Shoreline Adaptation Plans

Literature review

The use of nature-based solutions and ecological enhancement as a consideration for Shoreline Adaptation in Auckland Tāmaki Makaurau

December 2023

Mill Bay, Waitākere, Auckland. Photo credit: Mel Tupe

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Executive summary

Coastal environments around the world are under pressure from climate change. The pressures can vary from localised flooding, erosion, changes in habitats and species distribution, to the loss of coastal land to the sea. Responses often include the assessment of risk along stretches of coastline, the development of strategies or management options and plans to determine future actions.

Across the world and in New Zealand, these plans generally contain options that range from no intervention; preparing, planning or living with climate change; defending against specific coastal hazard effects from climate change with hard structures; and re-naturalisation of the coast and managed retreat inland. Impacts to the coastal environment from climate change can be supported by nature-based solutions and ecological enhancements for protection and to limit the impacts.

Climate change impact predictions presented within the Pearce et al., 2020 report and the Auckland Council Climate Change Risk Assessment series (Section 2.0) can help assist in understanding of climate change pressures on the coastline in Auckland, New Zealand, and aid in decision making and selection of nature-based solutions for shoreline management.

To understand the optimum adaptive strategy, information about climate change stressors, the assets that need to be protected and the current ecology and ecosystems present is required and should be a first step in the development of each of the 20 Shoreline Adaptation Plan for Auckland's coastal environment. These plans look at how council-owned assets and land can be managed in response to coastal hazards and climate change over the next 100 years.

A general theme across the national and international management plans reviewed, is that a naturalised approach is often the preferred option, however, this may not always be feasible due to asset protection, urgency, environmental suitability, consent conditions and cost. However, in many cases, a mix of nature-based solutions and hard structures are the preferred option with longer-term strategic planning having the ability to overcome the barriers of coastal protection and manage the shoreline in a more adaptable way.

The opportunity to utilise nature-based solutions for the protection of shorelines from climate change are progressively being adopted in favour of hard structure coastal protection, which can cause displacement of impacts further around the coastline, potentially requiring ongoing maintenance.

A benefit of nature-based solutions is the ability to future proof the coastline from impacts of climate change processes while providing multiple benefits, including social and economic. Case studies from around the world and New Zealand point towards the provision of ecosystem services such as storm management, water filtration, maintaining and enhancing coastal habitats, protection of existing assets and infrastructure as an outcome of nature based solutions.

Economic benefits from coastal protection through the use of nature-based solutions, reduces the impacts from storms and coastal erosion, through the reduction of impacts to infrastructure. Further economic gains could be made from ecological benefits that come with the provision of healthy ecosystems, including a potential increase in recreational and commercial fishing opportunities as a result of increased fish stocks from the provision of protective habitat, such as kelp forests and salt marsh for juveniles.

By implementing nature-based solutions and ecological enhancements, the positive outcomes can include accommodation for climate change effects, biodiversity conservation, helping to preserve the habitats and species of the local area, increased ecosystem services, and the connectedness with the region for years to come.

To ensure that a nature-based strategy is providing the intended function, monitoring is critical to the success of the work, allowing for intervention if required. Further, State of the Environment monitoring of local water quality and estuarine health, is one current mechanism to understand the current impacts on the coastline from climate change and ecosystem services provided by nature-based solutions.

This literature review supports the Auckland Council Shoreline Adaptation Plan Programme and provides information for community discussions; to inform spatial analysis for coastal management options, opportunities and constraints in a localised context. There are many resources that the review identifies, and these too, are valuable for discussions to inform Auckland Council's decision making for coastal management of council-owned assets and land.

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1.0 Introduction

Coasts and estuaries form a dynamic transition zone between the land and the sea. The coastline which provides benefits across all wellbeings (social, cultural, environmental and economic); a range of ecosystem services; opportunities for recreation, business; and spiritual connections.

Over 40% of the world's population is concentrated in 4% of land area within 100 km from the coast (Burket et al., 2001) and more than 75% of New Zealand's population live within 10 km of the coastline (LEARNZ, 2023).

Auckland has 3,103 km of coastline split between two coasts (Auckland Council, 2020a), with three large harbours; Kaipara and Manukau on the West Coast and Waitematā on the East Coast. Coastal exposures vary from high energy surf beaches and calm harbour beaches, to sheltered estuaries (Auckland Council, 2020a).

Weather events can result in catastrophic damage to coastal communities. To work towards future proofing our coastlines and protecting the assets and communities that utilise the area, the Ministry for the Environment has set out objectives to develop a national approach for nature and climate-based adaptive management solutions to protect our shorelines from the effects of climate change (MfE, 2022a).

Auckland Council is undertaking a Shoreline Adaptation Planning Programme to future proof the coastlines and manage risk to council-owned assets and land to respond to coastal hazards and climate change over the next 100 years.

This document provides a literature review that explores options for incorporating nature-based solutions and ecological enhancement in coastal areas, their application, the ecosystem services they provide, and how coastal management can be applied to mitigate for climate change pressures and provide an option for future coastal protection.

Literature considered for this report includes:

- New Zealand Government Ministry for the Environment guidance and reports
- International government and state/provincial reports and guidance
- Council project reports and websites
- Scientific reports
- The International Union for Conservation of Nature (IUCN) website and reports
- Non-profit organisations website and reports with a focus on nature-based solutions and ecological enhancement
- Tonkin + Taylor project reports.

There are few documented project examples of positive outcomes globally (WWF, 2023), and this literature review draws on those international and national reports that have been found, and the information available around nature-based solutions, ecological enhancement and shoreline adaptation management plans both internationally and within New Zealand.

1.1 The Shoreline Adaptation Plan programme

The development of adaptive management strategies is integral to the success of shoreline management. Adaptive shoreline management is being aware of and being prepared for the natural processes changing our coastline, and hazards that can arise suddenly (TCDC, 2023).

Adaptation strategies to manage and respond to different climate risks have been defined by the Ministry for the Environment as:

- Avoid risk: e.g. by locating development away from areas prone to hazard
- Protect assets from risk: e.g. by building protective structures such as sea walls
- Accommodate risk: e.g. by incorporating adaptation options such as raising the ground and/or levels of buildings, relocating infrastructure or providing alternative inundation pathways into the design of developments
- Retreat from risk: e.g. by relocating existing development away from high-risk areas (MfE, 2022a).

These adaptation management strategies have been in incorporated into the work that Auckland Council is implementing for the shoreline adaptation plans as:

- **No active intervention:** Natural processes are allowed to continue. This includes no investment in the provision or maintenance of any defences.
- **Limited intervention:** Limited works are undertaken to extend the existing asset life or to ensure assets remain safe, including localised retreat of individual assets. This approach acknowledges that the coastline's position will not be fixed into the future and may include small-scale nature-based measures (e.g. dune planting) to support the coastline's resilience.
- **Hold the line**: The coastal edge is fixed at a certain location, using nature-based options (e.g. beach nourishment) or hard structures (e.g. sea walls). Nature-based options are the preferred method where possible.
- **Managed retreat:** Assets and activities are moved away from hazard-prone areas in a controlled way over time. Managed retreat allows greater space for natural buffers and reduces asset exposure to natural hazards (Howe, 2022).

It is important to acknowledge here that the language used for these four adaptation strategies varies amongst countries and agencies, but generally have a similar meaning.

1.1.1 Coastal protection

Traditionally, popular coastal protection management options consisted of engineered solutions mostly comprised of hard structures such as seawalls, groynes and wave-breaks in front of coastal infrastructure and assets. For example, seawalls are the most widely used coastal defence strategy, and have been used for coastal defence for thousands of years. The earliest seawall was built in

Byzantium (now known as Istanbul) in around 195AD (Gallop, 2017). In the process of building these structures, natural marine and terrestrial ecosystems can be destroyed or hardened. These hard structures, provide localised protection, however, they can often have impacts on surrounding ecosystems causing negative changes to morphology, hydrodynamics, sediment and nutrient budgets as well as local economies (Cheong et al., 2013).

One example of this is where groynes are built to prevent or slow down the longshore sediment transport and result in sedimentation accretion on the updrift side of the structure (but they don't work well in protecting the coastline from storm surge or flooding) (Schoonees, et al., 2019).

Climate change presents a new challenge to the coastline and coastal communities, with climate-induced stressors such as sea-level rise, storm surges, freshwater flood inputs and coastal erosion predicted to increase, and can act as multiple stressors within coastal ecosystems (Cheong, et al., 2013).

The solution to the pressures and protection measures is a combination of strategies, including consideration of nature-based solutions (or ecological engineering), to allow the approach to be versatile and flexible to multiple stressors while protecting the shoreline, infrastructure and assets (Cheong et al., 2013). The implementation of ecological enhancement can aid in the restoration of habitat or ecosystems that were previously present, or the development of new habitat or ecosystems, which could contribute to coastal protection from climate change. Nature-based solutions and ecological enhancement

Nature-based solutions

Using nature-based solutions as protective strategies can be achieved through an understanding of the interactions between ecological communities and coastal dynamics, to protect or enhance the ecological ecosystem (Steele, 2016).

> *"The European Commission defines nature-based solutions as solutions that are "inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help to build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource efficient and systemic interventions" (European Commission, 2023)*

Nature-based solutions for coastal protection management have an additional benefit of providing opportunities for carbon storage and building climate resilience. It is estimated that nature-based solutions implemented in coastal and marine ecosystems will contribute approximately 4% of the required 62% contribution from nature-based solutions to the reduction and removals of emissions by 2030. The goal set is to reach net zero CO_2 emissions by 2050, implemented by the Intergovernmental Panel on Climate Change (IPCC) (UNEP, 2021)

Ecological enhancement

The purpose of ecological enhancement is to increase and/or improve the habitat for biodiversity whilst also protecting human health and the environment (ITRC, 20024). Adaptations can be made to coastal defence structures to encourage the colonisation and survival of intertidal species (Moscella et al., 2005, Dyson and Yocom, 2015).

As the definitions indicate, nature-based solutions and ecological enhancement are mutually supportive. However, ecological enhancement is the starting point of restoration to nature itself, whereas the starting point for nature-based solutions is to meet societal needs and goals (Waylen et al, 2022).

2.0 Climate change and the coastal environment

This section explores what climate change pressures are, and how they might affect Auckland's coastal environments.

The impacts of climate change on the coastal environment can be localised or widespread. General warming and extreme weather events are likely to affect coastal ecosystems, especially estuarine areas.

Understanding how climate change might impact localised areas and ecology will aid future coastal protection planning. Within Auckland, investigative reports have been completed that outline stressors or pressures, risks and vulnerabilities to our coastal areas (Bishop and Landers, 2019; Foley and Carbines, 2019).

When considering risk (including the vulnerability from the impacts of the changing hazards and climate change), it is important to understand how to build resilience and develop targeted actions for the Auckland region (Auckland Council, 2019).

RISK

The Intergovernmental Panel on Climate Change defines risk as the likelihood of an event occurring combined with the impacts. Specifically, for climate change, risk is comprised of three components:

- *The hazards*
- *Exposure of people, infrastructure, economy, and natural environment to the hazards*
- *Vulnerability to the hazards. (IPCC, 2014)*

Consideration of risk is understanding the likelihood of an event occurring, and how vulnerable the coast is to these events in relation to the community, the assets, the natural environment and how they respond to the pressures of climate change (Figure 2-1).

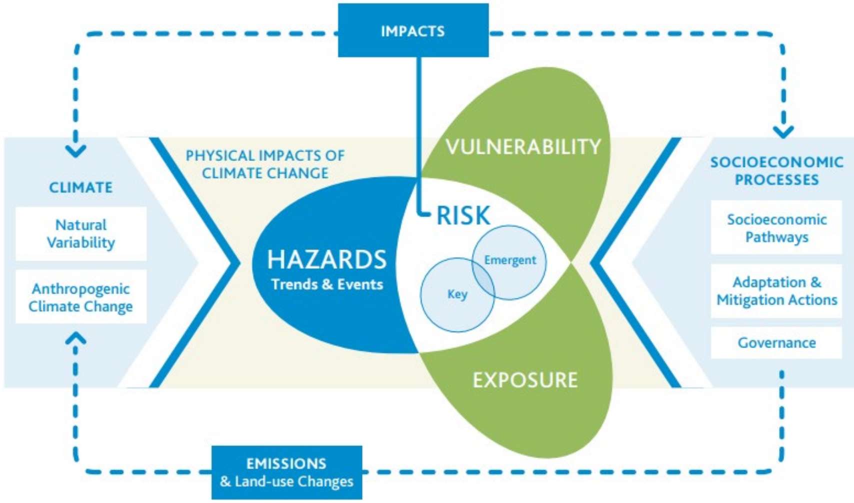

Figure 2-1: Relationships between vulnerability, risk, exposure, and hazards (IPCC, 2014)

"Climate change is exacerbating the risk of existing natural hazards – including flooding and drought – and creating new risks such as sea-level rise. We can build on our past experience with natural hazards to prepare for increased risk in the future" (MfE, 2022a)

2.1 Climate change pressures

Stressors or pressures to the coastal environment from climate change can include the following:

- **Sea-level rise**: Over the last century, sea level has risen in Auckland an average of 20 cm (Hauraki Gulf Forum, 2023). Sea-level rise projections in Auckland are around 0.5 m between 2060 and 2110, and 1 m between 2100 and 2200. Vertical Land Movement (VLM) rates apply to land subsidence, and across New Zealand range between -8 mm/yr to +5 mm/yr and will influence the sea-level rise projections (Auckland Council, 2019, Pearce et al., 2020, MfE, 2022). Rising sea levels in the coastal environment will have major impacts on coastal communities, infrastructure and habitats.

> *"A 2019 report by Auckland Council identified that **storm surge and sea-level rise** were already affecting Auckland's people and infrastructure (Auckland Council, 2019). This has been even more evident with the Auckland Anniversary 2023 weekend floods and impacts from heavy rainfall in the region".*

- **Changes to rainfall**: The number of rain days are set to decline, but the number of heavy rain days are set to increase, with the exception of a decline in the northeast of Auckland. Extreme rainfall events are likely to increase, because of a warmer atmosphere that can hold more moisture (Auckland Council, 2019; Pearce et al., 2020).
- **Relative humidity:** Annual relative humidity in Auckland is projected to slightly decrease while absolute humidity is expected to increase (Auckland Council, 2019). Relative humidity is expected to be higher in winter than in summer. Spring will experience the largest decreases in relative humidity, with small increases projected for autumn (Talbot, 2019).
- **Increasing sea surface temperature**: The increase in sea surface temperature is likely to encourage non-native marine species to establish and proliferate, threatening native biodiversity and species crucial to trade (Auckland Council, 2019; MfE, 2022a). Increasing water temperature can cause species such as birds or fish to move the location they breed in, and subsequently may affect the success rates of reproduction (Auckland Council, 2019).
- **Marine heatwaves (MHW):** A MHW is generally defined as a prolonged discrete anomalously warm water event that can be described by its duration, intensity, rate of evolution and spatial extent. MHW are expected to increase in intensity and frequency as a result of climate change (Hobday et al., 2016).
- **Increasing air temperature**: Over the last century, Auckland's mean annual temperature has increased by 1.6˚C (Hauraki Gulf Forum, 2023). Future temperatures are predicted to warm considerably, especially during autumn, the number of hot days set to increase, and the cold nights to decrease (Auckland Council, 2019; Pearce et al., 2020). Increases in air temperature can also have similar effects as sea temperature increases causing reproductive changes

and impacts to growth rates, and a shift in species distribution. Intertidal mud flats and rocky reefs are highly sensitive to air temperature increases (Auckland Council, 2019).

> *"Auckland's **air temperature** is projected to warm considerably into the future" Pearce et al., 2020)*

- **Deterioration in air quality**: Is likely to impact the health of Aucklanders. The deterioration can be from less dispersal of pollutants, longer lifetime for pollutants, increase in photo oxidation, increased plant stress and changes in atmospheric flow (Auckland Council, 2019).
- **Air pressure, wind and storms:** Mean sea level pressure is projected to increase in summer, causing more anticyclonic patterns. The number of windy days is set to decline, with ex-cyclone events having the potential to be stronger. The intensity of storms is set to increase due to the retention of cyclone characteristics further south than at present (Auckland Council, 2019; Pearce et al., 2020).
- **Solar radiation:** Most areas within Auckland are projected to experience up to 2 W/m^2 increase in solar radiation at the annual scale by 2110.
- **Ocean acidification**: Ocean acidification has been ranked the most serious human-based threat to New Zealand's marine habitats. Ocean acidification is being caused by the uptake of increasing atmospheric CO_2 by the oceans, reducing the concentration of calcium carbonate in our coastal waters. Calcium carbonate is the building block for skeletons and shells of many marine species, impacting ocean productivity and the development of marine species. Species which are particularly at risk include plankton, coastal algae, crustaceans, echinoderms and molluscs, affecting the ability to harvest for kai moana (MacDiarmid et al., 2012). In the Hauraki Gulf, high levels of nitrate from dairy industry run off increase ocean acidification through die-off of large algal blooms (Stats NZ, 2022).

