshwater ecosystems	Guidelines for ecological impact assessment, including a marine addendum.	Roper-Lindsay et al. (2018)
Auckland Council monitoring protocols	Technical publications and protocols for monitoring benthic ecology, water quality and contaminants.	https://knowledgeauckland.org.nz/publications/auckland-community-ecological-monitoring-guide-a-framework-for-selecting-monitoring-methods
Australian and New Zealand Guidelines for Fresh and Marine Water Quality	Guidelines for water quality impact assessments for freshwater and marine systems.	https://www.waterquality.gov.au/anz-guidelines
Technical options for marine coastal habitat restoration in Te Tauihu	Technical report and literature review on marine restoration options for Te Tauihu / Top of the South.	Handley (2022)
Tangaroa Tohu Mana, Tangaroa Tohu Mauri: Marine Cultural Health Programme	A monitoring programme developed between mana whenua hapū and Napier Port to monitor the health of the marine	https://marineculturalhealth.co.nz/

Document	Description	Links and citations
	environment in and around the Ahuriri / Napier area.	
Guidance for large wood installations in New Zealand rivers	Guidance on large wood installations in Aotearoa New Zealand rivers, relevant for habitat structure principles.	Barrett et al. (2024)
Kotahitanga mō te Taiao Strategy	Strategic document that provides guidance on high-level outcomes to achieve significant conservation gains and social, cultural and economic benefits for Te Tauihu / Top of the South.	https://www.marlborough.govt.nz/repository/libraries/id:2ifzri1o01cxbymxkvwz/hierarchy/documents/environment/biodiversity/Kotahitanga_mo_te_taiao_Strategy.PDF
Te Mana o te Taiao ki te Tai-o-Aorere Tasman Biodiversity Strategy	Strategic document that addresses the restoration of indigenous biodiversity and associated biosecurity.	https://www.tasman.govt.nz/my-region/environment/environmental-management/biodiversity/tasman-biodiversity-strategy
Fisheries (Kaimoana Customary Fishing) Regulations 1998	Legislation related to customary fishing practices.	https://www.legislation.govt.nz/regulation/public/1998/0434/latest/DLM267987.html

Technical

A clear suggestion from survey respondents was for guidelines to include a detailed technical section. Regarding materials, the paramount concern is preventing environmental harm. Respondents insisted that materials must be non-toxic, durable and demonstrably free of contaminants. There were specific calls for the guidelines to include standards for 'Concrete MPa strength, steel and fibre reinforcing' and 'Maximum leaching concentrations of any potential contaminants', and advice on 'whether certain types of concrete are more eco-friendly than others'. Alongside setting standards for conventional materials, there is a strong desire for the guidelines to encourage innovation by providing information on the 'performance of alternative materials to industry standard steel and concrete, such as natural fibres and cement replacements'.

Regarding design, the criteria focus on maximising ecological function and ensuring structural integrity. Respondents called for designs that account for a site's hydrodynamics and consider whether the reef will enhance or reduce ecological connectivity with nearby natural habitats. From an engineering perspective, the guidelines should include respondent input on the 'constructability and durability of artificial reef structures' and how different designs can impact water flow. There was also a practical suggestion for the guidelines to provide a general description of common design types (e.g. those that protrude into the water column, those focused on the benthic environment, specific products such as reef balls) and to identify known manufacturers of these units.

Costs

The implementation issue most consistently identified by survey respondents was cost. The financial burden of artificial reef projects was mentioned by respondents from engineering firms, community trusts, environmental consultancies and government agencies alike. This is not simply the cost of materials; the expenses are comprehensive, spanning the entire project life cycle.

Respondents detailed a long list of costs, including initial design and engineering, the fabrication of moulds, construction of the reef units, transportation to the site and deployment logistics. Added to this are the significant 'soft costs' associated with stakeholder and public engagement, and the substantial time and expense of navigating the resource consent process. These are summarised in the lists below.

Artificial reef planning and materials
- consent development and submission
- permits
- rezoning of marine areas
- material purchase
- design, fabrication, construction and / or repurposing of artificial reef materials
- transport of materials.

Public engagement
- stakeholder engagement (e.g. paying for people's time to meet).

Monitoring
- monitoring logistics (e.g. cars, vessels, equipment)
- data storage
- laboratory analysis.

Safety
- safety markers if the artificial reef becomes a navigational hazard
- funds for contingency planning if the artificial reef fails.

Crucially, the costs do not end upon deployment. The respondent consensus is that best practice demands robust, long-term monitoring, which itself carries significant costs for dive time, vessel use, laboratory analysis and reporting. This financial reality is compounded by a perceived 'limited funding from clients / central / local government and philanthropic / NGO channels to pay for artificial reefs [AAHs]'. This creates a critical paradox: the respondents agree on the need for high standards in design, materials and monitoring, but they simultaneously recognise that the high cost of meeting these very standards is a primary barrier preventing many projects from ever getting off the ground.

Case studies
The survey respondents identified 18 artificial reef projects throughout the country that could be considered for inclusion as examples in future guidelines (Table A1.3).

Table A1.3. Examples of artificial reef projects / case studies from across Aotearoa New Zealand. Note that these are not listed in any particular order.

Case study	Location	Description
Te Ara Tupua artificial reef	Wellington Harbour / Port Nicholson	Artificial aquatic reef deployed as compensation for lost marine habitat as a result of cycleway construction.
Rainbow Warrior wreck	Bay of Islands	Shipwreck as habitat enhancement and a dive site.
MV *Rena* wreck (Astrolabe Reef)	Bay of Plenty	Shipwreck
Napier Port's Te Ohooho o Parapara Reef	Hawke Bay	Seafloor enhancement project making use of reclaimed limestone boulders to support native species recovery.
Sea Nest / Kōhanga Moana pilot	Bluff Harbour	Seafloor enhancement project to support native species recovery.
Ōpōtiki Community Reef	Bay of Plenty	Community-led project for seafloor enhancement.
Long Bay–Okura Marine Reserve reef balls	Hauraki Gulf / Tīkapa Moana	Community-led project for seafloor enhancement.
Oriental Bay Reef	Wellington Harbour / Port Nicholson	A structure in Wellington Harbour / Port Nicholson, noted as functioning as a reef although its primary purpose was coastal protection.
Auckland waterfront mussel restoration	Hauraki Gulf / Tīkapa Moana	A project using non-tidal floats with mussels and spat rope, functioning as a non-seabed artificial reef.
Ōhope fishing reef	Bay of Plenty	Artificial reef created for recreational fishing purposes.
Waituna Creek woody debris	Southland	Habitat enhancement in a riverine environment using large woody debris.
SS *Taupo*	Bay of Plenty	Shipwreck
SS *Taioma*	Bay of Plenty	Shipwreck
Bounty	Golden Bay / Mohua – Tasman Bay / Te Tai-o-Aorere	Shipwreck
Golden Bay barge wreck	Golden Bay / Mohua – Tasman Bay / Te Tai-o-Aorere	Shipwreck
HMNZS *Canterbury* wreck	Bay of Islands	Shipwreck as habitat enhancement and a dive site.
Hippolas wreck	Marlborough Sounds	Shipwreck
MS *Mikhail Lermontov* wreck	Marlborough Sounds	Shipwreck

Section 5: Artificial reef [AAH] concerns

The survey explicitly asked respondents to rate their level of concern for 11 potential issues associated with artificial reef development and to list any other concerns. The collective responses form a comprehensive risk register, highlighting the issues that respondents perceive as most threatening to the success and integrity of artificial reef projects in Aotearoa New Zealand (Table A1.4).

Table A1.4. Summary of concerns for artificial reef development in Aotearoa New Zealand by survey respondents. Ratings were based on a scale of 1 (low concern) to 5 (extreme concern). For determination of perceived risk level: 'Very high' = ≥ 75% of respondents gave the highest possible rating of 5, 'High' = ≥ 75% of respondents gave a rating of either 4 or 5, 'Moderate' = 50–75% of respondents gave a rating of 4 or 5, 'Low' = < 50% of respondents rated the issue as either a 4 or a 5.

Concern ID	Concern description	Rating distribution (1 / 2 / 3 / 4 / 5)	Average rating	Perceived risk level
8A	Environmental impact	2 / 3 / 4 / 3 / 4	3.19	Moderate
8B	Invasive species	1 / 3 / 4 / 5 / 3	3.31	Moderate
8C	Pollution from materials	1 / 1 / 3 / 5 / 6	3.88	High
8D	Fishing pressure	2 / 3 / 4 / 3 / 4	3.13	Moderate
8E	Objections from fishing industry	5 / 5 / 4 / 1 / 1	2.19	Low
8F	Structural integrity	1 / 3 / 8 / 2 / 3	3.13	Moderate
8G	Mismanagement and over-placement	0 / 2 / 7 / 4 / 4	3.63	High
8H	Social and economic issues	2 / 8 / 6 / 0 / 1	2.38	Low
8I	Regulatory challenges	1 / 2 / 4 / 5 / 4	3.50	High
8J	Aesthetic concerns	2 / 4 / 9 / 4 / 0	2.75	Low / Moderate
8K	Limited research	2 / 2 / 4 / 4 / 4	3.38	Moderate

The highest-rated concerns are 'Pollution from materials' (8C), 'Mismanagement and over-placement' (8G) and 'Regulatory challenges' (8I). The strong majority of respondents expressed high levels of concern that 'if materials used for artificial reefs [AAHs] are not environmentally friendly, they can introduce harmful substances into the water'. Similarly, the concern about mismanagement and over-placement leading to 'ecological imbalance, with reefs overcrowding certain areas and leaving others barren' received consistently high ratings.

The risk of invasive species is also acknowledged as a moderate concern. However, one respondent provided a particularly insightful comment, suggesting that the language of a reef 'attracting' invasives should be reviewed. Instead, the reef structures 'would only enable settlement of invasives already present in the existing environment', a problem that 'could be managed through adaptive management processes and use of citizen science / dive groups for removals'.

Some of the most profound concerns were not captured by the rating scale but were articulated in the open-ended responses (8L). Several respondents voiced a deep-seated concern that AAHs could become a distraction or a 'quick fix'. One respondent asked pointedly, 'What is the benefit of artificial reefs [AAHs] in a region vs. looking after the reefs we already have … Are they a distraction from a poorly managed system that needs fixing?' This was echoed by another, who worried that publicity might mislead people into thinking that AAHs are a 'quick fix for biodiversity declines' and could 'draw attention and funding away from restoring natural environments'. Another respondent cautioned against their 'overuse', stressing the importance of understanding 'where and when they are effective and where and when we can look to implement other restoration solutions'.

Section 6: Common challenges

Implementation issues

A primary implementation issue that was frequently cited by respondents is the difficulty of navigating Aotearoa New Zealand's regulatory and consenting framework. Respondents from multiple sectors identified this as a significant barrier. The process was described as involving 'onerous' consent requirements that can present a major hurdle for projects. This is compounded by what are perceived as 'restrictive regulatory and planning frameworks from both central and local government' that are 'not helping facilitate implementation'. The general sentiment was one of 'regulatory roadblocks via consenting pathways'. The challenge is multi-layered. At a high level, many regional plans contain provisions that 'restrict placement of structures on the seabed', although one respondent acknowledged that this is 'not a bad thing necessarily [and] will require good assessments of effects, and monitoring'. The overall perception from respondents was of a complex, time-consuming regulatory environment that is a major deterrent to the implementation of artificial reef projects (e.g. Nair et al. 2004).

The implementation issue most consistently identified by respondents was cost. The financial burden of AAH projects was mentioned by respondents from engineering firms, community trusts, environmental consultancies and government agencies alike. This financial reality is compounded by a perceived 'limited funding from clients / central / local government and philanthropic / NGO channels to pay for artificial reefs [AAHs]'. This creates a critical paradox: the respondents agree on the need for high standards in design, materials and monitoring, but they simultaneously recognise that the high cost of meeting these standards is a primary barrier preventing many projects from ever getting off the ground. Additional implementation issues related to appropriate iwi 'engagement' and 'partnership', as well as the 'ability to stop fishing on the reefs'.

Communication

Respondents recommended modern, wide-reaching channels for communication with the general public and building broad social licence. Social media and broadcast media were frequently mentioned as the best platforms for this purpose. The goal is to provide 'publicly available resources that [are] easy to understand for general public and accessible'. Webinars were also identified as a 'very powerful' tool for public and professional outreach.

For engaging with mana whenua, the feedback recommended direct, relationship-based communication. Wānanga and face-to-face kōrero were repeatedly identified as the most critical means to achieve this. One respondent emphasised that from a Māori context, 'wānanga and relationship building via face-to-face kōrero are critical to build a consensus of support'.

For the AAH professional and practitioner community, a different set of tools is required. These include traditional academic and professional channels such as newsletters, conferences and journal articles.

The guidelines themselves, along with other guidance documents from government and NGOs, are also seen as key communication mediums for this audience. The suggestion to 'make a PowerPoint deck and hit the road' suggests that a proactive, hands-on approach to engagement may be necessary.

Knowledge gaps

Throughout Aotearoa New Zealand, respondents recognised a lack of specific, localised scientific knowledge around existing AAHs. While there is a body of international research on AAHs, respondents expressed significant scepticism about its direct applicability to Aotearoa New Zealand's unique freshwater and marine context. A number of respondents suggested a need for more 'long-term research on outcomes' from projects within Aotearoa New Zealand.

Research

The research needs were indicated as being specific and practical. Respondents identified a critical need for more information on the efficacy of different materials and designs, particularly research into understanding the 'best [design] for which use', with a feeling that design is often ad hoc rather than based on comparative evidence. Another major research area identified by respondents was active restoration and species colonisation. Key questions that need answering include:

- 'how to promote colonisation by indigenous species, in preference to pest species'
- the effectiveness of active restoration methods such as 'seeding native species onto reef units to kick start establishment – [like] kelp and shellfish' and whether 'growth on artificial reefs [AAHs] will compensate for breakdown of materials over time'
- 'developing artificial reefs [AAHs] to benefit soft sediment communities'
- 'monitoring effects of different materials, [shapes], and [designs]'
- 'long-term' monitoring of 'durability' and reef 'outcomes'
- 'success of adaptive management approaches including … invasive species management'
- 'biodiversity gains and any trade-off[s]'
- 'biodiversity accounting models (e.g. BOAM and BCM) to predict / quantify the biodiversity benefits expected to be produced by reef installations … whether these models could be used to inform the design of artificial reefs [AAHs]'
- 'how to use informed environmental and socio-cultural data to place the right reef, in the right place, for the right purpose'
- quantification of 'benefits to biodiversity [and] ecosystem function'
- 'how to promote colonisation by indigenous species'
- 'pros and cons of different reef designs'
- how artificial reef design 'links to relevant legislation, [i.e.] RMA, Takutai Moana Act, Fisheries Act, etc.'
- 'sedimentation on efficacy' of artificial reefs [AAHs].

To address these gaps, respondents called for a more structured approach to research, including a comprehensive 'literature review' of existing knowledge in Aotearoa New Zealand, followed by 'pilot studies of building actual reefs' and 'trials of different structures, locations, purposes and protection regime combinations'.

This leads to a fundamental question about who the ultimate beneficiary is. As one respondent put it, the key research question is, 'Who / what will the artificial reefs [AAHs] ultimately benefit – commercial interests or the environment?', or, as another respondent asked, 'Do we actually need artificial reefs [AAHs]?'