> *"**Ocean acidification** is threatening Auckland's marine ecosystems, including culturally, economically and ecologically significant species." (Auckland Council, 2019)*

2.2 Potential climate change impacts in Auckland

Table 2-1: Potential climate change impacts that may occur in Auckland

Climate change pressure	Coastal impact
Sea-level rise	• Gradual inundation of low-lying marsh, coastal wetlands, seagrass and adjoining dry land on spring high tides (Pearce et al., 2020; Hauraki Gulf Forum, 2023). • Escalation in the frequency of nuisance and damaging coastal flooding events (Pearce et al., 2020). • Exacerbated erosion of sand/gravel shorelines and unconsolidated cliffs (Pearce et al., 2020). • Increased incursion of saltwater in lowland rivers and nearby groundwater aquifers, raising water tables in tidally influenced groundwater systems (Pearce et al., 2020). • Some locations within Auckland will be subject to 'coastal squeeze', as there is little room to migrate up the shore due to coastal development or steep coastlines (Swales et al., 2008; Lundquist et al., 2011). • Combined with rainfall, wave and storm events are likely to increase the erosion rates of coastal cliffs (Auckland Council, 2019: Pearce et al., 2020; MfE, 2022a). • Increasing sea level will cause the loss of shorebird breeding, roosting and foraging habitat (Hauraki Gulf Forum, 2023).
Changes to rainfall	• Extreme rainfall can cause significant runoff into the waterways and oceans, potentially impacting the water quality from increased sedimentation and contaminant input from land (Auckland Council, 2019). • Increased turbidity decreases the feeding ability of visual predators, such as the Little Blue Penguin (Hauraki Gulf Forum, 2023). • Increases in rainfall will cause changes to river flows (both low flows and floods) (Auckland Council, 2019; Pearce et al., 2020). • Increased rainfall can cause pressure to coastal infrastructure and stormwater drainage networks (Lorrey et al., 2018). • Fire hazards will become more prevalent with periods of lower rainfall, along with warmer temperatures and stronger winds (Lorrey et al., 2018). • Natural and engineered coastal slopes may destabilise and be subject to more frequent slips (Lorrey et al., 2018). • Elevated stress is likely on native forests, indigenous wetlands and other plant and animal species (Lorrey et al., 2018). • Reduced rainfall coupled with increased soil moisture may lead to increased erosion potential (Lorrey et al., 2018).

Climate change pressure	Coastal impact
Relative humidity	• Increase in atmospheric water content may increase condensable surface areas that can transport viruses. (Talbot, 2019).
Increasing sea surface temperature	• Sea warming will affect reproduction and survival of numerous marine tropical and subtropical species, changing the composition of marine ecological communities (Hauraki Gulf Forum, 2023). • Pest and diseases are more likely to arrive and survive due to warmer temperatures. This poses a threat to Auckland's native biodiversity, as pests outcompete for habitat, food, and prey on native species. Increases in diseases and infection rates will occur as marine organisms are already stressed and more susceptible to diseases (Hauraki Gulf Forum, 2023). • Some fish grow slower in warmer waters (Hauraki Gulf Forum, 2023). • The toxicity of chemical contaminants increase with temperature (and pH) changes (Hauraki Gulf Forum, 2023). • Higher water temperatures increase stratification of coastal waters and constrict the supply of nutrients to the surface waters. This reduces the growth of phytoplankton, decreasing productivity through the food chain. Mass mortalities of the Little Blue Penguin have been seen in recent years from a decrease in the abundance of prey (Hauraki Gulf Forum, 2023).
Marine heatwaves	• MHW can cause shifts in the range of species, local extinctions, and economic impacts for seafood industries as a result in declines in fisheries and aquaculture species (Hobday et al., 2016). • MHW will kill species that can't move and are thought to have caused the widespread death of sponges in the Hauraki Gulf Marine Park (Hauraki Gulf Forum, 2023).
Increasing air temperature	• An increase in hot days per year will see an increase in plant growing days (Auckland Council, 2019). • Increasing air temperature increases changes to the diversity of crops that are able to be grown in Auckland, and food security (Lorrey et al., 2018). • Increasing temperature, may result in drier soils, altering the vegetation that can survive in those conditions (Auckland Council, 2019; Pearce et al., 2020).
Deterioration in air quality	• Impacts to the health of Aucklanders (Auckland Council, 2019). • Longer periods of drought promote plant stress which can increase the release of volatile organic compounds (VOCs). (Talbot, 2019).

Climate change pressure	Coastal impact
Air pressure, wind and storms	• More severe storms add additional sediment, contaminants, and litter to the marine environment (Hauraki Gulf Forum, 2023). • There is an amplified risk of damaging storm surges and flood impacts during extreme weather evens (like ex-tropical cyclones) (Lorrey et al., 2018). • Lower wind speeds would decrease the sea salt contribution to Auckland's air with greatest impacts on PM_{10} concentrations (Talbot, 2019).
Solar radiation	• Changes in solar radiation may result in a longer growing season for plants, increasing pollen concentrations (Talbot, 2019). • Increased susceptibility to respiratory and cardio-vascular issues due to heat stress. (Talbot, 2019). • More photochemical reaction potentially increasing tropospheric ozone. (Talbot, 2019).
Ocean acidification	• Ocean acidification causes malformation of shellfish larvae decreasing growth and survival rates (Hauraki Gulf Forum, 2023). • Decrease in primary production will cause mass mortalities from starvation (Hauraki Gulf Forum, 2023). • There may be serious impacts to kai moana availability and the aquaculture industry which relies heavily on wild-caught larvae (Hauraki Gulf Forum, 2023). • Altered marine ecosystems from lack of primary productivity from ocean acidification, may cause diminished recreational and economic benefits (Lorrey et al., 2018).

2.3 Climate change drivers and contaminants

Climate drivers such as ocean warming, ocean deoxygenation, changes in circulation, ocean acidification, and extreme events, interact with trace metals, organic pollutants, and excess nutrients in a complex manner. These can then alter the environmental fate, transport, chemical and physical speciation, availability and toxicity of contaminants, and pathways in food webs. In oceanic primary production, physiological rates are being altered, including those of phytoplankton. One of the main reasons is the potential shift in the distribution of essential trace metals (e.g. manganese, iron, zinc, copper, and cobalt), and availability that has a significant biological role, and can impact metabolic reactions essential for production

Coastal ecosystems such as seagrasses, mangroves and tidal marshes are important sinks for contaminants, but are also particularly sensitive to climate change (Hatje et al., 2022).

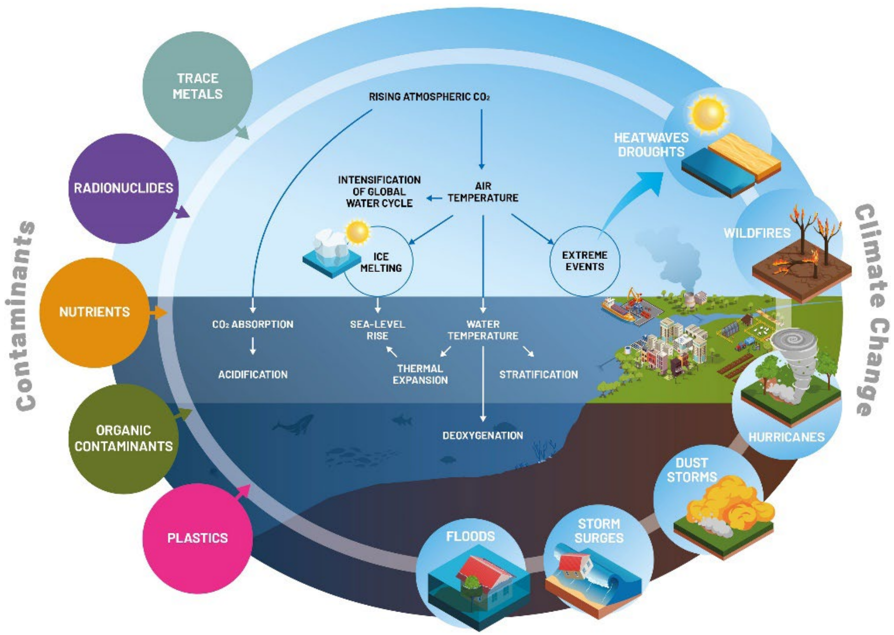

Figure 2-2: Conceptual model of the main climate change drivers and contaminants interacting and potentially exacerbating negative impacts on coastal and ocean ecosystems (Hatje et al., 2022)

2.4 Climate change threats to biodiversity

Climate change stressors are generally driving most of the change from cumulative human impacts in the coastal ecosystems, with coral reefs, seagrasses and mangroves most at risk. The impacts from climate change have been modelled to be increasing rapidly, with an increase in frequency of high sea-surface temperature and ocean acidification as the most quickly changing stressors. Sea-level rise is also considered to play an important role in the pace of change (Halpern, et al., 2019).

Auckland Council and Council Controlled Organisations commissioned NIWA to analyse projected climate changes scenarios for the Auckland region and potential impacts that may result. The report adresses 21 different climate variables out to 2120, drawing heavily on climate model simulations from the Intergovermental Panel on Climate Change (IPCC) Fifth Assessment Report (Pearce et al., 2020).

Terrestrial, marine and freshwater ecosystems and biodiversity are at risk from multiple stressors. These impacts from climate change are likely to affect Auckland's indigenous biodiversity both directly (e.g. through drought and temperature increase), and indirectly, by pest species and habitat loss (Pearce et al., 2020).

The most vulnerable species and habitats are those that have limited capacity to migrate and those that will experience a '**coastal squeeze'** (Auckland Council, 2019).

2.4.1 Marine environment

In the **marine environment**, these stressors or pressures may cause shifts in the distribution of species, impacts to primary producers such as phytoplankton and macroalgae and impact the viability of habitats (Foley and Carbines, 2019). Growth rates and growing season of native species may increase, as sea temperature increases, and then potentially decline as they reach functionality thresholds. Species such as pāua, oysters and sea urchins will be affected by ocean acidification, reducing growth rates and shell formation (Pearce et al., 2020).

2.4.2 Freshwater environment

In the **freshwater environment,** increased water temperatures may become lethal for some native species, and life-cycle patterns are expected to change. A change in stream flow as a result in rainfall alterations will also affect native biodiversity (Pearce et al., 2020).

2.4.3 Terrestrial environment

Within the coastal **terrestrial environment** uncertainty is a key message, with a huge range of variability depending on taxonomic grouping. Coastal forests are exposed to the impacts from climate change which include the increase and intensity of storm events, exacerbated coastal erosion, amplified risk of damaging high winds, salt spray damage, storm surge and flood impacts (Lorrey et al., 2018).

One of the major threats is from introduced plant or animal pests, and the risk of human intervention from clearance and the subsequent habitat fragmentation (Bishop and Landers, 2019).

Coastal forest and wetland ecosystems may be put under pressure from changes in rainfall patterns, frequency and intensity of drought, increased storm surges, and the frequency of coastal storms and cyclones (Bishop and Landers, 2019; Pearce et al., 2020).

2.4.4 Coastal vegetation

Coastal vegetation such as mangrove habitats may be at risk of inundation from sea-level rise, especially if this occurs faster than mangrove growth can keep up. Mangroves provide coastal protection and are a long-term sink for contaminants and support biodiversity and detrital food webs through primary production (Figure 2-3) (McBride et al., 2016). Mangroves comprise 73% of Auckland's total area of indigenous ecosystems affected by inundation, and duneland vegetation (which includes Oioi, knobby clubrush sedgeland and spinifex, pingao, grassland/sedgeland ecosystem types) adds another 13% to this. The remaining 14% affected by inundation includes lakeland and coastal turf, flaxland and coastal forests. Some of these ecosystems are found in such small amounts throughout the region, that if a portion were to be lost to inundation, this would have significant reduction to the regional distribution (Bishop and Landers, 2019).

Sedimentation in estuaries because of coastal erosion from climate change may cause expansion of mangroves (Bishop and Landers, 2019; Pearce et al., 2020). However, pressure from sea-level rise, will result in coastal squeeze and predictions have included that there could be an approximately a 24% reduction in mangroves by 2090. Sediment supply combined with the rate of sea-level rise will determine the future distributions of mangrove habitats within the Auckland region (Pearce et al., 2020).

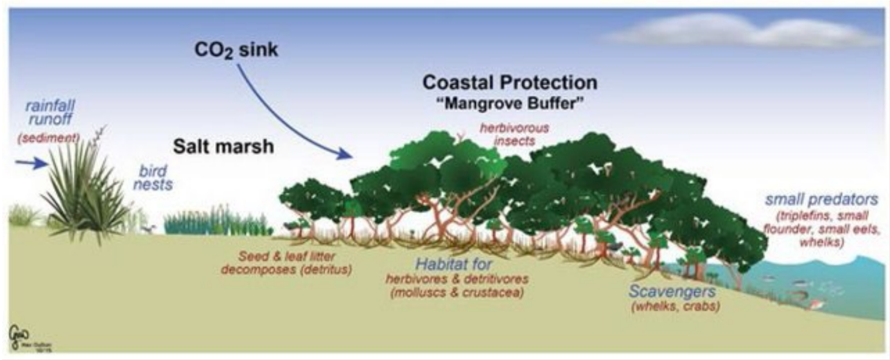

Figure 2-3: Ecological services provided by mangrove forests (McBride et al. 2016).

2.4.5 Biodiversity

Auckland's native **biodiversity** such as birds with small populations and low genetic diversity, may be less able to cope with the pressures from climate change. Native biodiversity will also come under threat from animal pest species, which are able to flourish because of increased temperatures and habitat suitability (Pearce et al., 2020).

As the climate changes, the environment, the unique ecosystems on land, in the sea and freshwaters will be pressured from the changes in food and water availability, the impacts to habitats and where species can live, the timing of natural events such as nesting, breeding, seed production, flowering time, pest outbreaks from increased food availability, and suitable physical environments all impact the success and survival of our native biodiversity (MfE, 2023a).

3.0 Ecosystem services

Identifying areas of importance for ecosystem services will help to inform decisions to ensure that these services are maintained, with the development of strategies to protect the coastline.

Ecosystem services can most simply be defined as the benefits people obtain from ecosystems (MEA, 2005), or 'the direct and indirect benefits that humans receive or value from natural or semi-natural habitats' (MacDiarmid et al., 2013). Ecosystems are widely considered to provide four categories of services:

1) **Supporting services:** e.g. nutrient cycling, soil formation, primary production, provision of biogenic habitat material
2) **Provisioning:** e.g. food, fresh water, wood, fibre and fuel
3) **Regulating:** e.g. carbon sequestration, climate regulation, flood and disease regulation, capture of sediment, pollutant detoxification, storm surge adaptability improvement, erosion dampening and water purification
4) **Cultural:** aesthetic, spiritual, educational and recreational, i.e. wildlife viewing, biological indicators of ecosystem health (MacDiarmid et al., 2015; Roberts et al., 2015).

Figure 3-1 presents a diagrammatic showing examples of ecosystems services that are present within the coastal environment.

Figure 3-1: Coastal ecosystem services (Swiderska et al., 2018)

4.0 Nature-based solutions for coastal management

Nature-based solutions are "actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". The term was coined by the World Bank in 2008, and adopted by the IUCN (IUCN, 2016).

Research indicates that nature-based solutions could provide over one-third of the cost-effective climate mitigation needed between now and 2030 to stabilise warming to below around 2°C (Griscom et al., 2017). From a coastal perspective, coastal restoration is the main mitigation method and can provide a powerful defence against the impacts of long-term hazards of climate change, which is considered the biggest threat to biodiversity. In addition to protection of biodiversity, nature-based solutions also provide significant energy savings and health benefits (Figure 4-1) (IUCN, 2020).

Nature-based solutions, when done well, can deliver many different benefits. Nature-based coastal defences can have direct benefits over traditional structures in terms of their use for coastal hazard risk reduction, with the potential to have co-benefits (hazard management and biodiversity) (Miles et al., 2021). By planning, designing and implementing these well, the benefits will be seen. However, these require appropriate planning, design and implementation to be effective (Miles et al., 2021).

Figure 4-1: Nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that addressed societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits (IUCN, 2016 in IUCN 2020).

"Two key considerations for the use of nature-based solutions need to be considered in the decision making.

1) *Environmental context*
2) *Risk level*

*Habitat suitability and hazard exposure need to be appropriate for the use of the option chosen. In general, lower energy environments are more suitable for the "**soft approach**", while "**hybrid approaches**" are more diverse and can be used in a larger range of environmental conditions.*

The IUCN global standard provides a systemic learning framework to improve and evolve applications of nature-based solutions, leading to greater confidence in their use. The standard aims to equip users with a robust framework for designing and verifying desired outcomes and challenges. The standard consists of 8 criteria and 28 indicators. Further information about the standard can be found in IUCN, 2020.

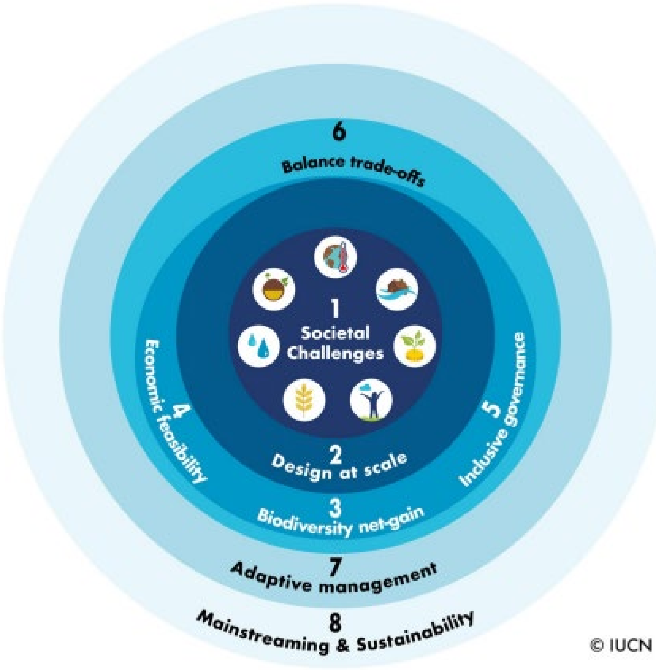

Figure 4-2: The 8 criteria that make up the IUCN Global Standard for nature-based solutions are all interconnected (IUCN, 2020)

Coastal adaptation strategies need to take into account several future scenarios occurring as a result of climate change, highlighting the importance of combined strategies to manage uncertainty.

The traditional approach is to identify a threat (e.g. sea-level rise) and then engineer a solution to mitigate it (e.g. a seawall, rock revetments). As a result, the natural ecosystems that are present are lost or modified, and the new structures tend to erode neighbouring coastal areas and alter natural processes such as hydrodynamics and sedimentation (Cheong et al., 2013).

Natural ecosystems contribute to coastal hazard risk reduction through ecosystems processes, e.g. increased bed friction, local shallowing of water, sediment deposition and building of vertical biomass. These processes cause responses such as a change to the shore profile and shore elevation relative to sea level, and wave attenuation, which in turn mitigate coastal hazards. Nature-based solutions can be implemented or can include no intervention and include leaving the shoreline to adapt. This allows the coastline to adapt to the changing climate and have the ability to self-repair after storm events, in contrast to “hard” structures which can be damaged and are expensive to repair or upgrade (Morris et al., 2021).

The benefits of implementing nature-based solutions in addition to coastal defence, are adaptability, lower maintenance costs, and higher benefit-cost ratios. Some ecological benefits include creation and preservation of habitat and biodiversity, climate mitigation through carbon sequestration, maintenance of fisheries, improvement of water quality and social value such as recreational activities (Figure 4-3), Morris et al., 2021).

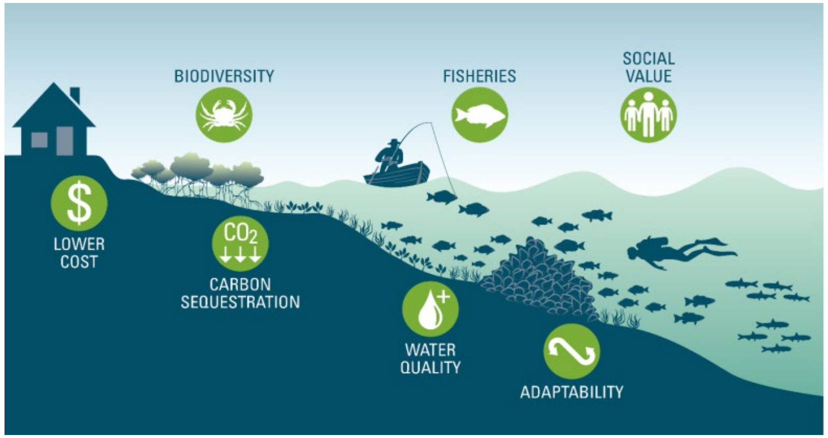

Figure 4-3: Benefits and co-benefits of nature-based methods (Morris et al., 2021)

> *"The combination of climate change and continued population growth are accelerating the need for diverse solutions to coastal protection. Traditionally shorelines are armoured with artificial non-adaptive structures, which come with significant economic, environmental, and social costs. While hard structures will continue to have a place in coastal protection, alternative methods that are more sustainable and climate-resilient should be more broadly adopted into the future where appropriate. Nature-based methods (through "soft" or "hybrid" techniques) have the potential to play important roles in climate adaptation and mitigation because of their ability to reduce the threats of coastal erosion and flooding and provide co-benefits such as carbon sequestration" (Morris et al., 2021)*

A systems approach is essential for the successful implementation of risk reduction and co-benefit treatments such as protection, management or restoration, including natural and nature-based features, because it incorporates an early appreciation of the context and further enhances the breadth of perspective on the natural system by including the interplay of ecology, geomorphology, and hydrodynamics, as well as social factors including the engagement of local stakeholders (Bridges et al. 2021).

Any design or assessment of nature-based systems must consider the site-specific setting, constraints and resilience (especially functional robustness and speed of recovery) given the effect of the biophysico-chemical environment in which they are situated. Allowance is required for both short-term extreme events (storms) and chronic changes in the environment (e.g. mean sea-level rise or changes in salinity or temperature). Nature-based solutions that rely on sediment must consider the sustainability of maintaining enough material via either natural morphological processes or artificial importation (e.g. beach nourishment). Solutions that rely on vegetation must consider the sustainability of the ecological system given the various physical, temperature, and water quality stressors. In the right environment, nature-based solutions may have the potential to be self-sustaining; however, their performance may take some time to mature, and they may be vulnerable to damage by extreme events while maturing. Even when they are mature, it may be necessary to assist natural healing processes by suitable maintenance and repair (Bridges et al. 2021).

While the use of nature-based solutions is high on the agenda, to date there have not been many examples of projects implemented globally (WWF, 2023).

The following sections provide a summary of potential nature-based solutions that could be implemented for coastal management and where possible, an example of the use of the solution for the following:

- Beaches-sediment supply
- Coastal dune management
- Salt marsh
- Seagrass
- Mangroves
- Riparian buffers.

Further nature-based solutions that could be applied for ecological benefit include:

- Kelp restoration
- Shellfish restoration
- Artificial reef creation.

Appendix A tabulates nature-based solutions and ecological enhancement, how these are implemented, the ecosystem services that they provide and the limitations to their implementation.

The Coastal Restoration Trust website is a valuable resource when considering restoration methods, and for Auckland ecosystem specific restoration *Te Haumanu Taiao: Restoring the natural environment of Tāmaki Makaurau* 2023, is also beneficial, in that it steps through site-specific conditions to guide the user on the appropriate option for the location.

Monitoring the outcome of nature-based solutions

MfE guidance recommends that monitoring is put in place and that reassessments of the actions taken, or in place, need to be undertaken within 10 years, unless significant change occurs, or new information arises earlier (MfE, 2017a). Information sources collected could include the likes of LIDAR (to monitor shoreline position) or aerial imagery to map changes over time (TCDC, 2023).

Monitoring of the nature-based solutions that have been implemented should include measures that assess the ecological, engineering and socio-economic objectives, of which can be qualitative, semi-quantitative, or quantitative. Monitoring will detect what has worked, what hasn't; any follow-up actions required for maintenance as time goes by; and inform future use of these solutions at other sites (Morris et al., 2021).

4.1 Nature-based solution options

4.1.1 Beaches – Sediment supply

Beach processes are dominated by sediment, wave climate and the tidal regime. The natural supply of sediment to a coastal system is critical as a buffer against inundation and erosion. In the Hauraki Gulf, a study determined that the region was controlled by event-driven sediment reworking input, and radiocarbon ages of up to > 10,000 years obtained on carbonate shell fragments and up to > 7,000 years on foraminifera within the upper 60 cm of sediment. Coarser sand in the north of Auckland is predicted to be supplied from easterly storms forcing sediment up from Colville Channel, which is marked by a higher shell content, while finer sediments in the south are more likely from fluvial input (Boxberg et al., 2019).

Beach nourishment is the process of depositing sand or coarser material onto beaches from external ‘borrow’ sites, while replenishment or enhancement is the processes of using the same sediment, such as physically redistributing or reshaping existing material along the beach. The process works to sustain the current natural environment, and as an option to avoid the construction of new hard coastal protection. However, the longer-term effects to the ecology and coastal processes are not well understood (Staudt et al., 2021).

While it is technically feasible to create or expand a beach, the prevailing forces will influence its shape and character. Therefore the use of beach nourishment as a method to mitigate climate change induced coastal erosion in the long term is not sustainable, and its likely managed retreat is the better option for future planning (Parkinson and Ogurcak, 2018). The success of sediment supply is dependent on the ability to restrict sediment movement once in situ where hard structures like groynes, rocky outcrops or seawalls are typically used to keep the sediment from drifting. The hard structures hold the interim space between infrastructure and the natural environment, and the success of trapping sediment is reliant on the availability of sediment supply from the source location (Morris et al., 2021). Hard structures can also be naturalised through a variety of methods that are outlined in Section 5.0.

When beach nourishment or replenishment is considered as a solution, some thought needs to be given to the sand source in relation to grain size, adaptability and spiritual context. The supply of sediment can be from sources of sand, gravel, shell or mud. To maintain supply, the processes involved in sediment creation need to continue, or sediment be moved to the required location. This could be achieved through:

- Catchment management
- Prohibiting gravel extraction in the active coastal zone
- Placing sediment from drain to stream mouth clearance on the downdrift side of a waterway to facilitate littoral transport and beach nourishment
- Maintenance of a healthy offshore ecosystem to encourage shell production
- Returning sediment that has been washed inland during large storms to the beach system rather than retaining it for use on the land (Hume, 2021).

One of the aims of beach nourishment can be to increase the protection for backshore assets from erosion, recession, inundation or wave runup by creating a wider beach. This is often referred to as a ‘soft’ engineering option, usually mimicking the natural beach or dune system (Morris et al., 2021).

4.1.1.1 Case studies

Beach nourishment projects have been undertaken at around 20 popular locations in Auckland at places such as at Point Chevalier Beach, Sandspit Reserve (Waiuku), Orewa Beach, Eastern Beach, Mission Bay, Kohimaramara, St Heliers, Onehunga, Herne Bay and Blockhouse Bay.

Beach nourishment at Point Chevalier beach was undertaken with the purpose of increasing the dry beach area. Extensive modification of the beach had occurred by the late 1940s, and until the mid-1980s, a beach of a reasonable width remained. Since then the beach dropped significantly, assuming that the sand was being lost from the beach system resulting in the need for beach nourishment (T+T, 2006). One of the mechanisms noted to potentially have contributed to the sand loss from the beach system is the increase in mean sea level since 1898 at a rate of 1.3 mm / yr (Hannah, 2004).

The Onehunga Foreshore Restoration Project (Taumanu Reserve) is thought to be one of the world's largest foreshore reclamation projects for recreational purposes. The project was intended to restore the natural character of the foreshore following impact from the bisection of State Highway 20 in 1970s, and to reconnect the community with the coast. Three beaches, requiring 11,000 m^3 of sand was deposited, and groynes constructed to reduce the loss of sand (T+T, 2015). The formed gravel and shell beaches provide habitat for native coastal birds, with some 30,000 plants and 350 trees planted to enhance biodiversity (Kinney, 2015).

4.1.2 Coastal dune management

Dune systems help to protect against coastal flooding by forming a physical barrier against elevated nearshore water levels from events such as storm surges and wave runup (Lodder et al., 2021). Vegetation helps to stabilise and bind sand at the surface, so that it is not as impacted by wind erosion and helps promote dune stability. Dune systems can help facilitate beach recovery after erosion events (Morris et al., 2021) through coastal accretion, where sediment is trapped in the vegetation and allows the shoreline to build out (MfE, 2017b).

An increase in dune size relative to the frequency and magnitude of storm impact enhances the resilience of dunes to erosion. The choice of method used for dune building depends on several factors including habitat stability, presence or absence of existing dunes, and space and time available for dunes to increase in size relative to the frequency of the hazards (e.g. storm surges) (Morris et al., 2021).

Interventions such as sand fences, vegetation planting, dune building with earth moving equipment, restriction of vehicles and people over the dune systems and dune construction with hard cores (a geotextile tube often filled with sand designed to resist erosion and promote dune formation) are options for the enhancement of the dune system (Morris et al., 2021).

4.1.2.1 Case studies

Within New Zealand there are many examples over the past few decades where community groups and councils have worked together to successfully restore frontal dune zones by planting varieties such as spinifex (*Spinifex sericeus*) and pingao (*Ficinia spiralis*).

A case study at Ngarahae Bay, on the west coast of the North Island demonstrated that it is practicable to restore badly damaged dunes that have been impacted over the past 150 years from severe wind erosion following the disruption of stabilising vegetation from stock grazing and human disturbance. However, there are limited resources to naturally restore them.

The project highlighted the importance of addressing and reducing the causes of vegetation disturbance such as fencing out grazing stock, reducing pest animals and controlling human disturbance (Figure 4-4).

Constraints that were considered included the available budget, which in turn reduced the number of plants that could be purchased; limited funds available for pest animal control or management (to reduce damage to the newly planted vegetation); and inability to mitigate the effects of wind erosion (i.e. through sand trapping or windbreak fencing) to assist in plant establishment (Coastal Restoration Trust of New Zealand, 2018).

Despite the constraints and the badly damaged dune, restoration efforts have been successful, and a well-established frontal dune has been created (Coastal Restoration Trust of New Zealand, 2018).

Figure 4-4: Dune establishment at Ngarahae Bay after 1 year (top), 2.5 years (middle) and 3.5 years (bottom)

A “whole of dune” approach to back dune restoration which involves the clearing and planting of the backdune area has proved very effective at restoring native dune vegetation communities along the seaward margin of coastal settlements in Whangapoua and Cooks Beach in the Eastern Coromandel. This methodology also provided the opportunity for biodiversity enhancement for some threatened species (e.g. *sand pimelea* and *sand coprosma*) (Figure 4-5) (Dune Restoration Trust of New Zealand, 2014).

The capital cost of this method is significantly more expensive in comparison to similar backdune work which focuses on spraying and hand clearance of pest weed species, however, the benefit of this approach is that maintenance requirements are significantly less moving forward (Dune Restoration Trust of New Zealand, 2014).

Figure 4-5: Whangapoua trial area before clearance (top), 1 month after planting (middle) and 15 months after planting (bottom)

4.1.3 Salt marsh

Salt marshes are ecosystems that are found on the coastal margins between the land and ocean. They are areas which are inundated by the tide each tidal cycle with little wave action and sediment is deposited. Salt marches comprise species such as sea rush, oioi, saltmarsh ribbon wood (Auckland Council, 2023b).

They are among the most productive ecosystems in the world, sequestering and storing a significant amount of carbon in their soils, where it remains for millennia, helping to mitigate the increasing carbon dioxide concentration in the atmosphere (GNS, 2023).

Salt marshes provide ecosystem services such as nurseries for juvenile fish, breeding and feeding areas for birds (Auckland Council, 2023b), increasing fish production from nurseries to benefit commercial fishing, enhanced carbon sequestration into marine sediments, and decreased terrestrial run-off into estuaries (Cheong et al., 2013).

Salt marshes can also help to facilitate deposition of sediments and organic matter, and reduce erosion rates, dampen wave action and flooding (Cheong et al., 2013, Morris et al., 2021). The presence of salt marsh vegetation helps to reduce erosion potential through sediment capture and soil stabilisation (Morris et al., 2021). Restoration and interventions to help rejuvenate existing salt marshes include:

- Invasive vegetation control
- Exclusion fencing
- Hydrological restoration
- Vegetation planting
- Hybrid approaches (Morris et al., 2021).

The two dominant factors controlling plant establishment and survival in salt marsh habitat are inundation period and frequency and salinity. Some species have optimum salinity ranges, with the salt marsh species tending to prefer the more estuarine, brackish environments (Partridge and Wilson, 1987).

4.1.3.1 Case studies

St Anne’s Crescent, Auckland

In Auckland, an eco-engineered hybrid approach to coastal protection along St Annes’s Crescent in the Pahurehure Inlet included salt marsh restoration, to provide weather protection to the sloping bank and planted rushes landward of the bund to provide protection to the bank and improve visual amenity and function (Figure 4-6).

Figure 4-6: Left. St Annes Crescent in 1993 (T+T, 2009). Right. St. Anne’s Crescent salt marsh restoration. Note the planted vegetation between the foreshore and the rocky outcrops

Virginia Point Wetland Protection Project, USA

This restoration project used a living shoreline approach to stabilise the eroding shoreline. The final design included over 6,000 linear feet of nearshore, and segmented limestone breakwaters parallel to the Virginia Point shoreline. The way the placement of the breakwaters was designed was to allow for the establishment behind these of up to 35 acres of future salt marsh planting. Breakwater cells were designed to retain and accumulate sediment naturally to create a sediment bed for marsh planting. In addition, these areas provide nesting options for birds, and habitats for other terrestrial species (WWF, 2023).