A1.3 Discussion

The comprehensive analysis of subject matter expert submissions provides a clear call for action. The collective expertise of Aotearoa New Zealand's leading practitioners, scientists and regulators points towards a future where AAHs are an effective and well-governed tool for marine habitat restoration. To realise this future, the significant risks and barriers identified must be addressed through a strategic, coordinated national approach. The following recommendations synthesise the key findings of the survey into a set of high-level, actionable steps for developing national artificial reef guidelines.

Recommendation 1: Prioritise the development of national artificial reef guidelines for Aotearoa New Zealand

There was an overwhelming and unambiguous consensus among all subject matter experts that standardised national guidelines are essential. It was recommended that somebody act on this mandate with urgency. These guidelines were seen as the primary mechanism to ensure ecological effectiveness, mitigate environmental and social risks, provide consistency and transparency, and build the stakeholder confidence necessary to move the artificial reef field beyond its current ad hoc state.

Recommendation 2: Adopt a 'Te Ao Māori first' approach

The guidelines must be framed within a Te Ao Māori worldview from their inception and should be authored in partnership with mana whenua / mana moana. This requires more than a chapter on consultation; it means embedding the principles of te Tiriti o Waitangi, mauri and kaitiakitanga as the foundational, non-negotiable pillars of the entire framework. Partnership with mana whenua must be positioned as a core value that shapes every stage of a project, from its initial definition and purpose to its long-term management and the stories that are told about it.

Recommendation 3: Establish a 'why, not just how' decision framework

To address the critical strategic concern that AAHs could become a distraction from solving systemic marine health issues, it is recommended that the first section of the guidelines be a rigorous decision-making framework. This framework must compel practitioners to first answer the question of why an AAH is the appropriate intervention. It should require a clear articulation of the environmental problem, an assessment of the underlying pressures, and a justification for why a purpose-built structure is a better solution than, or a necessary complement to, protecting and restoring existing natural habitats.

Recommendation 4: Design a 'firm but flexible' guideline structure
The guidelines must navigate the 'enabler vs blocker' paradox. It is recommended that the guideline structure is firm on core principles but flexible in its operational requirements. The foundational values (e.g. ecological net benefit, Te Ao Māori partnership, use of non-toxic materials) should be non-negotiable national standards. However, requirements for implementation, and particularly for monitoring, should consider being scalable and tiered based on the size, cost and potential risk of the project. This will prevent the guidelines from becoming an insurmountable barrier for smaller, community-led or low-risk restoration initiatives.

Recommendation 5: Initiate a coordinated national research strategy
The survey identified significant and critical knowledge gaps that cannot be filled by individual projects. It is recommended that a coordinated national research strategy for artificial reef projects be developed and, if possible, funded in parallel with the guidelines. This strategy should be designed to systematically address the key questions identified by respondents, including the long-term performance of reefs in Aotearoa New Zealand conditions, the efficacy and durability of alternative materials, and best practice methods for promoting indigenous species colonisation. This research should feed back into the guidelines, ensuring they remain a living, evidence-based document.

Recommendation 6: Explore and propose sustainable funding and resourcing models
The review of survey responses revealed a critical 'monitoring–funding–feasibility doom loop', where the high cost of the long-term monitoring required for best practice is a primary barrier to implementation. It was recommended that the practitioners investigate and propose potential sustainable funding mechanisms to break this cycle. Options could include advocating for a portion of fisheries levies or environmental fines to be directed to a restoration monitoring fund, establishing criteria for access to centralised government funds, or developing frameworks that support public–private partnerships for restoration projects.

Recommendation 7: Champion a 'community of practice'
The process of developing and implementing national guidelines provides a unique opportunity to foster a cohesive national community of practice. It was recommended that this be an explicit goal. This could be supported through the creation of a centralised, publicly accessible database for case studies, monitoring data and technical resources, as called for by multiple survey respondents. Such a platform would facilitate shared learning, prevent the repetition of mistakes and accelerate the continuous improvement of marine habitat restoration across Aotearoa New Zealand.

Appendix 2. Freshwater case studies

A2.1 Woody material

Contributed by Robin Holmes (Cawthron Institute).

Project name and location	Waituna Creek Revitalisation Project, Awarua–Waituna Wetlands, Southland
Structure archetype	Installation of large logs and branch bundles in a stream.
Year established	2018
Organisations involved	DOC, Fonterra / Living Water, Te Rūnaka o Awarua, Whakamana te Waituna
Current status	Trial completed, with logs removed after 6 years.
Approximate dimensions	12 large logs (4 m × 0.5 m) placed into two 100 m stream reaches. Up to five temporary (mānuka) branch bundles were also trialled (approximately 1 m × 0.5m) at each site.
Materials and design	Large standpipes were driven into the streambed using a digger bucket. These were used to anchor the large logs in place by lashing with steel wire. Logs were placed approximately 10 m apart, alternating from left and right banks. Branch bundles were secured to the stream bed using steel waratahs.  Figure A2.1. One of the large logs angled upstream at 45° from the stream edge to direct high flows into the centre of the stream.

	 Figure A2.2. Two mānuka branch bundles anchored with waratahs mid-stream 1 year after installation.
Project site characteristics	Waituna Creek contributes 90% of surface flow to Waituna Lagoon, which is part of the wider Awarua Wetland Ramsar site. The stream has been channelised through peat swamp and contains excessively high levels of fine sediment and macrophytes.
Funding source(s) and approximate costs	DOC, Fonterra / Living Water. Approximately NZ$25,000 for installation of logs and bank rebattering (excludes planting costs).
Project purpose	Waituna Creek has been extensively altered over the past century to allow drainage for the catchment's farms. The creek has been straightened and the streambed lowered. These actions reduced the amount and quality of habitat for stream life. This restoration project attempted to improve the habitat quality in Waituna Creek by replacing structural habitat that would have been a feature of the creek in its past forested state. The restoration included installing a 'two stage' channel to improve native fish habitat while maintaining acceptable erosion rates, land drainage and the capacity of the channel to carry floods.
Outcomes	Some erosion occurred within the restored reaches, mainly around a few of the logs that shifted position. In part, some of these issues were created by installing the logs in a manner that was reversible, in line with the resource consent requirements of the restoration trial. Nevertheless, erosion levels at the log installation reaches were similar (i.e. not significantly different) to bank erosion levels in the stream segment upstream and downstream of the site in non-restored areas. The native fish community responded rapidly and positively to the habitat additions. Giant kōkopu (*Galaxias argenteus*; classified as At Risk: Declining), which had been absent from the site during the previous 5 years of annual

	monitoring, were consistently recorded at the two restoration sites 1 year after log installation. Longfin eel / tuna (*Anguilla dieffenbachii*) biomass increased 10-fold around the log structures, relative to non-restored areas. Following log installation, juvenile kanakana / lamprey (*Geotria australis*) classified as Threatened: Nationally Vulnerable) were also recorded at the restoration site for the first time.
Additional notes	N/A

A2.2 Rock reefs

Contributed by Ian Kusabs (Ōpōtiki Community REAF Trust) and Robin Holmes (Cawthron Institute).

Project name and location	Lake Rotoiti freshwater crayfish reefs / pā kōura in Rotorua, Bay of Plenty
Structure archetype	Aggregate rock
Year established	2021–25
Organisations involved	Te Arawa Lakes Trust, Fish Futures, Cawthron Institute, Bay of Plenty Regional Council, Ngāti Pikiao, Kusabs and Associates Ltd, Te Arawa Lakes Trust, Greenfield Diving Services Ltd
Current status	Installed
Approximate dimensions	Type 1: **Mid-water reef** 5 m × 5 m × 0.5 m high. Type 2: **Weedbed reef** 5 m × 5 m × 0.5 m high. Type 3: **Bedrock reef** 5 m × 5 m × 0.5 m high. Type 4: **Jetty reef** 5 m × 5 m × 0.5 m high. Type 5: **Shallow lake-edge reef** 2.5 m × 2.5 m × 0.5 m high.
Materials and design	**Mid-water reef:** Rock boulders and cobbles placed on top of wide timber (rough-sawn 'green' eucalyptus and macrocarpa) slabs to prevent sinking into soft sediment. **Weedbed reef:** Rock boulders and cobbles placed on top of timber slabs to provide kōura / crayfish habitat and suppress aquatic weed growth. **Bedrock reef:** Rock cobbles piled directly on top of existing bedrock. **Jetty reef:** Rocks and cobbles arranged into a layer beneath a boat jetty. **Lake-edge reef:** Rocks and cobbles piled into a mound at the lake edge.
Project site characteristics	See above.
Funding source(s) and approximate costs	Ecological monitoring undertaken through the MBIE Endeavour fund as part of the Fish Futures research programme.[10] The habitat walls were paid for by the landowners. Construction costs vary by wall type. The boulder wall option (45 m long) costs approximately NZ$50,000 to install, while gabion basket walls cost around NZ$20,000. Timber walls are the lowest-cost option and are often constructed by the landowner for a few thousand dollars. The stone apron in front of the walls can also be installed by the landowner at minimal cost (a few hundred dollars), using locally sourced stone transported via a car trailer and placed using a wheelbarrow.

[10] https://fishfutures.co.nz

Project purpose	Brown bullhead catfish (*Ameiurus nebulosus*) were officially recorded in Lake Rotoiti / Te Roto kite ā Ihenga i ariki ai Kahu in 2016 and are now abundant and widely distributed there. Invasive catfish are well known predators of freshwater kōura / crayfish (*Paranephrops planifrons*), and their establishment has coincided with a 90% reduction in kōura catch rates in Lake Rotoiti. Kōura distribution in Lake Rotoiti is now limited to those areas with suitable cover, such as rocky substrates and woody debris, or at water depths greater than 15 m. The Rotorua Te Arawa Lakes are of volcanic origin, with lakebed and littoral sediments composed mainly of mud, silt and sand, providing little naturally hiding cover for kōura. As a result, kōura are more vulnerable to predation by catfish here than in habitats with greater natural cover. The constructed habitat reefs were designed to provide refuge for kōura, increasing survival and recruitment by reducing predation pressure from introduced fish such as catfish.
Outcomes	The three types of habitat walls have been installed and monitored. Kōura and fish abundance around the walls is being assessed using a before–after, control–impact (BACI) study design with night-time spotlighting surveys carried out seasonally. Ongoing BACI study design monitoring, using baited trapping and underwater ROV surveys, will assess whether kōura abundance increases as a result of the reef installation. A cultural monitoring programme will also be run in parallel by Te Arawa Lakes Trust. At the Rotorua Lakefront (completed in July 2021), 74 kōura were recorded in 2025, representing a 61% increase over the 46 individuals recorded in 2024, and a 252% increase over the 21 individuals recorded in 2023. No kōura were observed in 2022. Habitat walls in Lake Rotoiti were installed in late 2023 to 2025; as a result, it is too early to determine any associated changes in kōura abundance.  Figure A2.3. Mosaic showing diver installation of mid-water reefs by barge.

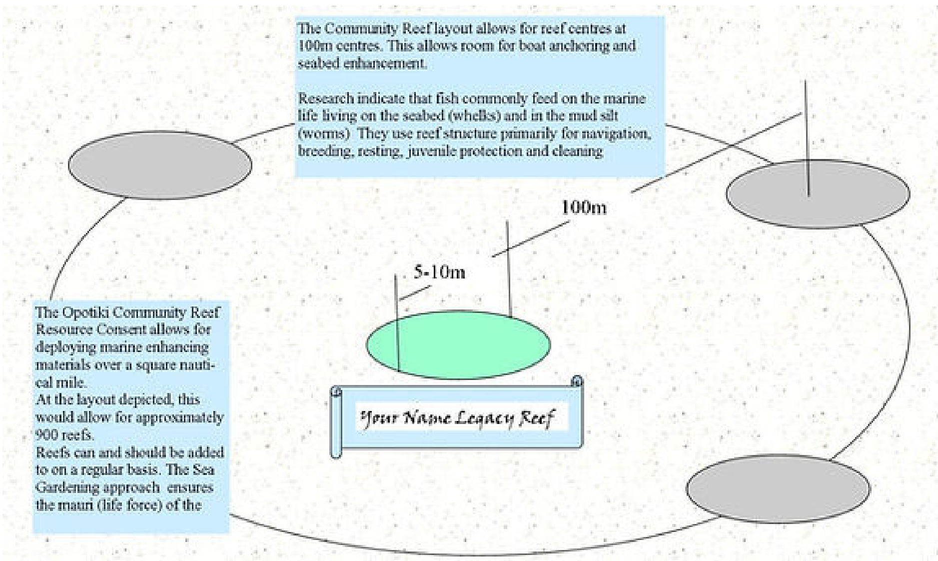
	 Fig A2.4. Lake-edge reef.  Figure A2.5. Mosaic of lakeshore habitat walls in Lakes Rotoiti and Rotorua. Top images: The stone apron placed in front of the habitat wall and a kōura / crayfish recorded during night-time spotlighting.
Additional notes	Following completion of the reefs, it was evident that the most time-consuming component of the operation was the placement of timber slabs. For future projects, the contractor recommends using a dump barge to place rocks and stones directly onto the lakebed. Although this approach would require a greater volume of rock, it is expected to be far more cost-effective than deploying divers for installation, enabling a greater number of reefs to be constructed. There are three key considerations when designing and constructing lakeshore habitat walls for kōura:

	1. Fluctuating lake levels can result in habitat structures becoming exposed during periods of low water. To maintain habitat cover, a layer of rocks or stones should extend lakeward, allowing kōura to move into deeper water as water levels recede. 2. The accumulation of aquatic weed can adversely affect kōura by smothering habitat, restricting movement and reducing water quality, particularly in shallow nearshore areas. Weed accumulations should be removed promptly to maintain suitable habitat for kōura and fish. If possible, habitat walls should be designed to minimise weed build-up. 3. The layer of stones placed in front of all three habitat wall types is the most critical component for kōura, providing shelter from predators, refuge during water-level fluctuations, and foraging habitat. Even existing timber walls, which on their own provide limited habitat for kōura, can be retrofitted with stone aprons to significantly enhance their habitat value.

Appendix 3. Marine case studies

A3.1 Prefabricated reef modules as seafloor enhancement

Contributed by Lloyd Hoskens (Ōpōtiki Community REAF Trust).

Project name and location	Ōpōtiki Community Reef. Cover an area of 1 nm^2, as depicted on Chart NZ 542 as a 'Fish Haven'. The area lies 1 nm off Hikuwai Beach, extending to the trawler inner limit line of 2 nm.
Structure archetype	Seafloor enhancement through the use of mostly concrete marine-enhancing modules.
Year established	First deployments of structure occurred in 2007.
Organisations involved	Initial involvement included the East Coast iwi Ngai Tama, Ōpōtiki Coast Guard members, Tauranga Polytechnic (now Toi Ohomai) Marine Studies department, international exchange students from AFS, and a mixed Ōpōtiki community group called the Coalition of the Willing.
Current status	The reef area is currently charted on NZ 542 and also appears on recent boat sonar charts, but the resource consent, which lasted for 10 years, has expired. The charitable Ōpōtiki Community REAF Trust now administers the reef and has renewal of the previously consented area in its sights.
Approximate dimensions	Covers an area of 1 nm^2. On the plan, this would allow for approximately 800 deployment sites. Currently, only about 10 of these have actual structure deployed on them.  Figure A3.1. Ōpōtiki Community REAF Trust concept and approximate dimensions.

Materials and design	The core research principle guiding reef module design was 'the more complex the structure, the more marine life it will encourage'. The reef deployments are mostly of varied concrete cast modules, easily lifted by one or two people (less than 50 kg) and able to be deployed from a 5–6 m recreational fishing craft.   Figure 3.2. Various designs were made, some registered by Design Marks and called Bio Links, Cray Haven and Sea Drops. They were deployed down a fused rope in an effort to aggregate the materials on the seabed.

Project site characteristics	The deployment area, east of Pakihikura Harbour, was chosen because the predominate current in the area is east to west, so silting from the Waioeka and Ōtara Rivers in flood events should be minimised. The seabed composition is charted as 'fsM' (fine sand mud), which does offer some firmness. The seabed could be described as of poor to limited ecological standing. The consented area lies just 2–3 nm from the new Pakihikura Harbour mouth.
Funding source(s) and approximate costs	Initial funding for the project came from the Environment Bay of Plenty Enhancement Fund, which put in a one-off NZ$30,000 to kickstart the project. This was to cover resource consent costs, module construction by six different community groups, deployment, monitoring and the production of an education resource that was constructed as a 'mind map'.
Project purpose	The purpose of the project was, and still is, 'to grow our connection with the marine world'. While artificial reefs [AAHs] worldwide commonly focus on growing more fish to harvest, the problem often described as the 'tragedy of the commons' keeps recurring. It is hoped that the concept of a community reef, while still deploying marine-enhancing concrete module structures, is an evolution beyond artificial reefs [AAHs] alone, which are commonly characterised as being large, one-off events (e.g. the sinking the HMNZS *Tui* and other ships) and then viewed by fishermen as another resource to be exploited. A community reef as envisaged here gives a unique opportunity for individuals, families or groups to deploy, say, one reef a year and hence grow a resource, leading to abundance for all the community. Indigenous sea gardens produced bountiful seafood for centuries by focusing on principles of reciprocity and the common good.[11] So, the purpose of the reef project was not only to grow more fish and enhance biodiversity, but also to tackle other problems in our relationship with the marine world. Simply put, many would describe our attitude to seafood harvesting as one of 'take' without any thought of 'giving back' (i.e. utu). Establishing a community reef opens an opportunity to reciprocate by giving back. From the outset, an educational component was also an integral component of the system. Currently, Aotearoa New Zealand relies primarily on its Quota Management System (QMS) and marine reserves as marine management tools. Within the QMS there is provision for customary Māori harvest and management. Once a marine reserve is established, the role of citizens is often reduced to being spying eyes for enforcement agencies. However, Aotearoa New Zealand is now a significantly multi-cultural society. So, the question arises: how are new citizens educated and encouraged to align with Kiwi values in regard to seafood harvest? Monetary fines can be educational but hardly help build a positive relationship with the moana.

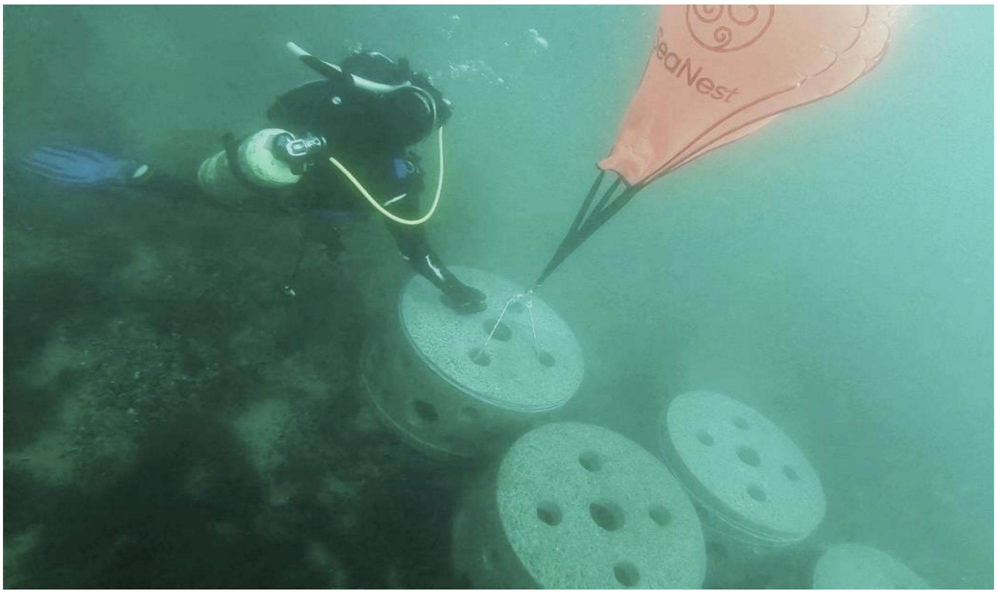
[11] www.seagardens.net

	A community reef structure, be it established through a charitable society or trust, offers an avenue for direct localised management of a marine resource to local community members from diverse cultures. While a community reef is still envisaged to be under the umbrella of the QMS, all kinds of other creative avenues are present, particularly around growing a greater diversity of seafood. Modules as homes for octopus / wheke, pāua, kingfish / haku and so on have all been deployed overseas. While the development of group, family and even legacy reefs might be encouraged, the GPS locations are shared for all on our Meta page, 'Community Reef', the focus being on creating wealth and health for all from fishing. This has a parallel in the creation of localised cycleways as part of a national programme to engender wealth and health. There are other important benefits of creating localised community reefs. During the COVID-19 pandemic, it was as if 'food security' became a newly discovered concept. Who knows when the next global crisis might hit? Having an enhanced recreational fishing area that is easily accessible by smaller craft, and even kayaks, would seem prudent. Even the price of petrol – an initial catalyst to forming a community reef in 2007 amid sharply accelerating costs, and a factor that greatly affects fisherfolk – needs to be considered. An easily accessible community reef also allows for significant cost savings in fishing, along with greater fishing action.
Outcomes	The Ōpōtiki Community Reef continues to attract positive informal comments from Ōpōtiki community. The reef area is often fished, even though a newly established open ocean mussel farm 10 km offshore has become a popular fishing area. Sea conditions are often rougher further out, and jet-ski fishers and those on smaller craft prefer fishing closer to shore in calmer waters. Many of the snapper caught recently in the area have been feeding on soft-bodied 'worms', perhaps propagated by the reef structures. The few reef module deployments made to date have had no known negative impacts. A dive survey made by the Toi Ohomai Marine Studies department during the COVID-19 pandemic noted that it was likely most structures had subsided significantly into the fSM seabed. No invasive species were found. The 'Community Reef' Meta page continues to have around 250 followers. However, little is being done to promote the reef or its benefits to the wider community beyond the social media posts on the page. It was always envisaged that the reef would be fed on a continuous basis to enhance the mauri of the area, but this has failed to materialise, primarily because of lack of funding. It is easy to garner verbal support for the reef concept, but hands in pockets are a different matter. We have learnt many times

	over that species resources are not unlimited. Sadly, however, building abundance seems yet to become part of our marine thinking. A change in marketing strategy has taken place recently to promote the reef as 'sea gardening'. Additionally, it is planned that small, 1-hour introductory tours will be conducted by reef trustees, with all koha going to the REAF Trust for further research and development.
Additional notes	The Ōpōtiki Community REAF Trust also incorporates some lesser considered scientific and esoteric principles: • As in home gardening, a little effort done at the right time pays dividends. To keep the mauri of a reef deployment alive and growing, all that may be needed is adding a mauri stone, more modules or shells, reciting a karakia or even returning fish offal to a dedicated reef. • We live in a non-linear world. While freak waves are a negative example of non-linear energy, there are many positive examples where doing something for the marine world produces exponential rewards. Ōhiwa Harbour mussel restoration is just one recent local example, where the mussel population increased from 80,000 in 2019 to 45 million in 2024. Personalising our connection with reef modules is a way of establishing whakapapa with the reef and moana. All concrete is personalised with art of some form. Each unit becomes unique and different, a principle of nature. • We live in a world of unseen forces, be it radio waves, Wi-Fi, wind and so on. The power of our thoughts is the theme of many books. So, too, do we call on fisherfolk to employ their best values and virtues when they are on the reef. Courtesy, sharing and caring are our key principles, among others. • Overall, our educational focus is about empowering a sense of the reality that we are all intimately interconnected, not just with the marine world but with our environment in general. A theme that is endemic in indigenous cultures around the world is brilliantly encapsulated in the Māori environmental concept of kaitiakitanga, which has been adopted and enshrined in the environmental legislation of Aotearoa New Zealand.

A3.2 Prefabricated reef modules supporting seafloor enhancement and taonga species recovery

Contributed by Gemma Davis and Bryony Miller (Sea Nest).

Project name and location	Sea Nest, Kōhanga Moana Pilot Reef, Awarua / Bluff Harbour
Structure archetype	Seafloor enhancement
Year established	2024
Organisations involved	Sea Nest Limited, Southern Marine Farms
Current status	Operational / intact
Approximate dimensions	The Sea Nest Kokoru module dimensions are 40 cm high × 80 cm diameter (top) × 86 cm diameter (bottom). Each wall is approximately 7–8 cm thick. Each unit weighs an estimated 180 kg in air and 103 kg submerged, and has a total surface area of approximately 3 m^2. The eight deployed modules provide 24 m^2 of artificial reef habitat.
Materials and design	Sea Nest modules are constructed using sustainable concrete (concrete overpours) and do not contain unnatural reinforcing fibres. Modules have been laboratory tested and do not contain contaminants (e.g. heavy metals, carbonates, or semi-volatile organic compounds [SVOCs]) with potential to erode into or adversely affect the marine environment.  Figure A3.3. Deployment of Awarua pilot reef, May 2024.

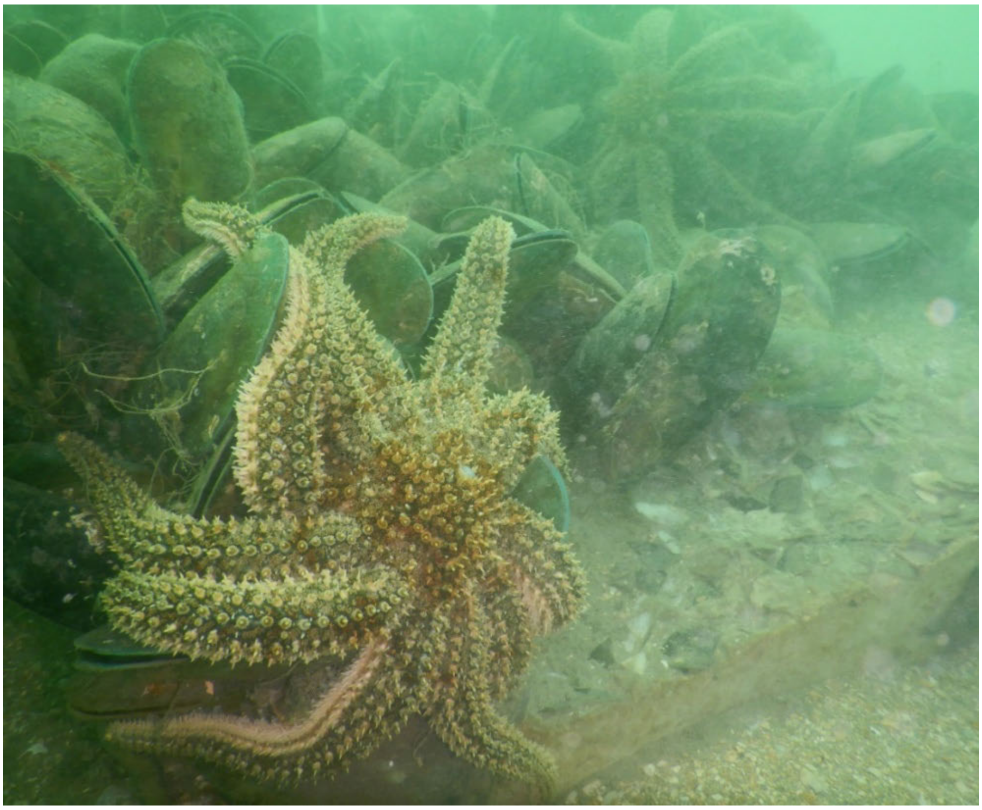
Project site characteristics	Consented marine farm in Bluff Harbour. This site has high current flow and lies within a depth band of 6–7 m. The seabed at this location consists of firm medium to fine sand, cobbles and pebbles, with occasional red filamentous algae present.
Funding source(s) and approximate costs	Privately funded by Sea Nest Ltd. Reef module construction (eight modules) and deployment cost totalled approximately NZ$20,000. Resource consent was not required for the pilot project; however, if consent is required, the total cost would be approximately NZ$30,000 (excluding monitoring costs).
Project purpose	To trial the performance of Sea Nest Kokoru artificial reef modules in Awarua Bluff Harbour and quantify their impact on ecological diversity, biomass of indigenous marine species, and sedimentology.
Outcomes	In the 12 months post-deployment, significant increases in species diversity and abundance were recorded at the artificial reef compared to the benthic baseline. The cumulative number of species observed at the Sea Nest artificial reef site increased from five species at the time of deployment to 30 species at week 53. The cumulative number of species recorded within the benthic baseline over this period was seven. Most species observed at the site over the monitoring period were endemic reef-associated species. No exotic / pest species were recorded. Spotties / paketi (*Notolabrus celidotus*), nudibranchs (sea slugs) and red blade macroalgae were the primary colonising species, followed by ascidians, triplefins and molluscs. Bladder kelp (*Macrocystis pyrifera*) and pāua (*Haliotis iris*) were actively seeded at the artificial reef site. Larger predators such as octopus and conger eels / kōiro (*Conger verreauxi*) were evident at the site within 2–3 months of reef establishment.  Figure A3.4. Marine species presence and algal growth over the year of monthly monitoring.

	Fish density at the artificial reef site increased from the benthic baseline of approximately 0.2 individuals per m^2 up to a mean of approximately 10 per m^2 (excluding cryptic fish and fish sheltering within the habitat). Observed fish densities increased significantly within 2 weeks of deployment and varied over the monitoring period due to variations in visibility and tidal and seasonal conditions. Spotties were the most abundant fish species. Other commonly recorded fish species included blue cod / rawaru (*Parapercis colias*), triplefins (family Tripterygiidae), gobies (family Gobiidae), crested blennies (*Parablennius laticlavius*) and scarlet wrasse / pūwaiwhakarua (*Pseudolabrus miles*). Recorded densities of these species increased over time, particularly in the period 6–10 months post-deployment. Modules were confirmed to be stable in tidal flows up to approximately 3.9 m/s (7.8 knots) of current (stacked and unstacked). Sediment erosion and deposition were limited and found to vary according to reef design.  Figure A3.5. Biodiversity 'overflow' evident up to 20 m from reef structures, 11 months after deployment.
Additional notes	N/A

A3.3 Prefabricated reefs supporting mussel restoration

Contributed by Emilee Benjamin (University of Auckland).

Project name and location	Mussel establishment pilot study, Golden Bay / Mohua
Structure archetype	Artificial substrate to support species restoration
Year established	2024
Organisations involved	University of Auckland, Marine Farming Association, Mana whenua Ki Mohua, The Nature Conservancy, Ministry for Primary Industries, Mohua Marine Trust, Clearwater Mussels, Talley's, Sollys, Te Tau Ihu Fisheries Forum, Earth Sciences New Zealand / National Institute of Water and Atmospheric Research
Current status	Ongoing project
Approximate dimensions	Each plot is 1 m^2 and there are six plots. Each plot was made up of six tiles (Figure A3.6). There were three treatment plots, with mussels added, and three control plots without mussels.  Figure A3.6. Concrete tiles with shell aggregate at subtidal deployment site.