The outcome of this project was the creation of a wetland, replacing unvegetated land. This will improve carbon storage in the soils, and allow for the bay, wetland and prairie to work in a connected manner to create a healthy ecosystem that can buffer sea-level rise and coastal pressures (WWF, 2023).

Figure 4-7: The protected and restored coastal wetland, pariries, and other important habitats within the Viriginia Point Preserve (NFWF, 2021)

4.1.4 Seagrass

Seagrasses are rated the third most valuable ecosystem globally (Swales et al., 2017). They provide ecosystem services such as water quality improvement, oxygenation into water and sediments (e.g. 1 m^2 releases 10 L per day), CO_2 absorption (seagrass accounts for about 10% of the ocean stores of carbon), carbon sequestration (some meadows can sequester up to 27% faster than forests on land), trap and transform nutrients (1 ha can absorb 1.2 kg N per year), foraging and feeding ground for marine life, intertidal and subtidal sediment stabilisation via a network of roots and rhizomes, coastal protection, nursery and refuge for many species and to support fisheries production, as well as contributing to biodiversity by being the only marine flowering plant (Swales et al., 2017; Sanchez – Vidal et al., 2021; Clark and Berthelsen, 2022).

Seagrasses have the potential to provide protection against flooding and erosion. The drag exerted by vegetation on the waves leads to attenuation of wave energy (through wave attenuation due to roughness), subsequently reducing wave runup levels and the potential for flooding. Seagrass also has the potential to capture sediment and to stabilise soil, resulting in the reduction of erosion potential (Morris et al., 2021).

When restoring or creating seagrass beds, consideration needs to be given to physical factors of the location such as light availability which may be impacted by eutrophication and suspended sediments to ensure the success of seagrass growth. If these physical factors are sufficient, then restoration through active planting, is considered to be a cost-effective and feasible option (Morris et al., 2021).

Tan et al., 2020 outlines a variety of tools and techniques that have recently been developed across Australia and New Zealand. The emerging approach focuses on a holistic and collaborative restorative method, which considers the local environment and community, drawing on information about successful and failed trials.

Options for emerging tools, techniques and approaches to seagrass restoration include those mentioned below. However, there is no "one solution fits all" approach, and the seagrass species, hydrodynamics and other local conditions need to be considered when applying each option:

- **Buoy deployed seeding** (BuDS): Unlikely to be suitable for all species and conditions such as areas with strong hydrodynamics.
- **Dispenser injection seeding:** Promising for strong tidal current areas, but may not be ideal for coarse-grained sediment sites, likely labour intensive.
- **Nursery reared plants for transplant:** Survival rates are species specific, good option for areas where seed production is already high.
- **Anchoring of shoots with iron nails:** Technique used should consider local conditions.
- **Artificial in water structures to protect restoration:** Helps to enhance physical properties of habitats such as sediment stabilisation and improve seagrass success through the establishment phase.
- **Alternative sources of transplant units and seagrass wrack:** A good local source of propagules in the seagrass wrack will contribute to the success of restoration method.
- **Promotion of positive biological interactions with other marine organisms (such as shellfish, mangroves):** Positive biological interactions can increase restoration success. Interactions with local species present should be considered, including intra and interspecific plant-substrate, plant-microbial communities, plant-plant.
- **Community involvement:** Volunteers are a valuable resource to the costly labour costs and provide an opportunity to engage with growing public awareness surrounding marine conservation.
- **Working with tangata whenua:** Provision of valuable insights, observations and interpretations relating to the state of the biological, physical and spiritual environments. It is recommended that restorations are grounded in tikanga and be co-designed with Māori (Tan et al., 2020).

4.1.4.1 Case studies

The exploration of successful seagrass restoration within New Zealand has been undertaken by Crown Research Institutes such as NIWA and Cawthron. NIWA installed artificial seagrass plates within the Tairua Harbour, for the intended purpose of providing increased habitat for fish nurseries. NIWA has continued its research and has successfully completed transplant trials in 2008 and 2012 in the Whangarei Harbour. The transplant trials also appeared to assist in the encouragement of natural regeneration, and as of 2016, the seagrass occupied 40% of its original extent in the harbour (Swales et al., 2017).

Community and mana whenua participation in seagrass transplantation trials in Whangarei and Porirua have led to successful restoration projects (Tan et al., 2020).

More recently, Cawthron has embarked on a three-year project to develop a blueprint for a seed-based seagrass restoration that can be carried out. The aim is to enable large-scale restoration of seagrass meadows, helping to support biodiversity, improve water quality and sequester carbon (Clark and Berthelsen, 2022).

4.1.5 Mangroves

Mangroves provide many physical and ecological functions in New Zealand. Ecologically, mangroves provide energy and organic matter in the form of leaf, seed and woody debris incorporated into the foodweb, supporting a diversity of animal life. Mangroves provide ecosystem services such as nursery grounds for fish, carbon sequestration and regulation of rainfall patterns (Donato et al., 2011).

Mangroves provide a natural defence against coastal hazards and play an important role in sequestering carbon (Lundquist, et al. 2017). By some, mangroves are considered a nuisance and many reasons for mangrove removal are put forward including visual amenity, recreational and cultural (Lundquist, et al. 2014).

However, allowing mangroves to continue growing, or the restoration and planting of mangroves is viewed as an adaptive strategy to sea-level rise and coastal storms, by facilitating sedimentation and dampening wave stress. Coastal protection would benefit from limiting mangrove removals (Hume, 2021).

Wide stands of mangroves have been reported to slow down and limit the extent of inundation from the sea during surge events and tsunamis providing protection against coastal erosion (Hume, 2021). The presence of mangroves has been found to influence wave dynamics by reducing current velocity and tidal amplitude across tidal flats (Haughey, 2017).

The restoration of mangroves requires the reinstatement of suitable hydrological regimes, either with planting or regeneration from natural recruitment (Morris et al., 2021). Mangrove planting can be used in amongst loosely placed stones, with the expectation that they will stabilise the rocks (Hume, 2021).

4.1.5.1 Case studies

An example is south of Kaiaua, where consolidated muddy sediments have formed a raised bank with mangroves that protrude seaward over 1 km, in comparison to the adjacent shoreline where mangroves are absent, and the shoreline is cut back (Hume, 2021).

4.1.6 Coastal forests

Coastal forests are a dominant terrestrial ecosystem in the Auckland region and are likely to show complex transient responses to rapid changes in climate (Prentice et al., 1993). Originally, forests covered a wide range of locations and landforms within Auckland, including gullies, hillslopes, ridges, swamps, floodplains, lava flows and stabilised dunes.

Climate change can impact coastal forests and ecosystems both directly and indirectly. Climate change alters the frequency of stressors such as fire, drought, disease, pathogen, storms and cyclones, while understanding that natural disturbance is fundamental to the development of structure and function of forest ecosystems. However, Auckland has undergone dramatic changes in the extent and composition of ecosystem types over the past 50,000 years in response to climate change (Bishop and Landers, 2019).

Responding to the pressures of sea-level rise on coastal forest ecosystems can be achieved through identifying sites where managed retreat of the shoreline can allow for inland migration of coastal ecosystem types (Auckland Council, 2023c) This requires the identification of intact examples of an ecosystem type at higher elevations to provide seed sources for regeneration of surrounding areas.

Figure 4-8: Pōhutukawa, pūriri, broadleaved forest on Waiheke Island. Photo credit Alastair Jamieson

The guidance document developed by Auckland Council, *Te Haumanu Taiao: Restoring the natural environment of Tāmaki Makaurau*, provides detailed information around how to restore each of the Singers et al, 2017 ecosystem types, and what to look for depending on the environmental parameters present, and climate change pressures in play (Auckland Council, 2023c).

4.1.6.1 Case study

A comparison of coastal restoration projects in Tauranga City with natural functioning ecosystems was undertaken to understand their restoration trajectory. Three forest types historically present in Tauranga were studied: *Metrosideros excelsa* coastal forest, semi-coastal broadleaved forest, and semi-coastal *Dacrycarpus dacrydioides* swamp forest (Dean, 2013).

Metrosideros excelsa restoration projects were found to be developing into forests but lacked the recruitment of mid and late successional species, likely due to predation from exotic animals and isolation of seed sources (Dean, 2013).

Planted restoration swamp forest sites in the Kopurererua Valley and Te Maunga were found to likely become *Dacrycarpus* dominated, with lower stem densities than natural stands. The older site at Te Maunga was beginning to naturally regenerate but seedlings were only likely to survive if there was sufficient light and reduced competition (Dean, 2013).

At semi-coastal broadleaved restoration sites, the understory was assessed to be regenerating, and colonisation of new species was occurring, which indicated that the vital ecosystem function of seed dispersal had been restored. However, successional canopy species were failing to recruit (Dean, 2013).

Recommendations for future coastal forest restoration included:

- Coastal forest:
  - Densities of 1000-2000 plants per ha, with a 1.5 m distance between plants
  - The introduction of key understory and successional canopy species should be carried out, however this can be relatively sparse, i.e. as little as 100 plants per ha
  - Ensure rabbit and pest plant control programmes, and monitoring to identify if these are successful.
- Semi-coastal broadleaved forest:
  - Initial plantings should be diverse and include species such as *Aristotelia serrata* and *Coprosma* to attract frugivorous birds, for seed dispersal
  - Dense buffer planting around the perimeter to reduce edge effects to be undertaken
  - Successional species to be introduced, either by planting or seeding
  - Weed control should be carried out
  - Pest animal control should also be considered to reduce predation of seeds and native animals.
- Swamp forest:
  - *Dacrycarpus* to be planted at a density of 2000 stems per ha
  - Planting of pioneer species should also be included
  - Weed control should be carried out
  - Pest animal control should also be considered to reduce predation of seeds and native animals (Dean, 2013).

4.2 Further nature-based solutions to address climate change stressors

4.2.1 Kelp restoration

Kelp provides ecosystem services such as habitat structure formation, providing a space to live and food for fish and marine invertebrates (Lohrer, 2023); act as a carbon sink; provide a bioremediation function by taking up extra nutrients; and can help support other adjacent and diverse ecosystems through the export of detritus (Hynes, et al., 2021). Kelp forests can provide valuable shoreline protection through sediment stabilisation and wave attenuation. Maximum value for shoreline protection is reached when canopy height and water-column height are equal (Altman et al., 2021).

Kelp restoration to a hard substrate reef, creates a greater portion of the water column that is interacted with in comparison to a bare reef, which increases drag, and the potential effect on wave transmission. Kelp forests help provide protection against erosion and flooding through their three-dimensional structure and can modify the transport of sediment along the coast (Morris et al., 2021).

Healthy kelp forests are self-maintaining. To restore or establish kelp forests can be done through assisted establishment, active methods of intervention such as transplantation, ex situ recruitment enhancement, and seeding. If suitable hard substrate is unavailable, then artificial reefs may provide a surface for kelps to settle (Morris et al., 2021).

Kelp forests provide many benefits to the ecosystem and for human communities, including:

- Nutrient cycling – uptake of nutrients (such as nitrogen) from the water and making them available for other species
- Enhancing food sources for other organisms including finfish and grazing invertebrates
- Improving water quality (e.g. excess nutrient removal, leading to reduced potential for harmful algae blooms and anoxia, improved water clarity)
- Provision of oxygen to water and sediments
- Biodiversity enhancement – provide habitat, sheltered environment, and structure in the marine environment
- Increasing biodiversity improves quality improves quality of experience for recreational users and tourism
- Importance for cultural heritage and values
- Enhancing fishing opportunities, including commercial, and culturally valued fisheries such as pāua
- Shoreline protection from reduced wave energy
- Carbon sequestration from the atmosphere (more commonly referred to as blue carbon)
- Organic carbon export to adjacent systems
- Prevention of sediment resuspension, and sediment stabilisation (Altman et al., 2021; Fisheries New Zealand, 2023).

4.2.1.1 Case study

Large areas of Auckland's Hauraki Gulf have been left as kina barrens, where historically, kelp forests existed. The current approach to restore kelp forests is to remove kina, implement fisheries control measures and allow for the process of natural regeneration (Hamilton, 2023).

A Smart Ideas Grant, a three-year Ministry for Business, Innovation and Employment (MBIE) fund awarded to Otago University is underway to develop the knowledge, and infrastructure needed to restore giant kelp forests as one of the most climate change resilient species to build a buffer against future climate impacts (Newsroom, 2019).

The map below (Figure 4-9) highlights locations of both kelp and shellfish restoration as of May 2023 in New Zealand.

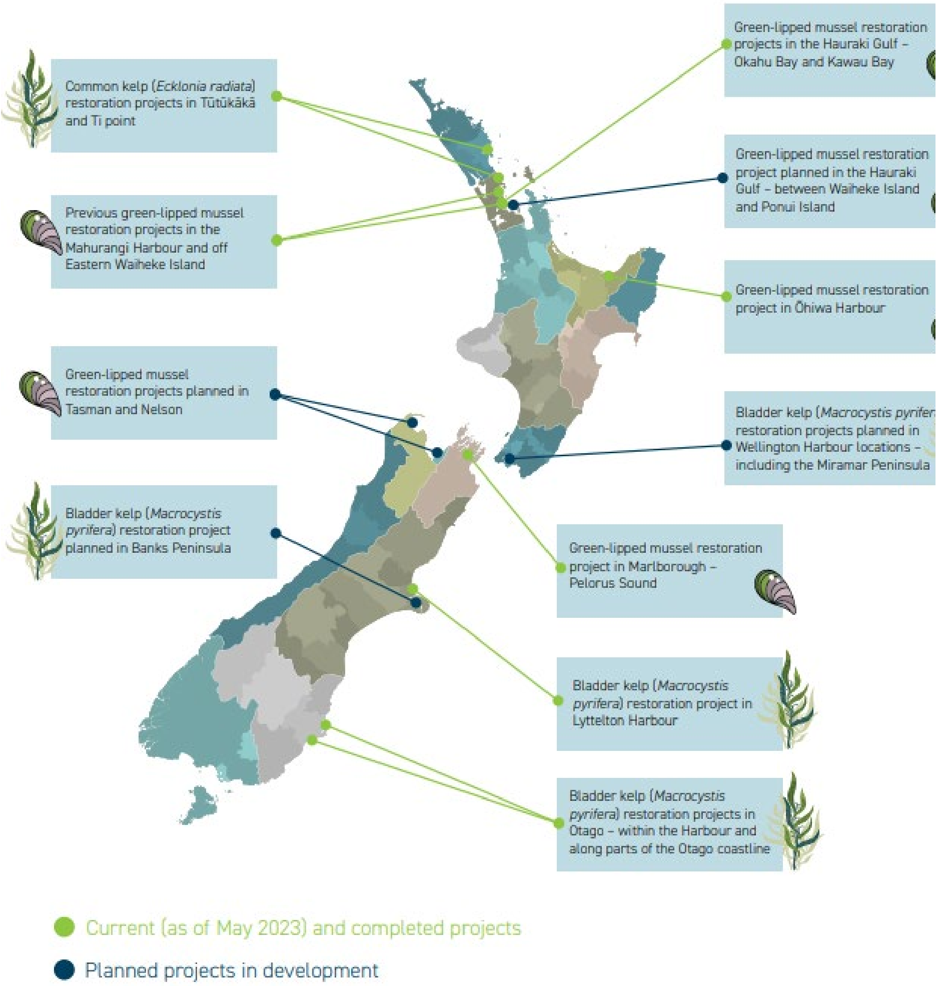

Figure 4-9: Locations of kelp and mussel restoration projects in New Zealand as of May 2023

4.2.2 Shellfish restoration

Shellfish restoration is regarded as a bottom-up approach to improving the health of the marine environment. Shellfish reefs deliver a range of ecosystems services and form important habitats which support many marine organisms.

Shellfish habitats provide many benefits to the ecosystem and human communities, including:

- Nutrient cycling – enhancing food sources for marine organisms including finfish and crustaceans
- Reducing nutrient load and improving water clarity
- Reducing resuspension of sediments by stabilising the substrate
- Enhancing broader shellfish populations through potential spill-over effects (restored reefs spreading to other areas)
- Biodiversity enhancement – reefs provide habitat, sheltered environments, and structure
- Increasing biodiversity improves the quality of experience of recreational users
- Important for cultural heritage and values
- Enhancing fishing opportunities
- Reducing shoreline erosion – protects coastal land (Fisheries New Zealand, 2023).

4.2.2.1 Case studies

Oysters

Oyster reefs are complex three-dimensional structures created from aggregations of oysters. Oyster reefs support diverse and abundant ecological communities and can be used as a nature-based solution to protect against climate change by absorbing wave energy, protection from wave erosion and storm damage and by sequestering carbon. The oyster reefs also improve the water quality as they filter feed and provide nursery habitat for economically valuable species (WWF, 2020; Howie and Bishop, 2021).

In South Carolina, oyster nature-based solutions are an opportunity to expand on already existing restoration programmes and resources to help build resilient coastal communities. The coastline and salt marshes are currently at risk from high tide coastal flooding, increased frequency and intensity of storms. Oyster reef restoration is a nature-based option for coastal protection (Thackaberry, 2021).