Materials and design	Concrete tiles with shell aggregate and shell lining the surface (Figure A3.7). The tiles were deployed to provide a secure attachment substrate for translocating green-lipped mussels (*Perna canaliculus*) onto the seabed from longline aquaculture farms.  Figure A3.7. Concrete tiles with shell aggregate and translocated mussels. An eleven-armed sea star (*Coscinasterias muricata*) is in the foreground.
Project site characteristics	Semi-open coastline with highly hydrodynamic conditions, mobile sand.
Funding source(s) and approximate costs	Ministry for Primary Industries Sustainable Food and Futures Fibres Fund, along with co-funding from the Marine Farming Association and The Nature Conservancy.
Project purpose	This project aimed to test the use of attachment tiles for restoring green-lipped mussels in degraded, overharvested locations in highly hydrodynamic conditions.

Outcomes	Researchers noted the importance of the attachment substrate as the mussels that were deployed directly onto the seabed appeared to be heavily impacted and dislodged by large storm events with heavy wave action. Despite heavy wave action and highly hydrodynamic conditions, the tiles remained above the sediment. Visually, the tiles appeared to attract many organisms in both the treatment plots (with mussels) and control plots (without mussels). Eleven-armed sea stars are a large, voracious mussel predator and were found on the treatment plots (Figure A3.7). This project has high community involvement from a diverse project steering committee made up of iwi, industry, NGO, scientist and student members, who together worked to develop, guide and implement this project.
Additional notes	N/A

A3.4 Prefabricated reef modules as compensation

Contributed by Marcus Cameron (Technical Director Marine Ecology, Tonkin + Taylor) on behalf of Te Ara Tupua Alliance.

Project name and location	Te Ara Tupua Alliance Reef Enhancement, between Ngā Ūranga and Pito-One in Te Whanganui-a-Tara / Wellington Harbour. The name and narrative of the enhanced reef has been gifted by Kura Moeahu, QSM (Te Āti Awa, Taranaki Whānui, Ngā Ruahine, Taranaki Tūturu, Ngāti Mutunga, Ngāti Tama, Ngāti Toa Rangatira). However, at the time of writing this case study, the blessing of the pathway (including the enhanced reef) had not been conducted by the people of Te Āti Awa Taranaki Whānui; therefore, the name and narrative could not be shared at that time. The wider Te Ara Tupua project comprises a 4.5 km-long, 5 m-wide shared pathway, located along the coastal edge of Te Whanganui-a-Tara (Figure A3.8). It is being constructed on existing and new land, on the seaward side of State Highway 2 (SH2) and the Hutt Valley railway corridor. It involves works in and adjacent to the coastal marine area (CMA), including reclamation, construction of 2.7 km of revetment, several ūranga (landings), six seawalls, groynes, beaches and offshore bird habitats. The reef enhancement component is approximately 150 m from the original shoreline (Figure A3.9) and provides part of the biodiversity compensation package for 5.17 ha of unavoidable permanent marine habitat loss associated with path construction.  Figure A3.8. Project location

	 Figure A3.9. Reef and control site locations.
Structure archetype	A novel artificial reef constructed from precast concrete pyramid units (Figure A3.11, top left) specifically designed for biodiversity compensation.
Year established	2024
Organisations involved	NZ Transport Agency Waka Kotahi (NZTA; funder), Te Ara Tupua Mana Whenua Steering Group (MWSG) with Taranaki Whānui ki te Ūpoko o te Ika (Taranaki Whānui) and Ngāti Toa Rangatira (Ngāti Toa) (co-design / partnership), Te Ara Tupua Alliance (HEB Construction, Downer, Tonkin + Taylor, Boffa Miskell) (co-design, consenting and oversight of delivery), MMA Offshore Australia (MMA) (unit design / fabrication and deployment oversight), Brian Perry Civil (BPC) (fabrication and deployment), SLR Consulting and Tonkin + Taylor (ecological monitoring and reporting), Taranaki Whānui Ltd (kaitiaki / cultural monitoring), Earth Sciences New Zealand (kelp translocation), and researchers engaged via Te Ara Tupua Alliance.
Current status	Pre-deployment baseline established in February 2024. Reef fully installed and operational as of July 2024. Five-year post-deployment scientific and cultural monitoring programme underway since February 2025, including ongoing comparison with two control sites located elsewhere in Te Whanganui-a-Tara (Figure A3.9).
Approximate dimensions	The enhancement area covers approximately 5 ha (Figure A3.10). Fifty-six concrete pyramid units, each measuring 4 m × 4 m at the base, 5 m high and weighing 23 tonnes, were placed in 18 clusters of three units and one cluster of two units. The units were placed in 7–9 m of water (based on lowest astronomical tide [LAT]), ensuring ≥ 2 m of freeboard above each unit for navigation purposes.

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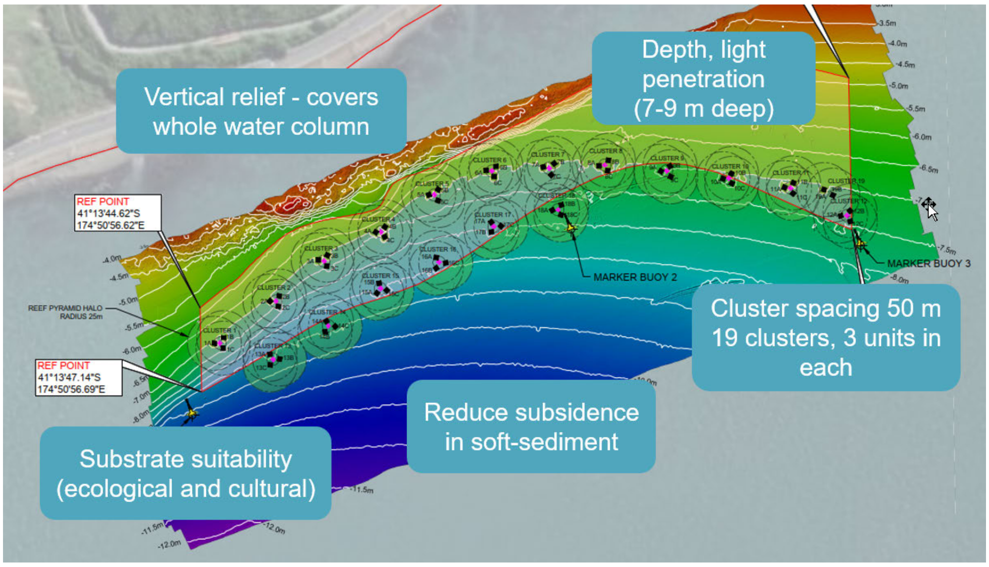

Figure A3.10. Reef location and design considerations.
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<td>Materials and design</td>
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Ecological input into key design elements for the wider project was integral to avoid, minimise, remedy, offset and compensate for impacts to marine ecology and coastal avifauna. This included developing two offshore habitats for bird roosting, installing penguin nesting boxes, undertaking sand nourishment to preserve beach habitat, and avoiding impacts to high-value habitats such as shingle beaches and some areas of rocky reef. However, it was assessed that a residual adverse effect to marine ecology would occur due to 5.17 ha of unavoidable permanent marine habitat loss. As such, additional compensation was proposed to address this loss.

In a first of its kind for a subtidal reef enhancement in Aotearoa New Zealand, a biodiversity compensation model (BCM [12]) was used to inform the scale and quantum of compensation, and to demonstrate how the proposed reef would effectively replace the biodiversity being lost to the project over a period of 5 years. The reef units are just one component within a broader compensation package that was informed by the BCM. That package includes a 5-year scientific and cultural monitoring programme, cultural research and diver training, kelp translocation to the reef units, artificial tide pools, Te Ripowai XBlocPlus® eco-enhanced concrete armour units in the revetment, and dune restoration.

Te Whanganui-a-Tara has great cultural, historical and spiritual significance to Māori. Mana whenua for the project area is held by Taranaki Whānui and Ngāti Toa, recognising multiple Te Āti Awa sites of significance, including Ngā Ūranga Pā (settlement), Pito-One Pā, Honiana Te Puni Reserve, and Korokoro and Waihinahina Streams, all of which are located within Te Ara Tupua Ngā Ūranga ki Pito-One.

To locate a suitable place for marine ecological enhancement, the project was guided by iwi representatives from the MWSG, cultural advisors from Taranaki Whānui and uri, who attended engagement hui at Te Tatau o Te Pō marae. A 5 ha area adjacent
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[12] https://www.tonkintaylor.com/nz/expertise/environmental/biodiversity-compensation-models/

	to the project and close to the area of impact was identified as a location that historically provided an abundance of fisheries, food and other resources for iwi, hapū and whānau. Underwater surveys identified the area as degraded, with predominantly muddy and some sandy / shelly seabed habitat and low to moderate ecological value. Geotechnical surveys identified areas of seabed that were suitable for reef unit placement. Coastal engineering input was also provided to ensure that the reef would not impact on coastal processes or adjacent shoreline dynamics. A range of different reef unit designs and configurations were considered. The precast concrete pyramid units ultimately deemed most suitable were chosen because they are designed to maximise surface area available for recruitment of sessile marine life and provide large areas of cryptic habitat. With their ramping geometry the units also provide substantial vertical relief, providing specific habitat for pelagic fish while also minimising the footprint on the existing seabed (Figures A3.10 and A3.11). Based on relevant literature and to maintain ecological connectivity, the unit clusters were spaced no more than 50 m apart and only approximately 150 m from the original shoreline (Figure A3.10). The design intent was to replicate and replace lost rocky reef functions, while minimising the seabed footprint and maximising settlement surfaces and refugia. The design maximises hard substrate surface area (approximately 5,700 m^2 of surface area is provided by the 56 units) and cryptic habitat, with substantial vertical relief to promote recruitment of habitat-forming seaweeds and invertebrates, and to attract mobile species including fish and large invertebrates. MMA designed the reef units and provided technical support for the nominated cluster arrangement and spacing. MMA mobilised their tooling and supervisors to Aotearoa New Zealand to fabricate the units in a local precasting yard in collaboration with local subcontractors BPC. This reduced costs and allowed for local knowledge development and materials usage, which also significantly reduced the carbon footprint compared to fabricating the units in Australia and shipping them to Aotearoa New Zealand. A total of 56 reef units were fabricated and deployed by BPC under subcontract to MMA. The units were deployed on the seabed over a period of 12 weeks between May and July 2024. The units were transported from the precasting yard to site using a tug and cargo barge, then GPS positioned and placed by crane off a jack-up barge (Figure A3.11). This is currently the largest example of subtidal marine biodiversity compensation using concrete reef units in Australasia.

Figure A3.11. Reef unit fabrication and deployment

Project site characteristics	Numerous factors were considered when selecting the site. Ecologically and culturally sensitive areas, as well as high-value and highly degraded / deep mud areas, were avoided. So, too, were areas of conflicting use, such as marine traffic routes, anchorages, submarine cables, dredge areas and existing monitoring sites (Figure A3.10). The chosen site is 5 ha in extent and located approximately 150 m from the shore in the northwestern corner of Te Whanganui-a-Tara, adjacent to the newly constructed Ngā Ūranga ki Pito-One shared pathway section of Te Ara Tupua (Figures A3.8–A3.10). The reef sits within an area of significance to Taranaki Whānui. Ngā Ūranga and Pito-One were the sites of several Te Āti Awa pā at the time the first European settlers arrived in the area. The rivers and streams that feed into Te Whanganui-a-Tara and the harbour fisheries were vital mahinga kai (food-gathering areas) for Te Āti Awa and their Taranaki iwi relatives. The 5 ha reef site comprises a historically degraded soft sediment (mud / sand / shell hash) seabed of low to moderate ecological value adjacent to a mainly rocky shoreline (with some shingle beaches) that is highly modified but has high ecological value. The depth is 7–9 m at LAT. The northwest corner of Te Whanganui-a-Tara generally has reduced visibility and can be subjected to spikes in turbidity and reduced salinity during storm events, which can drive substantial discharges from Te Awa Kairangi / Hutt River and cause wave-driven resuspension of bed sediments at shallow depths.
Funding source(s) and approximate costs	Funded by Waka Kotahi NZTA as part of Te Ara Tupua project. Total cost for concept development, detailed design, consenting, fabrication, installation, and the 5-year cultural and ecological monitoring and research programme is approximately NZ$11M.
Project purpose	To provide biodiversity compensation for 5.17 ha of unavoidable permanent marine habitat loss associated with path construction by establishing an adjacent, co-designed reef system to enhance biodiversity, restore mahinga kai opportunities, and support cultural values, research and education as part of a wider package.
Outcomes	The first post-deployment monitoring round was completed in February 2025, and a further monitoring round was completed in August 2025. Monitoring will continue annually for a further 4 years. Early colonisation and an ecological community broadly consistent with expectations has developed. Colonising species include native brown kelps (*Carpophyllum* spp., *Macrocystis pyrifera*), the invasive kelp *Undaria pinnatifida*, green algae (*Ulva* spp. and *Codium fragile*), and red algae (*Haraldiophyllum crispatum*, *Grateloupia turuturu*, *Schizymenia* spp.) (Figure A3.12). Tube worms, bryozoans and a number of other common sessile and mobile (e.g. cushion stars, *Patiriella regularis*; kina, *Evechinus chloroticus*) invertebrates have established, as have several fish species – in particular, triplefins (family Tripterygiidae), spotties / paketi (*Notolabrus celidotus*) and trevally / araara (*Pseudocaranx dentex*) (Figure A3.12). Brown macroalgae were also actively translocated to the units (predominantly *Carpophyllum* spp., but also a few *Macrocystis pyrifera* adult plants and sori), along with a few green-lipped mussels (*Perna canaliculus*) (Figure A3.12).

	A cultural monitoring kaupapa ūnga (attribute scoring) framework has been developed and implemented by kaitiaki alongside the scientific surveys to track cultural indicators of the mauri of the reef site and control sites. Cultural research investigating taonga species translocation and diver training is also underway. Collectively, the reef provides a co-designed habitat that ensures opportunities for both science and mātauranga Māori approaches to monitor and research its performance against predicted biodiversity gains and mātauranga Māori cultural indicators. These practices can be complementary and integrated, leading to more holistic ecological management and improved outcomes for the enhanced reef and the wider Te Whanganui-a-Tara area. It also strengthens mana whenua's role as kaitiaki of Te Whanganui-a-Tara.  Figure A3.12. *Carpophyllum* spp. and green-lipped mussel (*Perna canaliculus*) translocation, as well as natural recruitment of green and red algae, *Undaria* and fish.
Additional notes	The following paper, presented at the Australasian Coasts and Ports Conference in Adelaide, August 2025, provides further information: Cameron M, Bell J, Hunter L, Barber C, Underwood L, Shand T, O'Carroll J, D'Archino R, Allen M, Breese E. Creating a reef to compensate for habitat loss and enhance biodiversity for a major coastal infrastructure project. https://search.informit.org/doi/abs/10.3316/informit.T2025112200013190876936354

A3.5 Habitat mimics supporting functional seafloor restoration

Contributed by Brooke Ellis-Smith (University of Waikato).

Project name and location	Artificial horse mussel (*Atrina zelandica*) reefs, Tauranga Harbour
Structure archetype	Seafloor enhancement, addition of structural habitat complexity
Year established	April 2024
Organisations involved	University of Waikato, Bay of Plenty Regional Council
Current status	Removed after 17 months to comply with Rule SO 6 of the Bay of Plenty Coastal Environment Plan
Approximate dimensions	Four reef plots, each 4 m^2 in area.
Materials and design	Artificial *A. zelandica* reef plots were designed to replicate functional densities of natural beds (20 individuals per m^2; Figures A3.13–A3.15), with plot sizes sufficient to generate skimming flow and impact local community composition (Figure A3.16). Artificial *A. zelandica* were created by making silicone moulds from the top half of dead *A. zelandica* shells and filling the moulds with general purpose concrete. A section of rebar was placed into the centre of the concrete. Reefs were deployed by placing each *A. zelandica* mimic into the sediment, with the entire length of rebar inserted so that only the concrete portion remained above the sediment.  Figure A3.13. Artificial *Atrina zelandica* reef 7 months after installation.

	 Figure A3.14. Artificial *Atrina zelandica* reef 7 months after installation.  Figure A3.15. Artificial *Atrina zelandica*.

	 Figure A3.16. Live *Atrina zelandica* from the adjacent natural bed.
Reef site characteristics	Selection of the artificial reef site was informed by a habitat suitability model for *A. zelandica* (Ellis-Smith et al. 2025) in Tauranga Harbour, which identified it as having high predicted habitat suitability to increase restoration success. These reef plots were placed adjacent to a natural bed of *A. zelandica* (very sparse densities). Artificial reefs were placed on the edge of a channel in the shallow subtidal zone (approximately 2–4 m depth). The channel has a high tidal influence as it is located in the northern part of Tauranga Harbour, and it has moderately muddy sediments (20–30%).
Funding source(s) and approximate costs	Funded by Bay of Plenty Regional Council. Materials used in reef construction cost approximately NZ$1,000. Additional costs for reef installation included the use of a boat and two divers for 1 day.
Project purpose	The reefs were deployed for research purposes and aimed to use structural mimicry to restore the habitat complexity provided by natural *A. zelandica* reefs. The nationwide degradation of historical *A. zelandica* reefs is resulting in the loss of the critical ecosystem functions and services they provide; therefore, restoration is needed. Restoration of live *A. zelandica* is currently not viable due to a lack of sufficient source populations for translocation and a lack of hatchery-reared stock to reseed natural populations. Our recent survey of *A. zelandica* in Tauranga Harbour found that only remnant populations remain, and that many historical beds have been completely or almost completely lost. Through the creation of artificial reefs, we hope to restore the functional role of *A. zelandica* reefs associated with their physical structure. This includes enhancing biodiversity across multiple species scales through the provision of refugia, hard substrate habitat for epifaunal settlement, nursery habitat and modification of the benthic environment through altering near-bed flows.

Outcomes	The project outcomes included: • the creation of hard substrate habitat, with artificial *A. zelandica* supporting diverse epifaunal communities, including taxa such as bryozoans, macroalgae, sponges and nudibranchs • altered macrofaunal community structure in artificial reef habitats compared to bare sediment habitat • significant increase in species richness and abundance of residential reef fishes, primarily through increased use of artificial reef habitats by spotties / paketi (*Notolabrus celiodotus*) and triplefins (family Tripterygiidae).
Additional notes	N/A

A3.6 Living seawalls

Contributed by Shelley McMurtie and Jesse Burns (EOS Ecology).

Project name and location	Tupua Horo Nuku, a seawall and shared path along Marine Drive in Wellington's Eastern Bays
Structure archetype	Textured 4.4 km seawall and constructed tide pools
Year established	Construction is estimated to finish in 2026
Organisations involved	Design and consenting phase led by Hutt City Council: Stantec (project management, engineering, landscape design), EOS Ecology (marine ecology – intertidal and subtidal, fish passage), Earth Sciences New Zealand / National Institute of Water and Atmospheric Research (seagrass ecology, coastal processes), Sustainability Solutions (terrestrial vegetation), Kororā Ornithology (avifauna), Raukura Consultants (cultural values), McIndoe Urban (urban design), Drakeford Williams (landscape design), Rob Greenaway and Associates (recreation), and community representatives Construction phase undertaken by Te Ara Tupua Alliance: NZ Transport Agency Waka Kotahi, Downer, HEB Construction, Tonkin + Taylor.
Current status	Construction is still underway at the time of writing this case study (estimated to finish in 2026); completed sections are operational.
Approximate dimensions	The seawall texture has been applied to all newly constructed sections of curved seawall, and constructed small concrete tide pools have been attached to the curved seawall at several locations.
Materials and design	The bespoke seawall texture was designed by EOS Ecology in collaboration with the wider design and consenting project team. The design was inspired by bladder kelp (*Macrocystis pyrifera*) and Neptune's necklace (*Hormosira banksia*), two seaweed species iconic to Wellington Harbour / Port Nicholson, and offered a macrotexture that would substantially increase habitat complexity relative to the pre-existing (primarily smooth concrete) seawalls that were being replaced. The features of the design incorporated uneven surfaces, small nooks and crannies, and pools of varying depths and types (*in situ* micro-pools formed by applying the texture to the horizontal 'step' of the curved seawall, and small constructed pools attached to the vertical seawall face) to support biota with a variety of habitat requirements. The design, intent and application of these ecological features were described in a seawall and revetment habitat plan produced by marine ecologists in the design and consenting team. As the seawalls were to be installed in a high-traffic urban area, the pattern was also developed to be organic in nature to increase the visual appeal, and be matched at the end of the form liner to create a seamless repeating design across a long length of seawall. The curved textured seawalls were constructed with precast concrete panels (Figures A3.17 and A3.18). Horizontal 'steps' between the sections were constructed of precast concrete panels, with a panel in the centre constructed of poured concrete stamped with the texture *in situ* (Figure A3.19). The central panel allowed for necessary flexibility during seawall construction, but also provided more habitat diversity via the provision of a different surface texture and pattern depth relative to the precast sections.

Constructed micro tide pools were formed by applying the texture to the horizontal 'step' of the seawall (Figure A3.20), while small vertical pools were attached to the finished seawall in discrete locations using a precast unit (Figure A3.21).

Figure A3.17. Curved textured seawalls constructed with precast concrete panels, as seen after installation.

Figure A3.18. Curved textured seawalls constructed with precast concrete panels, as seen after installation.

Figure A3.19. Horizontal platform between curved sections of the seawall, with precast concrete panels on the sides and a central panel of poured concrete stamped with the texture *in situ*.

Figure A3.20. Small pools cast into the horizontal steps of the seawall.

	 Figure A3.21. Constructed tide pools, attached to the finished seawall using a precast design made from concrete.  Figure A3.22. Early colonisation of the textured seawall by filamentous green algae.

Figure A3.23. Early colonisation of the textured seawall by filamentous green algae and little black mussels (*Xenostrobus neozelanicus*).

Figure A3.24. Early colonisation of textured seawall by filamentous green algae and blue periwinkles / ngaeti (*Austrolittorina antipodum*).

	 Figure A3.25. The proximity of the new shared path to the textured seawall gives it high visibility to the public.  Figure A3.26. Stairs have been placed at key locations along the seawall, allowing the public to access the coastal area and engage with the intertidal zone while minimising encroachment into the coastal marine area.

Project site characteristics	Intertidal zone adjacent to roadway in an urban area. Moderately to very sheltered rocky reef, predominantly comprising bedrock and cobble substrate, intermixed with beaches with gravel and sand substrate. Pre-existing seawalls (constructed between the 1960s and 2008) along approximately 3.8 km of the Tupua Horo Nuku project length.
Funding source(s) and approximate costs	Confidential.
Project purpose	The upgrade of existing seawalls and installation of new seawalls under Tupua Hora Nuku was intended to increase the resilience of Marine Drive by providing improved protection against storm surges and sea-level rise, and enhance safety and recreational access alongside and adjacent to the coastal marine area.
Outcomes	The pre-existing seawalls along Marine Drive offered little ecological value to intertidal biota. While the community composition was similar to that found in other rocky shore areas of Wellington Harbour, epifaunal taxa richness and densities were lower on the pre-existing seawalls relative to intertidal rocky habitat on the adjacent harbour floor. Macroalgae occurrence was limited, with only 15% of the quadrats collected from the seawalls containing any macroalgae, and percentage cover of macroalgae when present ranging from 2% to 22%. Monitoring of the new textured seawalls and constructed tide pools has begun, but the data are not yet available. However, anecdotal observations indicate that colonisation of the textured seawalls and tide pools by marine species commenced relatively soon after installation (Figures A3.22–A3.24). An important aim of the seawall design was to retain public access to the coastal environment and create opportunities for engagement with the intertidal zone. These aims are achieved via the close proximity of the new shared path beside the seawall (Figure A3.25) and the inclusion of public access points at key locations along the seawall (Figure A3.26), which increases visibility of, and access to, the intertidal zone.
Additional notes	The design of the seawall texture remained as per the original specifications, while some changes to the construction approach occurred to allow for greater construction flexibility. This included the pouring of central panels for the horizontal 'steps' with *in situ* stamping of the seawall texture to these surfaces, not applying the texture to the straight sides of the access steps, and extending the curved seawall along more lineal length of the coastline.

A3.7 Artificial tide pools

Contributed by Tommaso Alestra, Gabe Ross, Crystal Lenky, Kirsty Brennan

<table>
<tr><td>Project name and location</td><td>Artificial tide pools, Lyttelton Port</td></tr>
<tr><td>Structure archetype</td><td>Artificial tide pools retrofitted within an existing rock revetment</td></tr>
<tr><td>Year established</td><td>2023</td></tr>
<tr><td>Organisations involved</td><td>Lyttelton Port Company, Boffa Miskell Ltd</td></tr>
<tr><td>Current status</td><td>Operational (four pools installed as part of an initial trial)</td></tr>
<tr><td>Approximate dimensions</td><td><table>
<tr><td>Total surface area</td><td>4.7 m²</td></tr>
<tr><td>Total volume of concrete</td><td>0.56 m³</td></tr>
<tr><td>Approximate weight of concrete</td><td>1,350 kg (1,490 kg with water)</td></tr>
<tr><td>Max. water capacity</td><td>140 L</td></tr>
<tr><td>Max. water depth</td><td>500 mm</td></tr>
<tr><td>Min. concrete cover / thickness</td><td>150 mm</td></tr>
<tr><td>Overall dimensions</td><td>1,400 mm × 1,000 mm × 700 mm</td></tr>
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<tr><td>Materials and design</td><td>The design and fabrication processes took into account:
the characteristics of the project site (described in the following section)
the need for a simple fabrication process, allowing Lyttelton Port Company to build the pools in-house using excess materials left over from other projects
the need to maximise water retention and the provision of substrate complexity to promote biodiversity.
The pools have an elliptical shape, with a length of approximately 1,400 mm and 1,000 mm along the two axes, and a height of 700 mm. The inside of the pools is characterised by a basin with a maximum depth of 500 mm. Habitat complexity within the basin is provided by an array of horizontal and vertical surfaces of different sizes arranged at different depths. Concrete texturing was added to these surfaces to produce a range of benthic microhabitats such as holes and cracks (Figure A3.27).</td></tr>
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Figure A3.27. Top: One of the pools installed at Lyttelton Port, with a close-up view of the inside basin in the insert. Bottom: Details of the concrete texturing.

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The fabrication process took place at Lyttelton Port, using a simple, low-tech approach. Low carbon eco concrete[13] was poured into a mould consisting of an outer frame of timber and plywood and an internal formwork with timber planks attached to a metal box. The internal formwork created the hollow basin of the pools, and the arrangement of the timber planks generated the array of horizontal and vertical surfaces inside the basin (Figure A3.28).
Before each pour, an eco-friendly concrete release agent was applied to the mould to facilitate its removal once the concrete had cured. Bubble wrap and a range of biodegradable elements, such as pieces of algal and plant material, were secured to the internal formwork to create surface texture in the concrete (Figure A3.28).
Following the pour, the bubble wrap was removed, while the biodegradable elements were either removed or left embedded in the concrete, as they would degrade naturally.

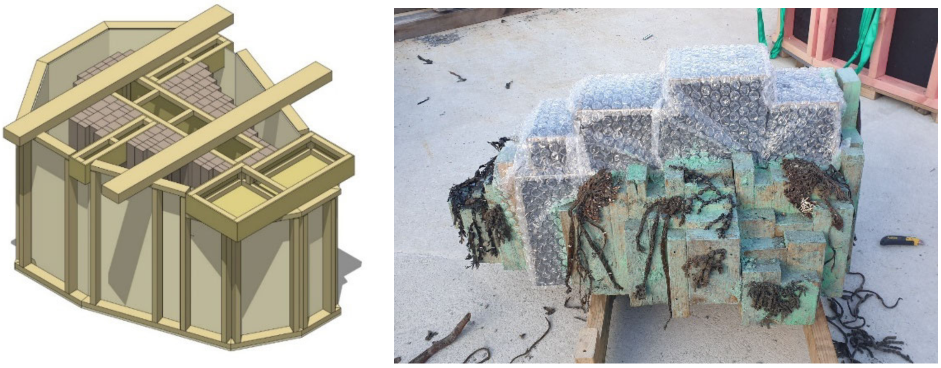

Figure A3.28. Left: Design of the mould. Right: Internal formwork covered with bubble wrap, biodegradable elements and release agent (visible as green paint on the timber planks) before a concrete pour.
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<tr>
<td>Project site characteristics</td>
<td>
The pools were installed at the Cruise Berth Revetment, a south-facing site along the outer perimeter of Lyttelton Port (Figure A3.29). Following an inspection of revetment structures throughout the port, this site was selected because it had a relatively gentle slope and comprised large boulders (so that removal of a single boulder was sufficient to make room for one pool). The large boulder size also allowed the design of relatively large pools, capable of retaining a substantial volume of water at low tide.
This site is also well exposed to waves and currents, which were expected to promote propagule supply and reduce excessive sediment accumulation. In addition, diverse benthic communities are present on the subtidal portion of the revetment. Although few species colonise the intertidal zone, the biodiversity observed in the subtidal zone was considered indicative of good potential for species to colonise the pools over time.
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[13] Alliance Concrete's Ecrete™ e30 mix.

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Figure A3.29. Location (top) and view of the project site (bottom). The position of the pools is indicated in the top image.</td>
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<td>Funding source(s) and approximate costs</td>
<td>Funding source: Lyttelton Port Company

Approximate costs:
• Concept and design: $30,000
• Materials (wood, plywood and concrete): nil (excess materials from other projects).
• Labour (mould construction): $1,180.
• Labour (concrete pours, installation): internal LPC costs (work carried out by LPC staff).
• Monitoring (four rounds): $ 4,000</td>
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Project purpose	The purpose of the project was to: • Develop a simple design and fabrication process that could be implemented using readily available materials and without specialised casting facilities. • Carry out a small trial of the pool units to obtain an initial quantitative assessment of the biodiversity associated with the pools, in comparison with the surrounding intertidal revetment habitat.
Outcomes	The results of a 2-year trial of four pool units showed that: • The pools supported a higher number of taxa and a distinct community compared to the surrounding revetment habitat (Figure A3.30). • Many taxa showed a strong affinity for the pool habitat, while they were absent or rarely found in the surrounding revetment habitat. These included recruits of the habitat-forming fucoid *Sargassum sinclairii*, several fleshy / foliose red algae, oysters, a variety of ascidians and bryozoans, as well as decapods, snails and triplefin fish (Figure A3.30). • Taxa commonly found in the pools included the Asian kelp (*Undaria pinnatifida*) and a range of introduced / cryptogenic ascidians and bryozoans commonly found in ports and harbours around the world. • Sediment tended to accumulate in the deepest part of the pool basin and on some of the horizontal surfaces. However, the monitoring results suggest that there is sufficient sediment-free space and diversity of microhabitats to allow colonisation by a wide range of benthic organisms. In summary, the artificial pools produced the expected ecological effects, facilitating the colonisation of the intertidal revetment habitat by species typically restricted to the adjacent subtidal environment. This effect extended to a large number of taxa, increasing the overall biodiversity of the intertidal zone of the revetment. The pools provided suitable habitat for both native and non-native species (which are common in the port area). The presence of non-native species and the accumulation of sediment have not prevented the recruitment and growth of a diverse range of native species.
Additional notes	While there are several proprietary tide pool designs available, these are typically expensive and require sophisticated casting facilities. This project shows that there are ways to make small-scale marine eco-engineering relatively affordable and low-tech. The monitoring programme carried out as part of this project is one of the first assessments of the performance of these devices in Aotearoa New Zealand.