The capacity of oyster reefs to grow vertically, spread horizontally, and transgress landward make them ideal for mitigating against erosion and sea-level rise. Consideration to limiting growth factors such as wave disturbance, predation and inundation is given to the success of the restoration. However, these can be mitigated against with good project design (Howie and Bishop, 2021). Alongside engineered structures, oyster restoration will help to mitigate coastal hazards such as sea-level rise, tidal flooding and protect against storm events (Thackaberry, 2021).

An option for reef development is by fortifying an existing seawall with oysters to aid in the longevity and reduce wave energy and erosion and promoting the spread of marsh grass to create a living oyster-based shoreline (Thackaberry, 2021).

Mussels

Mussels provide ecosystem services such as the filtration of water (Paul, 2012), provide habitats for invertebrates and nurseries for juvenile fish, and are a food source for crustaceans, fish and rays, they remove nitrogen from the water and lock away carbon (McLeod, 2009).

Mussel restoration in the Hauraki Gulf was carried out in 2013 and 2014 near eastern Waiheke. A project led by Mussel Reef Restoration Trust and supported by University of Auckland researchers, facilitated reseeding of 70 tonnes of mussels. Further sites in the Mahurangi Harbour facilitated several batches of mussels but they have not managed to self-recruit.

In addition to these projects, Revive our Gulf has a 35 year resource consent for mussel reef restoration around the Hauraki Gulf. A highly collaborative project between The Nature Conservancy, mana whenua, The University of Auckland, and The Mussel Reef Restoration Trust - and other government and Crown Research Institute support, has seen up to 372 tonnes of mussels deployed in the Gulf into Ōkahu Bay and Kawau Bay (Fisheries New Zealand, 2023; Revive our Gulf, 2023).

4.2.3 Artificial reef creation

Reef systems provide a wide variety of ecosystem services such as food, protection from flooding and erosion and sustaining fishing and tourism industries (IUCN, 2017), wave attenuation (Ferrario et al., 2014), structure complexity, substrate for colonisation of macroalgae, and habitat for fish and invertebrates (Hammond et al., 2020 and Folpp et al., 2020). Once implanted, the reef joins natural communities and consolidates itself in the environment (Pizzatto, 2004).

Artificial reefs are created to provide ecosystem services such as the enhancement of fish stocks (Folpp et al., 2020), and the supply of fish for fishermen, both recreational and commercial, and for the value of scuba diving and the tourism financial profit that comes with this (Chen et al., 2013). Internationally, it is well known that artificial reefs typically result in dense aggregations of fish, provide additional food, provide shelter from predation, and provide a location for recruitment (Layman and Allgeier, 2020).

Artificial reefs help to dissipate wave energy and protect shorelines from flooding and erosion (Morris et al., 2021). Artificial reefs can also be designed to provide recreational benefits for surfing and other water sports through improving the breaking characteristics of waves.

As described by the European Artificial Reef Research Network, an artificial reef is a submerged structure deliberately placed on the substratum (seabed) to mimic characteristics of a natural reef (Baine, 2001). There are a few options to artificial reef restoration which include the development of a shellfish reef, or by the installation of hard structures to encourage settlement.

Habitat suitability needs to be considered, and the availability of adequate supply of larvae to support the reef development, without having to actively introduce stock (Morris et al., 2021).

4.2.3.1 Case studies

Current planning for New Zealand’s first artificial reef creation, is underway in Wellington’s harbour as part of the Te Ara Tupua coastal walk/cycle way development project.

5.0 Ecological enhancement

When a nature-based solution is not feasible, and there are coastal assets (e.g. walkways, buildings or critical infrastructure such as roads and Watercare assets) that need to be protected from climate change, coastal engineered protection structures (e.g. seawalls or rock revetments) are built. These serve to protect the land from eroding from the effects of climate change. While in these instances the structures are critical to the protection of the coastal assets, they may cause negative morphological, hydrodynamic or ecological effects both locally, and transposed around the coastline (Schoonees et al., 2019).

Examples of hard coastal structures include:

- Offshore structures
  - Seawall (wooden)
  - Seawall (masonry grouted rock)
  - Seawall (concrete and mudcrete)
  - Sea dike – commonly consist of earth filled core made of granular or cohesive soil materials with a grass cover as surface protection, formed for flood defence (Schoonees et al., 2019).
- Foreshore structures
  - Rock revetment
  - Groynes – structures that extend towards the sea perpendicularly, or obliquely to the shoreline, usually constructed by timber, rock, or concrete (USACE, 2002)
  - Breakwaters – built parallel to the shore and designed either to protect the coastline or to improve the recreational conditions behind them (Pilarczyk and Zeidler, 1996)
  - Jetties.

Impacts caused from the presence of hard structures include:

- Changes to coastal processes, which cause active and passive erosion
- Habitat loss / modification
- Impacts due to introduction of hard substrata
- Interruption of ecological connectivity and biodiversity abundance and structure
- Changes in ecological communities
- Changes in plant communities
- Hazards for recreation
- Increase of turbidity (Schoonees et al., 2019).

Although detrimental effects of hard solutions cannot always be avoided, certain nature-based adaptations or ecological enhancements can be utilised to mitigate or reduce these effects (Schoonees et al., 2019). These include options to encourage and support the colonisation of hard substrates by natural subtidal or intertidal biota, to provide habitat benefits to the hard structure.

When implementing nature-based solutions or ecological enhancement, consideration should be given to the requirements involved for construction or replacement of hard structures protecting the coastline, to include the need for provision of habitats for intertidal biota.

Appendix B Table 10-2, provides a summary of ecological enhancement opportunities when hard structures are to be utilised for coastal protection.

The following sections discuss options for ecological enhancement of hard structure protection.

5.1 Seawalls

Seawalls are hard structures that are built to protect an asset against erosion from wave energy that can be constructed from many forms such as concrete, gabion baskets, or wooden planks. Sea walls also provide coastal flood protection against extreme water levels and are beneficial due to their design and the smaller space required compared with other coastal defences (Zhu et al., 2010) (Figure 5-2).

Seawalls can also cause problems to natural systems by interrupting natural sediment transport and can destroy natural habitats such as intertidal beaches and dune systems (Gallop, 2017).

Ecological enhancement of seawalls could include:

- An alteration of the design to enhance habitat diversity and complexity.
- Eco tiles provide surface roughness and introduction of microhabitats, or the alteration of rock material, to include some softer rocks which erode at a faster rate to provide surface roughness for habitat and the opportunity for settlement and increased species diversity. They can also include the chemical modification of concrete mixes to facilitate colonisation of biota.

5.2 Rock revetment

Rock revetment is the construction of a protective wall to prevent erosion or collapse of rock. These are usually constructed from stone, concrete, boulders or mounds of earth placed on a slope or on top of it (Chee et al., 2020) (Figure 5-2).

Ecological enhancement of rock revetment could include:

- Structure design
    - By using both soft and hard rocks, this creates complexity, as the weathering of the softer rocks occurs faster, creating surface roughness for species to attach (Chapman and Underwood, 2011).
    - Mixed rock sizes, which provide different habitats and can lead to greater species diversity and abundance (Weicek, 2012).
    - The introduction of surface roughness such as fine-scale millimetre to centimetre textures, sheltered overhanging areas, and in-built rock pools (Naylor et al., 2017).

Drilling holes into rock armour to create artificial rock pools in Penang, Malaysia found greater species richness and an increase in community structure in the drill-cored rock pools regardless of the depth of the artificial pools (Chee et al., 2020).

- Structure location
    - The placement of a rock revetment with enhanced features considers physical suitability of the habitat, and where the enhancement is required. A study in Hartlepool, United Kingdom found that an enhanced rock revetment had higher species densities, providing key prey species for birds (Naylor et al., 2017).
    - Placing the rock revetment on the foreshore to increase the elevation and allow for longer exposure during the tidal cycle is another design option to encourage the use by shorebirds as a roosting option (Naylor et al., 2017).

5.3 Sea dikes

Dikes are predominantly an earth structure consisting of a sand core, a watertight outer protection layer, toe protection and a drainage channel. They are conventionally built as hard engineering structures to withstand the forces of wind, waves and flooding, and to prevent or minimise overtopping. The primary function is to protect low-lying, coastal areas from inundation by the sea under extreme conditions (Figure 5-1; Figure 5-2).

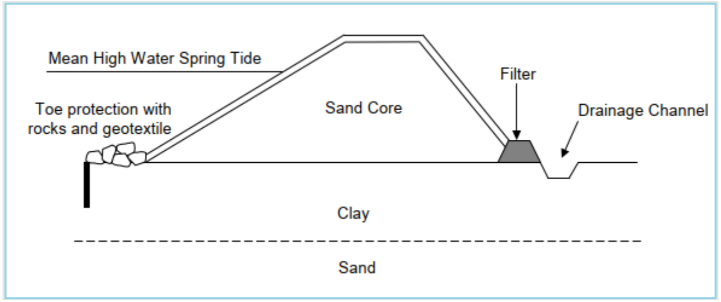

Figure 5-1: Typical sea dike cross section (Zhu et al., 2010)

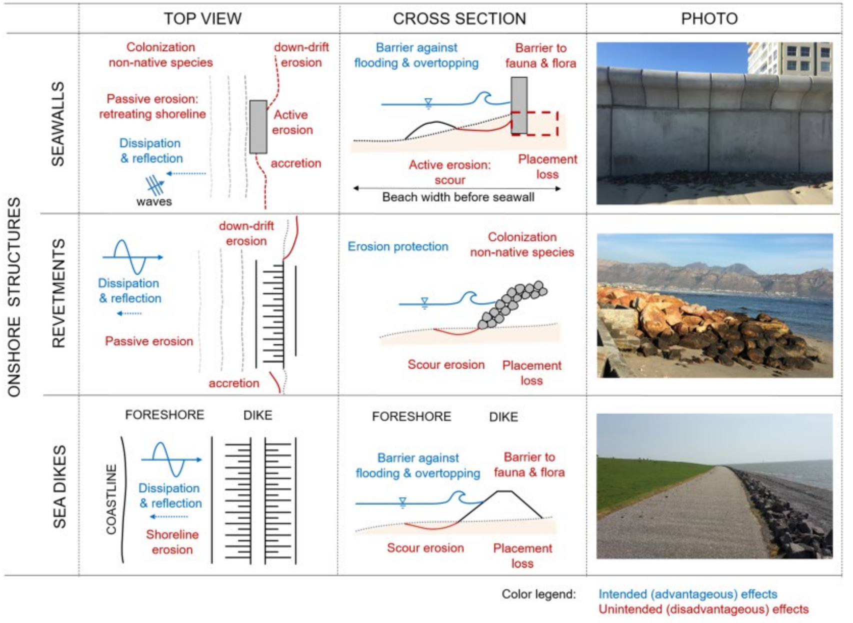

Figure 5-2: Overview of hydrodynamic and morphodynamic effects of seawalls, revetments, and sea dikes (Schoonees et al., 2019)

To date, the incorporation of ecological enhancement aspects in sea dike design have been limited. However, dikes do provide an opportunity for ecosystem enhancement to increase the value of the dike systems (Scheres and Schüttrumpf, 2019).

Ecological enhancement of sea dikes could include vegetative cover: seeded vegetation planting, with mixtures of species. The ecological value of a sea dike can be enhanced with this diversity towards more ecologically valuable species, with an aim to increase soil stability and erosion resistance. Various components of the dike are compatible with different ecological enhancement opportunities (Table 5-1) (Schoonees et al., 2019).

The literature search returned no instances when these have been implemented within New Zealand.

Table 5-1 Summary of methods for ecological enhancement of dikes and their limits/challenges (Scheres and Schüttrumpf, 2019)

Dike component	Common design	Ecological enhancement
Foreshore	Not directly integrated in dike design	• Ecosystem engineering (marshes, reefs etc.) or nature-based solutions (e.g. artificial reefs)
Slope inclination	Slope design as compromise between dike stability and material consumption/ footprint	• Milder seaward slopes for positive effects on nature, recreation and coastal processes
Dike roads	Asphalt roads	• Alternative vegetated fortified paths (e.g. vegetated geocellular containment systems)
Revetments	Grey revetments (rip-rap, placed blocks etc)	• Vegetated or colonised revetments
Vegetated dike cover	Dense grass covers, no woody vegetation	• Adaptation of seeding mixtures towards more ecologically valuable vegetation

5.4 Groynes / Breakwaters

Groynes and breakwaters are built on the foreshore to prevent or mitigate erosion. Breakwaters are generally built parallel to the shore and they are generally designed to protect the coastline or improve recreational conditions (Figure 5-3) (Schoonees et al., 2019).

Materials used to construct breakwaters can include concrete, rocks, sandbags or geotextiles. Groynes generally extend seaward perpendicularly or obliquely to the shoreline, and are usually constructed with timber, rocks or concrete (Schoonees et al., 2019).

Ecological enhancement of groynes/breakwaters could include:

- Small-scale opportunities such as drilling pits and rock pools into the structure.
- Large-scale opportunities such as the placement of precast habitat-enhancement units within the existing structure or during construction.
- Additional enhancement opportunities include transplanting of target species, or planted vegetation (e.g. saltmarsh, mangroves) or reef forming species (e.g. oysters, coral) that create built structures to mitigate erosion and rehabilitate coastal habitat (O'Shaughnessy, et al., 2019).

Foreshore redevelopment in Oriental Bay, Wellington Harbour included beach nourishment, the construction of a submerged breakwater reef, headland controls, a pier and an emergent breakwater. Monitoring indicated that marine biodiversity improved from the pre-construction status to include a range of marine species colonising the new man-made habitats (Miller et al., 2009).

5.5 Jetties

Jetties are structures perpendicular to the coast and extend seaward for the purpose of navigational channels and to protect the channel entrance against storm waves (Figure 5-3). Jetties divert tidal currents offshore and restrict the lateral transfer of sediment or interrupt longshore sediment transportation, reducing channel dredging costs (Van Rijn, 2013), essentially destabilising the coastal system and disrupting natural sediment regimes. Sand accumulation in the updrift side can create space for land-based activities, e.g. tourism and ports (Climate-ADAPT, 2016).

Ecological enhancement of jetties could include:

- Similar ecological enhancement opportunities as with groynes are available for jetties.

The literature search returned no instances when these have been implemented within New Zealand.

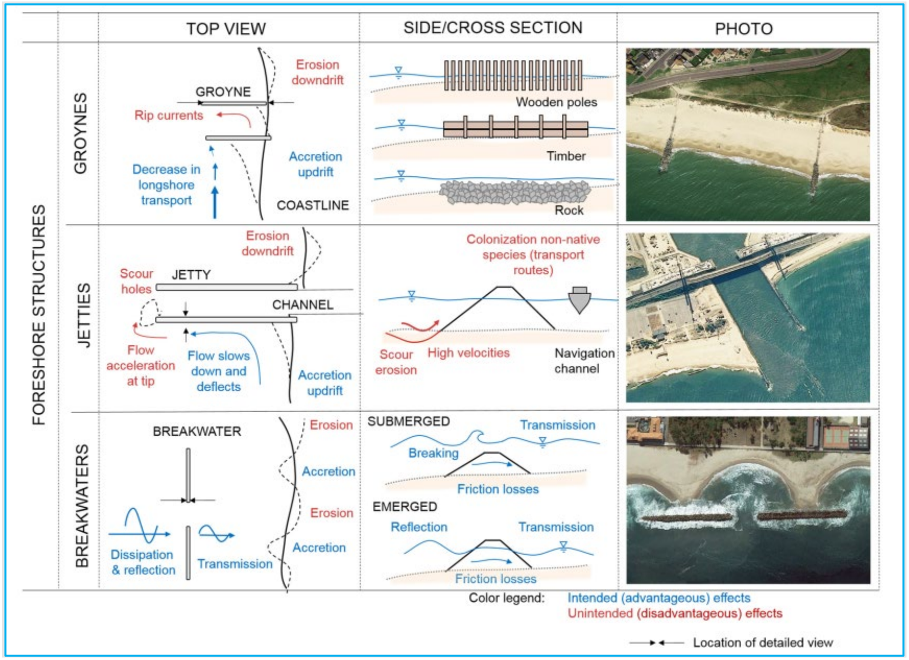

Figure 5-3: Overview of hydrodynamic and morphodynamic effects of groynes, jetties and breakwaters (Schoonees et al., 2019)

6.0 Utilising and incorporating nature-based solutions

For many years and in many places, natural resilience has been the answer to shoreline and coastal management. When ecosystems are healthy and diverse, they can adjust more effectively to climate threats (MfE, 2022a).

6.1 Guidance and policy

IUCN suggest that nature-based solutions can address climate change in three ways:

1) Decrease greenhouse gas emissions related to deforestation and land use
2) Capture and store CO_2 from the atmosphere
3) Enhance resilience of ecosystems, and as such support societies to adapt to climate hazards such as flooding, sea-level rise, and more frequent and intense droughts, floods, heatwaves and wildfires (IUCN, 2023).