Figure A3.30. Representative images of the pool communities.

6. Acknowledgements

This study was funded by a medium advice grant through the Ministry of Business, Innovation and Employment Envirolink programme (CAW2502 2535-NLCC132 Kia mau te Moana: an evaluation of artificial reefs in Aotearoa New Zealand). We thank the following people for supporting this work: Harry Allard (Nelson City Council), Oliver Wade (Marlborough District Council), Tania Bray (Tasman District Council), Megan Oliver (Greater Wellington Regional Council), Rachel Parry (Greater Wellington Regional Council), Ash Rabel (Environment Southland), Shannon Weaver (Hawke's Bay Regional Council), Sam Thomas (Otago Regional Council), everyone at e3Scientific, and the survey respondents. Allison Brownlee (Cawthron) created the report map and Laura Kelly (Cawthron) assisted with data visualisation. A thank you to Anna Berthelsen (Cawthron), who reviewed the report, and Susi Bailey (Cawthron), who edited it.

7. References

Allgeier JE, Griffith M. 2025. Greenwashing marine conservation: the use of artificial reefs for fisheries and coral restoration needs oversight. Conservation Letters. 18(5).

Artificial reefs built off Napier. 8 February 2021. Otago Daily Times. https://www.pressreader.com/new-zealand/otago-daily-times/20210208/281543703612938

Atalah J, Fletcher LM, Davidson IC, South PM, Forrest BM. 2020. Artificial habitat and biofouling species distributions in an aquaculture seascape. Aquaculture Environment Interactions. 12:495–509.

ARC Marine. 2023. 2023 impact report: beyond the horizon. Torquey: ARC Marine. https://arcmarine.co.uk/wp-content/uploads/2025/03/Impact-Report-2023-v9.pdf

Babaran RP. 2006. Payao fishing and its impact to tuna stocks: a preliminary analysis. In: Proceedings of the Scientific Committee Second Regular Session, Western and Central Pacific Fisheries Commission; 7–18 August 2006; Manila, Philippines. WCPFC-SC2-2006/FT WP-7.

Baillie BR, Davies TR. 2010. Influence of large woody debris on channel morphology in native forest and pine plantation streams in the Nelson Region, New Zealand. New Zealand Journal of Marine and Freshwater Research. 36(4):763–774.

Baillie BR, Garrett LG, Evanson AW. 2008. Spatial distribution and influence of large woody debris in an old-growth forest river system, New Zealand. Forest Ecology and Management. 256(1–2):20–27.

Baine M. 2001. Artificial reefs: a review of their design, application, management and performance. Ocean and Coastal Management. 44(3–4):241–259.

Baker CF. 2003. Effect of fall height and notch shape on the passage of inanga (*Galaxias maculatus*) and common bullies (*Gobiomorphus cotidianus*) over an experimental weir. New Zealand Journal of Marine and Freshwater Research. 37(2):283–290.

Baker CF. 2014. Effect of ramp length and slope on the efficacy of a baffled fish pass. Journal of Fish Biology. 84(2):491–502.

Baker CF, Boubée JAT. 2006. Upstream passage of inanga *Galaxias maculatus* and redfin bullies *Gobiomorphus huttoni* over artificial ramps. Journal of Fish Biology. 69(3):668–681.

Baker CF, Williams P, Pyper N, Franklin PA, Finlayson M. 2024. Rubber ramp and spat rope did not facilitate upstream passage of a galaxiid through a perched culvert. Marine and Freshwater Research. 75(3):MF23207.

Barber JS, Chosid DM, Glenn RP, Whitmore KA. 2009. A systematic model for artificial reef site selection. New Zealand Journal of Marine and Freshwater Research. 43(1):283–297.

Barrett I, Pahlow M, Cochrane T, Espiner C, Fisher P, Bloxham M, Hussain E, James T, Lee S. 2024. Guidance for large wood installations in New Zealand rivers. Wellington: Ministry of Business, Innovation and Employment.

Bartholomew A, Burt JA, Firth LB. 2022. Artificial reefs in the Arabian Gulf: benefits, challenges and recommendations for policy-makers. Regional Studies in Marine Science. 56:102723.

Battershill CN, Ross PR, Schiel DR. 2016. The MV *Rena* shipwreck: time-critical scientific response and environmental legacies. New Zealand Journal of Marine and Freshwater Research. 50(1):173–182.

Becker A, Taylor MD, Lowry MB, Grabowski J. 2017. Monitoring of reef associated and pelagic fish communities on Australia's first purpose built offshore artificial reef. ICES Journal of Marine Science. 74(1):277–285.

Beechie TJ, Sear DA, Olden JD, Pess GR, Buffington JM, Moir H, Roni P, Pollock MM. 2010. Process-based principles for restoring river ecosystems. BioScience. 60(3):209–222.

Bell BD, Brackenbury G. 2003. New Zealand dabchicks (*Poliocephalus reufopectus*) dive to gain access to nest under jetty at Lake Taupo, New Zealand. Notornis. 51:1.

Bell J, Bull L, Miller A, Burke S, Hetet L, Paine M, Shand T. 2023. Greening the grey – incorporating ecological enhancement into the Te Ara Tupua pathway. In: Proceedings of the Australasian Coasts and Ports 2023 Conference; 15–18 August 2023; Sunshine Coast, Queensland, Australia.

Benjamin ED, Hale R, Handley SJ, Hillman JR, Jeffs A. 2024. Addition of mussel shells enhance marine benthic biodiversity in two degraded coastal soft sediment ecosystems. Science of the Total Environment. 955:177066.

Black K. 2001. Artificial surfing reefs for erosion control and amenity: theory and application. Journal of Coastal Research. Special Issue 34:1–14.

Black SMK. 1999. A multipurpose, artificial reef at Mount Maunganui Beach, New Zealand. Coastal Management. 27(4):355–365.

Blakely TJ, Harding JS, McIntosh AR, Winterbourn MJ. 2006. Barriers to the recovery of aquatic insect communities in urban streams. Freshwater Biology. 51(9):1634–1645.

Bonnett ML. 2000. Critical habitat features of giant kokopu, *Galaxias argenteus* (Gmelin 1789) [MSc thesis]. Christchurch: University of Canterbury.

Bonnett ML, McDowall RM, Sykes JRE. 2002. Critical habitats for the conservation of giant kokopu, *Galaxias argenteus* (Gmelin, 1789). Wellington: Department of Conservation.

Bonnici L, Borg JA, Evans J, Lanfranco S, Schembri PJ. 2018. Of rocks and hard places: comparing biotic assemblages on concrete jetties versus natural rock along a microtidal Mediterranean shore. Journal of Coastal Research. 345:1136–1148.

Booth J. 2020. Marine biodiversity in Bay of Islands' Maunganui Bay, and consideration of the impact of 10 years' closure to fishing under a Fisheries Act Section 186A rāhui. Bay of Islands: Fish Forever.

Booth JD, Cox O. 2003. Marine fisheries enhancement in New Zealand: our perspective. New Zealand Journal of Marine and Freshwater Research. 37(4):673–690.

Booth JD, Forman JS, Stotter DR. 1998. Abundance of early life history stages of the red rock lobster, *Jasus edwardsii*, with management implications. Wellington: Ministry of Fisheries.

Borne KE, Fassman EA, Tanner CC. 2013. Floating treatment wetland retrofit to improve stormwater pond performance for suspended solids, copper and zinc. Ecological Engineering. 54:173–182.

Bortone SA. 1998. Resolving the attraction–production dilemma in artificial reef research: some yeas and nays. Fisheries. 23(3):6–10.

Bracho-Villavicencio C, Matthews-Cascon H, Rossi S. 2023. Artificial reefs around the world: a review of the state of the art and a meta-analysis of its effectiveness for the restoration of marine ecosystems. Environments. 10(7):121.

Brickhill MJ, Lee SY, Connolly RM. 2005. Fishes associated with artificial reefs: attributing changes to attraction or production using novel approaches. Journal of Fish Biology. 67:53–71.

Bright A, Waas JR, Innes J. 2004. Correlations between human-made structures, boat-pass frequency and the number of New Zealand dabchicks (*Poliocephalus rufopectus*) on the Rotorua Lakes, New Zealand. New Zealand Journal of Ecology. 28(1):6.

Brook FJ, Grace RV. 1981. Soft-bottom benthic faunal assemblages of Tutukaka Harbour, Northland, New Zealand. Tane. 27:24.

Burt J, Feary D, Usseglio P, Bauman A, Sale PF. 2010. The influence of wave exposure on coral community development on man-made breakwater reefs, with a comparison to a natural reef. Bulletin of Marine Science. 86(4):839–859.

Callier MD, Byron CJ, Bengtson DA, Cranford PJ, Cross SF, Focken U, Jansen HM, Kamermans P, Kiessling A, Landry T et al. 2017. Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Reviews in Aquaculture. 10(4):924–949.

Carr MH, Hixon MA. 1997. Artificial reefs: the importance of comparisons with natural reefs. Fisheries. 22(4):28–33.

Cawker S. June 2000. Captain Asparagus goes AWOL. Big balls in Napier. Boating New Zealand. p. 4. [accessed 23 February 2026]. https://www.artificialreefs.org/Articles/boatingnz/boatingnz.htm

Chan J, Blanchard L, Flocard F, Paine M, Shand T. 2023. Using physical model testing to inform coastal design in complex wave environments. In: Proceedings of the Australasian Coasts and Ports 2023 Conference; 15–18 August 2023; Sunshine Coast, Queensland, Australia.

Chong L, Siders ZA, Lorenzen K, Ahrens RN, Camp EV. 2024. Global synthesis of effects and feedbacks from artificial reefs on socioecological systems in recreational fisheries. Fish and Fisheries. 25(2):303–319.

Cinner JE. 2011. Social–ecological traps in reef fisheries. Global Environmental Change. 21:835–839.

Collins KJ, Jensen AC, Mallinson JJ, Roenelle V, Smith IP. 2002. Environmental impact assessment of a scrap tyre artificial reef. ICES Journal of Marine Science. 59:S243–S249.

Comfort JA, Single MB. 1997. Literature review on the effects of seawalls on beaches. Wellington: Department of Conservation.

da Silva RF, Hansen J, Lowe R, Rijnsdorp D. 2022. Wave run-up in the lee of submerged breakwaters. In: Proceedings of the Australasian Coasts and Ports 2021 Conference; 11–13 April 2022; Christchurch, New Zealand.

[DCEW] Department of Climate Change, the Environment and Water. 2023. National artificial reef guidelines. Version 1.0. Canberra (ACT): Department of Climate Change, the Environment and Water.

[DOC] Department of Conservation Freshwater Team. 2019. Fish habitat device trials in the Waikato Region. Wellington: Department of Conservation. [accessed 23 February 2026].

https://www.doc.govt.nz/globalassets/documents/conservation/land-and-freshwater/freshwater/habitat/freshwater-habitat-restoration-waikato-fish-habitat-devices.pdf

Dafforn KA, Glasby TM, Johnston EL. 2012. Comparing the invasibility of experimental 'reefs' with field observations of natural reefs and artificial structures. PLoS One. 7(5):e38124.

Ellery PM, Hicks BJ. 2009. Restoration of floodplain habitats for inanga (*Galaxias maculatus*) in the Kaituna River, North Island, New Zealand. New Zealand Natural Sciences. 34:10.

Ellis-Smith BG, Needham HR, Stephenson F, Hillman JR, Lohrer AM, Ellis JI, Pilditch CA. 2025. Environmental drivers of *Atrina zelandica* habitat suitability in Tauranga Harbour. New Zealand Journal of Marine and Freshwater Research. 59(5):1303–1323.

Escalle L, Mourot J, Hamer P, Hare SR, Phillip NB, Pilling GM. 2023. Towards non-entangling and biodegradable drifting fish aggregating devices: baselines and transition in the world's largest tuna purse seine fishery. Marine Policy. 149:105500.

Evans BF, Townsend CR, Crowl TA. 1993. Distribution and abundance of coarse woody debris in some southern New Zealand streams from contrasting forest catchments. New Zealand Journal of Marine and Freshwater Research. 27(2):227–239.

Faaui TN, Morgan TKKB, Hikuroa DCH. 2017. Ensuring objectivity by applying the Mauri Model to assess the post-disaster affected environments of the 2011 MV *Rena* disaster in the Bay of Plenty, New Zealand. Ecological Indicators. 79:228–246.

Faltinsen OM. 2015. Hydrodynamics of marine and offshore structures. Journal of Hydrodynamics, Series B. 26(6):835–847.

Fariñas-Franco JM, Roberts D. 2014. Early faunal successional patterns in artificial reefs used for restoration of impacted biogenic habitats. Hydrobiologia. 727(1):75–94.

Firth LB, Airoldi L, Bulleri F, Challinor S, Chee SY, Evans AJ, Hanley ME, Knights AM, O'Shaughnessy K, Thompson RC, et al. 2020. Greening of grey infrastructure should not be used as a Trojan horse to facilitate coastal development. Journal of Applied Ecology. 57(9):1762–1768.

Fitzgerald E, Guccione D. 2021. Review of Ōpōtiki community artificial reef structures deployed in 2010 – lessons for future deployments. Toiohomai Institute of Technology. Prepared for Ōpōtiki Community REAF.

FOCUS. 2013. Mount Maunganui Reef – Assessment of management options. Tauranga: Bay of Plenty Regional Council.

Folpp H, Lowry M, Gregson M, Suthers IM. 2014. Fish assemblages on estuarine artificial reefs: natural rocky-reef mimics or discrete assemblages? PLoS One. 8(6):e63505.

Folpp HR, Schilling HT, Clark GF, Lowry MB, Maslen B, Gregson M, Suthers IM. 2020. Artificial reefs increase fish abundance in habitat-limited estuaries. Journal of Applied Ecology. 57(9):1752–1761.

Fish Forever. 2012. Marine communities associated with the frigate *Canterbury* and on nearby shores, eastern Bay of Islands, 2012. Bay of Islands: Fish Forever.

Forrest BM, Fletcher LM, Atalah J, Piola RF, Hopkins GA. 2013. Predation limits spread of *Didemnum vexillum* into natural habitats from refuges on anthropogenic structures. PLoS One. 8(12):e82229.

Foster M, Burke S. 2015. The Onehunga foreshore restoration project – a collaborative approach. In: Proceedings of the 22nd Australasian Coastal and Ocean Engineering Conference and 15th Australasian Coasts and Ports Conference; 15–18 September 2015; Auckland, New Zealand.

Foster M, Shand M. 2023. Innovative design approaches on a major transport infrastructure project at the coast – the Te Ara Tupua experience. In: Proceedings of the Australasian Coasts and Ports 2023 Conference; 15–18 August 2023; Sunshine Coast, Queensland, Australia.

Franklin P, Gee E. 2019. Living in an amphidromous world: perspectives on the management of fish passage from an island nation. Aquatic Conservation: Marine and Freshwater Ecosystems. 29(9):1424–1437.

Franklin PA, Bartels B. 2012. Restoring connectivity for migratory native fish in a New Zealand stream: effectiveness of retrofitting a pipe culvert. Aquatic Conservation: Marine and Freshwater Ecosystems. 22(4):489–497.

Freeman D. 2014. Assessment of report by Bioresearches Group Ltd (2014), titled 'Fisheries and ecological effects of the proposal for leaving the wreck of MV *Rena* on Astrolabe Reef'. Wellington: Department of Conservation. [accessed 23 February 2026]. https://www.crownlaw.govt.nz/assets/Uploads/Reports/fisheries-and-ecology.pdf

Frehse FDA, Derviche P, Pereira FW, Hostim-Silva M, Vitule JRS. 2025. Artificial aquatic habitats: a systematic literature review and new perspectives. Hydrobiologia. 852(8):1997–2012.

Funnell LJ. 2019. Short-term impacts of physical instream restoration works on the invertebrate community in Waituna Creek, measured by Surber and kick-net sampling methods [MSc thesis]. Dunedin: University of Otago.

Gallagher F. 2025. Settlement and growth of marine organisms on artificial habitats [MSc thesis]. Wellington: Victoria University of Wellington.

García-Rama A, Ravazzolo D, Rainato R. 2015. Wood in world rivers. In: Proceedings of the Third International Wood in World Rivers Conference 2015; 6–10 July 2015; Padova, Italy.

Gardiner NM. 2022. Restoration of productive aquatic ecosystems by small-scale fisheries and aquaculture communities in Asia. Good practices, innovations, and success stories. Bangkok, Thailand. Bangkok: Food and Agriculture Organization of the United Nations.

Gershman D, Nickson A, O'Toole M. 2015. Estimating the use of FADs around the world. Philadelphia (PA) and Washington (DC): Pew Charitable Trust.

Gesing F. 2016. Working with nature in Aotearoa New Zealand: an ethnography of coastal protection. Bielefeld: Transcript Verlag.

Ghazali SM, Montgomery JC, Jeffs AG, Ibrahim Z, Radford CA. 2013. The diel variation and spatial extent of the underwater sound around a fish aggregation device (FAD). Fisheries Research. 148:9–17.

Gibbs MT. 2004. Interactions between bivalve shellfish farms and fishery resources. Aquaculture. 240:267–296.

Gordon. 2017. Repairing nature's mistakes – the contradictions of working with nature. In: Proceedings of the Australasian Coasts and Ports 2017 Conference; 21–23 June 2017; Cairns, Australia.

Gordon DP, Beaumont J, MacDiarmid A, Robertson DA, Ahyong ST. 2010. Marine biodiversity of Aotearoa New Zealand. PLoS One. 5(8):e10905.

Glassey P, Barrell D, Forsyth J, Macleod R. 2003. The geology of Dunedin, New Zealand, and the management of geological hazards. Quaternary International. 103(1):23–40.

Grzelewski D. 1999. The last cruise of *Mikhail Lermontov*. New Zealand Geographic. 042 (April–June).

Hale R, Thompson D, Brough T, Kregting L, Hayden M, Parsons D, Nodder SD, Beaumont J, Anderson O, Stevens C. 2024. Environmental implications of future offshore renewable energy development in Aotearoa New Zealand. Journal of the Royal Society of New Zealand. 55(4):912–945.

Hancock N, MacDiarmid A, Sturman J. 2009. Coastal structures: mapping their distribution and determining their impact on the marine ecosystem. In: Proceedings of the Australasian Coasts and Ports 2009 Conference; 16–18 September 2009; Wellington, New Zealand.

Handley S. 2006. An analysis of the historical impacts and composition of the benthic environments of Tasman and Golden Bays. Nelson: National Institute of Water and Atmospheric Research. NIWA Client Report NEL2006-002. Prepared for Tasman District Council.

Handley S. 2022. Technical options for coastal habitat restoration in Te Tauihu. Nelson, New Zealand. Nelson: National Institute of Water and Atmospheric Research. NIWA Client Report No. 2022170NE. Prepared for Marlborough District Council.

Harris LE. 2003. Artificial reef structures for shoreline stabilization and habitat enhancement. In: Proceedings of the 3rd International Surfing Reef Symposium; 23–25 June 2003; Raglan, New Zealand.

Hay CH, Luckens PA. 1987. The Asian kelp *Undaria pinnatifida* (Phaeophyta: Laminariales) found in a New Zealand harbour. New Zealand Journal of Botany. 25(2):329–332.

Headley TR, Tanner CC. 2006. Application of floating wetlands for enhanced stormwater treatment: A review. Auckland, New Zealand. Prepared for Auckland Regional Council.

Headley TR, Tanner CC. 2012. Constructed wetlands with floating emergent macrophytes: an innovative stormwater treatment technology. Critical Reviews in Environmental Science and Technology. 42(21):2261–2310.

Hickford MJH, Schiel DR. 2013. Artificial spawning habitats improve egg production of a declining diadromous fish, *Galaxias maculatus* (Jenyns, 1842). Restoration Ecology. 21(6):686–694.

Hicks B, Reeves G. 1994. Restoration of stream habitat for fish using in-stream structures. In: proceedings of the New Zealand Limnological Society 1993 Annual Conference; 10–12 May 2023; Wellington, New Zealand.

Higgins E, Metaxas A, Scheibling RE. 2022. A systematic review of artificial reefs as platforms for coral reef research and conservation. PLoS One. 17(1):e0261964.

Hill-Moana T, Neubauer P, Middleton DAJ, Vidal T, Escalle L, Cook D. 2025. Towards the development of a catch per unit effort (CPUE) index for the purse seine fishery. Wellington: Fisheries New Zealand. New Zealand Fisheries Assessment Report 2025/37.

Holmes R, Goodwin E. 2021. Waituna Creek instream restoration trial assessment: the effect of instream habitat structures on the fish community. Nelson: Cawthron Institute. Cawthron Report No. 3671. Prepared for Department of Conservation Southland.

Ilieva I, Jouvet L, Seidelin L, Best BD, Aldabet S, da Silva R, Conde DA. 2019. A global database of intentionally deployed wrecks to serve as artificial reefs. Data Brief. 23:103584.

[IMO / UNEP] International Maritime Organization / United Nations Environment Programme. 2009. London Convention and Protocol / UNEP guidelines for the placement of artificial reefs. London: International Maritime Organization. UNEP Regional Seas Reports and Studies No. 187.

Joshua C, Hu Y, Zhou W, Chaidir DM, Murdoch R. 2022. Restoration of native fish habitats in urban streams to mitigate the effects of pollution and fragmentation. [accessed 23 February 2026]. https://www.researchgate.net/publication/394408138_Restoration_of_Native_Fish_Habitats_in_Urban_Streams_to_Mitigate_the_Effects_of_Pollution_and_Fragmentation

Nauta J, Christianen MJ, Temmink RJ, Fivash GS, Marin-Diaz B, Reijers VC, Didderen K, Penning E, Borst AC, Heusinkveld JH, et al. 2023. Biodegradable artificial reefs enhance food web complexity and biodiversity in an intertidal soft-sediment ecosystem. Journal of Applied Ecology. 60(3):541–552.

Jackson L, Corbett B. 2007. Review of existing multi-functional artificial reefs. In: Proceedings of the 18th Australasian Coastal and Ocean Engineering Conference and the 11th Australasian Port and Harbour Conference 2007; 18–20 July 2007; Melbourne, Australia.

Jackson S, Cameron M, Paine M. 2022. Marine habitat enhancement and fauna management at Cobham Drive, Wellington. In: Proceedings of the Australasian Coasts and Ports 2021 Conference; 11–13 April 2022; Christchurch, New Zealand.

Jaffrey J. 2004. Report on an observational dive visit by J. Jaffrey to the Long Bay artificial reefs on Friday 23rd January 2004. Auckland: Auckland University of Technology.

Jaffrey J, Taylor T, Murphy P. 2002. Interim report on the artificial reef constructed in the Long Bay–Okura Marine Reserve, Auckland. Auckland: Auckland University of Technology.

Jaffrey J, Taylor T, Murphy P. 2003. Interim report on the artificial reef constructed in the Long Bay – Okura Marine Reserve, Auckland. Auckland: Auckland University of Technology.

Jaffrey J, Taylor T, Proesi A. 2001. Interim report on the artificial reef in the Long Bay – Okura Marine Reserve, Auckland. Auckland: Auckland University of Technology.

Jeffares M. 4 July 2023. Artificial reef now under two year fishing ban. New Zealand Herald.

Jellyman DJ, Chisnall BL. 1999. Habitat preferences of shortfinned eels (*Anguilla australis*) in two New Zealand lowland lakes. New Zealand Journal of Marine and Freshwater Research. 33(2):233–248.

Jenks GK. 2018. Restoring the natural functional capacity of coastal dune ecosystems: utilising research records for New Zealand littoral refurbishment as a proxy for analogous global responses. Journal of Coastal Conservation. 22(4):623–665.

Joshua C, Hu Y, Zhou W, Muhamad DC, Montgomery RM. 2022. Restoration of native fish habitats in urban streams to mitigate the effects of pollution and fragmentation. [accessed 16 February 2026]. https://www.researchgate.net/publication/394408138_Restoration_of_Native_Fish_Habitats_in_Urban_Streams_to_Mitigate_the_Effects_of_Pollution_and_Fragmentation

Joy MK, Death RG. 2013. Freshwater biodiversity. In: Dymond JR, editor. Ecosystem services in New Zealand: conditions and trends. Lincoln: Manaaki Whenua Press. p. 448–459.

Koneski G, Huteau J. 2023. Ecological and environmental considerations for a civil project in New Zealand water. In: Proceedings of the Australasian Coasts and Ports 2023 Conference; 15–18 August 2023; Sunshine Coast, Queensland, Australia

Kusabs IA, Hicks BJ, Quinn JM, Perry WL, Whaanga H. 2018. Evaluation of a traditional Māori harvesting method for sampling kōura (freshwater crayfish, *Paranephrops planifrons*) and toi toi (bully, *Gobiomorphus* spp.) populations in two New Zealand streams. New Zealand Journal of Marine and Freshwater Research. 52(4):603–625.

Kusabs IA, Duggan IC, Scholes P, Bruere A, Te Kurapa TW, Grant T, Burdon FJ. In prep. Invasive catfish linked to the decline of freshwater crayfish in two Aotearoa New Zealand lakes.

Larcombe MF, Russell BC. 1971. Egg laying behaviour of the broad squid, *Sepioteuthis bilineata*. New Zealand Journal of Marine and Freshwater Research. 5(1):3–11.

Larned ST, Moores J, Gadd J, Baillie B, Schallenberg M. 2020. Evidence for the effects of land use on freshwater ecosystems in New Zealand. New Zealand Journal of Marine and Freshwater Research. 54(3):551–591.

Layman CA, Allgeier JE. 2020. An ecosystem ecology perspective on artificial reef production. Journal of Applied Ecology. 57(11):2139–2148.

Leeworthy VR, Maher T, Stone EA. 2006. Can artificial reefs alter user pressure on adjacent natural reefs? Bulletin of Marine Science. 78(1):29–38.

Lima JS, Zalmon IR, Love M. 2019. Overview and trends of ecological and socioeconomic research on artificial reefs. Marine Environmental Research. 145:81–96.

Livingstone E, Belcher K, Wyke K, Payne R, Strange S. 2019. Options for the restoration and enhancement of the longfin eel / tuna kuwharuwharu population and habitat in the Ōtākaro Avon River. Christchurch: University of Canterbury.

Lohrer AM, McCartain LD, Buckthought D, MacDonald I, Parsons DM. 2018. Benthic structure and pelagic food sources determine post-settlement snapper (*Chrysophrys auratus*) abundance. Frontiers in Marine Science. 5:427.

McKenzie CJ. 2017. Using marine ecoengineering to mitigate biodiversity loss on modified structures in the Waitematā Harbour [MSc thesis]. Auckland: Massey University.

McLintock R, Rona L, Murray D. 2023. Te Ara Tupua: reef enhancement. Resource consent application and assessment of effects on the environment (AEE). Report NKP-TAT-000-REP-PP-NS-000004. Wellington: Te Ara Tupua Alliance. Prepared for Waka Kotahi.

Mead S, Black K. 1999. A multipurpose, artificial reef at Mount Maunganui Beach, New Zealand. Coastal Management. 27(4):355–365.

Mead S, Black K. 2005. Development of a multi-purpose reef at Orewa Beach, New Zealand. In: Proceedings of the 17th Australasian Coasts and Ports Conference; 20–23 September 2005; Adelaide, Australia.

Mead ST. 2009. Multiple-use options for coastal structures: unifying amenity, coastal protection and marine ecology. Reef Journal. 1(1):21.

Meleason MA, Davies-Colley R, Wright-Stow A, Horrox J, Costley K. 2005. Characteristics and geomorphic effect of wood in New Zealand's native forest streams. International Review of Hydrobiology. 90(5–6):466–485.

Meleason MA, Hall GM. 2005. Managing plantation forests to provide short- to long-term supplies of wood to streams: a simulation study using New Zealand's pine plantations. Environmental Management. 36(2):258–271.

[MfE] Ministry for the Environment. 2021. National works in waterways guideline. Prepared for the Ministry for the Environment by Boffa Miskell Limited. Wellington: Ministry for the Environment.

Moores A. 2006. Artificial surf reefs – coming to a beach near you. New Zealand Geographic. 078 (March–April).

Morrisey DJ, Cole RG, Davey NK, Handley SJ, Bradley A, Brown SN, Madarasz AL. 2006. Abundance and diversity of fish on mussel farms in New Zealand. Aquaculture. 252(2–4):277–288.

Morrison MA. 2021. Hauraki Gulf Marine Park habitat restoration potential. Wellington: Fisheries New Zealand. New Zealand Aquatic Environment and Biodiversity Report No. 265.

Morrison MA, Lowe ML, Parsons DM, Usmar NR, McLeod IM. 2009. A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. Wellington: Fisheries New Zealand. New Zealand Aquatic Environment and Biodiversity Report No. 37.

Morrison R. 2018. MV *Kay Dee*: the how to and why guide to artificial reefs in New Zealand. Tauranga: Toi Ohomai Institute.

Morton DN, Shima JS. 2013. Habitat configuration and availability influences the settlement of temperate reef fishes (Tripterygiidae). Journal of Experimental Marine Biology and Ecology. 449:215–220.

Murray J. 8 July 2025. Our changing world: Tauranga's living sea wall. RNZ. [accessed 23 February 2026]. https://www.rnz.co.nz/news/ourchangingworld/566233/our-changing-world-tauranga-s-living-sea-wall

Nair S, Clark V, Milne S. 2004. Making waves: artificial reefs and urban open space management in New Zealand. Auckland: New Zealand Tourism Research Institute, Auckland University of Technology.

Nielsen A, Jayewardene I, Klabbers M, Gordon A. 2022. Optimising the design of breakwaters and revetments with a flexible-scale basin model. In: Proceedings of the Australasian Coasts and Ports 2021 Conference; 11–13 April 2022; Christchurch, New Zealand.

Norman L. 2018. Soft solutions for hard engineering problems. In: Proceedings of the Water New Zealand Stormwater Conference 2018; 23–25 May 2018; Queenstown, New Zealand.

Noth EG, Francis RICC, Jellyman DJ. 2008. Factors influencing juvenile eel (*Anguilla* spp.) survival in lowland New Zealand streams. New Zealand Journal of Marine and Freshwater Research. 42(2):153–172.