The protection of nature and ecosystems is fundamental to the response to climate change. Native ecosystems help to provide a buffer from the impacts of climate change, store carbon and support biodiversity.

In order to ensure that ecosystems are healthy, and the biodiversity is thriving, the New Zealand Government has outlined steps to achieve this in the Ministry for the Environment's National Adaptation Plan. Chapter 5, 'Adaptation options included managed retreat', includes Action 5.9 'Prioritise nature-based solutions'.

These include:

- Key biodiversity policies and strategies to protect, restore and build resilience of indigenous biodiversity to climate change
- Deliver biosecurity actions to protect ecosystems and our economy from invasive species
- Implement key freshwater management programmes to ensure water availability and security and healthy waterways (MfE, 2022a).

> *"Chapter 5: Adaptation options including managed retreat.*
>
> *Action5.9: Prioritise nature-based solutions*
>
> *Timeframe 2022- 2028*
>
> *To address the climate and biodiversity crises together, the Government will prioritise nature-based solutions in planning and regulations, where possible, for both carbon removals and climate change adaptation. It will also investigate how to best ensure that climate change policy and planning use a biodiversity lens to prioritise nature-based solutions.*
>
> *By 2024, a framework will be developed, and prioritising of nature-based solutions in regulations and planning will be underway and future implementation measures confirmed.*
>
> *(MfE, 2022)*

Aotearoa's New Zealand's first emissions reduction plan, Chapter 4: Working with nature.

The plan provides the opportunity to use nature-based solutions to tackle climate change, in ways that protect, enhance and restore nature. Nature-based solutions provide the opportunity to remove carbon from the atmosphere, store it and build resilience to the impacts of climate change, while supporting biodiversity and wider environmental outcomes.

Action 4.1: Prioritise nature-based solutions looks, to address climate and biodiversity crises together by:

- Prioritising the use of nature-based solutions within planning and regulatory systems, for both carbon removals and climate change adaptation.
- Investigate how to best ensure that a biodiversity lens is applied to climate change policy development and planning in order to prioritise nature-based solutions.

Nature-based solutions that remove carbon and support biodiversity include:

- Restoration of wetlands and coastal ecosystems to sequester carbon and provide natural defences against flooding, drought and sea-level rise, while supporting abundant biodiversity.
- Restoring and planting native forests in upper catchments to sequester carbon, reduce flooding and sediment flow into downstream rivers and estuaries and improve habitats.

Nature-based solutions can reduce emissions indirectly by:

- Integrating green spaces and natural features into urban areas to help with temperature and flood control, improve air quality and create wildlife corridors (MfE, 2022b).

Table 6-1 describes a selection of guidelines and policies identified in both international and national programmes, literature and policy. These include examples of where these guidelines and policies direct or support the use of nature-based solutions.

6.2 National research programmes examples

National research programmes and research efforts seeking to explore New Zealand focused nature-based solutions include:

- **Future Coasts Aotearoa**: An Endeavour Fund research project supported by the Ministry of Business, Innovation and Employment:
    - This is a 5-year study that began in October 2021, which aims to provide tools and guidance to help rural communities living in lowlands to adapt and prosper, despite unavoidable sea-level rise.
    - The project led by NIWA, looks to build models of groundwater level and salinity changes, and wetland evolution, while highlighting the importance of social, economic, environmental and cultural importance for communities as the areas adapt to change.

  - The research will support adaptation planning, by helping to understand where and when natural habitats, productive landscapes, and associated well-being values will reach a critical point. Enabling management for coastal realignment or retreat for threatened coastal communities.
  - For further information refer to https://niwa.co.nz/natural-hazards/research-projects/future-coasts-aotearoa
- **Aotearoa New Zealand's first emissions reduction plan - Working with Nature:** Blue carbon sinks in Te Tauihu.
  - Led by Tasman Environmental Trust (TET) co-designed and delivered in partnership with Cawthron Institute, BECA, Ngāti Apa ki te Rā Tō, Nelson City Council and Onetahua Restoration, the project is a community-based initiative to measure, protect and restore coastal blue carbon habitats.
  - Alongside coring and analysis, the project is looking to determine whether local seagrass, saltmarsh and mud habitats are sequestering or releasing carbon (MfE, 2022b).
- **A playbook for nature positive infrastructure development**:
  - This document explores the challenges for developers looking at the dual threat of climate change and global biodiversity loss, and the growing pressure for projects to move from a "no net loss" outcome to a "nature positive" infrastructure development.
  - The playbook assesses nearly 200 existing projects worldwide, to identify proven solutions. As this report does, the playbook provides a high-level summary of the most common solutions and case studies. The key messages identified included:
    - Limited examples to date of successful and documented nature-based solutions.
    - Lack of awareness of the many options available beyond wetland restoration or reforestation.
    - Limited knowledge of the full range of benefits from nature-based solutions, and many of these are not measured or quantified, which ulitmately prevents the uptake.
    - Need to continue to build the evidence base, and share examples to ensure these are at the forefront of planning, implementing, maintainted and decommissioning of infrastructure (WWF, 2023).

Table 6-1: Summary of selected guidelines and policy examples relevant to nature-based coastal engineering

Guideline/policy	Location/Country or Institution	Objective and main features
International		
National Climate Resilience and Adaptation Strategy 2021 – 2025	Australia	• The National Climate Resilience and Adaptation Strategy positions Australia to better anticipate, managed and adapt to climate change. • The Strategy details three objectives to enable effective adaptation across Australia: ○ Drive investment and action through collaboration ○ Improve climate information and services ○ Assess progress and improve over time.
The Coastal Management Manual (CMM) (NSW, 2019)	New South Wales, Australia	• The Coastal Management Manual (CMM) was developed to address areas where a risk assessment study had identified an unacceptable coastal risk. • The management options put forward are termed 'risk treatment measures' and are relevant to different levels of and attitudes to risk. • There are 5 strategic options, Alert, Avoid, Active intervention, Planning for Change and Emergency Response.
Shoreline Management Plans (DEFRA, 2006)	United Kingdom	• Developing strategies to reduce the threat of flooding and erosion that are beneficial to the environment, society and the economy. • The environmental management options are to Hold the existing defense line, Advance the existing defense line, Managed realignment, No active intervention.
Engineering with Nature (USACE, 2023; Bridges et al., 2021)	USA	• The initiative enables more sustainable delivery of economic, social and environmental benefits associated with infrastructure. • The initiative presents a 2018-2023 plan to broaden and deepen engagement and collaboration, grow capability to apply EWN principles and increase the number and diversity while effectively communicating accomplishments and future opportunities.

Guideline/policy	Location/Country or Institution	Objective and main features
Nature-based solutions (IUCN, 2023)	International Union for Conservation of Nature	• IUCN works to advance practical nature-based solutions for climate mitigation and adaptation centred on better conservation, management and restoration of the world's ecosystems. • Not restricted to any one area of application. Includes different approaches, including nature-based solutions for adaptation and mitigation, restoring ecosystems, ecosystem-based infrastructure and ecosystem based management.
Ecological Engineering (Cheong et al., 2013)	Miscellaneous	• Coastal adaptation strategies which combine engineering structures and ecosystems, considering the societal functions and values of using synergies of the different measures, striving to increase coastal protection and make it more flexible.
National		
Coastal Hazards and Climate Change Guidance for Local Government (MfE, 2022a)	Ministry for the Environment	• MfE has outlined a process and a design pathway for the development of shoreline management plans. • This has begun to be implemented across the country, with a focus on adaptation and mitigation of the coastal environment in response to the pressures from climate change. • While not always specified within the plans, nature-based solutions are a preferential option from within the toolbox, pending their viability for the physical and ecological features of the location being considered.
Te Mana o te Taiao. Aotearoa New Zealand Biodiversity Strategy 2020 (DOC, 2020)	Department of Conservation	• The strategy sets out the strategic framework for the protection, restoration and sustainable use of biodiversity, particular indigenous biodiversity in Aotearoa, New Zealand 2020 to 2050. • Nature-based solutions are considered within the section, Protecting and restoring – 2050 objectives. Biodiversity provides nature-based solutions to climate change and is resilient to its effects.
New Zealand Coastal Policy Statement 2010 (DOC, 2010)	Department of Conservation with support from Ministry for the Environment	• Policy 26: Refers to the provision for protection, restoration or enhancement of natural defenses for coastal protection. • Policy 27: Refers to existing development that could be affected by coastal hazards, with consideration to the environment when considering coastal protection, especially when hard structures are deemed necessary.

Guideline/policy	Location/Country or Institution	Objective and main features
The National Policy Statement for Indigenous Biodiversity (NPSIB) (MfE, 2023b)	Ministry for the Environment with support from the Department of Conservation	• The NPSIB is an essential part of New Zealand's response to biodiversity decline in Aotearoa. • The guidelines provide direction to councils to protect, maintain and restore indigenous biodiversity requiring at least no further reduction on a national level. • Part 3.6 addresses resilience to climate change. • With local authorities required to adopt a precautionary approach toward proposed activities where the effects on indigenous biodiversity are unknown, uncertain, or if they are significant or can cause irreversible damage.

Te hau mārohi ki anamata. Towards a productive, sustainable and inclusive economy: Aotearoa New Zealand's first emissions reduction plan (MfE, 2022b)	Ministry for the Environment	• The emissions reduction plan puts New Zealand on a path to achieve long-term targets and contribute to global efforts to limit temperature rise to 1.5°C above pre-industrial levels.
		• A key focus of the plan is on enhancing nature in all aspects of the economy and landscapes.
		• This includes protecting, enhancing and restoring nature, through the use of nature-based solutions in four key actions:
		  ○ Encouraging greater levels of native afforestation to build a long-term carbon sink to support biodiversity
		  ○ Reduce the cost of restoring native forest and delivering pest control
		  ○ Protect native vegetation and the carbon it stores from climate change impacts
		  ○ Prioritising nature-based solutions such as dunes and wetlands to remove carbon and store carbon and provide protection from flooding and rising sea levels.

Auckland's Climate Plan (Auckland Council, 2020)	Auckland Council	• Implementing nature-based solutions in planning. • Action area N3: Integrate connected, nature-based solutions in development planning. This section includes enhancing natural ecosystems to provide for coastal management. • Of specific focus to the coastal area - includes the incorporation of protection, managed retreat and restoration of indigenous coastal ecosystems into planning for sea level change.

Guideline/policy	Location/Country or Institution	Objective and main features
Shoreline Adaptation Plans (SAPs) (Auckland Council, 2023a)	Auckland	• SAPs look at how council-owned assets and land are managed to respond to coastal hazards and climate change over the next 100 years. • Each SAP is developed in partnership with mana whenua and guidance from infrastructure providers, technical experts and coastal communities. • Each SAP applies four strategies to guide decisions around managing council-owned assets and land including no active intervention, hold the line, limited interventions and management realignment.
Shoreline Management Plans (SMP) (RHDHV, 2020; TCDC, 2023)	Thames Coromandel	• The aim of the plan is to establish a framework for management and reduction of risks to people, property, the environment and taonga associated with coastal hazards. • The process identified 138 Coastal Adaptation Plans, with the adaptation options of avoid, accommodate and protect. Nature-based solutions were considered a positive option, acknowledging some consenting challenges.
Coastal Strategy/ Takutai Kāpiti project (KCDC, 2021)	Kāpiti Coast	• The coastal strategy was developed to cover a 20 year period, to raise awareness about coastal hazards, develop management strategies, and record baseline knowledge. • The Takutai Kāpiti project is a partnership with iwi to empower iwi to be involved in developing the solutions for adapting to climate change. "*Climate change adaptation means altering our behaviour systems, and in some cases ways of life to protect our families, our economies and the environment which we live in from the impacts of climate change*".
Shoreline Adaptation Plan (Bendall, 2018)	Hawkes Bay	• A key part of the Hawkes Bay SAP process was the used of the multi-criteria decision analysis (MCDA) to rank possible pathways for units along the coastline. • The outcomes are timeframe based and do include some nature-based solution options.
Community Adaptation Planning (KDC, 2023)	Kaipara District Council	• Plan to carry out adaptation planning with the community to develop long-lasting approaches to adapt to the impacts of climate change. To do this for each section of the coastline will have multiple pathway options developed to respond, and a preferred option chosen. • When and how these are implemented falls with the community panel.

Note: This is a snapshot of guidelines and policy and is by no means an exhaustive list of all guidelines and policies that may exist.

7.0 National case studies

7.1 Thames Coromandel District Council

Nature-based solution	Various options, and mix with hard structures
Ecological enhancement	Ecotiles, vertipools
Guideline/Policy	Thames Coromandel District Council, Shoreline Management Pathways Project

Following a community-led process, a decision on the adaptive strategy applied to the coastal area should consider cost, ecological importance, and consent application challenges. An example of the comparison of different management options is from Thames-Coromandel District (Figure 5-2). Once this is understood, the list of implementation designs needs to be developed, with close consideration to the nature-based solutions that could be implemented. In many cases, there will be a mix of nature-based solutions and hard structures to maintain and protect the coastline.

An outcome of applying nature-based solutions can be that the local and wider area ecology benefits from increased habitat availability for species to colonise. Ecological enhancement techniques could also be considered as an add-on in instances where hard structures are chosen as the preferred coastal strategy to protect against climate change. For example, options such as ecotiles and vertipools, attached to structures (e.g. seawalls or rock revetments), provide habitat to encourage settlement of invertebrates and algae, and habitat use by fish species. These features can increase the biodiversity of the local area, particularly in the intertidal zone where hard structures can encroach into the tidal zone.

Another important component is coastal monitoring. The coastal area is dynamic, and current assessments may not identify the need for any management. In another 10 years, change may have occurred which requires intervention. The monitoring should be robust to account for the detection of these areas at a region-wide scale, and plans should accommodate for short term, medium term and long-term change.

No.	Option	Suitable locations	Social costs and benefits	Consenting challenges	Cost comparison
Be Prepared					
1	Provide regular information	All locations prone to risk	Neutral	None	Very low
2	Implement hazard warning systems	All locations prone to risk	The benefit will always outweigh the cost	None	Very low
No Active Intervention					
3	NAI	Locations where the level of risk is acceptable, the coast needs to fluctuate naturally, or funding is not available	In locations where the level of risk is acceptable the cost will be low and the benefit – maintenance of the beach and access – high. In locations where the coast needs to fluctuate or there is no funding, the benefit will remain but there will be a cost for affected landowners.	Limited to potential disputes with disaffected landowners	Low (possible need for decommissioning)
Accommodate					
4	Maintain natural protection	Locations with healthy beaches, sand dunes, natural beach berms etc. and/or wetlands, where the maintenance of such limits risk to a tolerable level (see Figure 3)	The benefits of such an approach will be high and aligned with community values relating to maintain of a natural environment. The social costs will be limited except where stakeholders do not like the natural	Unlikely to require Resource Consent (except where push-ups are involved); challenges will be limited to potential disputes with disaffected landowners	Relatively low (the unit cost of TCDC's dune planting is roughly \$20 per m^2 and push-ups cost between \$7 and \$14 per m^2)

Figure 7-1: Example from Thames/Coromandel of management option comparisons (TCDC, 2023)

7.2 Oriental Bay foreshore restoration

Wellington, New Zealand

Nature-based solution	Beach nourishment, submerged sill, augmenting headland controls, offshore submerged breakwater, sand gradings.
Ecological enhancement	Biodiversity/habitat creation from the structure hard substrates

In response to the depletion of sand and recreational demand, Oriental Bay beaches and the stormwater system were improved using nature-based solutions. The overall design objective was to enhance the values of Oriental Bay that naturally contribute to its popularity and ensure the project resulted in minimal visual intrusion. The design challenge was to have no visible engineering structures but still have a stable and dry high-tide beach and improved catchment discharge via the stormwater network.

A number of innovative nature-based solutions were used to address the challenge of Wellington's extremes in weather, from calm days to northerly gales gusting over 100 km per hour, and 2 ½ m waves. These included forming a submerged sill along the steepest part of the nearshore area to prevent offshore sand loss; augmenting headland controls to retain sand within the beach; to divert stormwater through installing offshore submerged breakwater to slow alongshore losses and provide improved ecological habitat; and designing sand gradings to reduce wind-blown losses (Bridges et al., 2018).

The success of the project came from a broad multi-disciplinary team, with a strong partnership with Wellington City Council. A community liaison group ensured that involvement was achieved, and community contributions to the design and construction process was acknowledged.

The redevelopment of the bay resulted in increased recreational usage, bringing economic benefit for the community through many restaurants and cafes (Bridges et al., 2018).

Figure 7-2: Oriental Bay, Wellington foreshore redevelopment, utilising nature-based solutions

7.3 Taumanu Reserve – Onehunga foreshore restoration

Auckland, New Zealand

Nature-based solution	Lava flow headland, beach creation/nourishment
Ecological enhancement	Vegetation planting, improvements to infrastructure which allowed for improvements in water quality.