O'Neil A. 21 April 2015. Navy frigate blown up to create Island Bay dive site. Stuff. [accessed 23 February 2026]. https://www.stuff.co.nz/dominion-post/news/67914889/navy-frigate-blown-up-to-create-island-bay-dive-site

Ōpōtiki Community REAF Trust. 2010. Fish monitoring efforts April 2009 – April 2010. Ōpōtiki: Ōpōtiki Community REAF Trust.

Orchard DSE, Hickford MJ, Schiel DR. 2018. Use of artificial habitats to detect spawning sites for the conservation of *Galaxias maculatus*, a riparian-spawning fish. Ecological Indicators. 91:617–625.

Parata RN. 2019. Quantifying relationships between kōura (*Paranephrops planifrons*) abundance and micro-habitat features in Waikato hill-country streams [MSc thesis]. Hamilton: University of Waikato.

Parsons DM, MacDonald I, Buckthought D, Middleton C. 2018. Do nursery habitats provide shelter from flow for juvenile fish? PLoS One. 13(1):e0186889.

Paul LJ. 2012. A history of the Firth of Thames dredge fishery for mussels: use and abuse of a coastal resource. Wellington: Ministry of Agriculture and Forestry. New Zealand Aquatic Environment and Biodiversity Report No. 94.

Paxton A, Steward D, Mille K, Renchen J, Harrison Z, Byrum J, Brinton C, Nelson A, Simpson E, Clarke P, et al. 2024a. Artificial reef footprint in the United States ocean. Nature Sustainability. 7(2):140–147.

Paxton AB, McGonigle C, Damour M, Holly G, Caporaso A, Campbell PB, Meyer-Kaiser KS, Hamdan LJ, Mires CH, Taylor JC. 2024b. Shipwreck ecology: understanding the function and processes from microbes to megafauna. BioScience. 74(1):12–24.

Paxton AB, Runde BJ, Smith CS, Lester SE, Vozzo ML, Saunders MI, Steward DaN, Lemoine HR, Valdez SR, Gittman RK et al. 2025. Leveraging built marine structures to benefit and minimize impacts on natural habitats. BioScience. 75(2):172–183.

Paxton AB, Shertzer KW, Bacheler NM, Kellison GT, Riley KL, Taylor JC. 2020. Meta-analysis reveals artificial reefs can be effective tools for fish community enhancement but are not one-size-fits-all. Frontiers in Marine Science. 7:282.

Peatman T, Allain V, Bell L, Muller B, Panizza A, Phillip NB, Pilling G, Nicol S. 2023. Estimating trends and magnitudes of bycatch in the tuna fisheries of the western and central Pacific Ocean. Fish and Fisheries. 24(5):812–828.

Perkol-Finkel S, Hadary T, Rella A, Shirazi R, Sella I. 2018. Seascape architecture – incorporating ecological considerations in design of coastal and marine infrastructure. Ecological Engineering. 120:645–654.

Phillips D, Black K, Healy T. 2009. Issues surrounding the construction of artificial reefs by detailed examination of a natural headland. Reef Journal. 1:162–176.

Pollard DA. 1989. Artificial habitats for fisheries enhancement in the Australian region. Marine Fisheries Review. 51(4):11–26.

Pomeroy AWM, Burmeister N. 2022. A new approach to increase the resilience of coastal structures. In: Proceedings of the Australasian Coasts and Ports 2021 Conference; 11–13 April 2022; Christchurch, New Zealand.

Pondella DJ, Claisse JT, Williams CM. 2022. Theory, practice, and design criteria for utilizing artificial reefs to increase production of marine fishes. Frontiers in Marine Science. 9:983253.

Napier Port. 4 February 2021. Hawke's Bay's newest reefs are a great example of collaboration in action. Napier: Napier Port. [accessed 23 February 2026]. Hawke's Bay's newest reefs are a great example of collaboration in action - Napier Port, Hawke's Bay, New Zealand

Pan Y, Tong H, Wei D, Xiao W, Xue D. 2022. Review of structure types and new development prospects of artificial reefs in China. Frontiers in Marine Science. 9:853452.

Pratt JR. 1994. Artificial habitats and ecosystem restoration: managing for the future. Bulletin of Marine Science. 55(2–3):268–275.

Reid M, Sumner B. 6 December 2021. The Kiwi scientist and the failed surf breaks. Newsroom. [accessed 19 February 2026]. https://newsroom.co.nz/2021/12/06/the-kiwi-scientist-and-the-failed-surf-breaks

Reihana K. 2016. Contrasting microbial communities across anthropogenic pollution gradients: MV *Rena* shipwreck versus urban pressures [MSc thesis]. Hamilton: University of Waikato.

Reinen-Hamill R, Sweeney M, Howat M, Hannah G. 2015. Onehunga foreshore restoration project. In: Proceedings of the Australasian Coasts and Ports 2015 Conference; 15–18 September 2015; Auckland, New Zealand.

Rideout A. 6 November 2025. Blown up in a blaze of glory – reborn as a reef: the world-class shipwreck dive on the edge of a city. Stuff. [accessed 23 February 2026]. https://www.stuff.co.nz/nz-news/360876102/world-class-shipwreck-dive-edge-city

RNZ. 7 February 2021. New artificial reefs off Napier coast aim to enhance marine life and improve fishing. RNZ. [accessed 23 February 2026]. New artificial reefs off Napier coast aim to enhance marine life and improve fishing | RNZ News

Robertson S. 2012. SS *Taioma* and SS *Taupo*: an analysis of fish assemblages at two artificial reefs in the Bay of Plenty, testing survey methodology and impacts of structures on sea floor sedimentology. Hamilton: University of Waikato.

Robertson S, Jacobs L. 2011. Annual monitoring of the marine community on the artificial reef HMNZS *Canterbury* and Maunganui Bay, 2011 [Dip. Marine Studies report]. Tauranga: Bay of Plenty Polytechnic.

Roni P, Beechie T, Pess G, Hanson K. 2015. Wood placement in river restoration: fact, fiction, and future direction. Canadian Journal of Fisheries and Aquatic Sciences. 72(3):466–478.

Roni P, Hanson K, Beechie T. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management. 28(3):856–890.

Roper-Lindsay J, Fuller SA, Hooson S, Sanders MD, Ussher GT. 2018. Ecological impact assessment (EcIA). EIANZ guidelines for use in New Zealand: terrestrial and freshwater ecosystems. 2nd ed. Melbourne: Environment Institute of Australia and New Zealand Inc.

Rose P. 2020. Fishery habitat (artificial reef) development plan. Napier: Port Napier.

Ross PM, Battershill CN, Loomb C. 2016. The wreck of the MV *Rena*: spatio-temporal analysis of ship-derived contaminants in the sediments and fauna of Astrolabe Reef. New Zealand Journal of Marine and Freshwater Research. 50(1):87–114.

Russell BC. 1975. The development and dynamics of a small artificial reef community. Helgoländer Wissenschaftliche Meeresuntersuchungen. 27:15.

Russell LK, Hepburn CD, Hurd CL, Stuart MD. 2007. The expanding range of *Undaria pinnatifida* in southern New Zealand: distribution, dispersal mechanisms and the invasion of wave-exposed environments. Biological Invasions. 10(1):103–115.

Salauddin M, O'Sullivan JJ, Abolfathi S, Pearson JM. 2021. Eco-engineering of seawalls – an opportunity for enhanced climate resilience from increased topographic complexity. Frontiers in Marine Science. 8:674630.

Schiel DR, Ross PM, Battershill CN. 2016. Environmental effects of the MV *Rena* ship wreck: cross-disciplinary investigations of oil and debris impacts on a coastal ecosystem. New Zealand Journal of Marine and Freshwater Research. 50(1):1–9.

Schulze A, Erdner DL, Grimes CJ, Holstein DM, Miglietta MP. 2020. Artificial reefs in the northern Gulf of Mexico: community ecology amid the 'ocean sprawl'. Frontiers in Marine Science. 7:447.

Sea M, Thorburn C, Woolford S. 2023. Supporting marine ecosystem recovery through a 'constructed' reef or submerged wreck. Auckland: Kelly Tarlton's Marine Wildlife Trust.

Seaman Jr W, Sprague LM. 2013. Artificial habitats for marine and freshwater fisheries. San Diego (CA) and London (UK: Academic Press.

Seaman W. 2007. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia. 580(1):143–155.

Sheehy DJ, Vik SF. 2010. The role of constructed reefs in non-indigenous species introductions and range expansions. Ecological Engineering. 36(1):1–11.

Shima JS, McNaughtan D, Geange SW, Wilkinson S. 2012. Ontogenetic variation in site fidelity and homing behaviour of a temperate reef fish. Journal of Experimental Marine Biology and Ecology. 416–417:162–167.

Skelton B, Jeffs A. 2021. Deployment plan for artificial rock lobster settlement habitats at Eastland Port. Auckland: Auckland UniServices Ltd.

Smith AM, Kregting L, Fern S, Fraser CI. 2011. Sedimentology of a wreck: the *Rainbow Warrior* revisited. Marine Pollution Bulletin. 62(11):2412–2419.

Smith JA, Lowry MB, Champion C, Suthers IM. 2016. A designed artificial reef is among the most productive marine fish habitats: new metrics to address 'production versus attraction'. Marine Biology. 163(9):188.

Sneddon R. 2023. Napier artificial reef site 1. Observations of reef community development: May 2021–November 2022. Nelson: Cawthron Institute. Cawthron Report No. 3925. Prepared for Port of Napier Ltd.

Spheres of influences! 2001. Employment Matters. 12(5). [accessed 23 February 2025]. http://www.artificialreefs.org/Articles/Spheres%20of%20Influence

Stenton-Dozey J, Broekhuizen N. 2019. Provision of ecological and ecosystem services by mussel farming in the Marlborough Sounds: a literature review in context of the state of the environment pre- and post-mussel farming. Christchurch: National Institute of Water and Atmospheric Research Ltd. NIWA Client Report No: 2019020CH. Prepared for Marine Farming Association.

Stuart MD. 2004. Review of research on *Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island. Wellington: Department of Conservation. DOC Science Internal Series 166.

Szabo M, Grace R. 1994. Wreck to reef – the transfiguration of the *Rainbow Warrior*. New Zealand Geographic. 023 (July–September).

Tanner CC, Headley TR. 2011. Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants. Ecological Engineering. 37(3):474–486.

Taranaki Regional Council. 2009. Opunake Artificial Reef Monitoring Programme 2005–2009. Technical Report. Stratford: Taranaki Regional Council.

Taylor DI, Wood SA, McNabb P, Ogilvie S, Cornelisen C, Walker J, Khor S, Cary SC. 2015. Facilitation effects of invasive and farmed bivalves on native populations of the sea slug *Pleurobranchaea maculata*. Marine Ecology Progress Series. 537:39–48.

Taylor T, Buckeridge J. 2002. Environmental engineering in action: enhancing marine biodiversity within the Long Bay–Okura Marine Reserve. Auckland: Auckland University of Technology.

Te Ūaka The Lyttelton Museum. 2025. The wreck of the 'Mikhail Lermontov'. Lyttelton: Te Ūaka The Lyttelton Museum. [accessed 23 February 2026]. https://www.teuaka.org.nz/stories/whakatere-moana-maritime/ships/the-wreck-of-the-mikhail-lermontov

[TNC] The Nature Conservancy. 2024. A global monitoring, evaluation and learning framework for regenerative and restorative aquaculture: helping nature thrive through aquaculture. Arlington (VA): The Nature Conservancy.

Turner SJ, Thrush SF, Hewitt JE, Cummings VJ, Funnell G. 1999. Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology. 6(5):401–420.

Underwood LH. 2023. Habitat value of green-lipped mussel (*Perna canaliculus*) farms for fish in northern Aotearoa New Zealand [PhD thesis]. Auckland: University of Auckland.

Underwood LH, Jeffs AG. 2023. Settlement and recruitment of fish in mussel farms. Aquaculture Environment Interactions. 15:85–100.

[USDA] United States Department of Agriculture. 2007. Chapter 4: Stream restoration design process. In: Stream restoration design: Part 654, National engineering handbook. Washington (DC): United States Department of Agriculture, Natural Resources Conservation Service. https://directives.nrcs.usda.gov/sites/default/files2/1712931087/7328.pdf

Viduka AJ. 2008. SS *Yongala* – a vested interest commercial utilisation model of public access site management. Adelaide: Flinders University, Archaeology Department.

Viduka A, Sutton B, Hutchison A, Low C, Dempsey TP. 2020. A report on the GIRT scientific diver survey of the *Rainbow Warrior*, Cavalli Islands, New Zealand. Journal of Maritime Archaeology. 16(1):3–26.

Wade BL. 2020. The consequences of complex habitat loss for the New Zealand blue cod, *Parapercis colias* [MSc thesis]. Wellington: Victoria University of Wellington.

Wade BL, Resende AC, Willis-Kaio D, Rogers A. 2025. Exploring the consequences of complex habitat loss for the New Zealand blue cod, *Parapercis colias*. Ecosphere. 16(3):e70233.

Walker SJ, Schlacher TA. 2014. Limited habitat and conservation value of a young artificial reef. Biodiversity and Conservation. 23(2):433–447.

Watchorn DJ, Cowan MA, Driscoll DA, Nimmo DG, Ashman KR, Garkaklis MJ, Wilson BA, Doherty TS. 2022. Artificial habitat structures for animal conservation: design and implementation, risks and opportunities. Frontiers in Ecology and the Environment. 20(5):301–309.

Watson SJ, Neil H, Ribó M, Lamarche G, Strachan LJ, MacKay K, Wilcox S, Kane T, Orpin A, Nodder S, et al. 2020. What we do in the shallows: natural and anthropogenic seafloor geomorphologies in a drowned river valley, New Zealand. Frontiers in Marine Science. 7:579626.

Webby AJ. 2014. Toxicological effects of MV *Rena* pollutants to New Zealand fish and lobster [MSc thesis]. Hamilton: University of Waikato.

Weeks ES, Death RG, Foote K, Anderson-Lederer R, Joy MK, Boyce P. 2016. Conservation science statement: the demise of New Zealand's freshwater flora and fauna – a forgotten treasure. Pacific Conservation Biology. 22(2):110–115.

Weppe S, Healy T, Scarfe B, Immenga D. 2009. Shoreline response to an offshore submerged multifunction reef at Mount Maunganui, New Zealand. In: Proceedings of the Australasian Coasts and Ports 2009 Conference; 16–18 September 2009; Wellington, New Zealand.

White JL, Healy TR. 2001. Volume changes on a sand gravel barrier at a groyne construction, Haumoana, Hawke Bay, New Zealand. Journal of Coastal Research. Special Issue 34:295–305.

Wilson P, Oliver MD. 2023. Marine offsetting and compensation – summary of management guidance and policy. Wellington: Greater Wellington Regional Council. Publication No. GW/KI-T-23/20.

Wodzicki KA, Eyles JR. 1945. White phase of the reef-heron (*Demigretta sacra*) in New Zealand. Emu – Austral Ornithology. 44(3):181–182.

WSP. 2025. Tauranga's living seawall. [accessed 10 July 2025]. https://www.wsp.com/en-nz/projects/tauranga-living-seawall

Young R, Smart G, Harding J. 2004. Impacts of hydro-dams, irrigation schemes and river control works. In: Harding J, Mosley P, Pearson C, Sorrell B, editors. Freshwaters of New Zealand. Christchurch: New Zealand Hydrological Society Inc. and New Zealand Limnological Society Inc. p. 37.1–37.15.

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