Created in 2015, Taumanu Reserve is a recreational park created from reclaimed land on the foreshores of Manukau Harbour. The project looked to restore the coastline which was cut off from the community when the State highway was built across the Onehunga Bay in the mid-1970s (Bridges et al., 2018).

The focus of the restoration was committed to a nature-based framework and used the natural environment to determine the starting point for each design element. Each functional infrastructure component was enhanced to meet aesthetic, ecological, cultural and social outcomes (Bridges et al., 2018).

The restoration of the coast included the creation of lava flow headlands in lieu of traditional rocky groynes, which reflected the adjacent environment with a natural appearance which enhanced the ecological function. Between these headlands, nine beaches were formed from sand or gravel (Bridges et al., 2018).

As part of the project, efforts to reduce contaminants and sewage outflows into the harbour were undertaken, and improvements to Onehunga Bay saw a reduction in *Escherichia coli* levels to bring the water back to safe swimming standards (Bridges et al., 2018).

Additional ecological enhancement through vegetation planting, increased the provision of habitats and the biodiversity, as the coastline was restored to a more natural setting, allowing for coastal processes of the bay increase the resilience of the coast (Bridges et al., 2018).

8.0 International case studies

8.1 Vancouver, Canada

Nature-based solution	Naturalization of shoreline
Ecological enhancement	Biodiversity/habitat creation, including kelp habitat, salt marsh and riparian habitat, increased beach elevation for surf smelt.
Guideline/Policy	Town Planning Act – 1926 Shoreline Protection Plan (SPP) 2012 North Shore Sea-Level Rise Strategy (2021) Coastal Marine Management Plan (CMMP) (2022)

Historically, popular coastal management strategies have sought to reflect wave-action with hard shorelines composed mostly of impervious, concrete surfaces. More recent thinking focuses on efforts to use soft shorelines approaches, which promise to resolve ecological issues associated with intensive coastal development, and eliminate future threats from sea-level rise (Steele, 2016).

This approach was used in West Vancouver, on Canada's west coast, hoping to achieve environmentally sound amenity for generations (Steele, 2016).

The area is a highly sensitive 30 km waterfront and extends from Capilano River to Horseshoe Bay, with largely expensive private properties. Historically, the coast hosted assets such as piers, ferry services and beach 'shacks'. A Town Planning Act in 1926 attempted to contain development, outlawing industry, and banning the beach 'shacks' which had been used by holiday makers. In 1954, the Cleveland dam on the upper Capilano River created a reservoir to supply West Vancouver with water, but the impacts of this had major detrimental effects on the shoreline and local ecosystems (Steele, 2016).

To protect the area from sea-level rise, the shoreline has been built up using sea walls, groynes and wave breaks. The dynamics of the coastal processes were not accommodated for in these hard-line structures, and caused an imbalance of the coastal sediment budget, with a subsequent increase in the rates of erosion in the surrounding areas (Steele, 2016).

In the early 1960s, projects to alter the shorelines included an extensive project to attract sand and hold it at Ambleside Beach, however by 1963 all of the introduced sand had washed away (Steele, 2016).

> *"With few exceptions every buildable waterfront lot is occupied and cultivated to the very limit of its boundaries…The friendly beaches in some places are now narrow shelves of noxious sand squeezed between tide and concrete retaining walls, sometimes 16' high. These divide the shoreline and prohibit the traverse from one beach to another without trespass upon private property; and indeed inhibit the actual use of the beach itself except at the lower stages of the tide" (West Vancouver Archives, 1972)*

Figure 8-1: Waterfront view west of Ambleside, West Vancouver. Photograph by F.W. Rivers (1920s) (Steel, 2016)

In 1972, a waterfront survey of the concerns surrounding the state of the shoreline, identified a huge number of private property violations, noting that coastal erosion as a major concern.

A history of extensive individual efforts to protect property has led to a major re-naturalisation effort. The focus is now on taking a holistic approach and understanding the past to work towards a cohesive future strategy.

In 2004, the District of West Vancouver commissioned a committee to prepare a report on the actions taken to protect the shoreline, and by 2006 they launched a Shoreline Protection Plan (SPP) to set forth a roadmap for the protection of the coastline. An updated plan was released in 2012 to set out the objectives to address climate change pressures such as sea-level rise (West Vancouver, 2012).

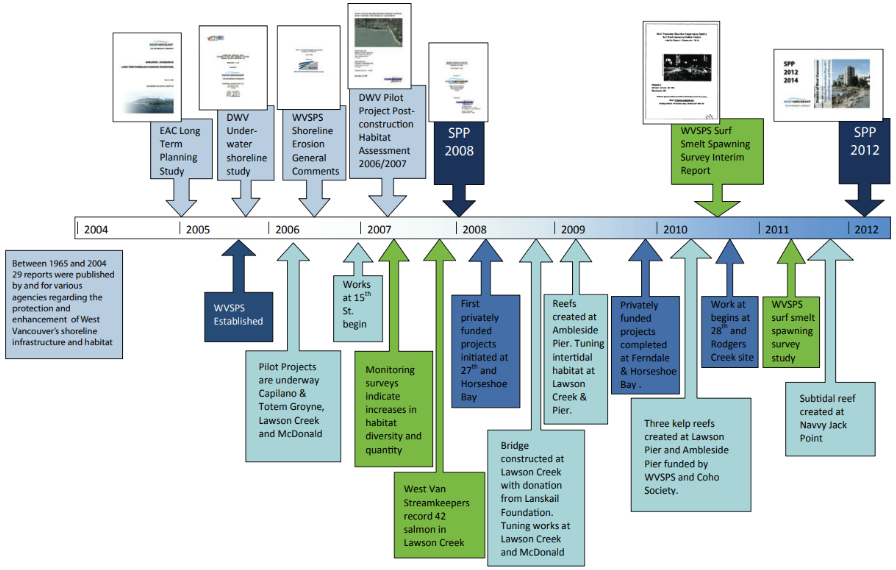

Figure 8-2: Timeline of actions taken to shoreline management in West Vancouver (West Vancouver District, 2012)

The 2012-2015 Shoreline Protection Plan focused on naturalising the shoreline. Shoreline restoration included sourcing local materials, and a concerted effort was made to sculpt the existing terrain into a seamless ecologically sound land-ocean interface, with the aim to naturalise the whole coastline to mitigate for the impacts caused by the remaining hard structures (Steele, 2016).

Priority projects for coastal protection looked to include a focus on communications and outreach. The projects also sought ecological enhancement opportunities to create new habitat to increase biodiversity and to develop existing habitat features, while recreating a more natural shoreline to protect and maintain the foreshore. Overall, these improvements aimed to increase biodiversity. Of the 4,500 m^2 of stable substrate along the shoreline, the habitat enhancements included:

- More than 1,500 m^2 of high value subtidal habitat for kelp (including abundant bull kelp, reef, lingcod)
- Approximately 3,000 m^2 of stable intertidal habitat, with an associated population increase of over 30 million barnacles (larvae is a valuable food source for juvenile herring and salmonids)
- 1, 000 m^2 of high value salt marsh and riparian habitat
- Replacement of 7,000 m^2 of low productivity intertidal habitat with high productivity habitat
- Increased beach elevation and kelp coverage, as key factors in the creation of habitat for surf smelt
- Creek enhancements that resulted in higher numbers of spawning salmon.

Prior to enhancement, several severe storms caused considerable flooding and damage to waterfront infrastructure and gradual ongoing erosion which cost a large amount to repair. Through the implementation of protective and enhancement projects, the economic benefits were seen as:

- Wave protection from the enhancement can result in considerable economic benefit by reducing storm and debris impacts to the sea wall and upper shore
- Positive impact on the productive capacity of the shore that will result in benefits to fish and in turn the recreational and commercial fisheries.

To understand the success of each project, monitoring was a requirement to ensure that the success of the future works and existing works continue into the long term, allowing for optimisation of future projects to ensure maximum benefits for key species (West Vancouver District, 2012).

Following this plan there were several more:

- Shoreline Protection Plan Compensatory Habitat Monitoring (2019)
  This report summarises monitoring and site investigations to understand the potential success for the implementation of the SPP on coastal habitat. The report makes recommendations for further incorporation of habitat enhancement and prioritisation for nature-based approaches.
- North Shore Sea-Level Rise Strategy (2021)
  West Vancouver District was an active partner in developing a strategy to address sea-level rise across the North Shore.

Coastal Planning and Preparation of a Foreshore Development Permit Area Study (2020)

Coastal planning and coastal flood mapping to inform planning and adaptation and makes recommendations for flood construction levels, and other site-specific measures to build coastal resilience to sea-level rise and coastal flooding.

- **Coastal Marine Management Plan (CMMP) (2022)**
  The plan provides a policy framework informed by past and recent initiatives to guide the District Council in management of coastal areas and asset with three focuses:
  - Coastal dynamics and ecosystems
  - Built infrastructure and parks
  - Public-private interface.

  The CMMP makes recommendations for funding, communication, and progress monitoring approaches to further support to implement the objectives for the next 10 to 20 years (West Vancouver District, 2022).

8.2 Hayward Area, USA

Nature-based solution	Creation of fine and coarse grain beaches, tidal marsh restoration, diked pond management, fine sediment augmentation, tributary connection, reefs and breakwaters, eelgrass restoration.
Ecological enhancement	Development of reefs and breakwaters which provide a hard substrate for ecological enhancement
Guideline/Policy	National Shoreline Management Study (NSMS) (2022) Hayward Regional Shoreline Adaptation Master Plan (SAMP) (2021)

A National Shoreline Management Study developed in 2022, that applies across every coastal region of the United States has recently been authorised. Amongst other things, the study will focus on erosion and accretion, including causes, and anticipated future climate risks to those processes. Eight regional assessments will provide information on the assessments of the causes and effects of erosion and accretion, social, cultural, economic and environmental importance of the shorelines, and current and future risks (USACE, 2023).

8.2.1 Hayward Regional Shoreline Adaptation Master Plan

Hayward is a low-lying area in San Francisco. The shoreline currently has eight salt marshes which provide a level of natural flood protection, however sea-level rise and stronger storm events caused by climate change were causing the barriers to the State Route 92 (SR 92) to be overtopped two to three times per year. If no adaptation actions were taken then many of these tidal marsh areas and managed wetlands will be inundated by 2050 (HSPA, 2021).

The Shoreline Adaptation Master Plan envisions a diverse mosaic of Bayland environment that host recreational opportunities, facilitate educational programmes and support the continued operation of critical urban infrastructure in response to the protection from sea-level rise, making the coastline more resilient to change.

The approach taken was to assess climate change impacts from sea-level rise and storm events and to work with the community to reach a preferred approach.

The project goals included:

- Enhancing the shoreline's ecological value and adaptability to sea-level rise
- Provide refuge to help endangered shoreline species to adapt to climate change
- Foster stewardship of the shoreline's cultural and ecological resources.

The process to reach these goals included community collaboration, modelling of sea-level rise scenarios, and identification of adaptation strategies.

To provide an ecological context for the adaptive management strategies to be assessed against, a summary of the ecological habitats, the species present and the critical infrastructure was outlined. The habitats and species in the Hayward area include a diversity of natural and restored tidal marshes, inactive industrial salt ponds, filtration marshes, storage ponds, diked wetlands, landfills, solar fields, and biosolids drying beds. The summary included an outline of the distribution of coastal birds, a salt marsh mouse and the eelgrass (seagrass) habitats (HSPA, 2021).

Ecological features at risk from sea-level rise and erosion, and their distribution, were identified for each sea level scenarios.

Following the contextual summaries and community stakeholder engagement, a suite of nature-based, engineered and non-structural strategies were selected to mitigate future risk to a complex diversity of shoreline assets, including ecological assets, built infrastructure, and recreational resources (HSPA, 2021).

Nature-based strategies that incorporate coastal risk reduction and ecological infrastructure to adapt shoreline assets to sea-level rise options included:

- **Creation of fine and coarse grain beaches:** To reduce erosion of levees and provide ecological enhancement via provision of shorebird nesting habitat.
- **Tidal marsh restoration:** To reduce erosion risk along the shoreline, and attenuate waves, and provide ecological enhancement via provision of critical habitat.
- **Diked pond management:** To provide stormwater storage space for flood control and provide ecological enhancement via provision of shorebird habitat.
- **Fine sediment augmentation:** To maximize the potential of marshes to maintain themselves in the future with sea-level rise.
- **Tributary connection to Baylands:** To provide ecological enhancement through the restoration of sediment and tidal flows for marsh restoration and health.
- **Reefs and breakwaters:** To reduce erosion to critical infrastructure and provide ecological enhancement of hard substrate habitat.
- **Eelgrass (seagrass) restoration:** To provide ecological enhancement in the form of habitat creation and reduce erosion.

The adaptation strategies were identified based on stakeholder feedback and a combination of nature-based strategies, non-structural strategies, and hard infrastructure strategies. This hybrid configuration balances risk reduction and ecological enhancement. The strategies aimed to provide a line of protection, create tidal habitat, provide erosion control, stormwater management, wastewater treatment, and maintenance of recreational walking tracks and recreational assets.

The nature-based solutions included a large extent of tidal habitat and tidal marshes existing and restored to make the perimeter levee maintenance less feasible. A layered system of erosion control measures to reduce erosion to the levees that shelter the marshes behind, and additional levees and interior levees for additional layered protection from erosion were retained. Detention ponds to hold stormwater, and critical wastewater treatment functions were maintained and enhanced. A bay trail was aligned to promote a diversity of experiences while reducing the risk of flooding (Figure 8-3) (HSPA, 2021).

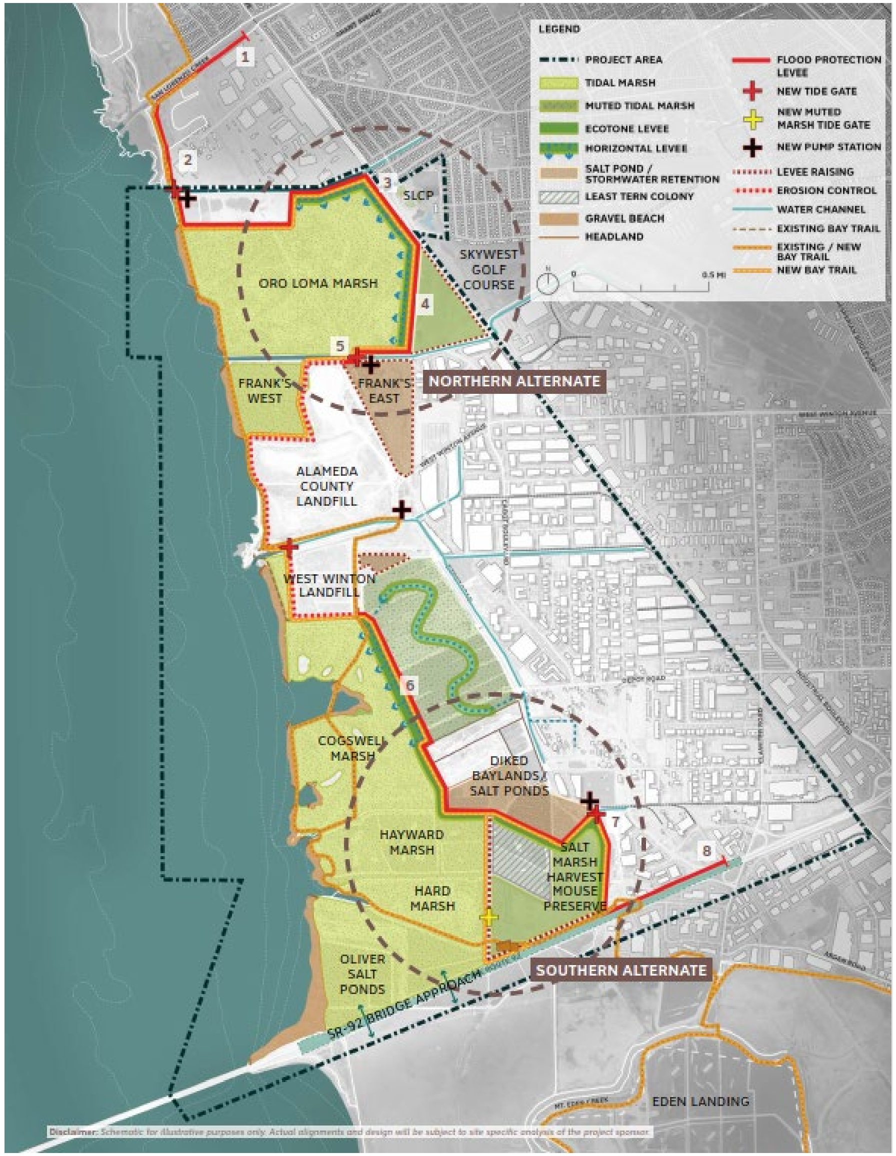

Figure 8-3: Hayward Regional Shoreline Master Plan preferred option

8.3 Australia

Nature-based solution	Seagrass and mangrove restoration, reef restoration (Great Barrier Reef)
Ecological enhancement	Tree planting
Guideline/Policy	National Climate Resilience and Adaptation Strategy (2021) Reef (2050) Long Term Sustainability Plan Oceans Leadership Package (2021)

The National Climate Resilience and Adaptation Strategy requires a coordinated response across natural, built, social and economic domains, acknowledging that climate change will impact each differently (DAWE, 2021).

Examples of coastal nature-based solutions for adaptation that have been implemented include:

- Constructing artificial wetlands to provide nutrient, pollutant and sediment capture, reduce stormwater flow during flooding events and enhance biodiversity.
- Restoring seagrasses, mangroves and tidal wetlands (blue carbon) to protect coastal infrastructure from storm surges and maintain the productivity of fisheries and marine industries.

The success of the strategy is built on guiding principles for adaptation:

- Shared responsibility
- Factor climate risks into decisions
- Evidence-based, risk management approach
- Assist the vulnerable
- Collaborative, values based choices
- Revisit decisions and outcomes over time.

8.3.1 Great Barrier Reef restoration

An example of a major initiative driving adaptation across the four domains is the “Reef 2050 Long Term Sustainability Plan” for the Great Barrier Reef. The focus of the plan is to reduce local and regional pressure to support the reef’s health while adapting to climate change.

One way that this is being achieved is through the provision of $150 million from the Australian Government for research into restoration and development of an adaptation plan to put the Great Barrier Reef at the cutting edge of global efforts to help coral reefs adapt to climate change.

8.3.2 Barangaroo – city development to mitigate climate change

Another example is Barangaroo, one of the world's largest waterfront urban renewal projects and is a significant extension of Sydney's CBD. The development includes sustainable commercial office space, residential apartments, a hotel, shops, cafes, restaurants, public open space and cultural facilities.

A range of adaption actions to address climate change impacts have been implemented including:

- Increasing shade, water availability, planting trees and using high solar reflectance materials to reduce heat impacts
- Upgrading stormwater systems to cope with increased extreme events
- A variety of approaches to reduce water use
- Prevention of negative consequences of sea-level rise, including planning for a 0.9 m sea-level rise.

8.3.3 Blue carbon ecosystems

The $100 million Australian Government Oceans Leadership Package includes action to restore blue carbon ecosystems such as seagrass and mangroves that play a key role in improving the health of coastal environments and protective native species and habitat. This is just one way in which the plan helps to ensure the natural environment can adapt to the changing climate while preserving the natural capital, improving productivity and protecting heritage (DAWE, 2021).

9.0 Summary

A general theme across national and international management plans reviewed, is that a naturalised approach is often the preferred option, but this may not always be feasible due to asset protection, urgency, environmental suitability, consent conditions and cost. However, in many cases, a mix of nature-based solutions and hard structures are the preferred option with longer-term strategic planning having the ability to overcome the barriers of coastal protection and manage the shoreline in a more adaptable way.

The opportunity to utilise nature-based solutions for the protection of shorelines from climate change are progressively being adopted in favour of hard-structure coastal protection, which can cause displacement of impacts further around the coastline, potentially requiring ongoing maintenance.

A benefit of nature-based solutions is the ability to future proof the coastline from impacts of climate change processes while providing multiple benefits, such as social and economic. Case studies from around the world and New Zealand point towards the provision of ecosystem services such as storm management, water filtration, maintaining and enhancing coastal habitats, protection of existing assets and infrastructure as an outcome of nature-based solutions.

Economic benefits from coastal protection through the use of nature-based solutions, reduces the impacts from storms and coastal erosion, through the reduction of impacts to infrastructure. Further economic gains could be made from ecological benefits that come with the provision of healthy ecosystems, including a potential increase in recreational and commercial fishing opportunities as a result of increased fish stocks from the provision of protective habitat, such as kelp forests and salt marsh for juveniles.

By implementing nature-based solutions and ecological enhancements, the positive outcomes can include accommodation for climate change effects, biodiversity conservation, helping to preserve the habitats and species of the local area, increased ecosystem services, and the connectedness with the region for years to come.

To ensure that a nature-based strategy is providing the intended function, monitoring is critical to the success of the work, allowing for intervention if required. Further, State of the Environment monitoring of local water quality and estuarine health, is one current mechanism to understand the current impacts on the coastline from climate change and ecosystem services provided by nature-based solutions.

> *"Adaptation is a continuous process of assessing and managing risk, evaluating the effectiveness of actions taken and adjusting those actions as needed. By adapting to the unavoidable effects of climate change, we become more resilient to those risks" (MfE, 2022)*

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Appendices

Appendix A

Table 10-1: Options for nature-based solutions and ecological enhancement - their application and ecosystem services they provide

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
Soft-engineering – Nature-based solutions			
Beach nourishment / sediment maintenance **(Hume, 2021; T+T Subject Matter Expert (SME))**	• Transfer of sediment between locations • Catchment management for sediment supply • Prohibition of gravel extraction • Movement of sediment deposited downdrift of a waterway to facilitate littoral transport for beach nourishment • Maintaining a healthy ecosystem offshore so that shell production continues • Returning sediment washed inland from storms to the beach system	**Regulating services:** • Protection from coastal erosion and inundation • Beach stabilisation / maintenance **Habitat and supporting services:** • Roost area for coastal birds **Cultural services:** • Amenity and recreation	• Temporary fix, as the nourishment material will dissipate with time • Source of sand needs to consider cultural preferences and values
Dune management **(Morris et al., 2021, Coastal Restoration Trust Handbook, 2011, T+T SME)**	• Native vegetation planting of foredune and backdune • Pest plant and animal management • Sand fences to promote dune stabilisation • Dune building or recontouring	**Regulating services:** • Beach stabilisation • Protection from coastal flooding and storm surge	• Potential for wind erosion • Dune modification from associated development works, such as coastal subdivisions • Displacement of native dune vegetation by exotic species

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
	• Restriction of impact from vehicles and people • Construction with hard cores (often geotextile tubes filed with sand) designed specifically to resist erosion • Information and education • Monitoring and maintenance	**Habitat and supporting services:** • Habitat formation for native species, e.g. coastal birds and skinks	• May be limited if activities such as sand extraction are taking place nearby • Impacts to coastal process from coastal structures such as seawalls, stormwater drains, gyrones, etc. • Pressures from pest plants and animals.
Shell banks **(Jackson, 2017, T+T SME)**	• Placement of nourishment material on top of existing shell bank • Construction of new bank area using imported materials • Revegetation with low-lying grasses to promote stabilisation • Pest management on existing shell banks	**Regulating services:** • Wave attenuation • Protection against coastal inundation by providing areas above the high-tide zone **Habitat and supporting services:** • Creation of a roost area to reduce energetic demands for coastal birds • Habitat formation for native species, e.g. coastal birds, skinks • Protection of nesting areas away from predators	• May need to be renourished with time • Increased pressure from pest animals
Habitat restoration or formation – Nature-based solutions			
Artificial reef **(Hammond et al., 2020, Ferrario et al., 2014, Folpp et al., 2020, T+T SME)**	• Artificially designed reef units that create the structural complexity for reef forming species to establish, e.g. kelp	**Regulating services:** • Wave attenuation **Habitat and supporting services:** • Structural complexity • Promotion of biofouling colonisation, e.g. macroalgae	• Not suitable in all environments • Potential navigational hazard

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
		• Habitat for fish and invertebrates	
Kelp restoration **(Wernberg et al., 2019, Morris et al., 2020; Hynes et al., 2021, Morris et al., 2021, Graham et al., 2022; Fisheries NZ, 2023)**	• Protection and enhancement of existing kelp reefs • Seed out of lab-cultured kelp into new or degraded areas • Active transplantation of mature kelp • Transplantation can include use of artificial or natural materials as a temporary colonisation substrate • Provision of artificial substrate for natural biofouling colonisation	**Regulating services:** • Primary production • Localised buffer to ocean acidification (via CO_2 uptake) • Carbon sequestration • Bioremediation function via the uptake of nutrients • Export of kelp detritus to the seafloor or as beachcast • Helps to create drag and reduces wave energy • Reduction in wave energy reduces the impact of erosion **Habitat and supporting services:** • Ecosystem engineers or creator of habitat structure (for fish and marine invertebrates) • Food resource for fish and invertebrates	• Impacts from climate change such as sea water temperature. • Need to understand local biotic and abiotic (such as sedimentation, water flow, herbivore species) processes that may affect settlement, post settlement/transplantation survival of kelp • Management of local stressors such as developing fisheries for grazors or competitors, improving wastewater treatment, legislation to reduce pollution. • Understanding local social economic barriers, such association with kelp as an important food source, recreational and cultural importance. These factors will define the best restoration method that is most cost effective, and the scale of effort.
Mangrove restoration **(Donato et al., 2011; Hume, 2021; Lundquist et al., 2014; Morris et al., 2021; Auckland Council, 2023c)**	• Vegetation planting • Protection of existing mangroves from removal • Restoration of hydrology to previously drained areas • Allow for managed retreat	**Regulating services:** • Carbon sequestration • Provision of energy and organic matter to support the food web • Protection from coastal erosion	• Community push back • Previous mangrove clearance can disrupt the ecosystem processes.

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
	• Exclusion of stock from waterways draining into the estuary and carry out buffer planting. • Reduce sediment inputs. • Implement pest animal control and monitoring programme.	• Sediment binding and capture • Nutrient removal, e.g. decrease terrestrial run-off into estuaries **Habitat and supporting services:** • Nursery habitat for fish • Habitat for benthic invertebrates (annelids, molluscs, crustaceans) Habitat for wading birds, e.g. banded rail	
Salt marsh restoration (Cheong et al., 2013; Morris et al., 2021; HSPA, 2021; Auckland Council, 2023c)	• Invasive vegetation control • Hydrological restoration e.g. tidal inundation • Native vegetation planting • Translocation of target species e.g. glasswort • Reduce sediment inputs • Restoration of hydrology to previously drained areas • Exclusion of stock from waterways draining into the estuary and carry out buffer planting. • Implement pest animal control and monitoring programme	**Regulating services:** • Enhance carbon sequestration into marine sediments • Nutrient removal, e.g. decrease terrestrial run-off into estuaries • Wave attenuation • Coastal flood mitigation • Coastal erosion protection through sediment capture and stabilisation **Habitat and supporting services:** • Habitat formation for fauna, e.g. coastal birds and skinks	• Pressures from sea-level rise may inundate this ecosystem type. • Increases in farming and urban development in surrounding catchments may raise nutrient and sediment levels, may cause increase in mangrove growth at the expense of salt marsh. • Pressures from pest plants and animals which may invade and affect recruitment of indigenous species.
Seagrass restoration (Mtwana Nordlund et al., 2016, Morris et al., 2021; Sanchez-Videl et al., 2021; Auckland Council, 2023c)	• Vegetation planting where seagrass is lost or degraded • Transplantation of seagrass from an area of impact or donor site	**Regulating services:** • Primary production • Nutrient removal from water column • Carbon sequestration	• Pressures from sea-level rise may inundate this ecosystem type. • Increases in farming and urban development in surrounding catchments may raise nutrient and sediment levels,

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
	• Can include use of artificial mats to promote establishment	• Sediment capture and binding for subtidal and intertidal seafloor stabilisation • Coastal protection from erosion and flooding • Wave attenuation • Provision of energy and organic matter to support the foodweb **Habitat and supporting services:** • Settlement substrate for larval fish • Nursery habitat and refuge for species, especially juvenile fish	may cause increase in mangrove growth at the expense of salt marsh. • Pressures from pest plants and animals which may invade and affect recruitment of indigenous species.
Shellfish restoration (Alleway et al., 2019, Fitzsimons et al., 2020)	• Protection and enhancement of existing shellfish beds • Establishment of shellfish reefs • Active transplantation of shellfish to new or degraded areas e.g. soft-sediment green-lipped mussel reefs • Use of artificial housing devices to store and transplant shellfish e.g. oyster baskets • Seeded lines of shellfish attached to existing structures, e.g. pile wraps or floats	**Regulating services:** • Carbon sequestration via shell and tissue production • Water filtration and removal of nutrients • Denitrification • Sediment stabilisation **Habitat and supporting services:** • Provision of shelter and refuge • Food resource for fish and invertebrates • Structural complexity	• External conditions such as temperature that affects the successful survival. • Pressure from marine pest species for habitat and food.

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
Ecological enhancement			
Artificial rock pools **(Evans et al., 2016, Firth et al., 2013, Perkol-Finkel and Sella, 2015; Chee et al.,2020, WWF, 2023)**	• Pre-cast rock pool designs that can be installed into new coastal infrastructure • Drilled holes into existing or new hard coastal infrastructure	**Habitat and supporting services:** • Shelter and ecological niches • Structural complexity • Provide intertidal habitat features including moist refugia • Substrate for biofouling to colonise, e.g. algae • Habitat for fish and invertebrates • Increase species richness and community structure Improved water quality via sessile organism filter feeding • Better marine habitat for a diverse range of species	• Effects from heat and desiccation • Sedimentation pressures from land, rock pool design should be considered to accommodate for the flushing and removal of sediment.
Bird roosts **(Shealer et al., 2006, Hancock,2000, Jackson, 2017, T+T SME)**	• Use of purpose built wooden frames • Construction of a roost area using artificial substrates, e.g. wooden piles • Construction of offshore vegetated or unvegetated islands • Floating island rafts	**Habitat and supporting services:** • Reduce energetic demands for coastal birds • Habitat formation for native species, e.g. coastal birds	• May cause navigational hazards
Ecological armouring units **(Ido and Shimrit, 2015; Naylor et al., 2017)**	• Subtidal armouring units with complex surfaces, holes and crevices	**Habitat and supporting services:** • Shelter and ecological niches • Structural complexity	• Coastal squeeze challenges from sea-level rise if there are limitations with landward realignment of the rock amour.

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
	• Achievable habitat and species colonisation and succession is achievable on hard coastal structures.	• Promotion of biofouling colonisation e.g. macroalgae • Habitat for fish and invertebrates • Recolonisation can occur within 12-18 months • Provide a habitat for good recruitment of food species and favourable conditions for birds	
Pile wraps (Perkol-Finkel and Sella, 2015)	• An attachment of textured rope to existing piles (seeded or unseeded with marine species, e.g. shellfish) • Can also involve more comprehensive construction of concrete pile encapsulations that provide the textured substrate for colonisation	**Habitat and supporting services:** • Structural complexity • Promotion of biofouling colonisation, e.g. macroalgae • Habitat for fish and invertebrates	
Reef balls (Folpp et al., 2020, Lee, 2023, T+T SME).	• Circular concrete balls which are placed in an otherwise structureless environment and create artificial habitats for a variety of marine organisms	**Habitat and supporting services:** • Shelter and ecological niches • Structural complexity • Promotion of biofouling colonisation, e.g. macroalgae • Habitat for fish and invertebrates	• May cause navigational hazard if they are placed where water is not deep enough • May be challenging to find to monitor ecological progress
Seawall panels and tiles (Bishop et al., 2022, Bradford et al., 2020, T+T SME)	• Range from large precast panels to small tiles that can be attached either during construction or retrospectively to coastal infrastructure	**Habitat and supporting services:** • Shelter and ecological niches	• Natural availability of larvae for self-recruitment

Ecological option	Application	Potential ecosystem services provided / benefits	Limitations
	• Can include chemical modification to concrete mix to facilitate biofouling colonisation • Includes design of grooved carvings in substrate, swim throughs, and crevices	• Provide intertidal habitat features that retain water, increase shading and reduce desiccation • Substrate for biofouling to colonise, e.g. algae • Refuge for fish and invertebrates	
Textured substrates and complexity **(Hall et al., 2018, Bishop et al., 2022, Bradford et al., 2020, T+T SME)**	• Alteration of soft and hard rock for the creation of rock revetments (so they deteriorate at different rates) • Different 'eco-concrete' mixes that promote a rough surface finish • Textured finish to coastal infrastructure to promote biofouling colonisation	**Habitat and supporting services:** • Structural complexity Promotion of biofouling colonisation, e.g. macroalgae	• Natural availability of larvae for self-recruitment
Vertipools **(Firth et al., 2013, T+T SME)**	• Similar to an artificial rockpool however can be installed up vertical seawall structures	**Habitat and supporting services:** • Shelter and ecological niches • Provide intertidal habitat features that retain water, increase shading and reduce desiccation • Substrate for biofouling to colonise, e.g. algae • Refuge for fish and invertebrates	• Navigational hazard if they are used on structures close to vessel activity

Appendix B

Table 10-2: Opportunities for the use of ecological enhancement on hard structures used for coastal protection (Coastal structures described in Section 5.0)

Coastal structure	Ecology tiles	Vertipools	Artificial reef	Rockpools drilled into in situ rock	Reuse in situ rock/cobble material	Diversity of habitat creating rock material	Vegetation planting	Bird roosting (poles, shell hash)
Onshore options								
Seawall (wooden)								X
Seawall (masonry grouted rock)	X	X						
Seawall (concrete and mudcrete)	X	X		X				
Rock revetment	X	X		X	X	X		X
Sea dike							X	
Foreshore options								
Groynes	X	X						
Breakwaters	X	X	X					
Jetties	X	X						

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